"Full-scale industrial methods must be applied by introducing standardization of individual components".

— Le Corbusier, 1920.

PRECAST CONCRETE PANEL SYSTEMS FOR HOUSING

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ABSTRACT

Among the various industrialized building systems using precast concrete for housing, panel systems are the most successful.

To study this type of building system, this thesis first reviews the general principles of precast concrete construction and how concrete components can be applied to housing. The major emphasis of this review is on the structural use of precast concrete components and the methods of joining them.

The development of the various panel systems illustrates how they were improved through experience gained in European countries.

The case studies examine several widely used systems and indicate how general and structural principles are actually applied. They also help us to conclude that cross-wall and two-way span systems are the most suitable for housing application.

Résumé

Parmi les divers systèmes de construction industrialises utilisant le béton préfabriques pour l'habitation, les systèmes de panneaux ont eu le plus de succès.

Afin d'étudier cette méthode de construction cette thèse examine d'abord les principes généraux de la construction en béton préfabriques et l'usage d'éléments de béton dans la construction d'habitations.

Cette revue met l'accent sur l'emploi en construction d'éléments de béton précontraint et des méthodes employées à leur assemblage.

L'évolution des divers systèmes de panneaux illustre leur développement en fonction de l'expérience acquise en pays européens.

Nous examinons ici plusieurs systèmes largement employés et nous indiquons les principes généraux et les principes de construction qui y sont mis en oeuvre.

Ces études nous amènent à la conclusion que le système à murs latéraux portants et celui employant des dalles à deux sens sont les mieux adaptés à la construction d'habitations.

PREFACE

This thesis is a study of numerous efforts which have been made to employ precast concrete panels in industrialized building systems for housing.

In response to the growing attention of architects to the changes in modern architectural practice brought about by industrialization and technological innovation, this study seeks to develop the author's ability to analyze existing precast concrete panel systems before selecting one for the design of a building, and also to use the knowledge in managing the building process.

The knowledge and experience gained in the development of precast concrete panel systems to its present state will serve as a useful tool in continuing efforts to achieve further success in the wider use of building systems in providing mass housing.

ACKNOWLEDGEMENT

I am indebted to Professor Radoslav Žuk for his persistent guidance and suggestions, especially his understanding during difficult periods.

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This thesis could not have been completed without the constant support and encouragement of my dear wife, Lily, to whom I dedicate this thesis.

I. INTRODUCTION

1. BACKGROUND

Since World War II, due to the population explosion and the concentration of urban development, the demand for housing has been increasing tremendously. Simultaneously, the improvement of technology, such as the invention of light-weight building materials, the innovations in hoisting machinery, and the development of new joining methods has encouraged the development of systems building. Systems building gained initial impetus in Europe during the 50s and 60s as countries rebuilt, cleared slums, and developed new towns. Volume was the priority. Systems building offered speed while manufacturers could produce units in high enough volume. The achievement of housing construction of postwar Europe was a long range development under the government's policy. The Governments of many European countries established building codes to support systems building for housing. Many examples of systems building for housing were constructed in Eastern Europe and Russia. Here government housing policies employing a completely systemized method of housing construction have solved many of their housing shortage problems.

In the United States, the Department of Housing and Urban Development (HUD) announced in 1969, a program called "Operation

Breakthrough" which encouraged the employment of industrialized methods for housing construction to solve the housing problem. After a worldwide response to a call for submissions, 22 contracts were awarded to systems producers. 8 of the 22 chosen systems utilized precast concrete construction, of which 5 were Panel Systems.

With the idea of encouraging the development of a group of building systems similar to those successful in Europe, the Congress of the United States added Section S-108 to the Housing Law of 1968. With the requirements of concrete panel systems in mind, the law authorized a program which could guarantee a market of 1000 units a year for five years, for each of the five panel systems. The idea is clear. A guaranteed market will stimulate investment in factories. Factories, once built, can compete on the basis of lower price.[1]

In Canada, there were significant contributions to the new approach towards housing. The Habitat project at Expo '67 implemented the idea of using the box as a basic module to form a housing unit. In connection with the Operation Breakthrough program of HUD, the submission made by the Canadian firm Descon/Concordia Systems Ltd. was the only non-U.S. proposal accepted. Canadian situations parallel those in the U.S. Studies in this field are being conducted in various institutions such as the Central Mortgage and Housing Corporation, The National Research Council, and the Department of Industry, etc.

2. PRECAST CONCRETE IN INDUSTRIALIZED BUILDING SYSTEMS

Precast concrete has many advantages when compared to other modern materials such as wood, steel, or plastics. The low cost and ready availability of concrete make it a very popular building material. Its plastic character is most suitable for mass production. Other characteristics such as high structural strength, high fire-resistance and durability are very important for high-rise multi-unit dwellings.

The constituent materials of concrete are cement, fine and coarse aggregates, and water. The aggregates, either sand or gravel or other lightweight materials are cheap and easily obtainable. Cement is the most expensive raw material of concrete. Its constituent parts of calcium and silicates are made from limestone, kaolin, or calcium chloride which are also inexpensive and readily available materials. In some countries, where the natural reserves of timber, iron ore and metallurgical coal are poor, it is inexpensive to manufacture cement. This is also the reason why concrete became so popular after the war in Europe and Russia when the supplies of natural resources, such as wood and steel had been decreased. This artificial material has become the most important building material of post-war Europe.

The primary goal of the industrialization of building construction is to manufacture components on an industrialized basis.

Concrete, as a plastic material, can be poured into moulds in the factory. It becomes a strong and rigid material of almost any practical size and configuration for almost any building component. Of the modern construction materials, only plastic possesses this character; however, the use of plastic in industrialized building is still under investigation since its longterm stability and fire resisting properties have not been verified.

From the viewpoint of safety, fire resistance becomes an increasingly important factor. Concrete is a very good fire-proofing material because of its nature. The use of concrete for the structural frame can give good fire-proofing, thus simultaneously solve fire safety and structural problems. For these reasons, in high-rise housing in areas of high population density, concrete systems have proven to be very adaptable to fire safety regulations.

Precast concrete, however presents several disadvantages. Among these, weight and the need for heavy handling equipment are the most serious; yet, many methods of solving these problems have been explored.

No matter how elegant and light precast concrete is compared to cast-in-place concrete, its weight is the most serious problem in industrialized construction. The bulky and dense mass of this material creates problems of transportation and hoisting. In multi-story construction, the heavy dead-load increases the cost of the structural system, particularly the foundation. For approximately one half of a century efforts have been made to reduce the weight of concrete by introducing light weight aggregates, self-stressing cements, large voids in the concrete and prestressing techniques.

The permeability of concrete due to its porous character may adversely affect its durability, especially since the entry of moisture and air results in the corrosion of steel reinforcement. The porous character of concrete also makes it a poor insulator, requiring additional insulating material. The insulating quality of concrete has been greatly improved, however, with the use of light-weight concrete. Various types of light-weight concrete have been applied without additional insulation in industrialized housing, but the subsequently lowered strength is a disadvantage.

Low resistance to the frost and thawing cycle creates another problem. Efflorescence presents problems for the exposed concrete surface which may detract from the appearance of the building. These negative properties of concrete may be greatly minimized in factory-made precast concrete since the manufacturing process can be controlled under precise factory conditions, e.g. the use of precise molds, dry mixes, mechanical compaction, steam curing methods, etc.

One of the advantages of cast-in-place concrete construction-structural continuity is, however, lost in precast concrete. In concrete high-rise industrialized housing, continuity is necessary for safety. This creates a joining problem which is usually costly and labour intensive. Recently, the wide use of post-tensioning to achieve rigid connections for precast components has been an important innovation in solving this problem. A more detailed discussion of this subject is presented in section 3 of Chapter II.

The color and texture of raw concrete are generally considered rather plain and crude. Usually attention must be paid to the choice of molding material, the application of surface-protection materials, and the use of mechanical means to create surface texture. This however requires extra work and expanse.

In general, as the weight of concrete is reduced, its use in systems building for housing can be expected to increase.

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1. Bender, Richard - <u>A Crack In The Rear-View Mirror,</u> 1973 p. 110.

II. GENERAL PRINCIPLES OF PRECAST CONCRETE CONSTRUCTION IN SYSTEMS BUILDING FOR HOUSING

When precast concrete is used in systems building for housing, it is usually in high-rise developments. This means new concepts in housing design, components and structural lay-out. Precast concrete components can be cast either in the factory or on the building site, depending on the size of components required.

To achieve high industrialization, the systems approach is used. Through this approach, the most efficient organization of the entire building process should result. The key factors which produce successful precast concrete housing are: 1. standardization of component type and structural system; 2. modular co-ordination; 3. performance control; 4. consideration of design and manufacturing tolerances; 5. size and shape of components.

The selection of a structural system is a very important factor in determining the success of precast concrete housing. This selection is a function of several factors, such as housing lay-out, type of housing, manufacturing equipment, safety considerations, erection procedures, and joining methods. Usually, three different types of precast concrete structural systems are applied, as will be discussed at the end of this chapter.

The general principle of the use of precast concrete in different types of housing is shown in Figure 2.1.

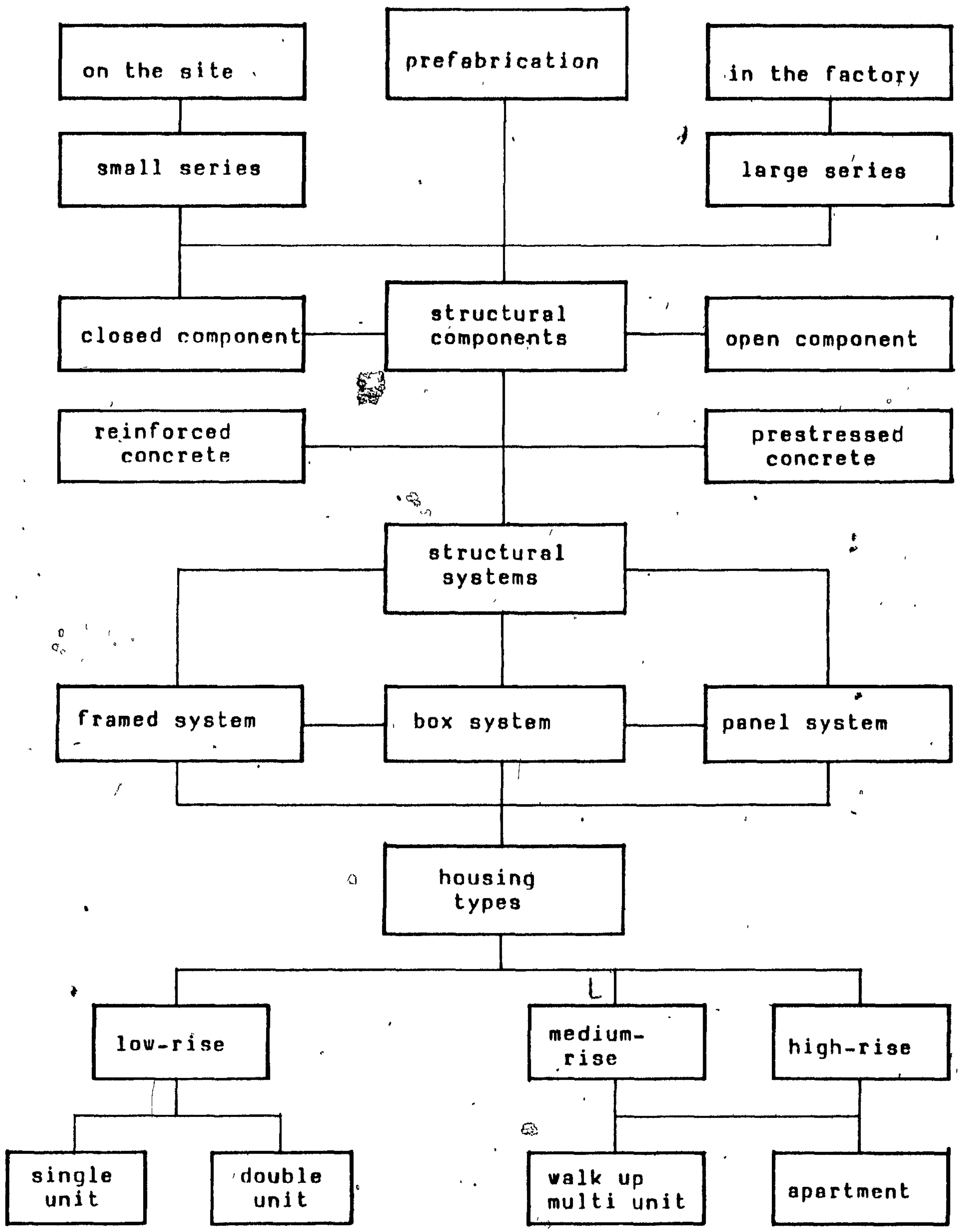

FIG. 2.1

CLASSIFICATION OF PRECAST CONCRETE CONSTRUCTION

IN DIFFERENT TYPES OF HOUSING

1. CLASSIFICATION OF PRECAST CONCRETE CONSTRUCTION

Two types of construction methods can be distinguished relative to the location of the precasting work: factory produced and on-site produced. The former is appropriate for mass production of large series of standardized housing components. The latter is appropriately used as the auxiliary method to produce smaller series of large-size components which are inconvenient to produce in the factory due to transportation limitations. Some systems adopt on-site precasting for individual projects primarily because of economies in transportation costs and the variety of component designs.

A. Factory produced

1. Advantages: (compared to on-site precasting)

a) Independent of weather conditions since the work is performed within permanent factories;

b) Reduction of labor cost due to the well-organized work force;

c) High mechanization and automation under good and continuous factory-control;

d) Precision products because of easy compacting of dry mix and better controlling of the curing process.

2. Disadvantages: (compared to on-site precasting)

a) Precast products must be transported to the erection site, sometimes over great distances thereby raising costs;

b) The number of joints in the structure is increased because smaller sized members are produced for the sake of transportability;

c) High breakage rate during transportation and erection.

B. <u>On-site Precasting</u>

1. <u>Advantages</u>: (compared to the factory-produced method)

a) The elimination of the need for transporting precast products over great distances.

b) Large-size components precast on the site require only vertical hoist equipment;

c) Reduction in the number of hoists and joints since the number of precasting components is reduced;

d) The breakage rate of the products is decreased.

2. <u>Disadvantages</u>: (compared to factory-produced method)

a) Dependency on weather conditions;

b) A low degree of mechanization because of the temporary nature of site work;

c) A lower quality of precast products, resulting from less precise mixture and curing control.

2. <u>COMPONENT HOUSING</u>

A. <u>Components of a Housing System</u>

The components of a housing system are composed of the following parts:

1. structural member
2. outside wall
3. window
4. outside door
5. interior wall
6. interior door
7. framing
8. kitchen
9. bathroom
10. foundation
11. ceiling
12. roof
13. lift shaft
14. stairway
15. others

B. Closed and Open Systems[1,2]

1. Closed system: Components are assembled in such a way that only housing parts from one system or one producer can be employed. Such housing systems, with a closed set of components are Wates in England, Larsson & Nielsen in Denmark, and Camus in France.

2. Open system: Components can be interchanged within groups of different systems. Instead of the original single producer, different manufacturers can incorporate their products in one and the same system. This trend towards an expansion of system may lead an open market where no longer a real system exists. The components in such a system are not confined to be used in housing construction only. They can be adopted by builders of different types of building construction. The same wall panel component for examples can be employed for dwelling or for office building. The final stage is so called comprehensive component buildings.

To achieve this stage, the following steps must be taken into account:

a) Setting of norms (or normalization) and standardization for the components;

b) Modular coordination of the components;

c) Type standardization; and

d) Standardization of joints.

C. Normalization and Standardization of Components[3]

Many industrialized countries have a central bureau or institute to regulate the standardized norms for the building components. The setting of standardized norms prescribes the properties and the quality required of building components.

The closed systems need not be standardized for mass production. Only a requirement for a sufficient number of identical units is needed so that an economically satisfactory production can be established. This is why some of the closed housing systems adopted on-site precasting technique with a lower degree of mechanization compared to that applied in a permanent factory.

However, standardization may contribute to the success of closed systems in several ways:

1. Less costly when components of closed systems are made in part from standard units;

2. Freedom of choice of finished material obtained from other sources and offered in standard sizes; and

3. The use of selected components of closed systems in other applications if they are standardized, thus reducing the cost through increased production.

The gradual evolution of components of closed systems has been considered as a natural and logical approach to the development of open systems. In fully developed open systems, all the components for housing are available from various sources and they are standardized to fit perfectly together.

D. Modular Coordination[4,5]

"Modular coordination" is the name that has been almost universally adopted for an internationally agreed system of uniform dimensioning in the building process.

The module is a unit of measurement. All those dimensions of the various components, which are important for their coordination with other components are whole multiples of this basic module. Thus, modular coordination would serve a dimensional guide both to the manufacturers, offering them a limited set of coordinated product sizes, and to designers, offering them an adequate choice of building sizes and planning grid. Normalization and standardization only give general measures for components, while the modules are exact sizes which both prescribe the dimensions of components, and indicate their position in the system.

1. Multimodules and submodules: The size of the basic module, M, is internationally established as 10 centimeters for metric countries and 4 inches for foot-inch countries. For some

product, a selection of preferred modular sizes must be made, such as whole multiples of 3 M and 6 M which serve as multi-modules or a whole fraction of the basic module such as M/4 (2.5 centimeters respectively 1 inch) which serves as a sub-module (or an infra-module).

The common multimodules used in the C.M.E.A. (Council for Mutual Economic Assistance) countries are 3M-6M-12M-15M-30M-60M. For the submodule, the United Kingdom modular coordination standards recommend for such sizes up to 30 centimeters, the use of 5 centimeters (M/2) and 2.5 centimeters (in descending order of preference). In the C.M.E.A. countries, the use of 1/2M-1/5M-1/10M-1/20M-1/50M-1/100M is common.

2. Single and additive components:

a) Single components: Components, having at least one dimension equal to the functional element which it is intended to create or be a part of, may be called single components, e.g. the length of the floor components.

b) Additive components: Components, which on the building site are added to other components of the same kind so as to form in combination a functional element, may be called additive components, e.g. the width of the floor components.

The purpose of single component is for size standardization while the additive components permit them to form, in various combination, all modular dimensions.

3. Planning grid of housing: Certain dimensions such as thickness, resulting from considerations of an economic nature may possibly not be modular. The thickness of floor may influence the room height. It is usually not possible to have both story heights and room heights modular at the same time. Thus it is internationally agreed that the vertical coordinating dimension is the story height. For housing construction it is to be chosen from amongst the following dimensions: 26M-27M-28M-30M. The modular room height is chosen from amongst the following dimensions: 23M-24M-25M-26M-27M-28M.

For the plans of housing, the horizontal dimensions most commonly used are 3M and 6M.

The thickness of the wall like that of the floor slab may not be given modular dimensions with good economy. In order to keep the planning grid in modular coordination, the center-lines of walls or one-side surface lines of walls are put on grid lines, regardless of the wall thicknesses. When the center-lines of walls coincide with grid lines, the room dimensions will be non-modular (Fig. 2.2a), and when the surface lines of walls coincide with grid lines, one side of the wall is maintaining a fully modular situation, on the other side a non-modular one (Fig. 2.2b). Sometimes regardless of grid lines and to keep every room in a modular situation, a "neutral zone" is arranged to take up the difference between actual wall thickness and the corresponding modular thickness (Fig. 2.2c).

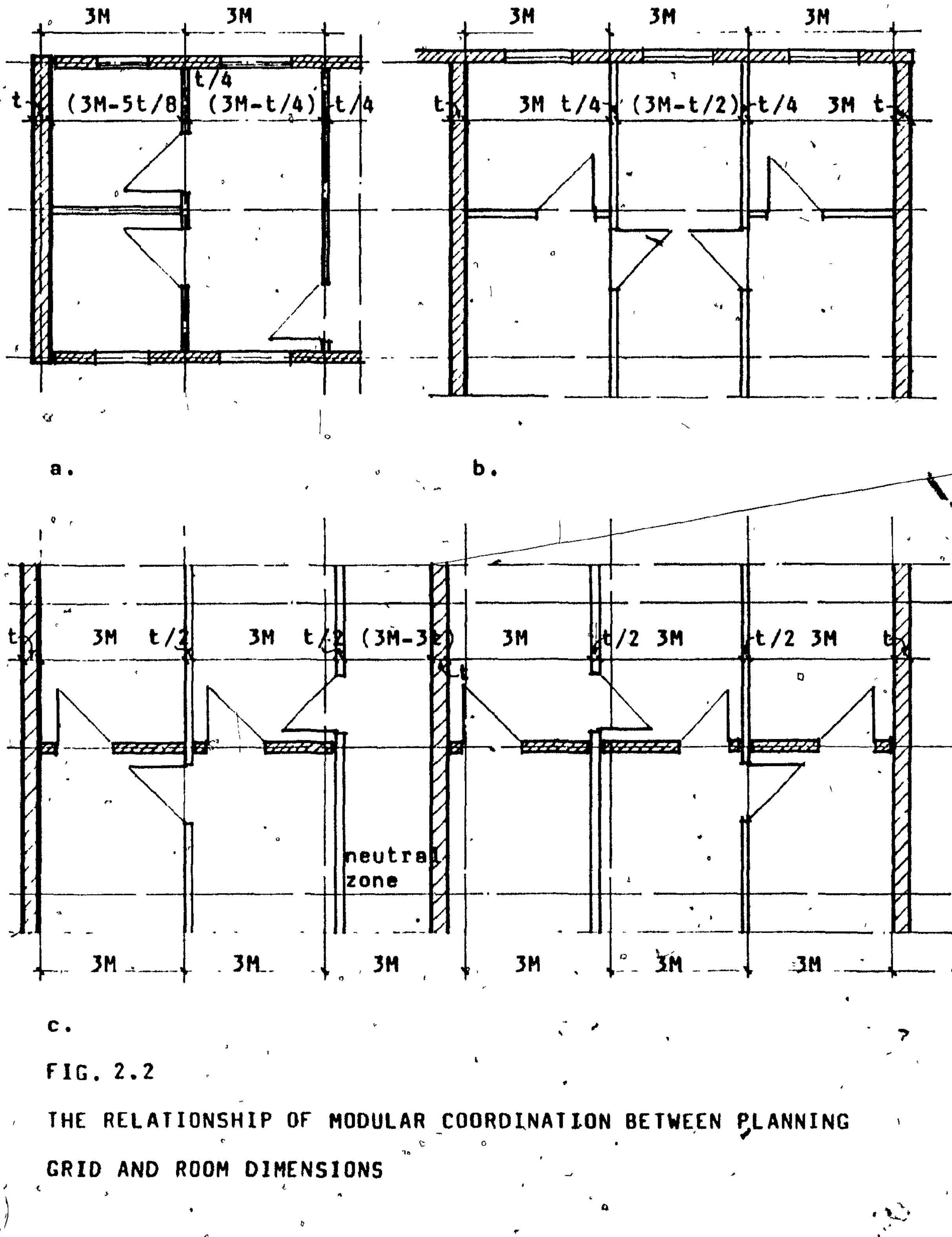

FIG. 2.2

THE RELATIONSHIP OF MODULAR COORDINATION BETWEEN PLANNING GRID AND ROOM DIMENSIONS

E. Type Standardization[6]

Type standardization of material, component, and structure in housing construction gives the possibility of obtaining the greatest degree of repetition of all operations and products in design and production. The reduction of the infinite variety of types to a small number of types is the first and the most important step towards industrialization. The difficulty of type standardization is that it sets up a completely new pattern of satisfying demand, and affects the client as well as the component manufacturer and designer. Therefore, standardization is rather a psychological attitude before it becomes a technical measure. Speaking of economy and efficiency, the less the types and sizes of component, the cheaper the cost. Meanwhile, type standardization permits a specification of assembly groups acting on the site, simplifies and decreases the variety of the erecting equipment, which results in considerable economy in the housing cost.

1. Cycle of Type Standardization: Type standardization is limited by technical progress. New requirements of designer as well as new methods of production and new material make it impossible to maintain the stability of production quality over a long period of time. In European countries, a typification cycle was tried. In the process of preparation of typified designs, a new planning and volume scheme was designed on the

basis of currently produced components, structures, and technologies in order to satisfy new performance requirements and new requirements imposed on the standard of building. Then in accordance with the possibilities of the technical development of construction or the successful results of research and development, a typified design using new products, structures, or a new technology should be taken into consideration. It enables the preparation of high standard typified design. However, it is necessary to shorten the typified cycle and thus speed up the preparation of the new typified design.

As precast concrete is used as a typified material, the development of type standardization must be adjusted in accordance with the new research and development, for instance, the various lightweight concrete, prestressing techniques, etc.

F. Standardization of Joints

The development of modular coordination and of industrialization can only progress when the joining problems can be adequately solved. Joints usually serve two purposes, they not only join precast components together but also can be adjusted to take up the dimensional deviation. Versatile types of joints will be required to fit for various component combinations. However to simplify the assembly procedure, the principles of type standardization should also be applied for the joint design.

For type standardization of joints, the tolerances for both production and assembly must be worked out in advance during the design stage. As soon as the systems are opened and housing is planned with interchangeable components, the tolerance concepts represent the decisive precondition for easy exchanging of components.

G. Tolerances[8,9]

One major requirement for precast units in industrialized housing is dimensional accuracy. It is necessary for components to be interchangeable, to fit together easily, and to ensure that joints of satisfactory appearance can be applied between them. Factors affecting dimensional accuracy are usually due to:

1. Inaccuracy in mold dimension at the time of casting;
2. Inaccuracy due to the placing and compaction; especially the tolerance in thickness when casting horizontally;
3. Warp in the panel due to unsymmetrical curing and uneven stacking; and
4. Volume changes due to shrinkage and temperature.

The following table gives a general concept that in a highly mechanized factory, the tolerances of components can be reduced a great amount in comparison with those produced by on-site precasting or low mechanized factory.

TABLE 2.1 - SUGGESTED TOLERANCES

	TYPE OF COMPONENT		
	On-site Precasting	In Factory	In Highly Mechanized Factory
Mold tolerance	3.0 mm	1.5 mm	0.5 mm
Production tolerance	8.0 mm	5.0 mm	2.0mm
Erection tolerance	6.0 mm	5.0 mm	4.0 mm
Total tolerance	10.0 mm	7.0 mm	4.5 mm

H. The Size, Shape, and Weight of the Individual Component

The heavy weight of precast concrete causes greater problems in transportation, handling, and lifting of the individual components as well as increasing the expenses for the transportation and erection equipment. In addition, the dead weight of the structural system is also increased and thus creates additional expense for the foundations. Therefore it is important to investigate the appropriate size and shape of the precast components. These components should be selected on the basis of the considerations such as:

1. Limitation of means of transportation;

2. Lifting capacity of the crane since economy can be achieved as the weight of component is designed as closer as the lifting capacity of the crane;

3. Tolerance requirements necessary for modular coordination; and

4. Easy operation of joining with other components.

One important advantage of the machine-produced components is the repetitive production. That is, components of complicated shape are possible without the difficulties of many expensive molds. However, the shape of the product should be designed to ease the handling work for the hoisting equipment.

The choice of the size and shape of the component depends on a compromise between the conflicting objectives: 1. To create the largest possible element in order to have the fewest number of joints, 2. To create the smallest or lightest possible element to achieve flexibility and ease in transporting, handling, and lifting into position.

There are many methods to lower the weight of large-size component:

1. Increasing the strength of concrete by using high-strength cement, mechanical compaction, high-pressure and high temperature steam curing, etc.;

2. Decreasing the dimension of the cross-section by using the high-strength materials for prestressing or by using the wire-mesh for reinforcement;

3. Decreasing the density of concrete by using lightweight aggregates or introducing air or gas bubbles into the concrete;

4. Using the most efficient shape analysed from the precise structural design; and

5. Providing complete continuity by post-tensioning or other jointing methods.

3. STRUCTURAL SYSTEMS AND JOINING OF COMPONENTS

Precast concrete structures are of many types, primarily because almost all concrete structures, whether plain, reinforced, or prestressed, can be prefabricated.

Basically, the use of precast concrete for the structural frame of a housing project can be divided into three systems: 1. framed (Fig. 2.3); 2. panel (Fig. 2.4) and 3. box (Fig. 2.5).

In precast concrete construction, due to the need to reduce members into component sizes suitable for manufacturing in the factory, and easy to transport and erect, one of the most important features of concrete construction - continuity - is forfeited. In comparison, cast-in-place concrete construction is completed in one single operation and reinforcing steel is not terminated at the ends of a member but is carried over at the joints into adjacent members, the continuity is maintained and the joints are rigid enough to transfer moments from one member to another (Figs. 2.6a & b). However, the individually manufactured precast components are usually joined together by bolts, welds, or dowels.

Unless the joints are especially designed for rigidity, similar to those of cast-in-place or post-tensioned joints, they are too flexible to transfer moments of significant magnitude from one member to another.

With rigid joints, the distortion caused by a load on one single member is seen to spread to all other members of the structural frame, although the magnitude of deformation decreases with increasing distance from the loaded member. If a member carries transverse load, such as element 3-4, the end rotation "r" caused by the load must be superimposed on those due to rotation ∂ caused by the continuity at the joints (Fig. 2-6c). The final end slopes are seen to be the sums of ∂ and r. The deflected shape of the member is considerably smaller than that of a simple span.

In multi-storey structures, the structural stability against horizontal loads requires sufficient rigidity of joints. Fig. 2-5d shows that in addition to the rotation ∂_2 and ∂_4, one end is displaced horizontally with respect to the other by the amount d, resulting in an additional rotation d/l. The final end slope θ_4 should be the sums of individual contributions ∂, d/l and r.

Because the joining of components is a weak spot in the overall structural system, the response of a structure to moving or pulsating loads or to suddenly applied loads such as may result from earthquake, wind, or explosion must be investigated.

There are basically two ways to make a building safely withstand earthquake loadings. First, a bracing system with enough

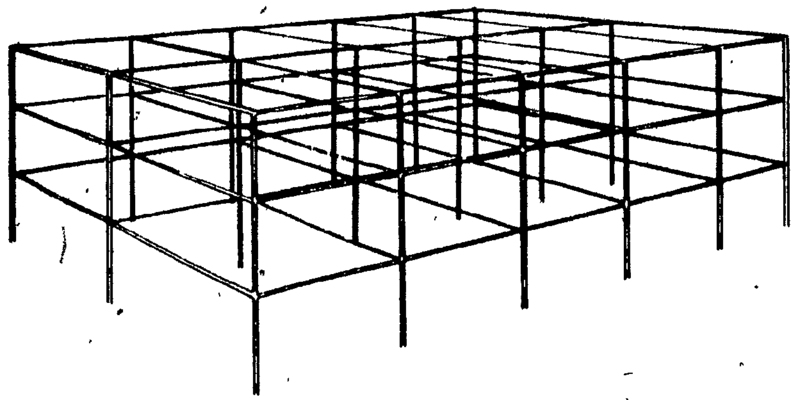

FIG. 2.3
FRAME SYSTEM

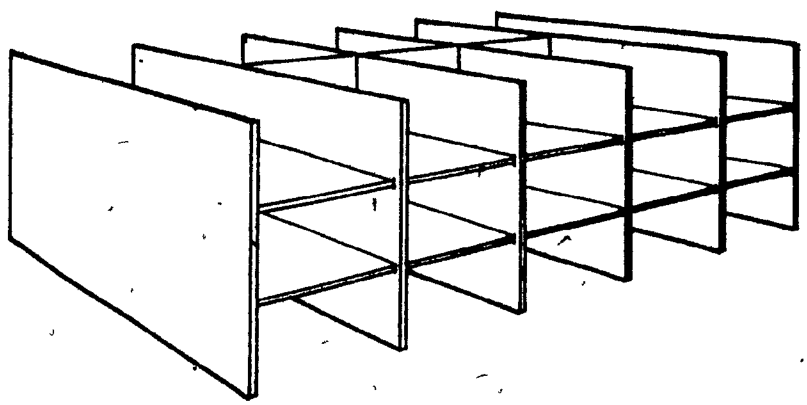

FIG. 2.4
PANEL SYSTEM

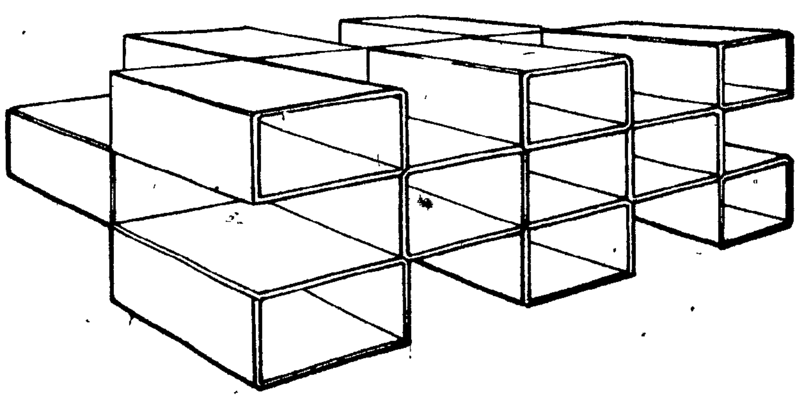

FIG. 2.5
BOX SYSTEM

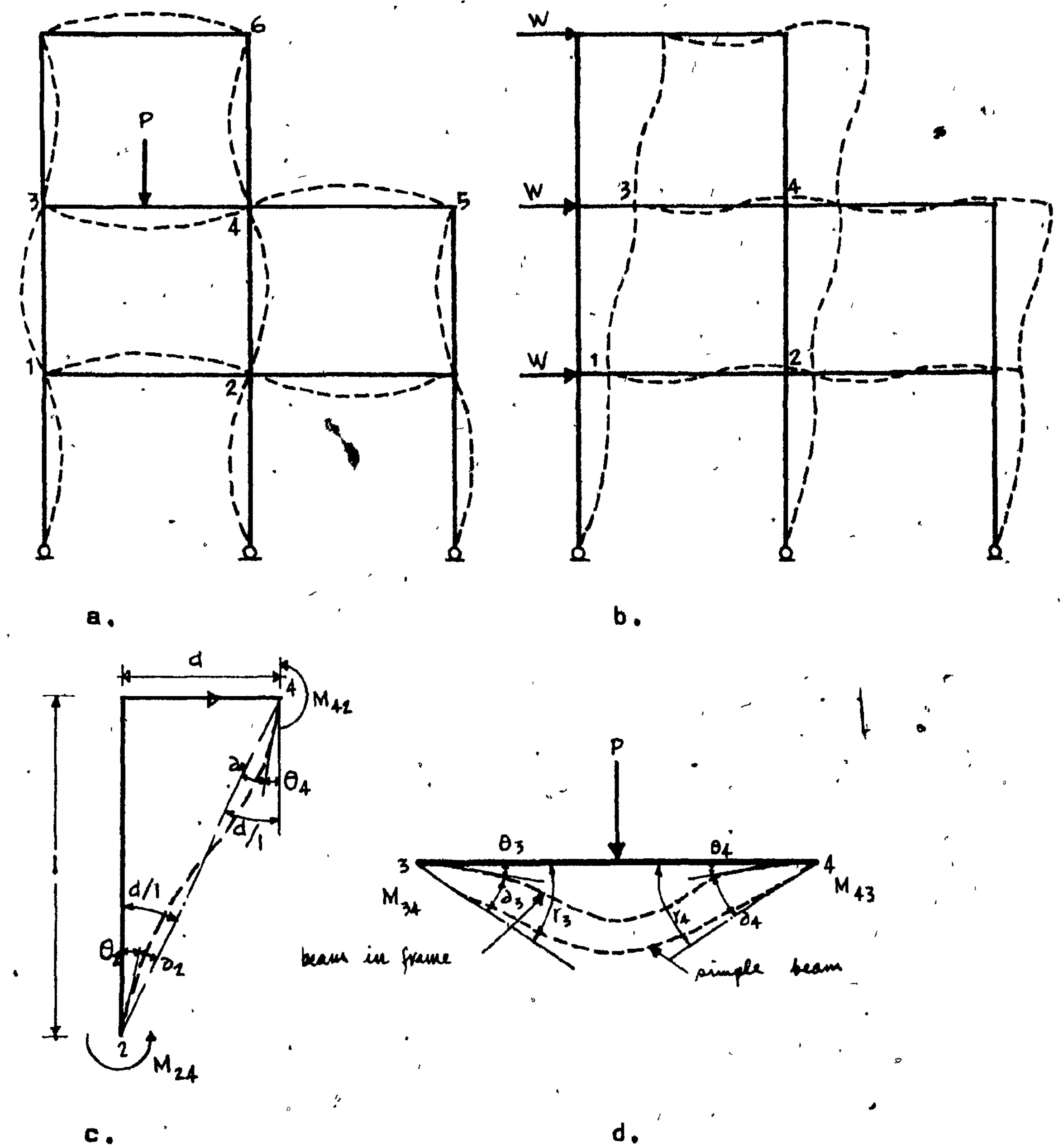

FIG. Z.6

DEFLECTIONS AND SLOPES OF RIGID FRAMES

strength to respond within the elastic range is used to withstand seismic or base shear. Secondly, it is necessary to design into the structural frame properties that are moment resisting in the elastic range and which offer ductility and energy absorption beyond the yield level into the plastic range during a major earthquake. This second method is cheaper since we draw on the reserve strength in the plastic range. Generally, a rigid moment-resisting frame system can take considerably more earthquake load than a more rigid panel system with shear wall. For example, the horizontal force factor 'K' is 1.33 with the shear wall type of panel system (Fig. 2-7) whereas for the moment-resisting three-dimensional frame "K" is 0.67, only half as much. This means that due to its built-in ductility, the moment-resisting three-dimensional frame can be designed for half as much lateral load as the shear-wall type of panel system.[10]

Quantitatively, the lateral force applied to the building varies not only proportionately with the seismic intensity in any given area, but also must be adjusted for the "period" of the building. The "period" is the time it takes the structure to sway back and forth during the earthquake vibration. It is dependent upon the structural height and plan dimension. In practice, the lateral force used in design is further modified to reflect the type of bracing system. Experience has shown that the panel system has relatively intermediate periods and should design with an increased force. However the moment-

Total Base Shear, $V = KCW$
K_o is determined by the structural system.
$C = \dfrac{0.05}{3T}$ where T is the fundamental period of vibration of the structure.
W = weight of building.

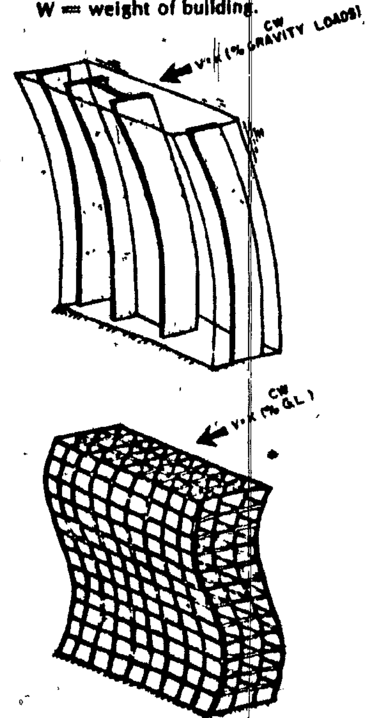

FIG. 2.7

A MOMENT-RESISTING FRAME CAN TAKE MORE EARTHQUAKE LOAD THAN A RIGID SHEAR WALL STRUCTURE SYSTEM resisting three-dimensional frame can be designed based on a lower force than for common types of framing.

Wind loads are also important in the design of most structures, but accurate predictions of the wind loads to which a structure may be subjected cannot be made in the same manner as those of seismic intensity. Especially for tall buildings, the velocity gradient of the wind is unknown. Usually instruments are installed on tall buildings to measure the wind pressure which actually occurs and provides information as recommendation for design of tall building. For low-rise buildings, however, there have been few field measurements of wind loading and recommendations for design have relied almost entirely upon the results of model studies. The controlled wind flow from a wind tunnel simulates the natural wind on the model being tested.[11]

In structural design applications, the usual practice is to convert the dynamic pressure arising from wind action to the equivalent static forces.[12] In multi-storey housing, the external and internal wind forces on building must be taken in design application. For building with wall openings, the internal pressure or suction acting on the walls and roof are especially important. The joints must provide sufficient strength to hold structural components together.

Explosion is another type of impact loading although it is not a usual case. The collapse of a 24-storey wing of a high-rise appartment in London, England, in May, 1968, due to a gas explosion, is making experts take a long, hard retrospective look at the disaster in an inquiry that could have implications for prefabrication in high-rise structures.[13,14] Since an explosion is a potential hazard, even though remote, an effective type of joint continuity should have been provided. While wind and other normal loads were provided for, evidently the possibility of an internal explosion was simply never considered.

The choice of structural system to satisfy the local codes and regulations is a considerable factor in systems building. The joints, therefore become important and their design will require much expert skill and greater assembly care. There are basically four ways to connect the precast components:

1. Bolted joints;
2. Welded reinforcement and concrete protection;
3. The combination of precast concrete with cast-in-place concrete (composite joints);
4. Post-tensioning.

A. Framed Systems

The basic elements of framed systems are beams, columns, and floor slabs. Beams and columns can be cast either as separate linear components or combined rigid frame components, depending on the size of the structure and the convenience of transporting and handling.

The cross-section of beams and columns can be generally distinguished as rectangular, I-, T-, Double T-shaped and hollow sections.

B. Panel Systems

These types of systems ideally comply with the character of reinforced concrete where the structures bear the load in their own plane. Structural components belonging to this group are load-bearing walls, two-way load-bearing plates and slabs, folded plates, and shells. In housing construction, only load-bearing walls and slabs are greatly used.

The joining problem is difficult since there is a long joining line where the two surfaces meet. The joint can be designed for only one degree of freedom. Usually the floor panels are supported along their edges by a sufficient number of load-bearing wall panels, arranged to unite the floor panels within the building. Joints between the vertical and horizontal planes are only adequate for resisting horizontal and vertical forces, but they are not moment-resisting. Special precautions must be taken for this kind of joining method:

1. Carefully designed joints of adequate strength;

2. Precise manufacturing tolerances for components in the factory and precise erection tolerances on the site;

3. Strict and careful supervision of erection on the site;

4. A secondary moment-resisting system in the structure for wind and lateral forces must be provided.

C. Box Systems

In high labor cost countries, there is a tendency to use large elements, despite their heavy weight, for industrialized housing system; especially in the United States and Canada. The entire house is prefabricated in the factory, then transported to the erecting site. The original form of this kind of prefabrication is the mobile home. The reason for this is primarily economy, as the on-site labor cost is almost entirely eliminated. Recently, the box of a complete dwelling unit was used as a basic module and combined with other boxes to form a housing complex. This idea was first implemented in the Habitat project of Expo '67 in Montreal. Later, the Puerto Rico Habitat, and the Uniment and Shelley systems adopted a similar concept.

From the structural viewpoint, the whole box is prefabricated in the factory by using either the beam and column or rigid frames with infilling panels or the wall panels rigidly connected with floor or ceiling slabs. This way, the joints for one complete box unit are all joined together or cast monolithically in the factory, therefore only the joints between boxes are needed and much of the on-site erection cost is eliminated. However, the use of heavy machinery such as gantry cranes is necessary on the site to lift up the box. The most serious problem in using this system is optimum box dimensions and weight with respect to the transportation methods.

In general, the framed box is lighter than the monolithic box as the infilling panels can be made of light-weight material, while the manufacturing process of monolithic boxes is simpler.

4. THE APPLICATION OF STRUCTURAL SYSTEMS

The structure which can be satisfactorily produced by an industrialized building system for housing must be suitable for both mass production and simplified erection procedures.

Eastern Europe has employed large panel systems which are mainly based on the two-way span system where interior load-bearing concrete walls and concrete prestressed floor panels are used. The self-supporting non-structural walls provide only thermal insulation.

Russia has achieved much success in using large panel systems in the past decade. Initially this type of system encountered a number of problems, particularly with joints of components. Thus the trend in Russia today leads to the box design by assembly of panels into box shapes in the factory. Since the box is very heavy, sometimes weighing up to 13 tons, heavy gantry cranes are required for on-site handling. Another type of Russian box system is based on the framed box system. A reinforced concrete base slab, precast prestressed columns and a horizontal precast concrete bracing rib is used as the structural frame of the box. The use of light-weight boarding material of asbesto cement for the enclosure walls and ceilings alleviate the weight problems.

Most of the Western European countries have adopted the panel system. They include:

1. Longitudinal wall systems;
2. Cross-wall systems;
3. Two-way span systems.

In recent years, the impetus of the housing demand makes us look back toward the experience and the achievement gained by the European Systems. Many large panel systems have been adopted by architects and prefabrication firms. The Techcrete System, for example, is a panel structural system developed by Carl Koch and Engineer Sepp Firnkas, which had its first application in 1963 when 200 four-storey units were built in Roxbury, Massachusetts.

"Operation Breakthrough" as described in the previous chapter, resulted in the selection of twenty systems, of which eight were precast concrete systems. Among the eight, five were Panel systems:[15-18]

1. Henry C. Beck Company proposed a system based on the French Balency precast concrete system.

2. Descon/Concordia proposed to use prestressed post-tensioned concrete or simple reinforced concrete cross-wall system.

3. Modular Communities Incorporated has acquired the American rights to the French developed Tracoba I cross-wall system, and proposed this.

4. Rouse-Wates proposed a system based on the English on-site and factory produced precast concrete bearing wall system.

5. Forest City Enterprises, Incorporated proposed a precast concrete system using both floor and wall panels which it had developed.

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1. Blachere, G., "The Consequences of the Open System on Design and Integration", Toward Industrialized Building, 1967, pp. 238-239.
2. Parkanyi, K., "The Inherent Contradictions of the Closed Systems of Prefabrication and the Future Trends of Evolution", pp. 295-296.
3. Sittig, J., "Standardization as a Basic Condition of Industrialized Building" pp. 39-41.
4. Schmidt, H., "Modular Coordination, Repetition and Architecture", Towards Industrialized Building, 1967, pp. 216-218.
5. Ministry of Public Building and Works, Dimensional Coordination, DC5-7, London, 1967.
6. Janicki, S., "Typification as a Basis for Industrialized Building", Towards Industrialized Buildings, 1967, p. 80.
7. Harrison, H.W., "Joints and Component Interchange", Building, Nov. 11th, 1966, pp. 145-148.
8. Halasz, R., von, "Tolerances in Manufacture and Erection", Building, Sept. 2nd, 1966, pp. 113-116.
9. Griffiths, T.J., "Standardization and Tolerance in Precast Concrete Construction", Toward Industrialized Buildings, 1968 pp. 176-180.
10. Wing, W.C., "Concrete Frame Is Made 'Flexible' To Absorb Earthquake Loads", Architectural Record, April 1968, pp. 191-194.
11. Menzies, J.B., "Wind Loads on Low-rise Structures"
12. ASCE Task Committee in Wind Forces, "Wind Forces On Structures (Final Report)," Trans. Am. Soc. Civil Engrs., 126(II), pp. 1124-1198, 1961.
13. Anon, "Failure of High-Rise System - How Safe Should Structure Really Be?", Architectural Record, Nov. 1968, pp. 169-170.
14. Anon, "Ronon Point", Building Research Station News, Winter, 1968, pp. 10-11.

*15. HUD, Breakthrough, May 1969.

16. HUD, Operation Breakthrough - Mass produced and Industrialized Housing, a Bibliography, 1970.

17. Anon., "Operation Breakthrough" - Arch. Record, April 1970, pp. 137-152.

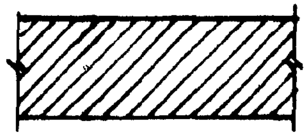
18. Raney, D., Stephens, S., "Operation Breakthrough - Operation P/R" Progressive Architecture, April 1970, pp. 120-133.

III. STRUCTURAL BEHAVIOURS AND JOINTS OF PANEL SYSTEMS

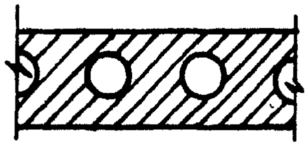
There are many ways in which the components of panel systems can be classified: 1. From the viewpoint of design, the components can be distinguished according to their function in the building. Therefore, walls may be external or internal, structural or non-structural, while slabs may be floors, stairs or roofs; 2. They may be classified according to their structure, fabrication, or material qualities. Thus depending on the materials used in their production, they may be homogeneous (Fig. 3.1) or composite (Fig. 3.2,3.3); 3. According to their cross sections, they may be solid, hollow or cored, tray or pan, folded plate, or ribbed with infilling (Fig. 3.4); 4. The components can be further differentiated by their method of support and reinforcement, for instance, slabs can be one-way or two-way.[1]

Interior structural walls are generally built of homogeneous panels of ordinary concrete. Partition walls usually use other materials lighter than ordinary concrete. Exterior walls are built of homogeneous panels, composite panels, or less often, skeletal panels. However, for thermal insulation there is little difference between load-bearing walls or non-load bearing walls.

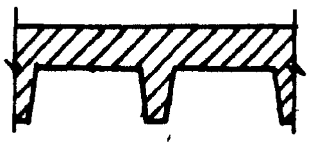
Generally speaking, a panel system consists of two major components, walls and slabs. Walls carry loads in their own plane, axially loaded-in compression. They can be divided



a. Solid



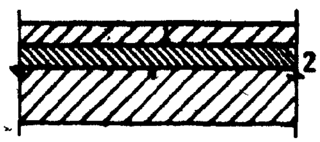
b. Cored



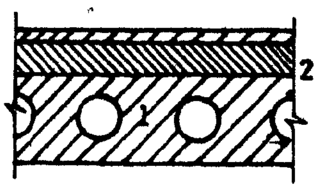
c. Ribbed

FIG. 3.1

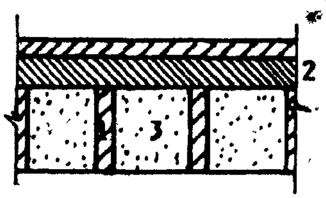
HOMOGENEOUS COMPONENTS



a. Solid



b. Cored

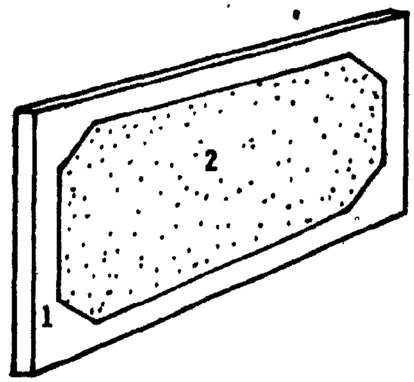


c. Ribbed

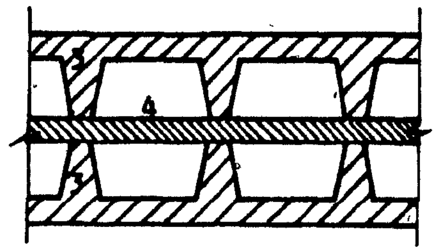
FIG. 3.2

COMPOSITE COMPONENTS

1. precast concrete layer 2. insulating layer
3. filler



a. Skeletal



b. Compound

FIG. 3.3

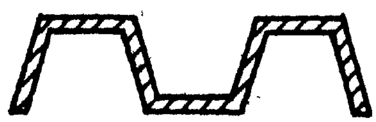
COMPOSITE COMPONENTS

1. precast concrete frame
2. filler
3. ribbed concrete
4. insulating layer

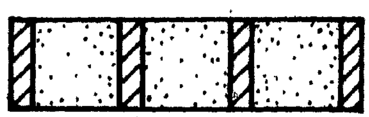
a. Solid

b. Hollow

c. Tray Panel



d. Folded Plate



e. Ribbed With Infilling

FIG. 3.4
TYPICAL CROSS SECTION OF
SURFACE FORMING COMPONENTS

into three categories:

1. Load bearing wall panel: It bears the load in its own plane.

2. Non-load bearing wall panel: It carries its own weight and does not support the floor loads.

3. Shear wall: It provides three dimensional stiffness to the total structural assembly since the wall itself is placed perpendicular to both the slabs and the load bearing walls and thus the complete assemblage can resist horizontal as well as vertical loads. Slabs are loaded perpendicular to planes and carry forces in bending and shear. Two-way slabs are usually supported along at least three edges while one-way slab are usually supported along two edges.

For single level housing construction, the floor or roof slabs are usually sufficiently strong to provide the required lateral stiffness. For multi-storey housing, the shear walls are employed to provide rigidity in both longitudinal and transverse directions. The main task of load bearing walls, which are considered to be effectively supported laterally along their horizontal edges by floor slabs, is to carry vertical loading from slabs and upper storey walls. The vertical forces acting on the floors are transmitted to the load-bearing walls as uniformly distributed line forces. The horizontal forces, mainly the wind loads and seismic loads are also transmitted to the load-bearing walls as transverse shear forces which act on the joining strip between the floor and wall and they are usually only considered in high-rise building construction.

In low-rise housing, the floor slabs can resist horizontal loading by bending in their own planes in the same manner as a girder wall and thus effectively transfer the horizontal loads to the load-bearing walls. The slabs can be assumed to be an infinitely rigid plate.

In multi-storey housing, the load bearing walls are usually supported by the intersecting structural or shear walls. If right angles are maintained, it becomes impossible for the edges of load bearing walls to deflect a substantial amount horizontally. Even though the shear wall is not used for vertical load transfer, the lateral bracing potential of this rigid vertical plane is utilized in stabilizing multi-storey building against the forces of wind or seismic shock.

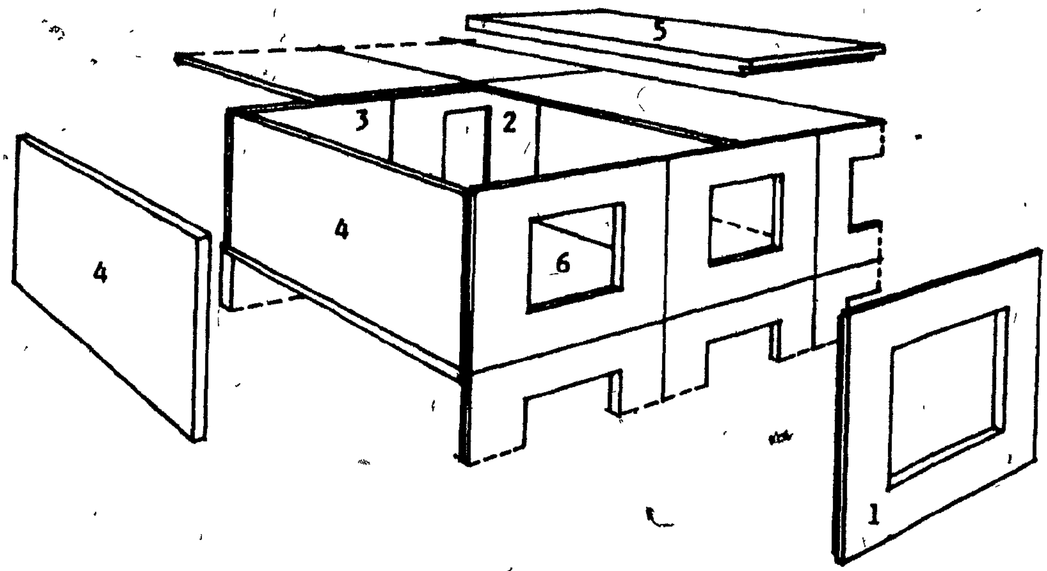
Joints in the panel system are very important. The constructional requirement governing the joining of components depends on the participation of the wall and slab in the functions of the building as a whole. The joints must be able to withstand the same forces as would exist in the corresponding sections of a monolithic structure. The joints strips between wall and slab are mainly acted upon by normal vertical forces, and the joint strips between load-bearing wall and load-bearing or shear wall by tangential forces.

Joints in the exterior wall must be weatherproof and thermal barriers must be formed to prevent heat losses. Joints in interior walls should form effective acoustical barriers.

A. Longitudinal Wall System

The longitudinal-wall system applied to housing has much in common with traditional block and brickwork techniques. The main load-bearing precast concrete walls with proper thermal properties are placed longitudinally, e.g., parallel to the main axis of the building. External walls in this system serve as both structural members and also barriers for visual, thermal and acoustic purposes. However the load-carrying character limits the window opening. This system is seldom employed in detached housing design since the required large glazed areas of the exterior panels dictate the use of precast framed systems. Longitudinal wall systems are more appropriate in the building of schools, hospitals or offices where smaller window openings are sufficient for the space requirement.

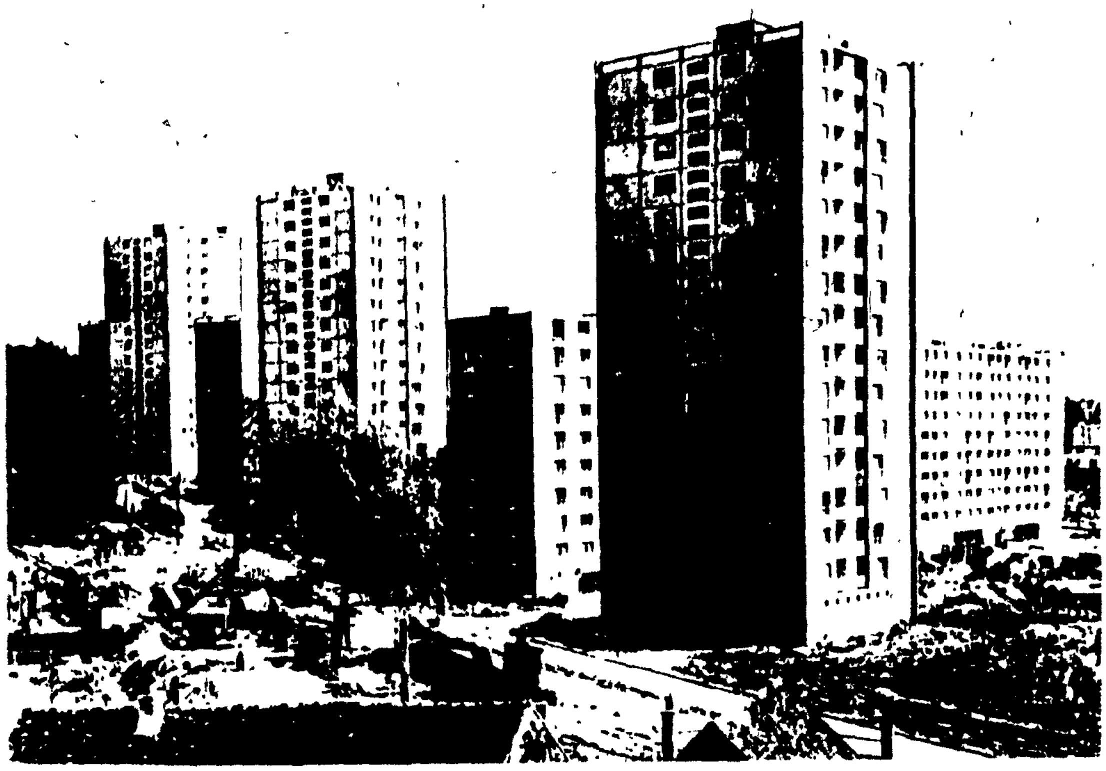
Longitudinal wall systems have been used extensively in France for the quick and economical construction of the apartment blocks. The basic French traditional construction is typified by rows of houses with middle longitudinal bearing walls, and one-way floor slabs supported between these middle walls, and the front and back walls incorporating the "French balconies" (Fig. 3.5). Figure 3.6 is an example of a housing construction employing the typical longitudinal wall system which is best known as "Coignet system". This system, designed by Edmond Coignet, was the first prefabricated system used in France. He used a longitudinal wall system for the first time



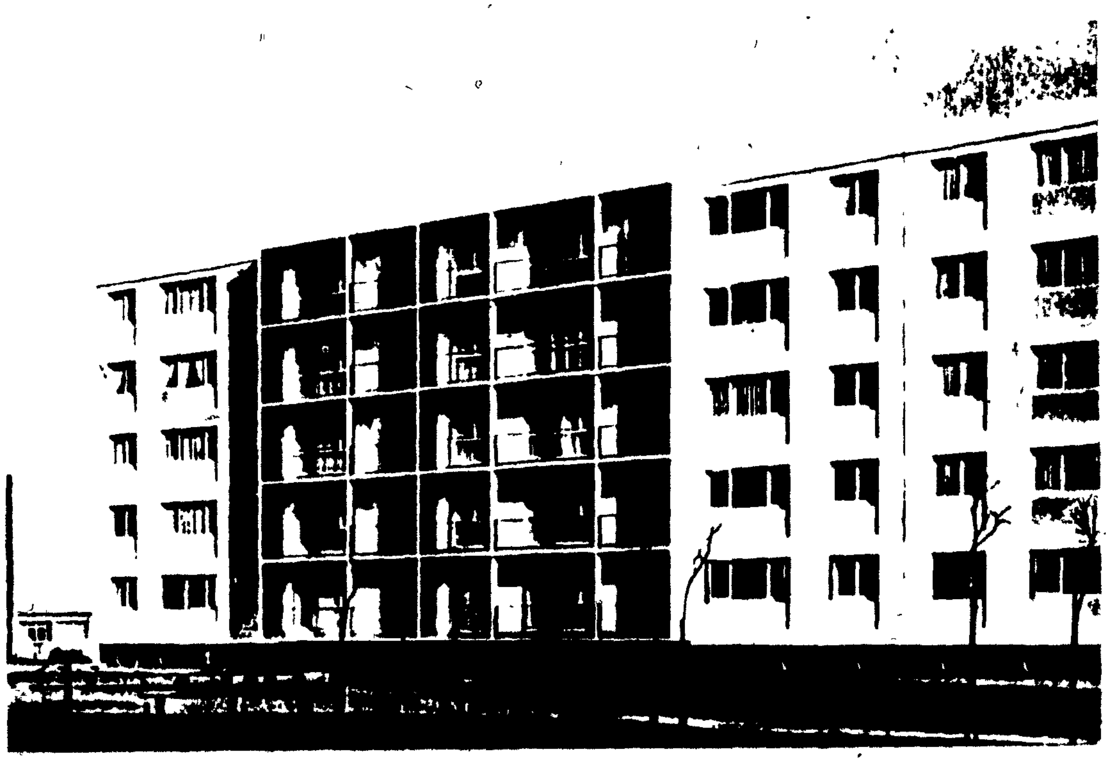
1. Load-bearing Window Wall
2. Load-bearing Wall With Door Opening
3. Load-bearing Wall
4. Partition
5. One-way Roof Slab
6. One-way Floor Slab

FIG. 3.5

TYPICAL LONGITUDINAL WALL SYSTEM



Savigny-sur-Orge, France, 900 apartments



Blanc-Mesnil, France, 1016 apartments

FIG. 3.6

COIGNET SYSTEM

in building the Casino at Biarritz. A typical floor plan of a housing project built on this system is shown in Fig. 3.7. The joining method can be seen in Fig. 3.8. Figure 3.8a shows a vertical joint while Fig. 3.8b shows a horizontal one. From this joining example an open drain type joint is used as a vertical joint for weather protection. The design is such that elements are simply placed in contact with appropriate tongues and grooves ensuring accurate registry. This automatically leaves the necessary spaces for grouping. Except for the steel bars protruding from the precast elements, all additional reinforcement is inserted in the field. No special shuttering is required on site for grouting concrete.[2]

Variation of this system are shown in Fig. 3.9.[3] The Leningrad System in Fig. 3.9 uses piers and lintels to replace the longitudinal walls. The piers between windows carry loads from lintels which bear both the floor load and the load from the piers above. The horizontal sills are non-load bearing. In some designs, the space between the piers is filled by a reinforced concrete window.

Figure 3.9b is a sketch showing the Moscow system where the floor slabs are supported on the transverse lintels which in turn sit on the longitudinal bearing wall. Normally the interior partitions coincide with the line of cross lintels. In this case, the spans for the floor slabs resting on the lintel are changed from the transverse direction into the longitudinal one and are considerably shorter than in the previous scheme. The use of this system is particularly justified in building with large cross spans over 20'-0" long.

A further development of the Moscow system can be seen in Fig. 3.9c. The middle row of longitudinal bearing wall is changed into transverse direction to bear the load from the cross lintels. This system has found wide use in Czechoslovakia. Brick is normally used instead of concrete for the bearing wall. These variants of longitudinal wall systems are obviously the transformation of framed construction, especially the latter two systems whose arrangement of beams and piers resemble that of framed construction.

Two much more clear examples of mixed framed and panel structures can be seen in Fig. 3.9d and 3.9e. Both arrangements have been used in the Russian building industry. The scheme in Fig. 3.9d is similar to Leningrad system where a longitudinal framed component of beams and columns is employed to replace the middle longitudinal bearing wall. In three-bay or corridor housing arrangement, this framed component can be replaced by two similar rows. The example if Fig. 3.9e is a slide variation of the Czechoslavakian system where the transverse framed component of a double-cross shaped precast unit is employed to replace the transverse load-bearing pier.

The use of piers and lintels instead of exterior wall can eliminate the limitation of window opening although large openings may increase the cross-sections of the lintels. However the exterior piers still maintain the various functions such as load-bearing, thermal, visual, and acoustic purposes. In the last two figures, (Fig. 3.9d,e) the employment of the framed components allows a freer architectural design of the interior space.

B. Cross-Wall System

This system is the most common system in prefabricated housing construction (Fig. 3.10). Since the main load-bearing walls are placed at right angles to the main axis of the building, the exterior wall can be non-load bearing or curtain wall. Thus no restriction is placed on the window openings. If the facade wall is non-load bearing wall, the appearance may still be similar to a longitudinal bearing wall system. The distinction between them is in the internal structure of the wall components. Their thermal insulation property however is the same.

Figure 3.11 shows the floor plan of a three-bed room apartment which is a housing project built in Rotterdam, Netherlands by adopting the French Coignet system. According to the Dutch building regulations, the floor must not be supported on the external walls. Thus the original Coignet system (Fig. 3.7) of longitudinal walls had to be changed. In this project, the

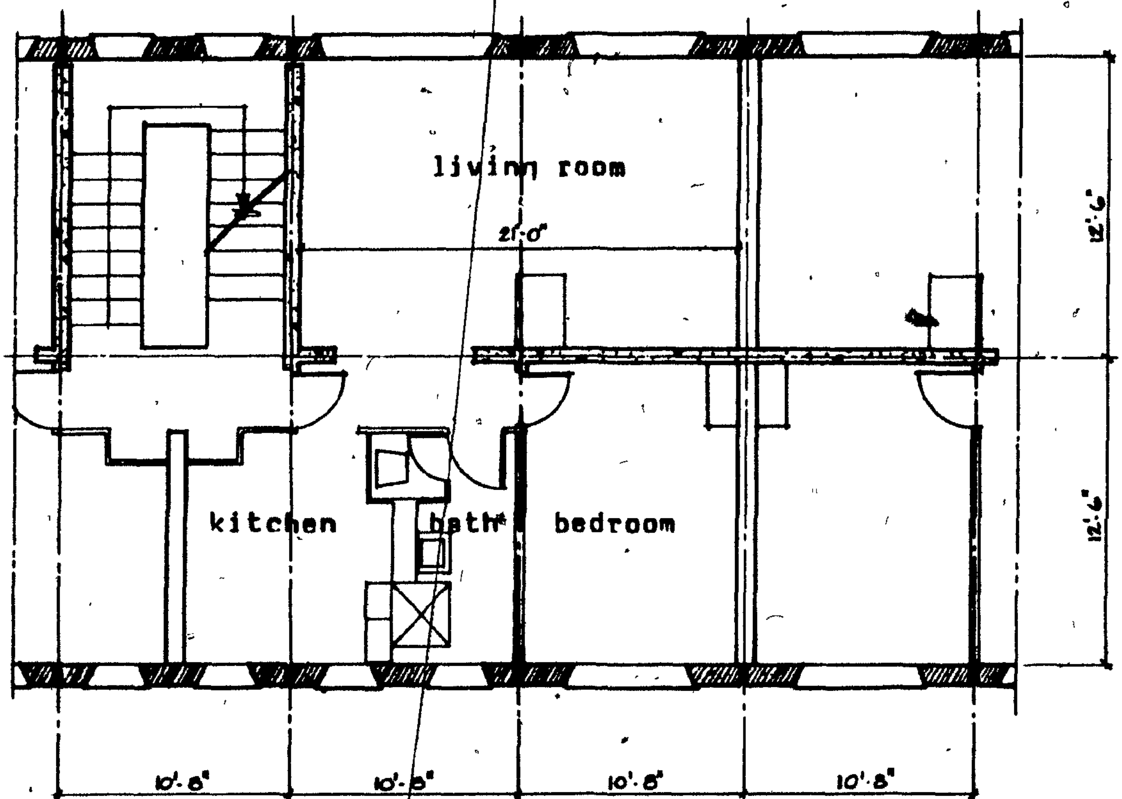
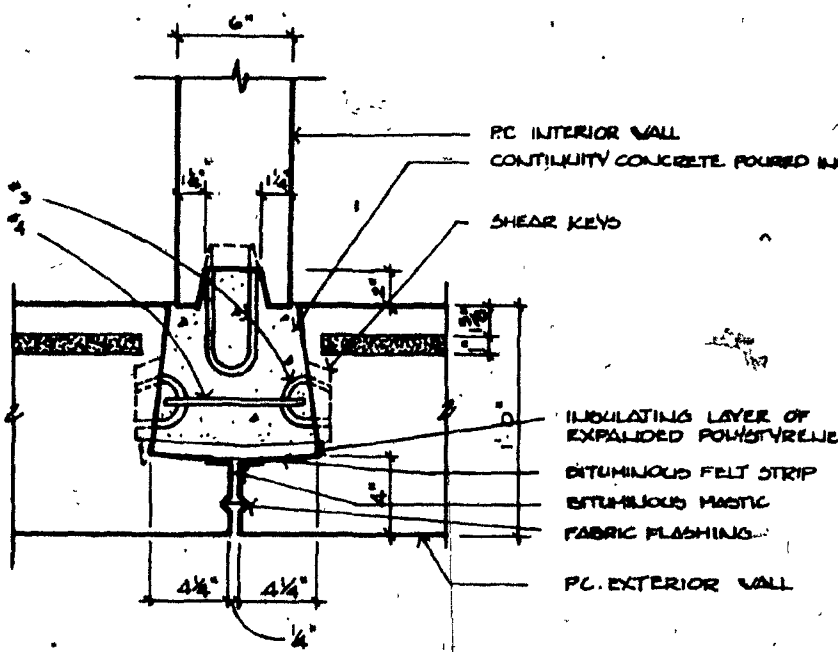
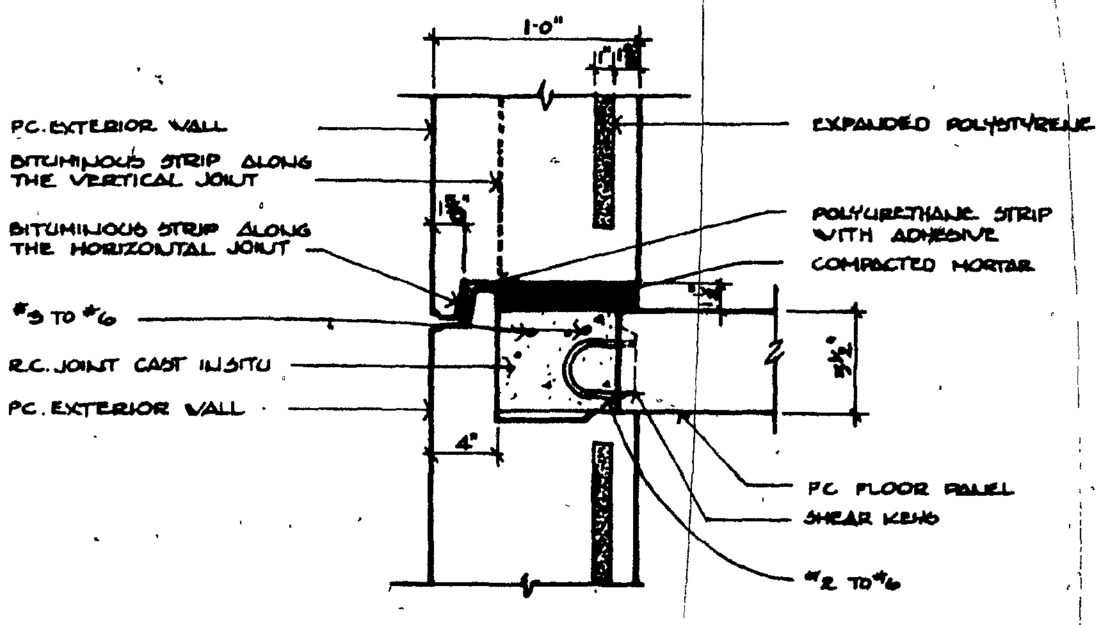


FIG. 3.7

FRENCH COIGNET SYSTEM - TYPICAL FLOOR PLAN



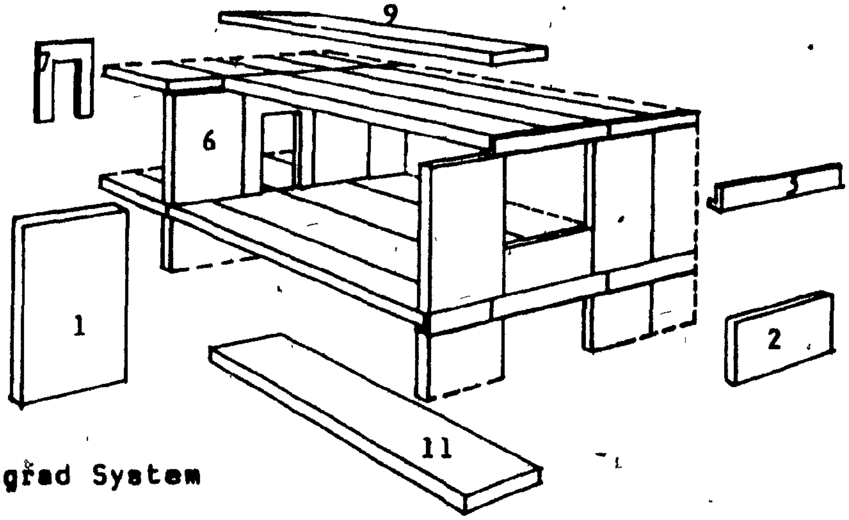
a. PLAN SECTION: WALL - WALL



b. VERTICAL SECTION : WALL - FLOOR

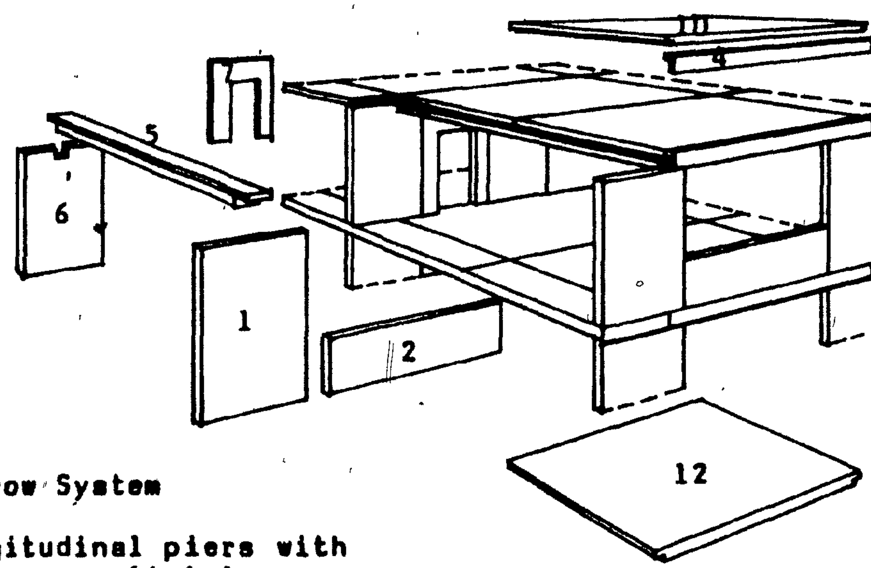
FIG. 3.8

TYPICAL JOINTS - COIGNET SYSTEM



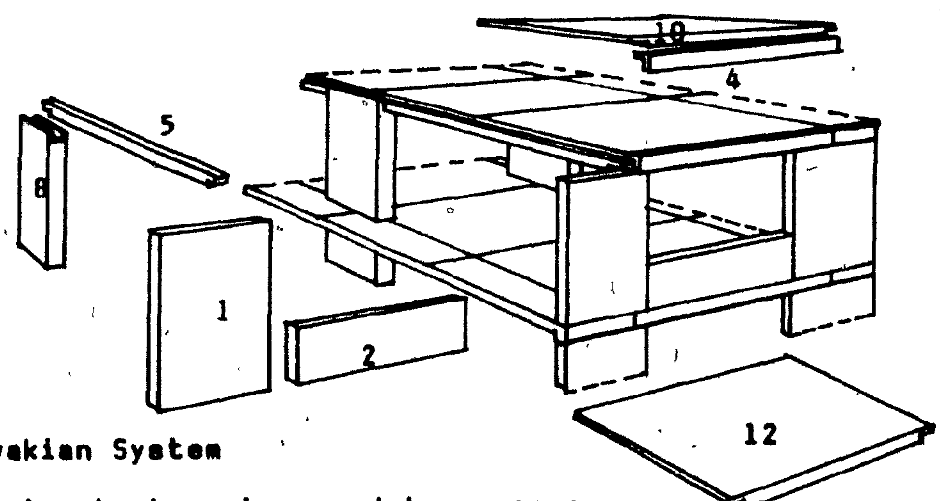
a. Leningrad System

piers and lintels in longitudinal direction



b. Moscow System

longitudinal piers with
transverse lintels

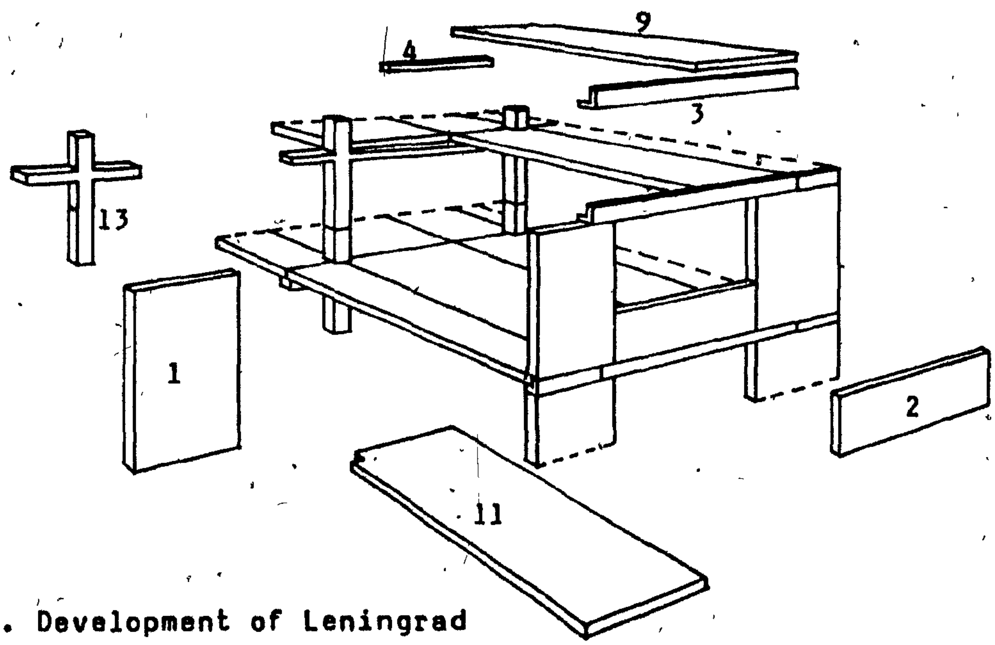


c. Czechoslovakian System

longitudinal exterior piers and transverse
interior with transverse lintels

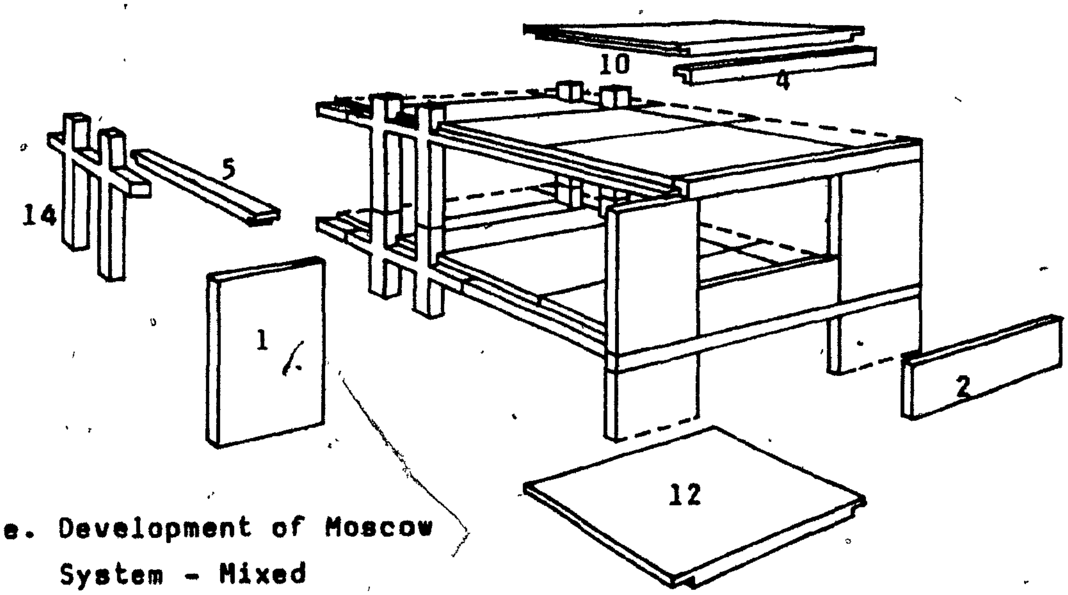
FIG 3.9

SEE ALSO NEXT PAGE



d. Development of Leningrad
System - Mixed

longitudinal piers and frames in longitudinal direction



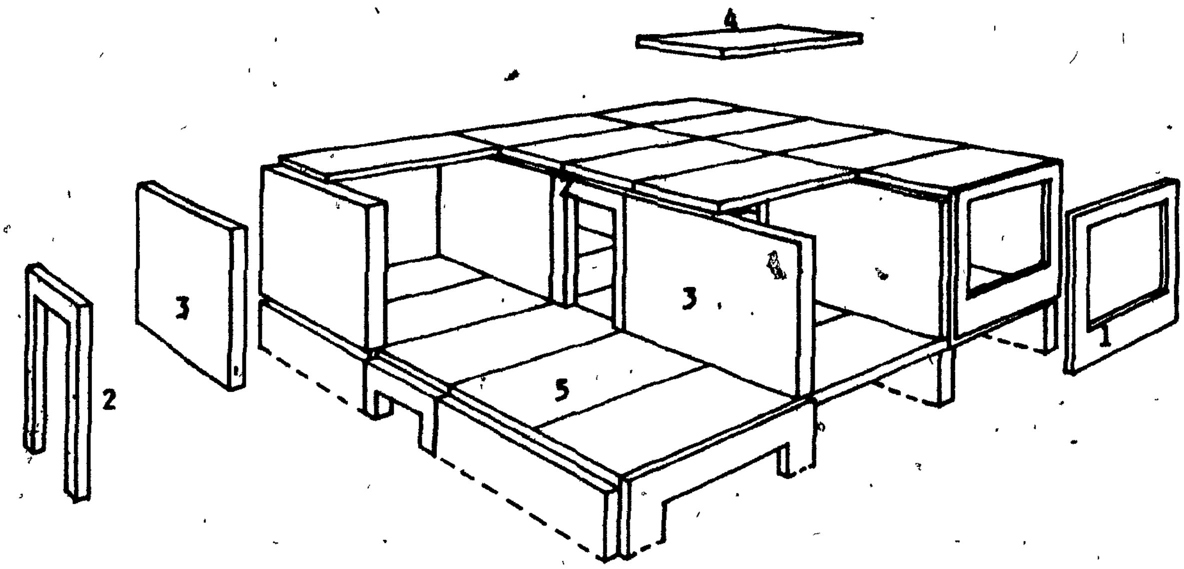
e. Development of Moscow
System - Mixed

longitudinal piers and frames in transverse direction

FIG. 3.9

DEVELOPMENT OF PANEL STRUCTURAL SYSTEM

LONGITUDINAL WALL



1. non-load bearing or curtain window panel
2. load-bearing door panel or rigid frame
3. load-bearing wall
4. one-way roof slab
5. one-way floor slab

FIG. 3.10

TYPICAL CROSS _ WALL SYSTEM

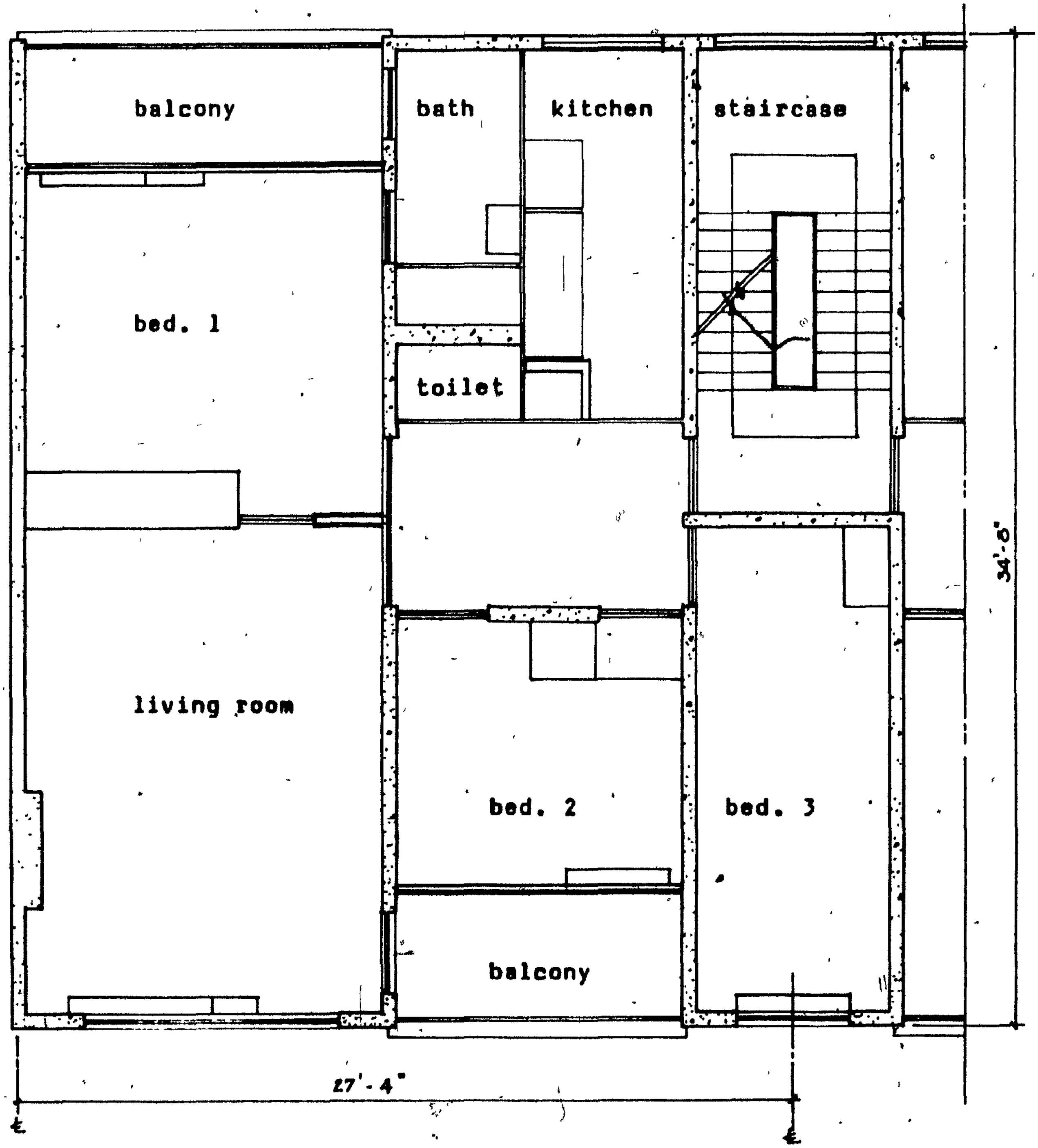
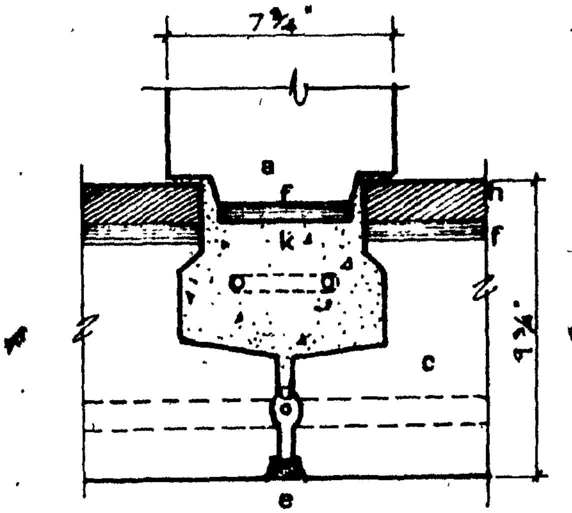


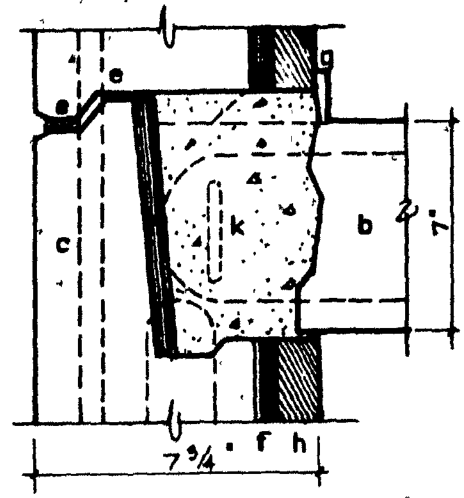
FIG. 3.11

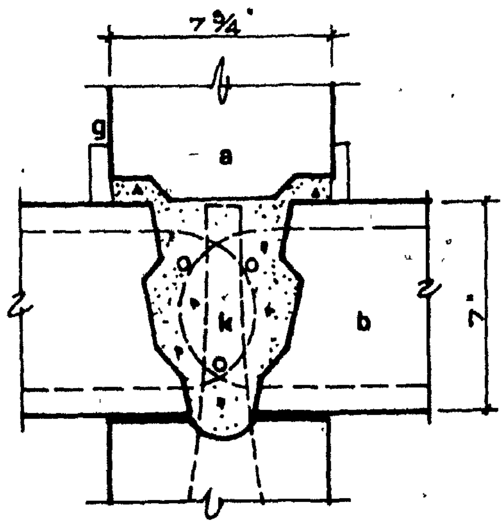
DUTCH DURA-COIGNET N.V. SYSTEM - TYPICAL PLAN cross-walls adjoining the staircase wall, the ventillation blocks, and additional planes parallel to the facade are used to provide the required longitudinal stiffness.

Usually, satisfactory joints between the load-bearing cross-walls and non-load bearing external wall ~~or~~ the joints between non-load bearing walls and floor slabs are not easy to attain. The construction of the joints for this Dutch Dura-Coignet system can be seen in Fig. 3.12. The principle of construction is the same as used in that of Coignet system (Fig. 3.8).[4]

Another French building of the "Camus" system utilizes the cross-wall system (Fig. 3.13 & 3.14). The Camus system has many points of similarity with the Coignet system. Both systems were the pioneers in the use of large prefabricated panel in France, although following close behind are the Barets, Estitot, Cauvet, Costamagna, and Balency systems. The Coignet and Camus systems each have a special factory for panel manufacturing operations. Figure 3.14a shows the typical plan of this system. Facade panels in the Camus system are made by laying a sheet of colored tile mounted on brown paper into the bottom of mold. A thin layer of mortar is spread, followed by a layer of concrete, a light reinforcement mat, and more concrete. Expanded polystyrene is next added with a substantial inner leaf of reinforced concrete which is smoothed sufficiently so that it will not require plastering. The units are assembled in a







a. interior wall

b. floor slab

c. facade wall

d. baffle

e. weather seals

f. insulation

g. permanent shuttering for in-situ concrete

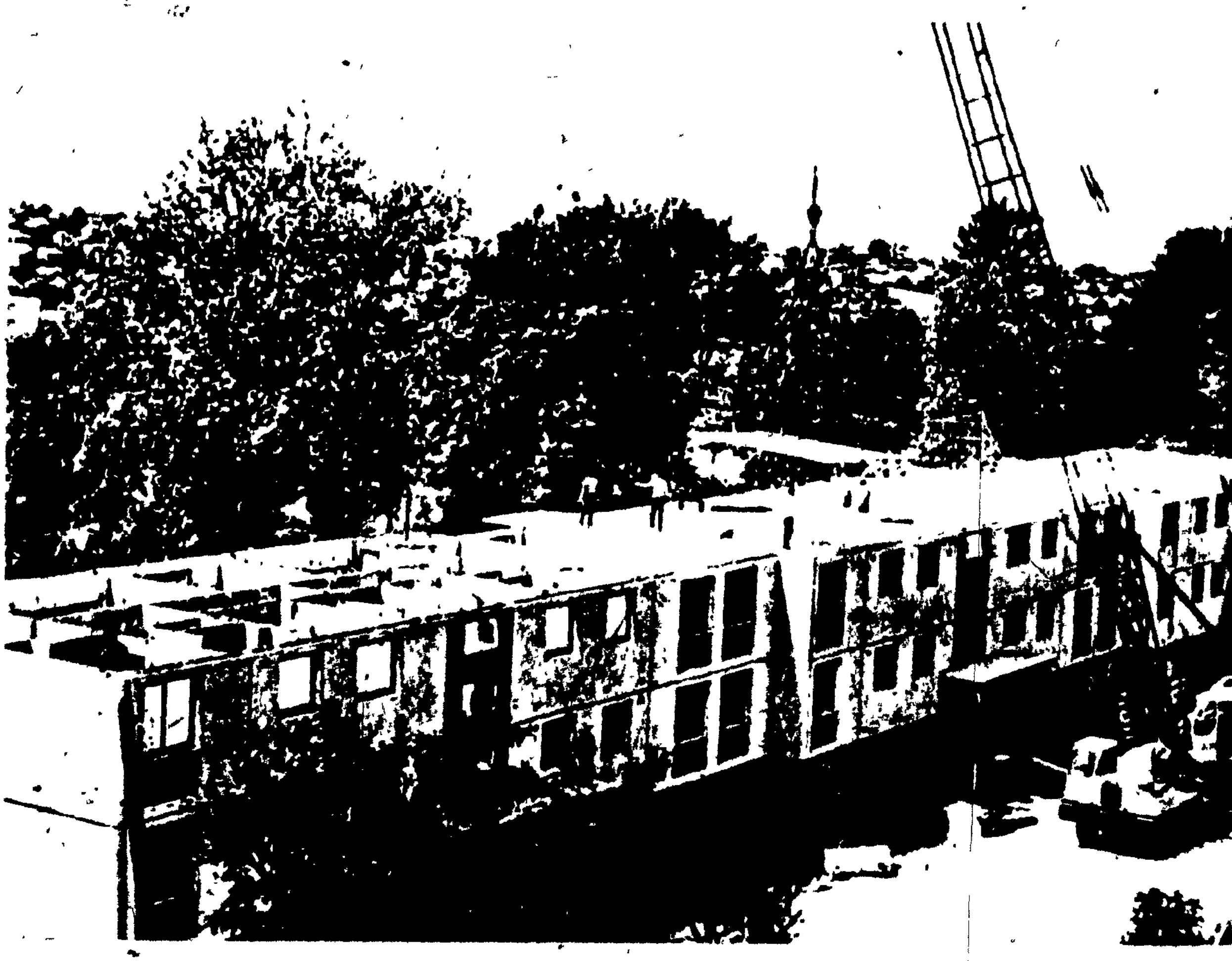
h. interior finishes

j. additional reinforcement

k. in-situ concrete

FIG. 3.12

TYPICAL JOINTS - DUTCH DURA-COIGNET N.V. SYSTEM



element being placed in position

FIG. 3.13

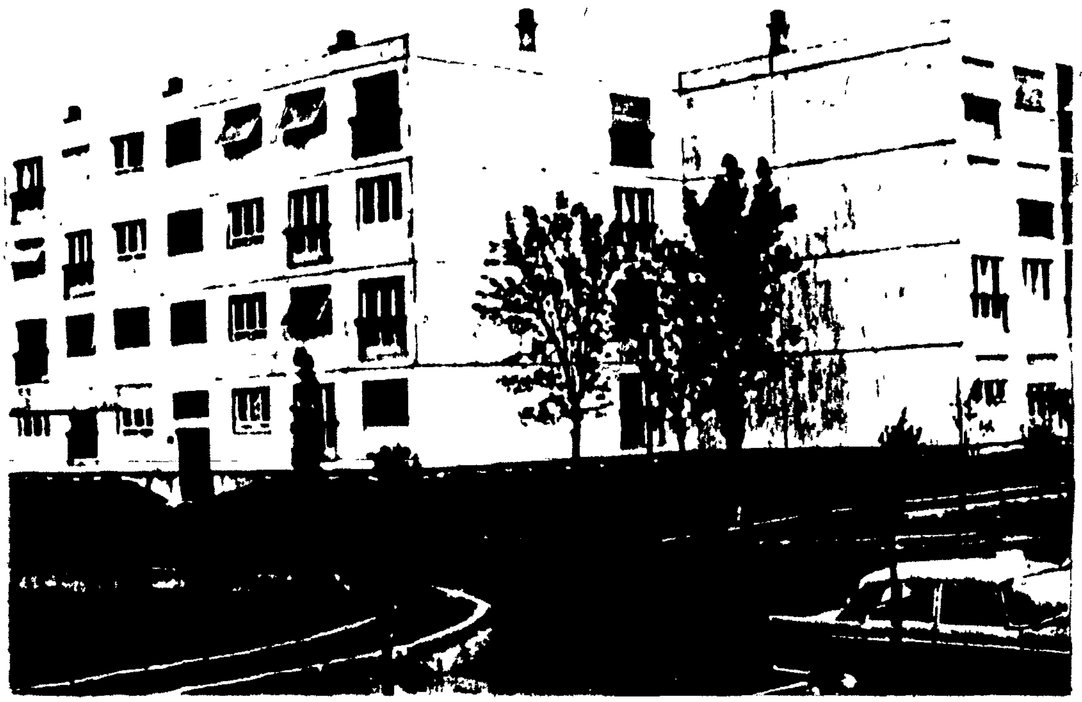
CAMUS SYSTEM

medium rent apartment
near Paris

thirteen story apartment
block in Paris

FIG. 3.13a

CAMUS SYSTEM

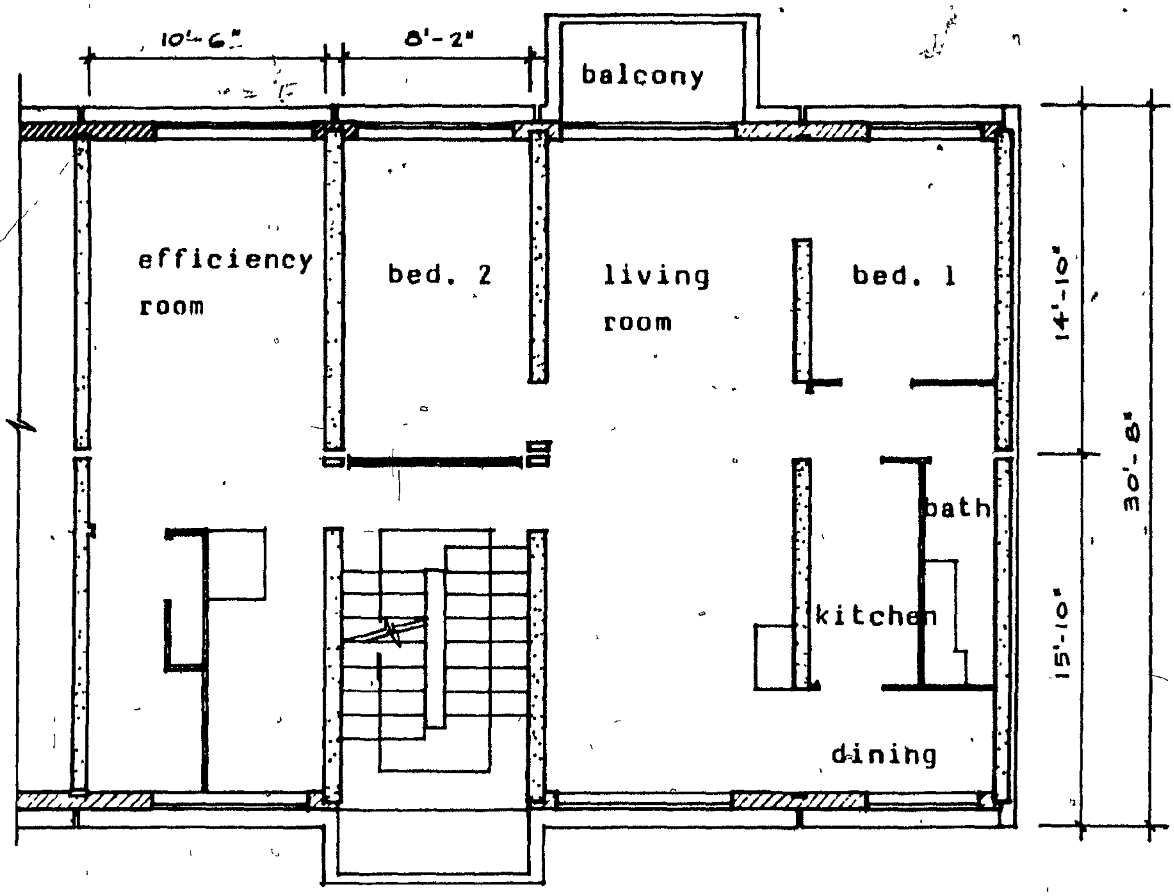


luxury apartment near Paris

medium rent apartment project

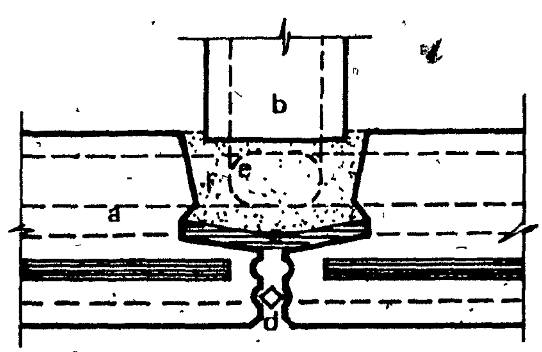
FIG. 3.13b

CAMUS SYSTEM



A. typical floor plan

a. exterior wall
b. cross wall
c. insulation
d. buffle
e. reinforcing
f. in-situ concrete



B. joining of exterior walls and cross-wall

FIG. 3.14

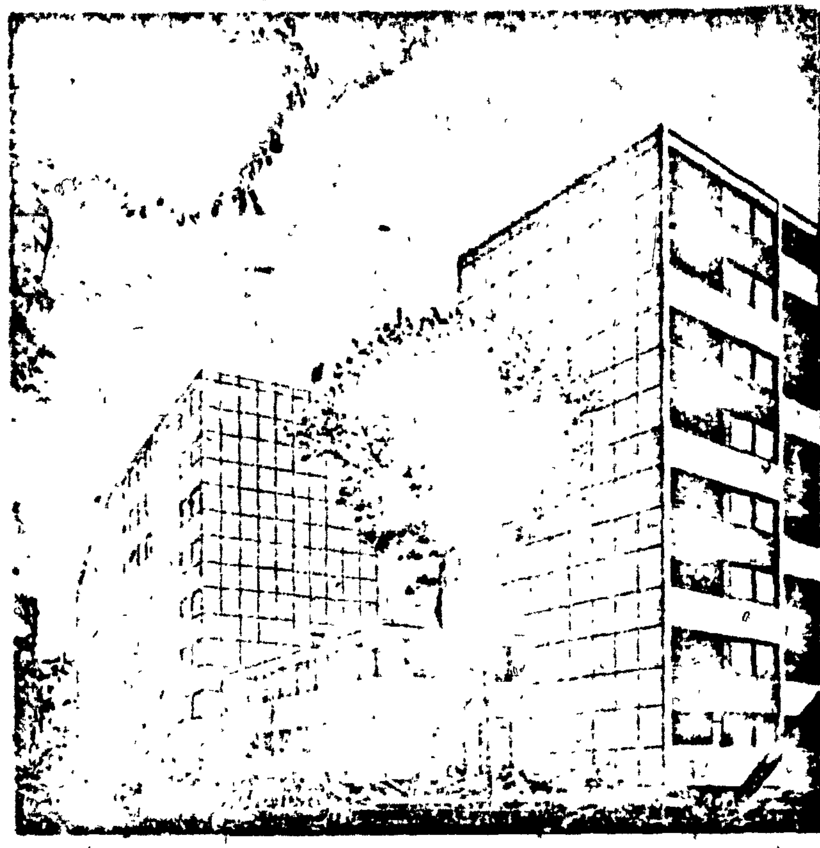
FRENCH CAMUS SYSTEM

rather unique manner. In the joining of facade walls and cross-wall (Fig. 3.14b), steel reinforcement loops protrude at both exterior non-load bearing walls and interior cross wall. These are allowed to overlap, and a steel rod is pushed in between them, tying the panels together. Joints are then grouted, producing an extremely rigid structure.[5,6]

The Danish Larsen-Nielsen system produces similar system as Camus for industrialized housing (Fig. 3.15).[7]

Normally there are two different ways to treat the joints. The facade walls cover the outside edges of the structural cross-wall and covering strips are used for the edges of the floor slab. The examples already discussed are in Fig. 3.8, 3.12, 3.14. In the second method, the facade walls are laid on the floor slabs and flush with the edges of the cross walls. In this case the edges of the floor slab and crosswalls are visible on the facade. Figure 3.16 shows a Polish T-3 type system erected at Nowe Tychy Silesia is an example of this type.[8] Since the exposure of the edges of the internal structural units easily cause excessive heat losses due to the "Cold joint", this arrangement should be avoided in the cold weather. Furthermore a special effort should be taken into account for a acoustic and visual reasons. Even in the first case, suitable thermal insulation should be applied to the edges of the exterior wall to avoid excessive heat loss.

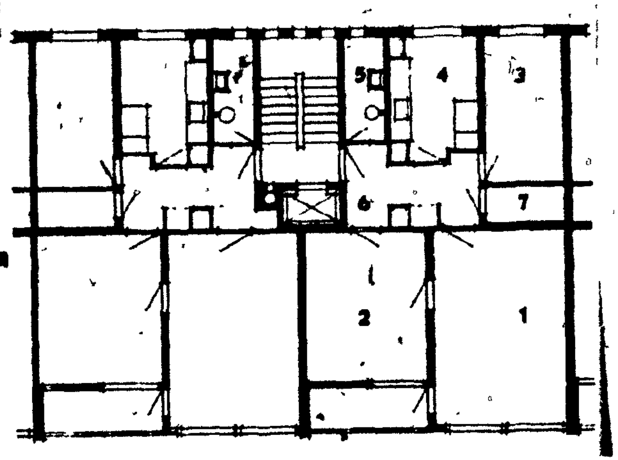
The exterior walls of the crosswall system are not necessarily made of concrete, and frequently the external cladding



a. exterior view

Type of flat: 3 rooms
(81^2)

1. Living room
2. Bedroom or living room
3. Bedroom
4. Dining kitchen
5. Bath
6. Hall
7. Store room



b. typical floor plan

FIG. 3.15

DANISH LARSEN & NIELSON SYSTEM

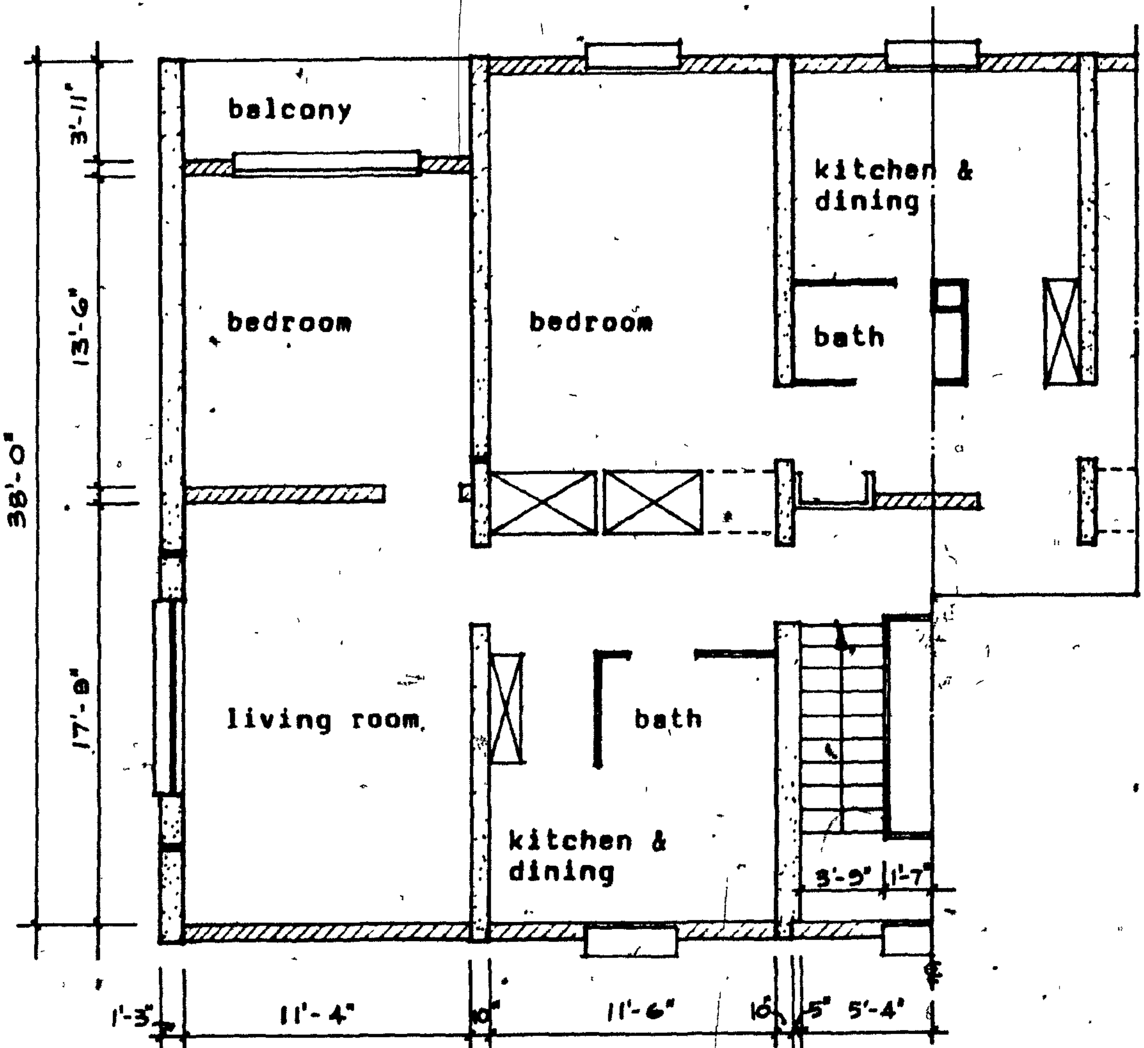


FIG. 3.16

POLISH T-3 TYPE SYSTEM

panels are constructed with other materials. However the use of large lightweight concrete panels for exterior walls is most common.

Examples of the development of crosswall system can be seen in Figs. 3.17 & 3.18. Figure 3.17 shows an arrangement of the girder walls which replace the interior cross-walls. A Russian housing project in Moscow has adopted this system. The loading from upper stories are distributed to the end column portions of the girder walls. Each floor slab is carried by the beam at the upper edge of this wall and is inserted in the recess. The girder wall itself is actually a frame infilled with a thin concrete panel. Since the main loads are carried by the frame, doors can be opened on the thin panel as required. In the case of Fig. 3.18, the L-shape load-bearing walls replace the crosswalls. The main advantage is that such walls are stable during the erection process and do not require temporary propping. Polish WUF-62 (Fig. 3.19) is an example of this type of construction.[9]

1. non-load bearing window panel
2. girder-wall with door opening
3. girder wall
4. partition
5. longitudinal one-way roof slab
6. longitudinal one-way floor slab

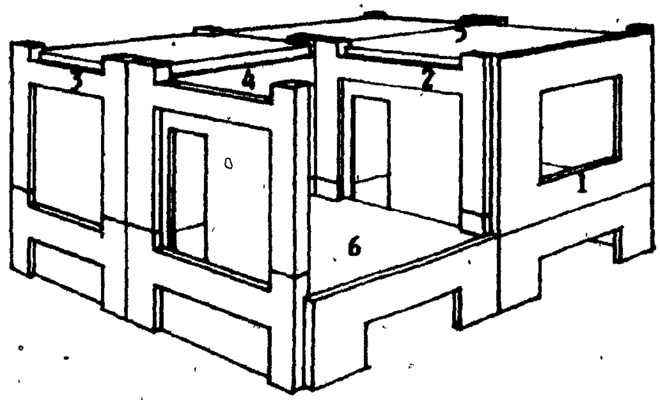


FIG. 3.17

DEVELOPMENT OF PANEL SYSTEM - CROSS WALL
GIRDER-WALL CONSTRUCTION

1. non-load bearing window panel
2. L shaped load-bearing wall
3. two-way roof slab
4. two-way floor slab

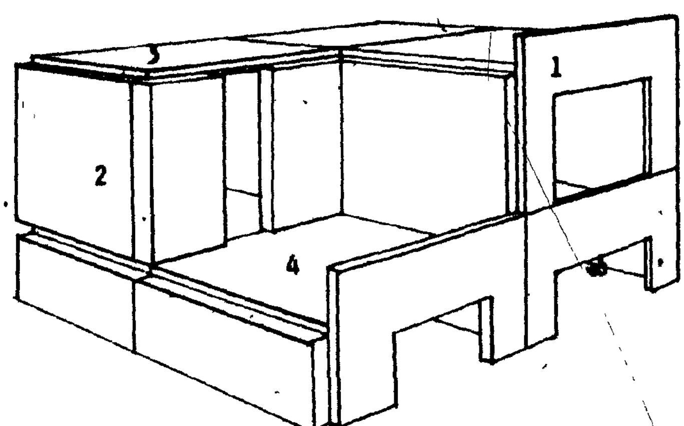


FIG. 3.18

DEVELOPMENT OF PANEL SYSTEM - CROSS WALL
L SHAPED LOAD-BEARING WALL CONSTRUCTION

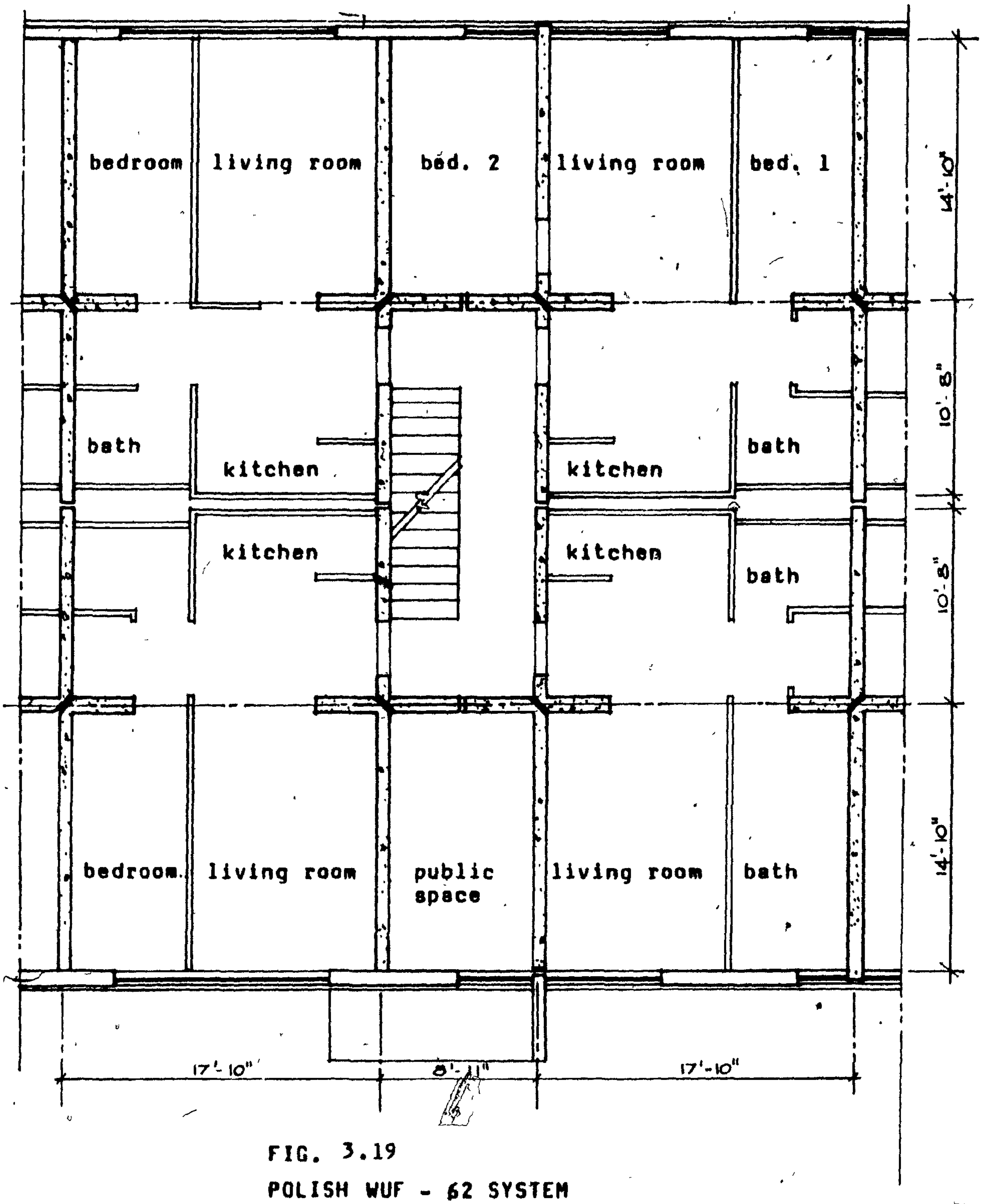


FIG. 3.19

POLISH WUF - 62 SYSTEM

C. Two-Way Span System

In this system, since the load-bearing walls are replaced in both longitudinal and transverse directions, the finished building are rigid in both directions (Fig. 3.20). Maximum benefit is derived from the Two-way spanning, if the spans are equal. Another merit of this system is the reduced deflection compared with one-way system.

The two-way span system is seldom used in housing construction. The main reasons can be as follows:

1. The load-carrying character of the facade wall restricts freedom in the design of the large glazed area for the window openings as in the case of the longitudinal wall system.

2. The structural wall panels should usually coincide with the room-dividing wall from the view point of economy. If the interior space arrangement can form square-shaped rooms, the two-way slabs are the most economical solution, effecting substantial saving in steel reinforcement. However typical housing plan arrangement usually adopt a double-loaded corridor, and thus the use of this system increases the number of interior longitudinal wall components and restricts the plan layout.

3. Slabs are usually prefabricated as long staves which will be mainly reinforced in the long direction, since the long staves may be more easily handled than a monolithic flat plate. Therefore, the crosswall system is more popular than two-way system.

1. load-bearing window panel
2. load-bearing wall with door opening
3. load-bearing wall
4. two-way roof slab
5. two-way floor slab

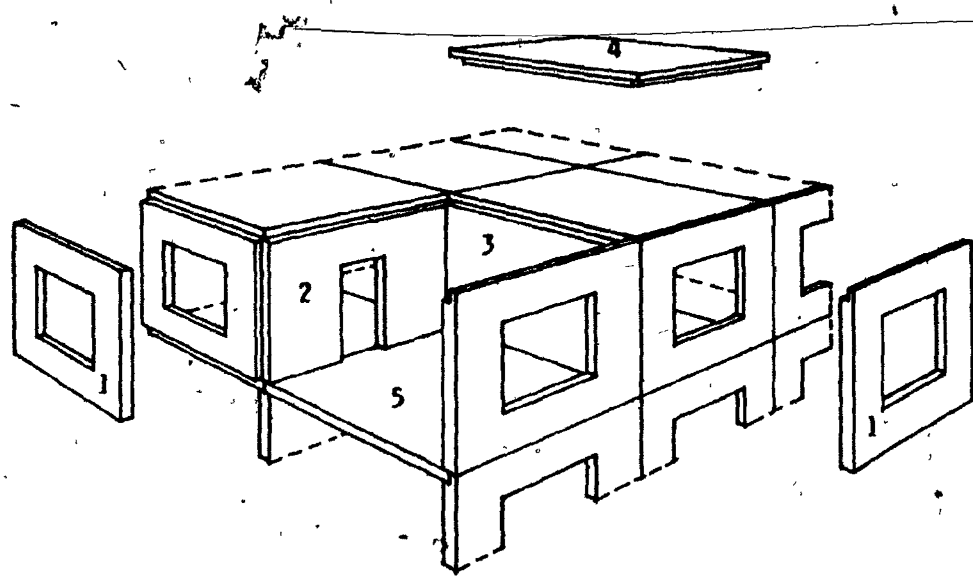


FIG. 3.20

TYPICAL TWO-WAY SPAN SYSTEM

In a typical two-bed room apartment built in East Germany, exterior walls are made from reinforced lightweight concrete of 76 lb/cu. ft. density and supplied with windows and window sills. The surface is finished with colored cement mortar, ceramic stucco or other material. The ducts for electric, sanitary and heating insulation were cast into the exterior wall. A 3/16 in. layer of plaster was prefinished for the interior surface in the factory. The interior walls are made from ordinary reinforced stone concrete of 137 lb/cu. ft. density, in thickness of either 4 or 6 in. These walls sustain the load directly from the floor slabs. 5'-2" "castellated" floor slabs are also made from reinforced stone concrete and fit neatly upon the top of the interior load-bearing wall. The walls are connected by welding together the exposed eyelets precast at the edge of the walls. A subsequent concreting of the gaps provides an extremely rigid frame work, which is able to withstand horizontal wind forces. The floor slabs are then placed into position. The staircase and landing were also precast components. Figure 3.21 shows a typical plan for this system.[10]

Figure 3.22 is a Polish Ow-1700 type system. In this system, the two-way slabs rest only on three edges of interior walls while the exterior walls are non-load bearing sill panels.[11]

A schematic view of a ring-frame construction (Fig. 3.23) illustrates the method used to reduce the unit weight of the structure. Figure 3.24 is a typical floor plan of a Czechoslo-

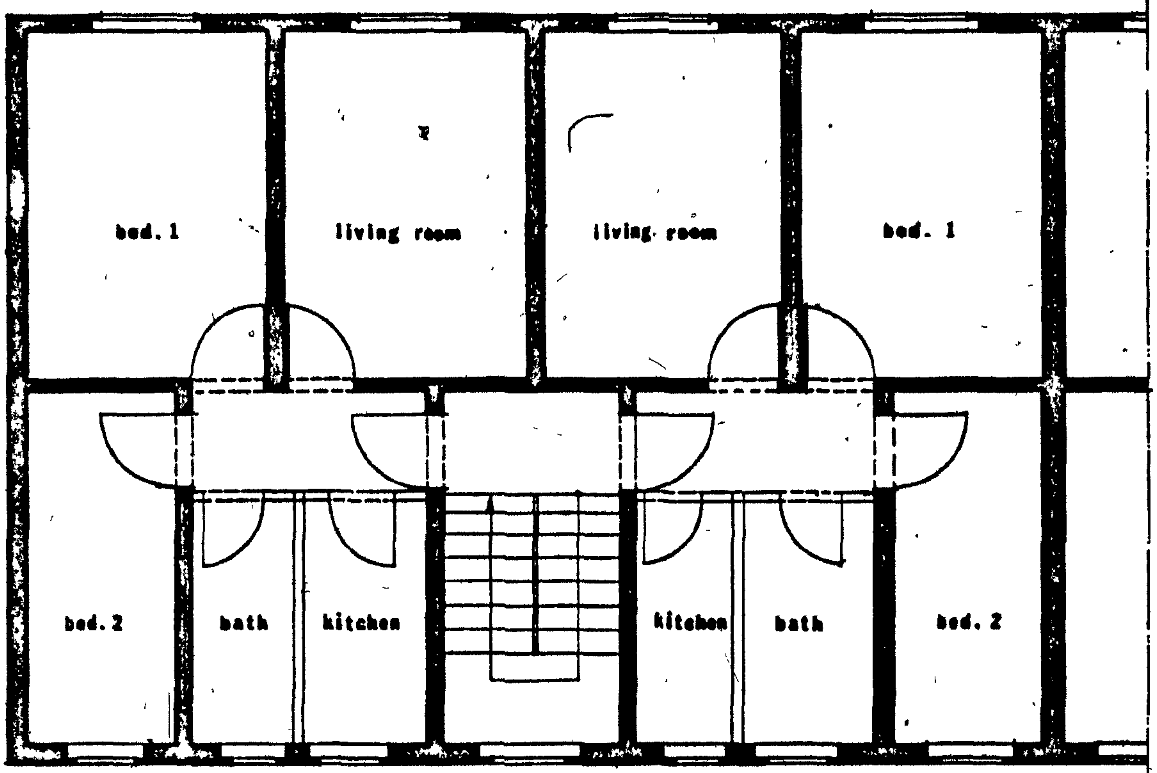


FIG. 3.21

EAST GERMANY FLATS

Typical floor plan

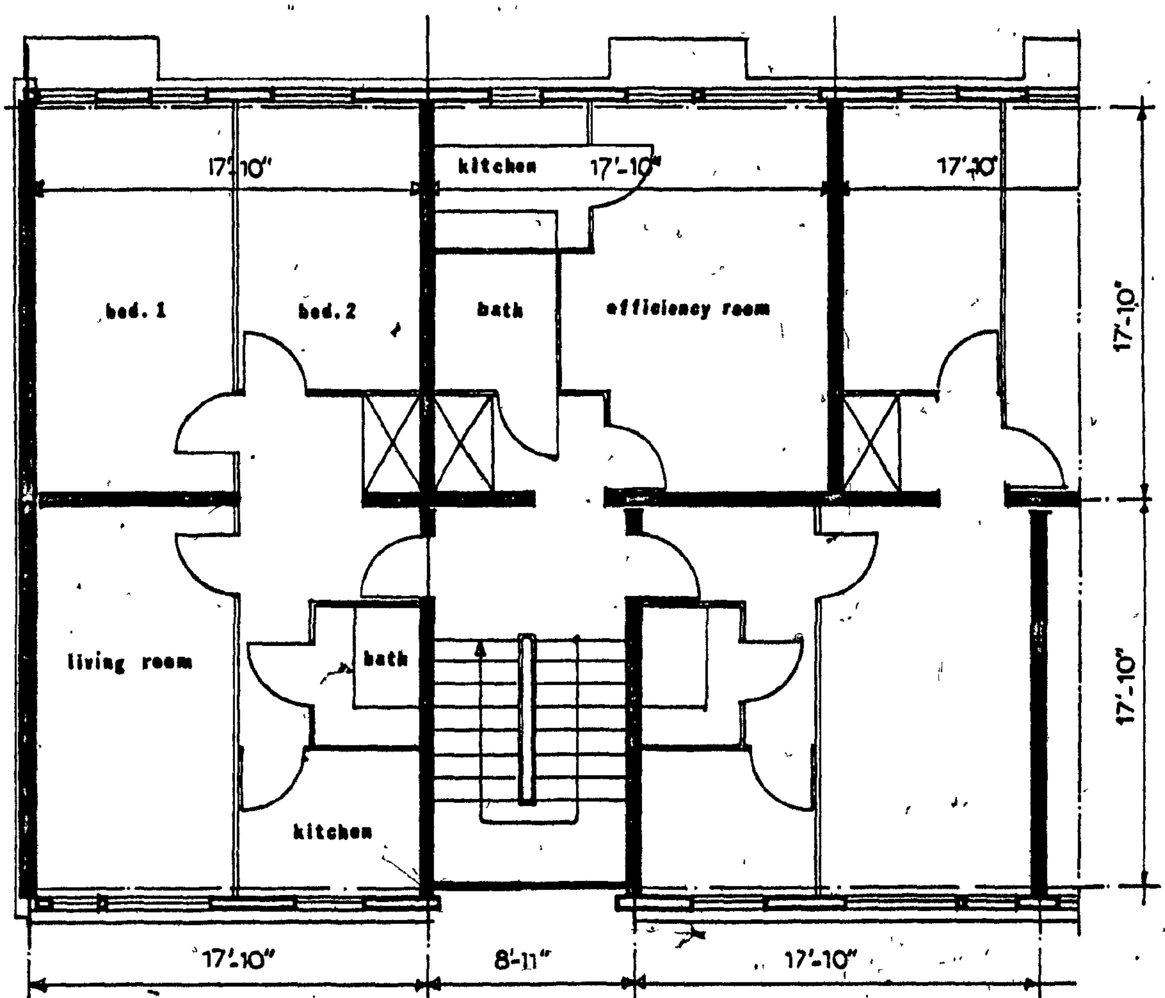


FIG. 3.22

POLISH OW-1700 TYPE SYSTEM

Typical floor plan

1. load-bearing window panel
2. ring frame
3. two-way roof slab
4. two-way floor slab

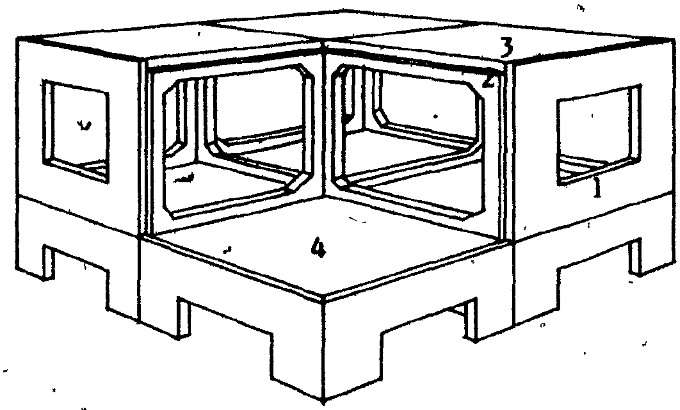


FIG. 3.23

DEVELOPMENT OF PANEL SYSTEM

Two-way span, ring frame construction

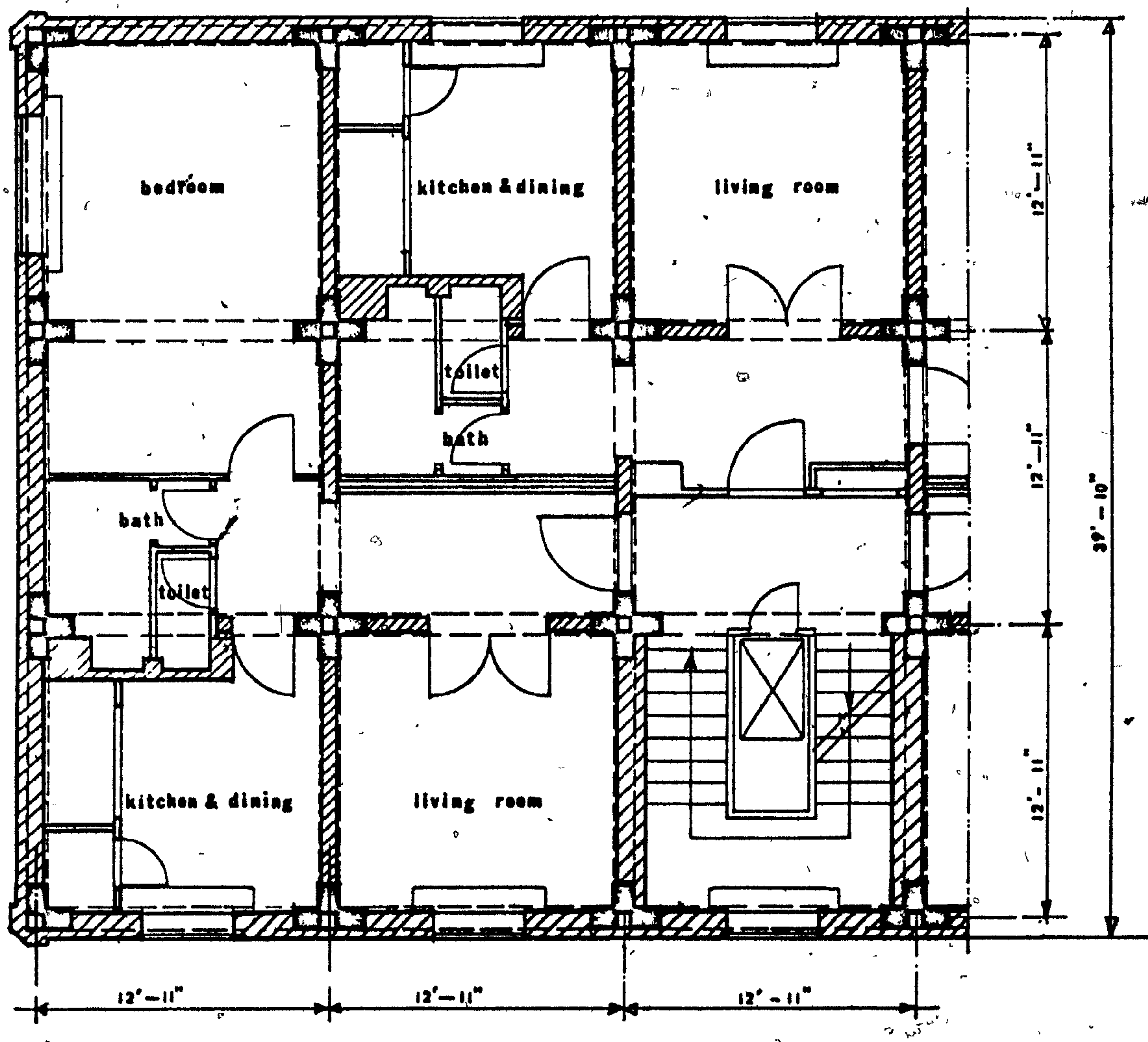


Fig 3.24

CZECHOSLOVAKIAN BA TYPE SYSTEM

Typical floor plan

vakian BA type building for such a system which originated in Moscow by W.W. Michajlov. The interior walls are composite walls which are not practical. The new variations of the BA buildings adopted battery-molded, homogeneous precast concrete panels instead.

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1. Lewicki, B., Building With Large Prefabricates, (Translated by Express Translation Service, London), 1966, pp. 11-14.
2. Diamant, R.M.E., Industrialized Building, 50 International methods, 1964.
3. Lewicki, B., Building With Large Prefabricates, (Translated by Express Translation Service, London), 1966, pp. 18-22.
4. Anon., "Prefabrication of Flats", Engineer, London, 1962, pp. 1003-1006.
5. See 2
6. Diamant, R.M.E., "Vive Concrete Panel System", Building Construction, July, 1966, pp. 80-81.
7. Kjeldsen, M., Simonsen, W.R., Industrialized Building in Denmark, 1965.

8 & 9. Lewicki, B., Building With Large Prefabricates, (Translated by Express Translation Service, London), 1966, pp. 30,32, 38-41.

10. Diamant, R.M.E. "Mass Production Flats", Industrialized Building, 1964, pp. 119-122.
11. Lewicki, B., Building With Large Prefabricates, 1966, p. 35-36.

IV. CASE STUDIES

A few of the cases chosen and studied in this chapter represent some typical examples of precast concrete panel housing systems. They are used to illustrate the general and structural principles of precast concrete panels systems which are introduced in the previous chapters. Techcrete is an original American system. Tracoba Balency and Wates were originally developed in Europe and have been popular ever since. They have obtained U.S. and Canadian licenses and are also the chosen systems in Operation Breakthrough.

The structural systems of these representative examples only include cross wall, two-way span systems, as these seem to be the most suitable systems to be applied to systems building for housing.

1. TRACOBA SYSTEM[1-4]

DEVELOPING COMPANY:

France: Omnium Technique (OTH)*

Britain: Gilbert-Ash Ltd.

United States: Module Communities Inc. (MCI)

COUNTRY OF ORIGIN:

France

DISTRIBUTION OF SYSTEM:

France, Italy, Switzerland, Greece, Spain, U.K., Algeria, and U.S.

SCOPE OF SERVICE:

Design of units and production method; manufacture

YEAR OF 1ST PRODUCTION:

1961

TYPE OF PREFABRICATION:

On-site factory produced and on-site casting

SCOPE OF COMPONENTS:

Load-bearing, cross-walls, precast floor slabs, sandwich type non-loadbearing facade panels, sandwich type loadbearing gable walls, precast shear walls, shaft walls, precast stairs, etc.

BASIC STRUCTURAL SYSTEM:

Cross-wall system

JOINING METHOD:

Slab-wall joints

---

* OTH is a civil engineering firm started in France in 1955.

TYPE OF FOUNDATION:

All types

ROOF CONSTRUCTION:

Terrace roofing

PLANNING GRID:

Basic grid is 1'-0", structural grid is 1'-0", maximum span is 18'-0", possible 22'-0"

MAXIMUM MODULE SIZE:

Floor: 8'-6" x 33'-0"

Exterior walls: 8'-6" x 33'-0"

Interior walls: 8'-6" x 33'-0"

MAXIMUM BUILDING HEIGHT:

23 stories, possible 30

EXTERIOR FINISHES OF UNITS:

Washed-concrete, untreated concrete, mosaicss tiles, molded shapes, sand-blasted, bush-hammered or exposed aggregate

INTERIOR FINISHES OF UNITS:

Paints, paper, fabric or any desired finish

INTERIOR PARTITIONS:

Light construction components 8'-3" high (plaster elements or wooden element)

MECHANICAL INSTALLATION:

Integration during manufacturing: electrical wiring and outlets in exterior walls, interior walls and floor slabs; plumbing wall for bearing or non-bearing wall; HVAC sub-components precast in facade wall

TYPE OF HOUSING:

Medium-rise and high-rise apartment

This is a one-contract system. There are no standard plans. Each scheme is considered individually, but architect must work with the company and the structural engineers as a team so that the basic requirements of the system are absorbed. Minimum number of dwellings for one contract is between 300 and 400 units. Usually the simple floor and wall units are manufactured in a casting bay adjacent to the building site while the more complex facade or other special elements such as stairs, sandwich gable walls are made in a covered temporary site factory which is highly mechanized. These factory-produced components are usually larger and more complicated.

As the other cross-wall system introduced in Chapter III, the non-loadbearing wall of this system can be of concrete or any other suitable material. It is possible for balconies or loggias or sculptured elevations to be incorporated (Fig. 4.1). However, the use of a precast concrete sandwich panels for the facade wall in order to reduce the types of material and increase the repetitive use of machinery is usually adopted. In this Tracoba system, the facade walls are made in special molds which can be pivoted through 80 degrees in the temporary on-site factory. The wall panels are cast horizontally. The mold is slightly greased. The window frame and ventilators are placed into the shuttering. First layer of facing material which may either be ceramic or mosaic glass tile, or any other suitable facing material which can be mounted on brown paper with a water-soluble glue, are placed into the molds.

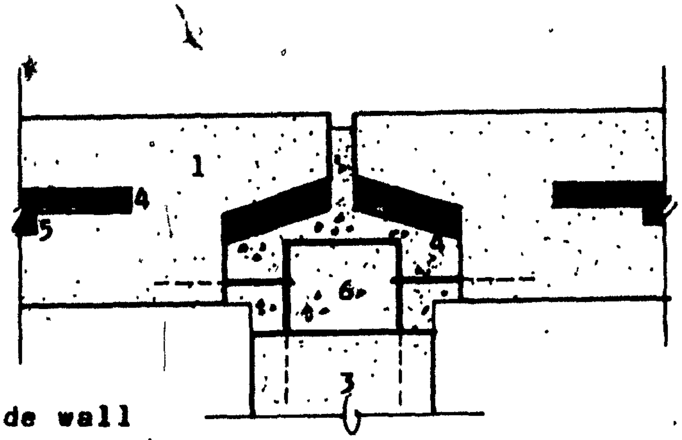
FIG. 4.1

TRACOBA SYSTEM - FACADE

A thin layer of mortar is laid to joint the facing material, followed by a 3" thick layer of reinforced concrete. A layer of thermal insulation material such as 41/2" gas entrained concrete or 13/4" thick expanded polystyrene follows. Then the internal reinforced concrete leaf of 2" thick is cast on top and the units are made monolithic by the cross-connection of the reinforcement network. The steel loops for handling are cast into the inner wall leaf and welded to the reinforcement of the inner leaf. While the shuttering is filled, the internal steam heating of the mold has been put into operation. The mold is covered by a lid and cured. Discharge of the mold takes place by rotating the molds through the pivot to an almost vertical position. An overhead crane then lifts the components through the precast steel loop. The component is then transported to a storage yard where it is kept for some weeks to allow for final hardening of the concrete.

Structural joints of this system are also the typical joints of panel systems (Figs. 4.2, 4.3 & 4.4). Non-loadbearing facade walls are carried on the inside loadbearing crosswall with a connection by metal plates which protrude from the inner leaf of the facade wall. These plates rest on steel stirrups set in the inside wall panels and the two are welded together and the joints filled with cast-in-place concrete. The same principle is applied on the connections between loadbearing sandwich wall gable and facade wall (Fig. 4.2) and between partition panels and facade walls. At connections of wall and floor, the vertical section through the window frame can be seen in Fig. 4.4. A sheet of expanded polystyrene is inserted which acts as thermal insulation at this point and also as permanent shuttering. Concrete is placed into this space and is compacted by poker vibrators. Interior connection of wall and floor can be seen in Fig. 4.3. The precast floor slab are reinforced in transverse direction and cast with four specially designed lugs at the sides. The slabs are set down upon the cross walls at these four points, which leave a considerable space at the sides which can then be grouted.

This system allows flexibility in design and layout (Figs. 4.6 & 4.1). The large wall panel can be mass-produced. American (MCI) adopted this system as the basis of their Breakthrough proposals. The engineering firm incorporated on-site and near-site factories producing walls and slabs for use in single family dwellings or garden or high-rise apartments. The modified interior wall junction detail of the Tracoba system can be seen in Fig. 4.5 for American practice.



1, non-loadbearing facade wall
2, sandwich load-bearing
   gable wall
3, interior load-bearing
   cross-wall
4, expanded polystyrene
5, gas concrete
6, in-situ concrete

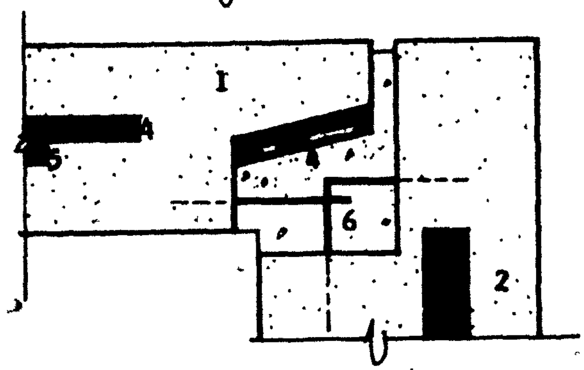
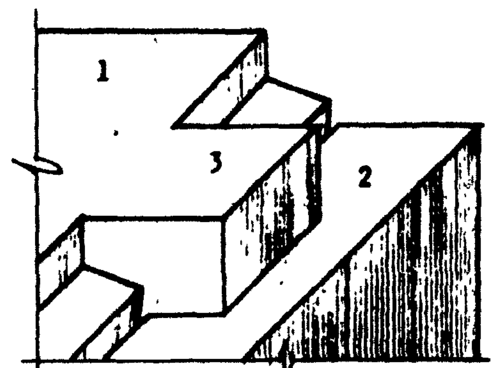
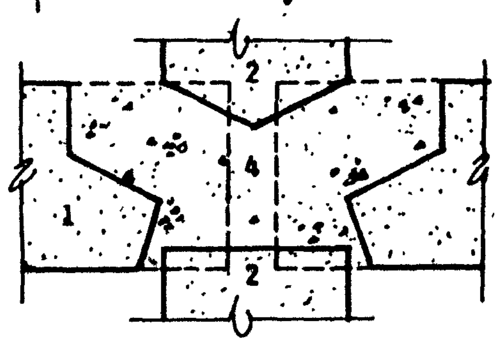


FIG. 4.2

JOINTS OF EXTERIOR WALLS AND INTERIOR WALLS

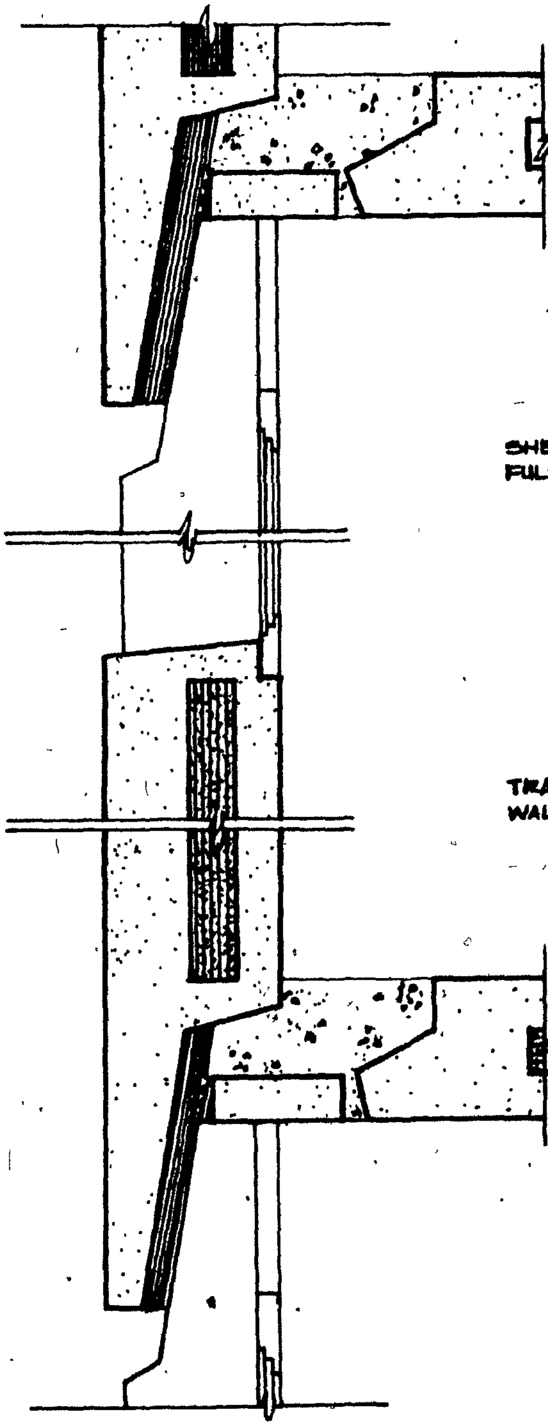


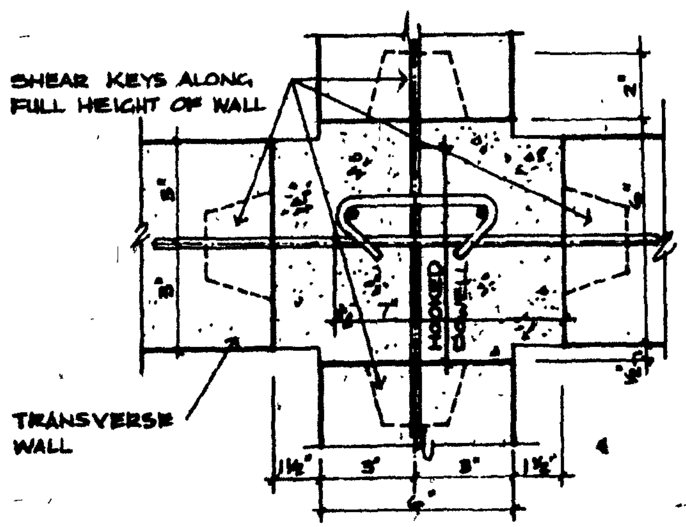


1, floor slab
2, load-bearing cross-wall
3, lug
4, in-situ concrete

FIG. 4.3

JOINTS OF INTERIOR CROSS-WALLS AND FLOOR SLAB





PLAN SECTION:
INTERIOR WALLS

FIG. 4.5

MODIFIED TRACOBA JOINT

FIG. 4.4

JOINTS OF EXTERIOR WALLS AND
FLOOR SLAB - VERTICAL SECTION

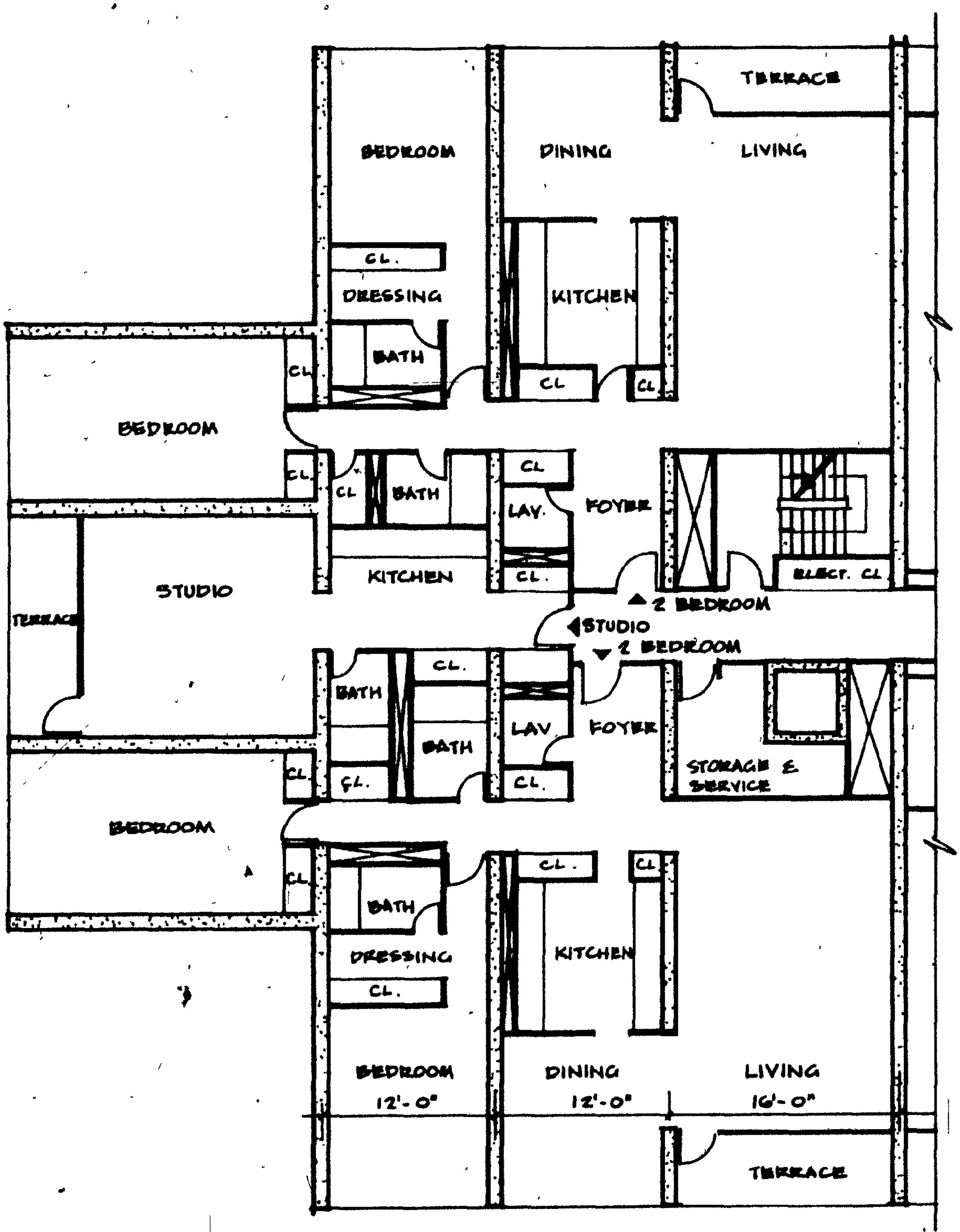


FIG. 4.6

AMERICAN MCI SYSTEM - TYPICAL FLOOR PLAN AT YONKER, N.Y.

2. WATES SYSTEM[5-8]

DEVELOPING COMPANY:

United Kingdom: Wates Ltd.

United States: Rouse-Wates Inc.

Canada: Modular Precast Structures Ltd.

COUNTRY OF ORIGIN:

United Kingdom

DISTRIBUTION OF SYSTEM:

U.K., U.S. & Canada

SCOPE OF SERVICE:

Technical to architects/engineers/contractors; production of components and erection.

YEAR OF 1ST PRODUCTION:

1962

TYPES OF PREFABRICATION:

On-site factory and on-site casting

SCOPE OF COMPONENTS:

Structural crosswall grid; exterior walls, panels, solid or with windows; precast floor slabs; stitched joints.

BASIC STRUCTURAL SYSTEM:

Panel system with either loadbearing crosswall or two-way span floor slabs depending on architects requirements

TYPE OF MODULES:

Precast cross walls, exterior wall panels, precast floor slabs, non-structural partitions, staircase, balconies, the story-height refuse chutes, certain types of non-loadbearing cladding whenever the standard types of loadbearing exterior walls are non-applicable. They include glazed joinery units, concrete panel, story height window units, profile units, etc.

JOINING METHOD:

"Stitched" joints

TYPES OF FOUNDATION:

Conventional construction depending on soil composition

ROOF CONSTRUCTION:

Concrete panels, gravel stucco roof

PLANNING GRID:

Basic module is 1'-0", structural grid is 8'-3", maximum span is 20'-0"

MAXIMUM MODULE SIZE:

Floor: 20' x 20'

Exterior walls: 20' x story height

Interior walls: 20' x story height

MAX. BUILDING HEIGHT:

25 stories, practical limit

EXTERIOR FINISHES OF UNITS:

Form pattern, ceramics, mosaics exposed aggregates, paints, tile and brick facing, etc.

INTERIOR FINISHES OF UNITS:

Paint, paper, laminates, textured plaster finishes direct to concrete walls and ceiling

INTERIOR PARTITION:

Concrete panels or light panels

INTEGRATION DURING MANUFACTURING:

Lines of electricity, plumbing and heating are cast in the interior walls and floor slabs.

TYPES OF HOUSING:

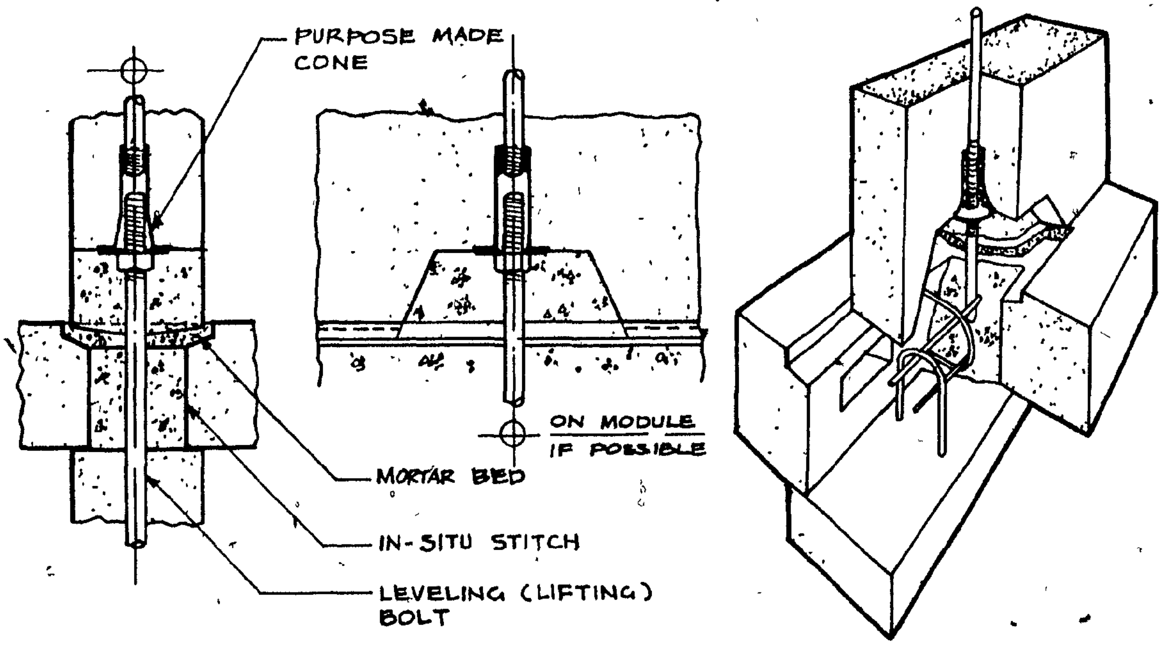
Low-rise and high-rise apartment

The Wates system which is a typical closed housing system is more of a method of production than a set of standard components. The employment of on-site factory equipped with highly mechanized production line is the main feature of this system. This production line is usually 30'-0" wide, covered with mobile shelters running on rails to avoid winter layoff of workers and ensure all weather operations. This manufacturing area is controlled and operated by a team of skilled laborers. The use of a corrugated steel mold which can be adjusted by moving its side plates in 12" increments is another feature. Interior crosswall panels are cast in vertical batteries. External walls and some of the flooring units are cast in horizontal molds capable of being tilted up to nearly a vertical position. Steam and electric curing speeds production and ensures that molds can be emptied and re-used in a 24-hour cycle. The products are comparable in quality with any produced in a permanent factory. Since this is a typical one-tract closed system, minimum number of dwellings to maintain its economy is between 200-300, depending on the degree of repetition.

Because of the use of on-site precasting, construction joints can be kept to a minimum by the production of the largest possible components within the capacity of the hoisting equipment. The location and layout of the site factory is made at the pre-contract stage. Both tower crane and portal cranes are used. Units are normally within the three or four tons range but sometimes larger cranes are used to increase lifting capacity up to six tons.

Since the different projects have their own standard components, every attempt is made at the design stage to reduce the number of different types employed in the construction. The planning grid of 12" for the panels is strictly followed in each project, and the thickness of units are kept standard. However, in the project of cluster housing at Leyton, England, which is only part of a housing scheme, sixteen 4-story or 5-story blocks have nearly two-hundred different types of components including sixty types of floor slabs, fifty-six types of wall panels, and fifteen types of edge beams. The degree of industrialization is obviously low.

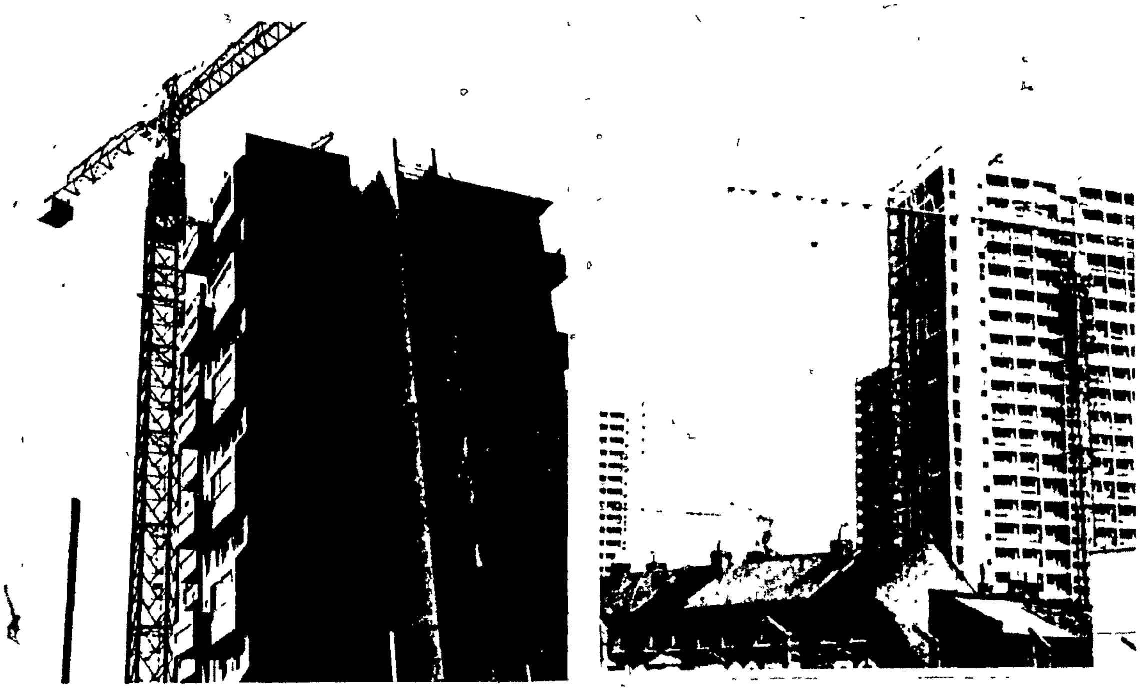
This system allows flexibility in design and plan layout, especially because of its one-contract character. The free selection of the exterior finishes either for the load-bearing facade wall or the non-loadbearing cladding panel gives the greatest possibility of exterior appearance (Fig. 4.8). The unique joints (Fig. 4.7) are used extensively for every Wates project. Wall panels are equipped with levelling bolts and nuts



Typical Internal Crosswall - To - Floor Joint

FIG. 4.7

WATES SYSTEM



tower block for Greater London (one form of standard tower) Council

FIG. 4.8

WATES SYSTEM

to align and connect vertically, while reinforcing bars inserted in loops projecting from the slabs give the joint lateral strength. The joint then is grouted.

3. BALENCY SYSTEM[9-12]

DEVELOPING COMPANY:

Origin system: French Entreprises Balency & Schuhl

Italy: Impresa Generale Costruzioni MBM SpA

Great Britain: Bernard Sunley & Sons Ltd. Holland & Hannen and Cubitts Ltd.

United States: Balency-MBM-US Corp.

COUNTRY OF ORIGIN:

France

DISTRIBUTION OF SYSTEM:

Italy, Belgium, France, Ireland, Israel, United Kingdom, Spain, United States

SCOPE OF SERVICE:

Engineering of structure, layout and design, project management and marketing service. Furnish and erect components

YEARS OF 1ST PRODUCTION:

France: 1948

Italy: 1964

United Kingdom & Ireland: 1964

Israel: 1964

YEARS OF 1ST U.S. PRODUCTION:

1970

TYPES OF PREFABRICATION:

Cast in factory, on-site casting

SCOPE OF COMPONENTS:

Precast wall panels including load-bearing sandwich facade walls, crosswalls (party walls), partitions, lift shafts, stairs, core units which include the piping units, the toilet unit, the combined sanitary unit, the conduit unit, chimney unit, cast-in-place concrete floors or roofs.

BASIC STRUCTURAL SYSTEM:

Two-way span panel system

TYPES OF MODULES:

Panels, Core units, stairs and lift shaft.

JOINING METHOD:

Cast-in-place concrete floor combined with the load-bearing wall

TYPES OF FOUNDATION:

Foundation slab or direct foundations, conventional

ROOF CONSTRUCTION:

Concrete panels, gravel stucco or accessible promenade roof

PLANNING GRID:

Optional; The use of cast-in-place concrete for floors gives flexibility in planning, usually using 12" grid, for exterior and interior with spans up to 19 ft. The maximum span can reach 26 ft.

MAXIMUM MODULE SIZE:

Floor: room-size

Exterior walls: 30' by story height

Interior walls: 30' by story height

MAXIMUM BUILDING HEIGHT:

30 story, In Italy: 14, In Ireland: 16

EXTERIOR FINISHES OF UNITS:

Patterns, ceramics, exposed aggregate, smooth or profile

MECHANICAL INSTALLATION:

Integration during manufacturing: lines of electricity and heating in floors, exterior walls and interior walls; chases for plumbing and ventilation in interior walls

TYPES OF HOUSING:

The structural components can be used in low-rise medium-rise, and high-rise housing. For Operation Breakthrough, the Balency-MBM-U.S. company preposed a cluster dwelling environment, combining five-story deck houses, two types of high-rise housing, and garden-type apartments.

The Balency system basically is an industrialized system of precast concrete consisting of the rational manufacture of large components in a highly mechanized central factory. Like many other French systems, it is a closed system where the components are not modular. The height and width of the load-bearing panel components can be varied to suit any design. Although this allows flexibility in design and versatile arrangements of plans and facade, the degree of industrialization is lowered. Therefore this system allows a minimum number of housing units produced annually to compensate for the high initial investment of the equipment and maintenance. The economics of one particular project depends largely on the distance between sites and central factory. According to J.P. Grezaud of Balency and Schuhl, the system applies to the manufacturing of small series, which may be two or three flats per day, with 500 flats a year as a minimum.

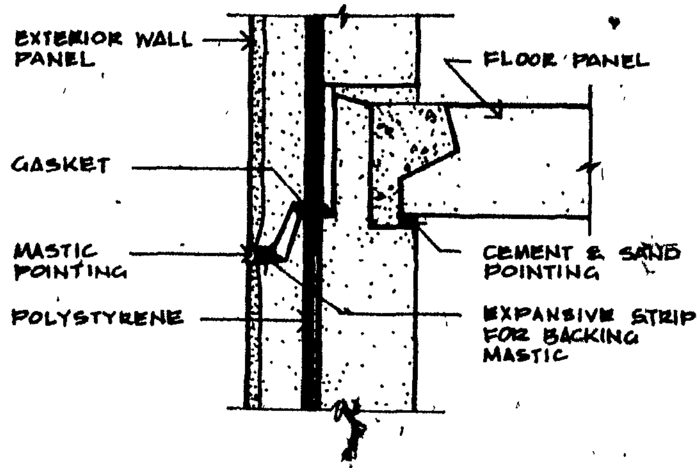
One of the reasons of using the cast-in-place concrete floor is to eliminate the cost of transportation of this bulky component and the possible problem of traffic limitation from central factory to sites. Another advantage of the cast-in-place concrete floor is the monolithic character of the finished structure. However in the American Balency proposal, precast concrete floor slabs of room size will be used since on-site labor costs are high and climate conditions inhibit on-site winter concreting. In France, the cast-in-place construction can be used while in the North-East United States, concrete cannot be cast-in-place during the winter.

The joining method has to be carefully designed to the load-bearing character and the sound and thermal insulation requirement, especially the joints in exterior load-bearing facade wall.

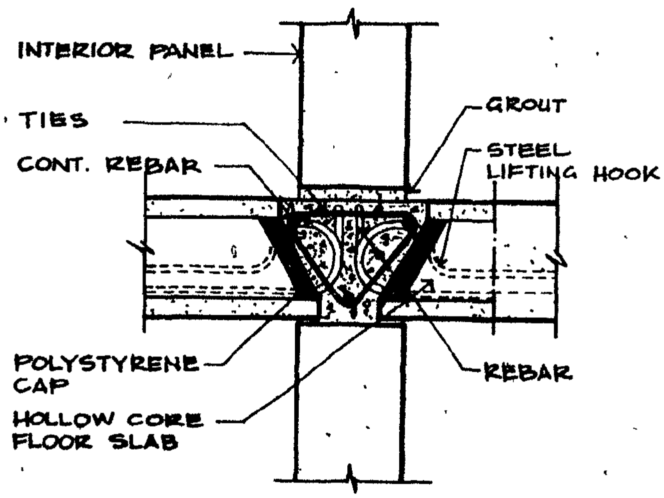
Figure 4.9 shows that the edges of the exterior wall panels have twin grooves and are joined there using cast-in-place concrete with a mastic sealer. Horizontal joints are made by supporting the inner leaf of the facade unit on a packed mortar bed, and employing cement and sand to bear the floor panel.

This system employs rather complicated functional units which are manufactured in the factory. For example, the cored units using in the Italy Balancy-MBM are made twice as wide (or more) as ordinary internal wall panels. They contain numerous outlets for water, ventilation, sewage and other utilities. The components are manufactured in a Horizontal mold and also bear handling loops, as do the other types of wall components. The removable covers are cast on these units and permit pipeline joints to be carried out readily. Other types of functional units may be manufactured according to different design. In the French Balency system, the piping, toilet, kitchen, conduit, etc. are separately produced into different types of units. These factory-made units allow fast on-site assembly. However, the erection must be in accordance with the drawings prepared by the architect for different projects.

Most of the French and Italian Balency systems are applied on high-rise housing. In the U.S., the Henry C. Beck Company employed this system for its Operation Breakthrough Project. This system is very suitable for high-density locations in urban centers, especially the deck house apartment layout where the deck areas provide private open space for occupants (Fig. 4.10). In a recently completed new town project in Thamesmead, England, this system was used for towers, linear blocks, and low-rise housing (Fig. 4.11).



VERTICAL SECTION:
EXTERIOR WALL-FLOOR



VERTICAL SECTION:
INTERIOR WALL-FLOOR

FIG. 4.9

BALENCY - MBM - US SYSTEM - TYPICAL JOINTS

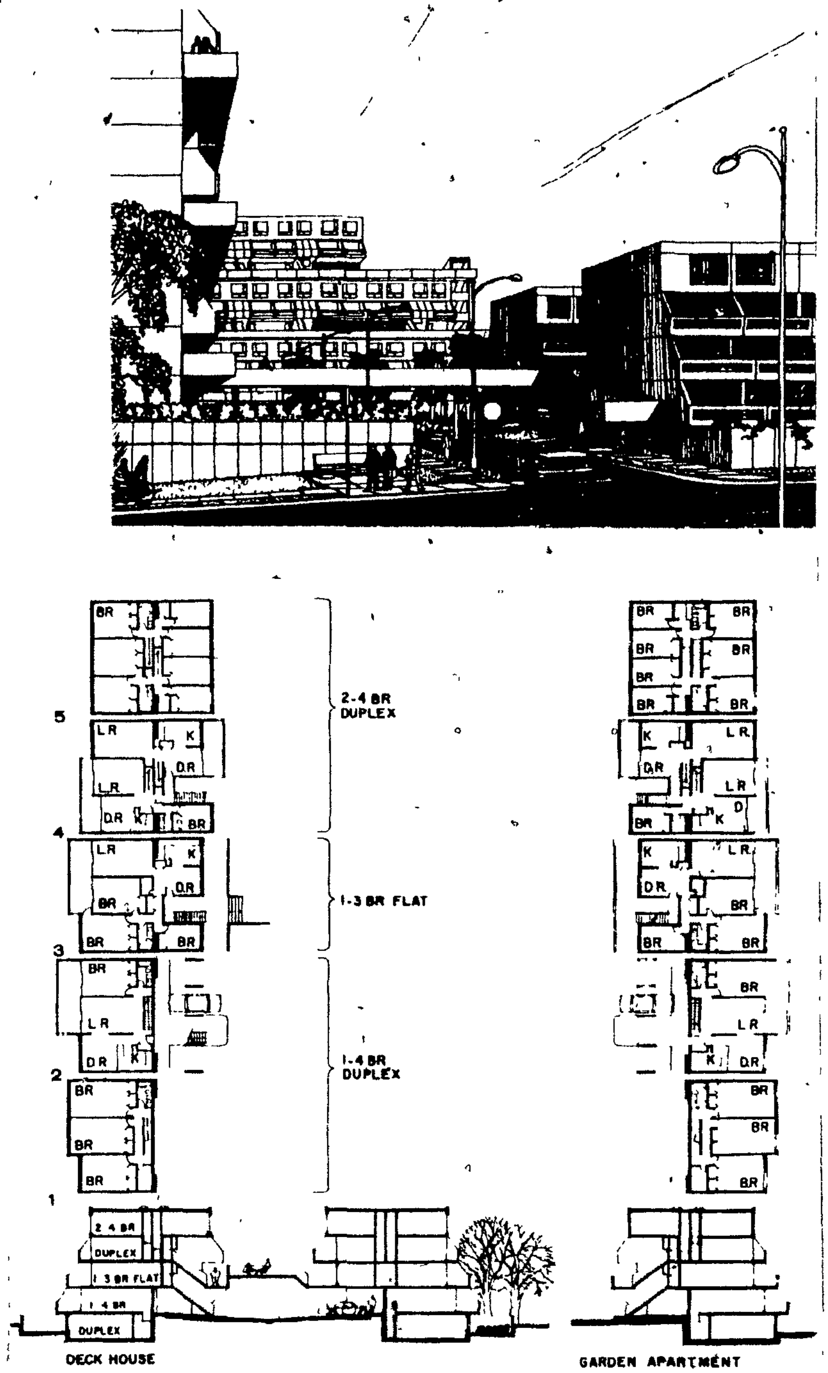
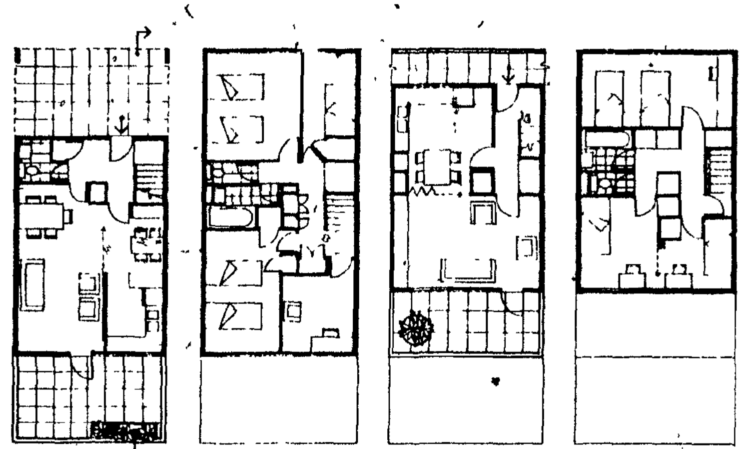
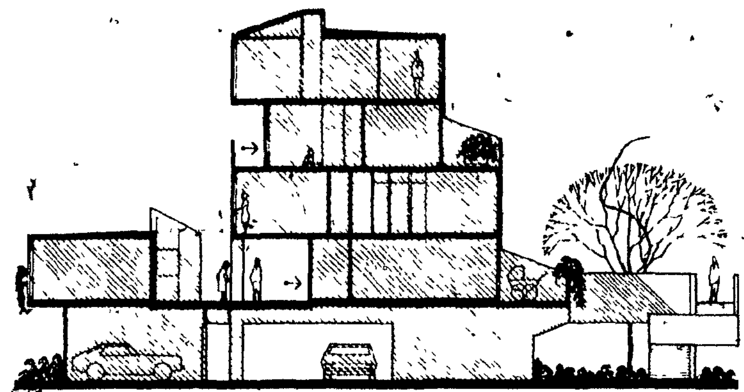


FIG.4.10

BALENCY - MBM - US SYSTEM
BECK'S PROPOSAL





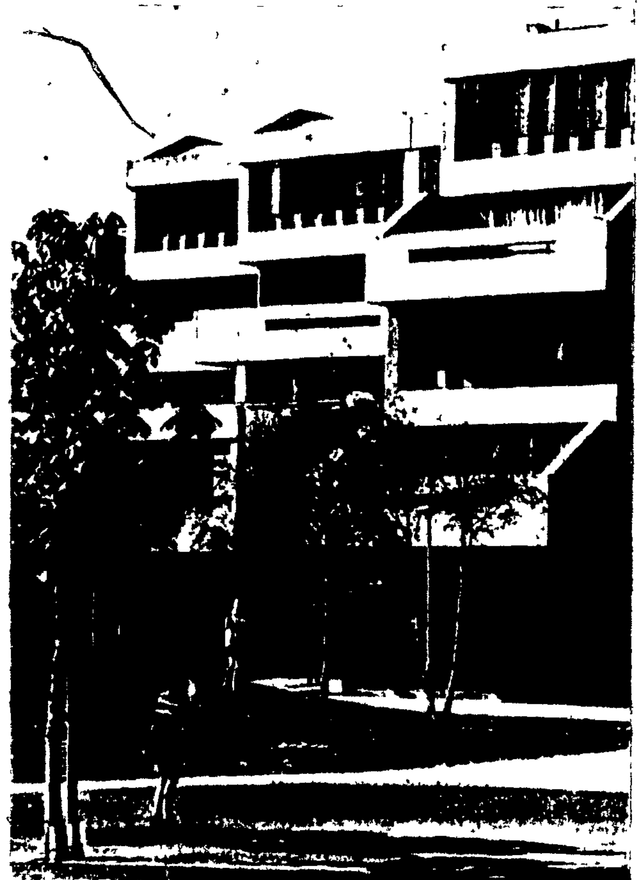


FIG. 4.11

BALENCY SYSTEM

THAMESMEAD NEW TOWN,
ENGLAND

4. TECHCRETE SYSTEM[13,14]

DEVELOPING COMPANY:

Carl Koch & Association

COUNTRY OF ORIGIN:

U.S.A.

SCOPE OF SERVICE:

Architectural planning and design, construction engineering. Units by selected precaster.

YEAR OF 1ST U.S. PRODUCTION:

1967

TYPES OF PREFABRICATION:

Using extruded molds in on-site factory and on-site precasting.

SCOPE OF COMPONENTS:

Facade wall and cross-wall precast on-site, precast prestressed floor planks extruded in factory, precast staircase, precast bathroom and kitchen units, etc.

BASIC STRUCTURAL SYSTEM:

Crosswall panel system with precast floor panels.

TYPES OF MODULES:

Floor, wall panels, stairs, sanitary units, etc.

JOINING METHOD:

Post-tensioned vertically over height of building

TYPES OF FOUNDATION:

Precast concrete panels or conventional construction

ROOF CONSTRUCTION:

Concrete panels with gravel stucco

PLANNING GRID:

Basic module is 1ft, 2ft, 3ft, and 4ft. The structural grid is 32'-0" span.

MAX. MODULE SIZE:

Floor: 32'-6" long by 4'-0" wide and 8" thick.

Exterior walls: 32'-6" by story height (8'-0") and 8" thick.

Interior walls: 32'-6" by story height (8'-0") and 8" thick.

MAX. BUILDING HEIGHT:

30 stories

EXTERIOR FINISHES OF UNITS:

Conventional construction of concrete panels or aluminum panels as curtain wall, options in applied surfacings.

INTERIOR FINISHES OF UNITS:

Paint or surfacing by others.

INTERIOR PARTITION:

Conventional plaster panels on steel framing

INTEGRATION DURING MANUFACTURE:

Utility lines including electricity, plumbing, and HVAC may fit into the hollow cores of the floor planks or risers may be stacked vertically in interior walls.

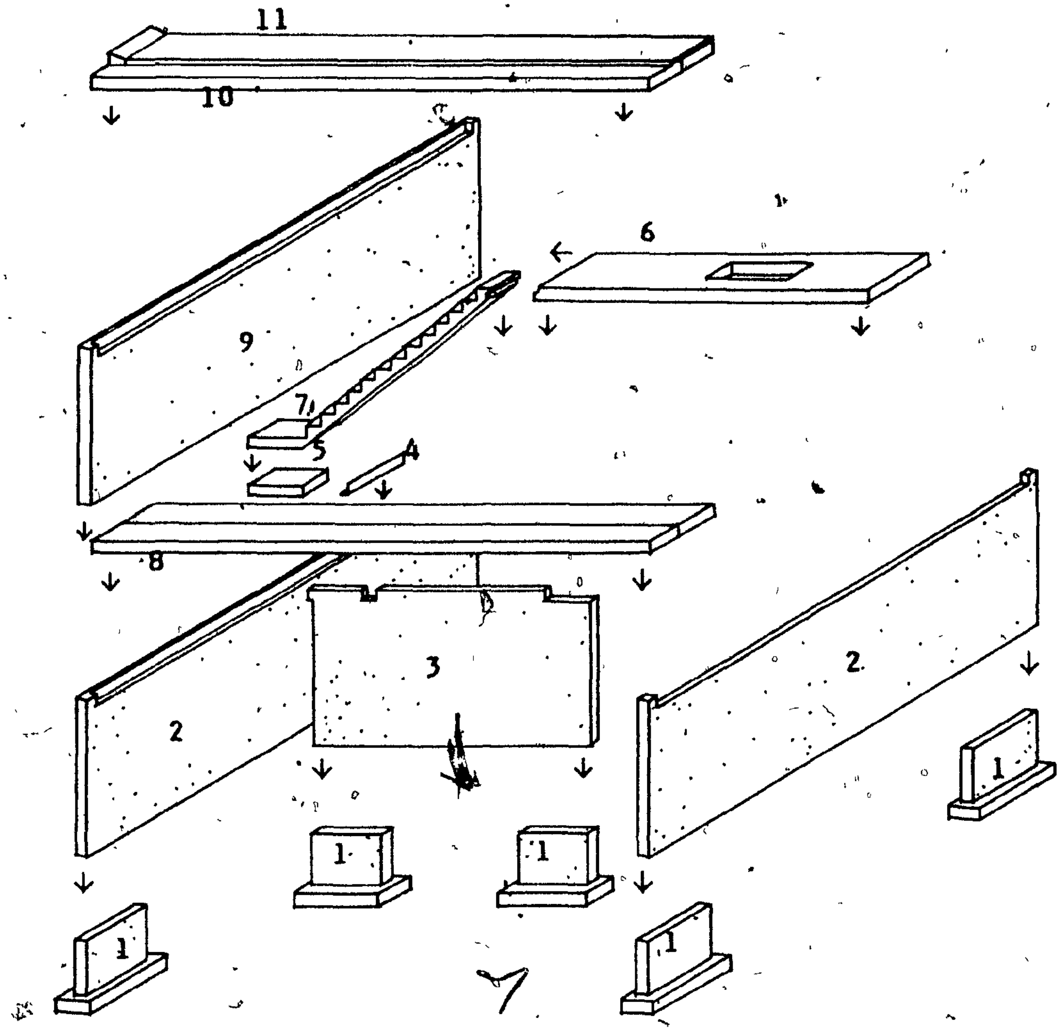
TYPES OF HOUSING:

Low-rise and medium-rise units, including town houses and walk-up units, and high-rise urban communities.

Carl Koch's Techcrete System was an early attempt to adopt a systems approach for planning and design of housing in the United States. It was an effort to choose concrete for industrialized housing. Compared to European precast concrete systems, especially those of East European countries, the degree of mechanization and automation has been greatly reduced. This system adopted a simple panel system, on the basis of the European experience. The use of load-bearing concrete crosswalls gave the most effective way to use the material to meet housing requirements. Concrete floor staves are precast and prestressed to provide the large span. Post-tensioning gives an easy means to join the structural components together. With prestressing technologies, wide spans at low cost will provide adequate planning flexibility to meet all reasonable housing requirements. The bulky crosswall elements are usually precast at the building site while the floor staves are mostly manufactured in the factory. Other structural components which can be seen in Fig. 4.12 are manufactured separately at the site or in the factory depending on the size and shape of the components. The structural principle and erection sequence can be easily read from Fig. 4.12 and 4.13.

A whole set of related non-structural components, such as mechanical ~~units and~~ sanitary units has been designed and prefabricated in the factory, but projects completed to date have conventional partitions and exterior walls constructed on site. This allows flexibility of design and planning both in use and appearance.

Since this system emphasizes the concept of flexibility, a



1, footings
2, bearing walls
3, shear wall
4, landing lintel
5, sub-landing

6, floor slab with lintel
7, stair
8, floor planks
9, bearing walls
10 roof planks
11 roofing, insulation, and flashing

FIG. 4.12

TECHCRETE SYSTEM - STRUCTURAL COMPONENTS AND ERECTION SEQUENCE

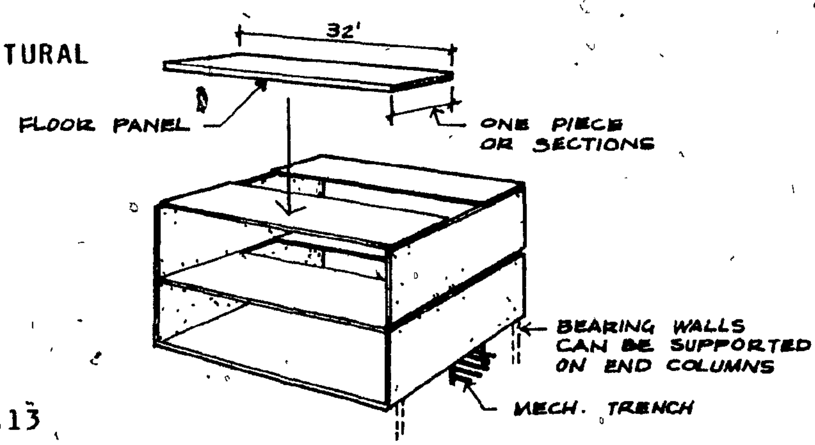


FIG. 4.13

STRUCTURAL PRINCIPLE

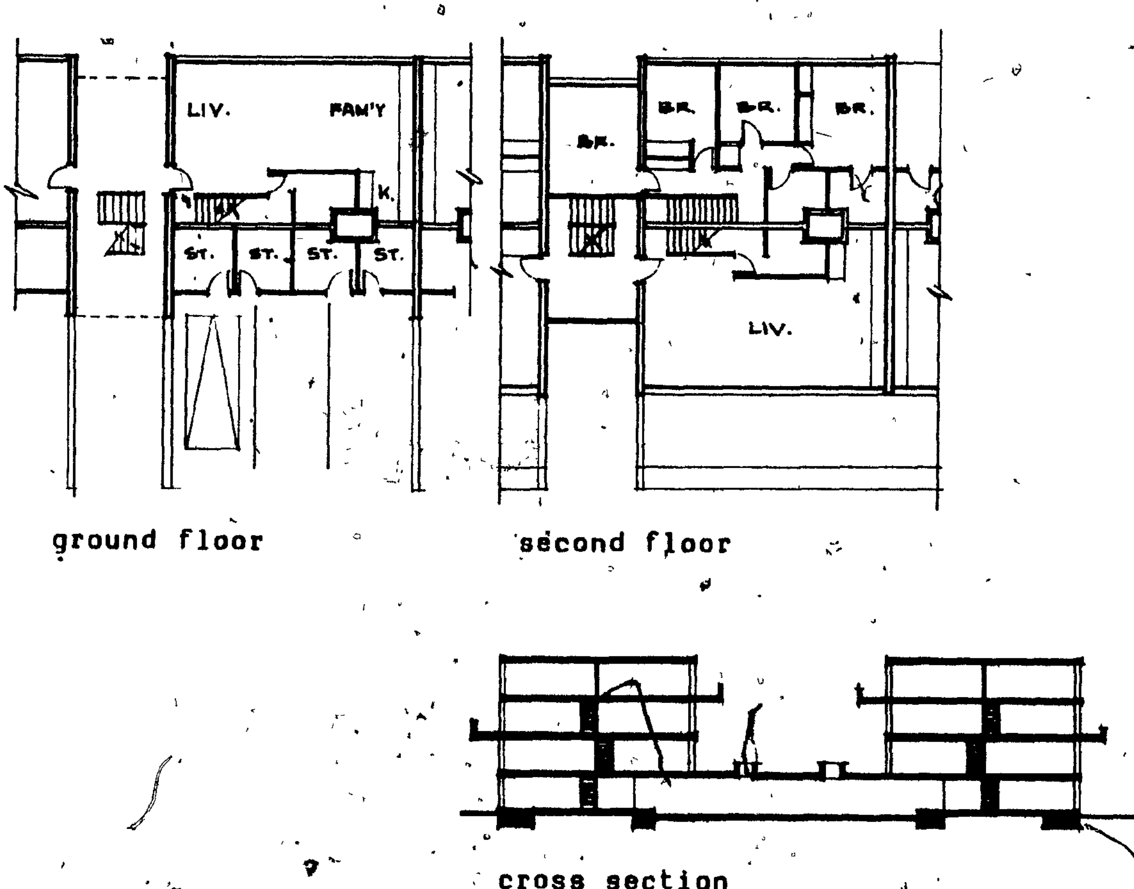


FIG. 4.14

TYPICAL FLOOR PLANS AND SECTION

series of planning modules was designed to achieve this goal, neglecting the possibility of greatest standardization of components. According to Mr. Koch, there was less than one-third of the system which would be standardized and the rest would depend on discretion of the architect.

Fig. 4.14 shows the panel structural frame with both facade ends open. The conventional method for the non-loadbearing facade walls can provide great flexibility and determine the appearance of the building. If Fig. 4.14, the flexible arrangement of the interior partitions within the crosswalls gives different layouts for different housing types.

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1. Anon., "Operation Breakthrough", Architectural Record, April 1970, p. 145.
2. Diamont, R.M.E., "The Tracoba - 4 System of Industrialized Building", Architect and Building News, 1967, pp. 201-203.
3. Anon., "Operation Breakthrough: Operation P/R". Progressive Architecture, April 1970, p. 124.
4. Anon., "Industrialized Housing - Concrete System", Building Design and Construction, Sept. 1970, p. 74.
5. Anon., "Some On-Site Systems for Industrialized Building", Concrete and Constructional Engineering, 1966, pp. 5-14.
6. Anon., "Precast Concrete Housing Systems", House and Home, Sept. 1970, p. 78.

7. Anon., "The Wates System in Action - Lambeth, England", Building Construction, June 1969, pp. 72-76.

8. Anon., "Industrialized Housing - Concrete System", Building Design and Construction, Sept. 1970, p. 77.

9. Diamant, R.M.E., "The Balency System of Building", Architect and Building News, 1963, pp. 412-415.

10. Anon., "Operation Breakthrough", Architectural Record, April 1970, p. 141.

11. See 4.

12. Anon., "Thamesmead", Architectural Forum, July-Aug. 1967, pp. 58-65.

13. Anon., "Lowering the Cost of Housing", Progressive Architecture, June 1968, pp. 140-145.

14. See 4.

V. CONCLUSION

Summary

The industrialized building system means the large scale use of standardized factory-produced building components. It also means a mechanized building process, either in the factory, on-site, or in near-site factories. It is a continuous process, involving planning, programming, design coordination, the manufacturing of building components, and finally the execution of repetive construction work on-site.

The research into and development of precast concrete has led to a great deal of improvement in the strength, surface finish, joining methods, and lightness of this material. Building code authorities have attempted to establish standards which will enable designers of industrialized building systems to ensure the safety of their structure.

The design of adequate structural joints or connections reduces on-site labour and ensures continuity of structural components. Cast-in-place concrete joints and post-tensioning with a layer of mortar between components are the most effective ways to satisfy structural and weather requirements.

Large precast concrete panels for walls and floor slabs in panel systems are a feature of many of the successful building systems for housing. Apart from the time saving in assembly, there is also the cost saving achieved by the elimination

of interior finishes and the incorporation of services within the panels. They provide not only load-bearing capabilities but also high standards of acoustical privacy, thermal insulation, and fire-resistance. The mechanical requirement and utility lines of a housing system can be precast into these components before erection.

Large load-bearing panels can be used for single storey, medium-rise, and high-rise housing, where they are adaptable for different circulation patterns such as stairwells, access, corridors, and balconies as well as for tower construction.

Sandwich walls which combine the dense load-bearing panels with additional insulation such as expanded polystyrene or gas-entrained concrete can be used for facade walls, gable walls, party walls, and partitions. The floor slabs may be one-way slabs supported on either longitudinal walls or cross-walls. They may also span in two directions.

In comparing the structural behaviour of the three panel systems, the cross-wall system is the most popular one in use today because of the flexibility it provides in the architectural treatments of facades and in interior planning, while maintaining all the advantages of other two.

The success of precast concrete panel systems described above has led to large-scale programs to develop these systems. Some of these programs are proceeding rapidly, and there is little doubt that precast concrete panel systems will play a large part in the production of mass housing in the future.

Future Outlook

To increase the use of precast concrete panel systems, action must be taken:

1. To further meet the dual goals of increased production and reduced cost;
2. To increase productivity through more mechanization, and to decrease on-site labour;
3. To obtain more standardization, interchangeability, and quality;
4. To secure more modular co-ordination in the design and manufacturing of components;
5. To shorten the construction period.

Continuous research and development in precast concrete construction, therefore, must be undertaken to obtain a high-strength, low-density material. Improvements in lightweight concrete and in prestressing techniques are essential.

The system approach must involve the organization of programming, planning, design, financing, manufacturing, construction, and evaluation of buildings under a single or highly co-ordinated management. That is, it must become an efficient total process. All too often, discussions of "systems" tend to focus on the "Kit of parts" or "hardware of building" rather than the process of building. Future efforts must, therefore, emphasize the total process, the integration of management principles with building systems.

In an overview, the future success of systems building lies not only in the technological advancement, but also in the improvement of the socio-political-economic environment. In the future, central governments must regulate demand, assuring a steady volume and market. The building industry must respond to social forces, and evolve to fit emerging social views such as environmental concerns, increasing individualism, privacy, etc. It is important that the building industry recognize both collective and individual needs. As many have advocated, the establishing of a "Professional Service" to mediate between manufacturers and users may aid this recognition and provide a mean to interpret the users' needs into material and quantitative demand.

The full potential of systems building for housing will become a reality when there is collaborations between designers, builders, building system manufacturers, owners, users, and governments. On October 25, 1977, a seminar named "Overview of Industrialized building systems, with an emphasis on housing" was sponsored by the Order of Architect of Quebec, the Canadian Portland Cement Association, and the University of Montreal. The great enthusiasm for collaboration shown by all participants in this seminar provides a hopeful note for the future.

In conclusion, the author shares the opinion of Time Magazine, in its February 19, 1973 issue, that -

"the housing industry today is in the same state as the auto business in the early 1900's . . . . no Henry Ford of housing has yet appeared to show conclusively the benefit of assembly-line production at a moderate price"

BIBLIOGRAPHY

1. BOOKS

Ambrose, J.E., Building Structure Primer, N.Y., John Wiley & Sons, Inc., 1967.

Babinovich, L.K., Reiz, L.B. and Mishel, G.V., Construction of Buildings made from Large Elements, Moscow, 1962.

Bemis, A.F., The Evolving House, Cambridge (Mass.), Technology Press, M.I.T., 1936.

Bender, R., A Crack In the Rear View Mirror, Van Norstrand Reinhold, New York, 1973.

Bruce, A., Sandbank, H., A History of Prefabrication, N.Y., John B. Pierce Foundation, 1943.

Cowan, H.J., Industrialized Architecture, Dept. of Architectural Science, University of Sydney, 1964.

Crane, T., Architectural Construction: The Choice of Structural Design, N.Y., John Wiley & Sons, 1956.

Diamant, R.M.E., (in collaboration with The Architect & Building News), Industrialized Building, 50 International Methods, London, Iliffe Books, 1964.

Fisher, R.E., Architectural Engineering - New Structures, N.Y. McGraw-Hill Book Co., 1964.

Giedion, S., Space, Time and Architecture, Cambridge, (Mass.) Harvard University Press, 5th ed. 1967.

Harrison, D., Albery, J.M., Whiting, M.W., A Survey of Prefabrication, London, Ministry of Works, 1945.

Hornbostel, C., Materials for Architecture, N.Y. Reinhold Publishing Co., 1961.

Howard, H.S. Jr., Structures: An Architect's Approach N.Y., McGraw-Hill Book Co., 1966.

Kelly, B., The Prefabrication of Houses, Cambridge (Mass.) Technology Press, M.I.T., 1951.

Kjeldsen, M., Simousen, W.R., Industrialized Building In Denmark, Skandinavisk Bogtryk, Copenhagen, 1965.

Koncz, T., Manual of Precast Concrete Construction with Large Reinforced Concrete and Prestressed Concrete Components: Design, Analysis and Construction (Translated by Van Amerougen, C.), Berlin, 1968.

Krymsku, N., Precast Concrete in the Soviet Union, (Translated by Amron, I.) Foreign Languages Public House, Moscow, 1958.

Leonhardt, F., Prestressed Concrete: Design and Construction, (Translated by Van Amerongen, C.), W. Erust, 2nd ed., 1964.

Lewicki, B., Building with Large Prefabricates, (Translated by Express Translation Service, London, Amsterdam, New York, Elsevier Publishing Co., 1966.

Michaels, L., Contemporary Structure in Architecture, N.Y., Reinhold Publishing Co., 1950.

Morris, A.E.J., Precast-Concrete Cladding, London, Fountain P., 1966.

Nervi, P.L., Structures, N.Y., McGraw-Hill book Co., 1956.

Parker, H., Gay, C.M., MacGuire, J.W., Materials & Methods of Architectural Construction, N.Y., John Wiley & Sons, Inc., 3rd ed. 1958.

Promyslov, V.F., Moscow in Construction, (Translated by Kuznetsov), 1967.

Rosenthal, H.W., Structural Decisions, London, Chapman and Hall, 1962.

Salvadori, M., Heller, R., Structure in Architecture, N.Y., Prentice-Hall, 1963.

Sanoff, H., A Bibliography and Critical Review of Industrialized Housing, Monticello, Ill., 1970.

Sebestyén, G., Large-Panel Buildings, (Translated by Frankovszky, A.), Budapest, 1965.

Sheppard, P., Prefabrication in Building, London, Architectural Press, 1946.

Siegel, C., Structure and Form in Modern Architecture, N.Y., Reinhold Publishing Corp., 1962.

Timoshenko, S.P., Young, D.H., Theory of Structure, N.Y., McGraw-Hill, 2nd ed. 1965.

Volkov, G.F., Lantsov, V.A. and Sharyi, Y.V., Mechanizen Housing-Estate Construction with Large (concrete) Components, Leningrad Branch of Academy of Building Construction and Architecture, 1959.

Wachsmann, K., The Turning Point of Building: Structure and Design, N.Y., Reinhold, 1961.

White, R.B., Prefabrication: A History of Its Development in Great Britain, London, Her Majesty's Stationary Office, 1965.

Winter, G., Urquhart, L.C., O'Rourke, C.E., Nilson, A.H., Design of Concrete Structures, N.Y. McGraw-Hill, 7th ed., 1964.

Yuzbashev, L.G., Experience in Designing and Building Houses With Large Panels, Moscow, State Publishing House on Building Construction, Architecture and Building Materials, 1959.

Zuk, W., Concepts of Structure, N.Y., Reinhold, 1963.

2. ARTICLES IN TECHNICAL JOURNALS

American Concrete Institute, Journal:

1948 : Mathews, M.L., "Prefabricated Pumice Concrete House", 19 (Proc. 44) (9), pp. 797-811

1954 : Peterson, J.L., "History & Development of Precast Concrete in the U.S." (Feb.), pp. 477-496

1962 : Geifen, W.H., Anderson, J.R., "Joinery of Precast Concrete" (Oct.), pp. 1435-1442

1964 : "Suggested Design of Joints & Connections in Precast Structural Concrete", (Aug.), pp. 921-937

1966 : Birkeland, P.W., Birkeland, H.W., "Connections in Precast Concrete Construction" (Mar.) pp. 345-368

1970 : "Fabrication, Handling and Erection of Precast Concrete Wall Panels" (Apr.), pp. 310-340.

American Institute of Architects, Journal:

1948 : Fisher, H.T., "Prefabrication. What Does It Mean to the Architect?" (Nov.)

1960 : "History of Concrete Building" (Oct.), pp. 66-69.

Architect & Building News:

1959 : "Prefabricated Buildings" 215 (March 25th), pp. 373-398

1962 : "Prefabricated Construction, Suppliers of Systems and Buildings" 222 (33) (Aug. 15th), pp. 227-244

1963 : Diamant, R.M.E., "The Balency System of Building" 224 (11), pp. 412-415

1963 : Diamant, R.M.E., "The Camus System" 223 (21), pp. 792-795

1964 : Bishop, D., "Large-Panel Construction", 226 (1), pp. 23-28 and (2) pp. 86-88

1965 : "Large Concrete Panel Production: Report from the Building Research Station", (Dec. 1st), pp. 1046-1047

1966 : "System Appraised, List of 33 Systems Dealt with by National Building Agency" (March 2), pp. 380-383

1967 : Diamant, R.M.E., "The Tracoba-4 System of Industrialized Building", 231 (5), pp. 201-203

1968 : Claxton, K., "The Nature of Industrialization 30 - The Changing State of Industrialization in Building" (July 17th), pp. 100-103

<u>Architectural and Engineering News</u>

1965 : Halle, R., "Modular Systems, Basis for an Integrates Building Industry" (Sept.), pp. 26-28, 33

1965 : Robinson, R.C., "Tolerance in Precast Construction", (Sept.), pp. 56-58, 61

1967 : "Research for Better Concrete", (Nov.), pp. 38-43

1968 : Chipman, L., "Precast Walls & Other Building Components" (Oct.), pp. 58-59

1969 : Firnkas, S., Camellerie, J.F., and Moran, J.R., "Towards Quality Concrete", (Apr.) pp. 25-35

Architectural Forum:

1961 : Lin, T.Y., "Revolution In Concrete", 114 (5,6) (May) pp. 121-127, (June), pp. 116-122

1965 : "Housing" (July-Aug.), pp. 58-65

1967 : Huxtable, A.L., "Building the Soviet Society" (Nov.) pp. 34-41

1969 : "Thamesinead", (July-Aug.), pp. 58-65

1969 : Dixon, J.M., "Industrialized Housing - Can It Happen Here?" (July-Aug.) pp. 101-107

1970 : Pellish, D.M., "A New Government and Industry Partnership for Building More Housing", (July/Aug.), pp. 58-61

Architectural Record:

1965 : "Precast Bearing Walls: 3 Examples" (May), pp. 218-220

1965 : "Precast Girder Wall", (June), pp. 217-218

1965 : Lin, T.Y., "Tall Buildings in Prestressed Concrete" (Dec.), pp. 165-170

1966 : Rothenstein, G.G., "In-Factory or On-Site for Concreting" (Apr.), pp. 221-227

1967 : Koch, C., "Low Cost Precast Component System For Apartment Building", (March), pp. 187-194

1967 : "Post-Tensioning Apartment Flat Plate Slabs" (June), pp. 193-196

1968 : Wing, W.C., "Concrete Frame Is Made 'Flexible' To Absorb Earthquake Loads", (Apr.) pp. 191-194

1968 : "Failure of High-Rise System - How Safe Should Structure Really Be" (Nov.), pp. 169-170

1969 : Winkler, J., "Russia's Approach to Housing is Reorganized" (Oct.), pp. 169-171

1970 : "Operation Breakthrough" (Apr.) pp. 137-160

Australian Building Science & Technology:

1967 : Gvozdev, A.A., "Research On Precast In U.S.S.R. & Neighbouring Countries", (Jan.), pp. 9-11, 13-15, 17-18

1967 : Hognestad, E., "Research On Precast In Non-European Countries", (Feb.), pp. 5-9

Build International:

1969 : Blachere, G., "Definition & Control of Tolerances in Buildings", 2 (3), pp. 10-13

1969 : Eglit, V.I., "Mounting Acuracy of Prefabricated Building Components", 2 (3), pp. 14-18

1969 : Rozanor, N., "Large-Panel Construction in the U.S.S.R. 2 (4), pp. 18-21

1969 : Khazanor, D., Madera, G., "Unified Modular Elements in the U.S.S.R." 2 (67), pp. 16-19

Builder, (London):

1962 : Reiners, W.G., & Bishop, D., "Construction of Multi-Storey Flats. The Economics of Large-Panel Methods" pp. 879-886

1962 : Cambell, K.G., "Housing from the Factory" 203 (6036) pp. 1040-1042

1963 : Wood, K.M., "Industrialized Building; Some Associated Economic Problems", (May 24th), pp. 1031-1038

1963 : Rosner, R., "Prefabricated Building in W. Germany" 204 (6251), pp. 501-503

1963 : "The Tracoba System of Prefabrication", 204 (6254), pp. 501-503

1963 : "System Building 7: The Coignet System", 204 (6257), pp. 795-796

1963 : "System Building 8: The Balency System", 204 (6258), pp. 851-852

1963 : "System Building 12: The Wates System of Precasting on Site", 204, pp. 1057-1058

1963 : "System Building 13: The Camus System of Load-Bearing Cross & External Walls", 204, pp. 1107-1108

1963 : "System Building 14: The Larsen Nielsen System of Load-Bearing Cross-Wall Construction", 204, pp. 1155-1156

1965 : Wood, K.M., Whittington, R.O., Tozer, W.A., "The Economics of Industrialized Building", 208 (6348), pp. 139-140

1965 : Wates, N.E., Cleevebarr, A.W., Culdin, C., "Symposium on Modern Methods of House Buildings". 208 (6352), pp. 367-369

1965 : Danison, C., "Towards Industrialized Building: Report on the 3rd Congress of the International Council for Building Research, Studies, and Documentation (CIB), Copenhagen, (Sept. 24th), pp. 651-656

1966 : Seymour-Walker, K.G., "Techniques for Making Large Concrete Units", 210 (6401), pp. 143-149

1968 : Morris, E.J., "Precast Concrete Wall Units", 215 (6550) pp. 67-72

Building:

1966 : Von Halasz, R., "Tolerances in Manufacture and Erection". (Sept.) pp. 113-116

1966 : Harrison, H.W., "Joints and Component Interchange" (Nov.) pp. 145-146, 9, 150, 3, 4, 7, 8

Civil Engineering (London):

1954 : McKelvey, K.K., "Some Aspects of Prefabricated Construction", 49 (579), pp. 933-935, (580), pp. 1082-1083

1958 : Spyra, J.J., Smith, R.B.L., "Tests of Efficiency of Joints to Precast Concrete Members", pp. 1143-1151, (Nov.), pp. 1284-1286, (Dec.), pp. 1403-1404

1962 : Rees, M., "Some Recent Developments in Structural Precast Concrete" (July), pp. 881-884

Concrete and Constructional Engineering:

1963 : Courey, J.W., "Structural Joints", (May), pp. 196-198

1966 : "Some On-Site Systems for Industrialized Building" 61 (1), pp. 5-14, (2), pp. 67-73, (3), pp. 95-99, (4), pp. 131-134

Engineer, (London):

1962 : "Prefabrication of Flats", 214 (5576), pp. 1003-1006

1964 : "Will Factory-Made Flats Speed Housing", 197 (5099), pp. 52-53

1965 : "What a Production Line for Housing Meaus", 200 (5194), pp. 590-591

House and Home:

1970 : "Here's a New High-Rise System that Mixes Light and Heavy Construction", (Aug.), p. 26

1970 : "Precast Concrete Housing Systems", (Sept.), p. 78

1971 : Grasso, J.C., "When Will the Building Product Manufacturers Realize Modular Housing Companies Have Their Own Special Need?" (Jan.), p. 62

1971 : Carlson, J. "Apartments: Adapting to a Changing Market", (Feb.), pp. 60, 62

Progressive Architecture:

1963 : Joseph, J., "Expansive Concrete Additive", (Nov.) pp. 178, 180, 182

1964 : Shiffer, E.T., "Industrialized Building System in West Europe". (Oct.), pp. 192-200

1966 : Cossutts, A., "From Precast Concrete to Integral Architecture", (Oct.), pp. 196-207

1968 : Pinter, G., "Cheaper Multistorey Building in Sight with Prefabricates Concrete System", (Feb.), pp. 146-149

1968 : "Precast Concrete Panel", (March), p. 149

1968 : Cheskin, D.B., "Precast Units for Multistorey Apartments", (Nov.), pp. 142-143

1970 : "Finland-Russia: Two Sides of a Gulf", (March), pp. 72-99

1970 : "Operation Breakthrough: Operation P/R". (April), pp. 120-133

<u>Royal Institute of British Architects, Journal</u>:

1947 : Fitzmaurice, R., "Scientific Research on Alternative Methods of Construction for Permanent Houses", (Apr.), pp. 309-315, 359-365

1948 : Llewelyn Davies, R., "The Choice of Structural Type and Its Cladding", (Feb.), pp. 164-169

1949 : Fitzmaurice, R., "Changes in Building Technique", (Dec.), pp. 49-58

1954 : Broughton, H.F., "Economy in Building", (Feb.), pp. 149-154

1960 : Trench, P., "Looking ahead at the Building Industry", (Aug.)

1962 : Lea, F.M., "The Building Industry in an Expanding Economy" (July)

1963 : Benson, A.C., Jones, F.M., Vaughan, J.E., "Early Example of Prefabrication", (June), p. 251 .

1967 : Whitfield Lewis, H.J., "Symposium on Industrialized Housing and Architect", 74 (2), pp. 66-73

3. GOVERNMENT PUBLICATIONS AND MISCELLANEOUS PAPERS

(in chronological order)

- International Congress for Housing and Town Planning, 20th Congress, Amsterdam, 1950, Fitzmaurice, R., Kelly, B., Dr. Mazure, Prefabrication and New Building Techniques, Amsterdam, 1950
- Albert Farwell Berius Foundation, Kelly, P.M., Shillabar, C., International Bibliography of Prefabricated Housing, M.I.T., Cambridge (Mass.), 1954
- Organization for European Economic Co-operation - European Productivity Agency, Prefabricated Building, A Survey of Some European Systems, Project No. 226, Paris, 1958
- National Research Council, Building Research Institute: Division of Engineering and Industrial Research, Fall Conference, 1960, Preassembled Building Components, Washington, 1961
- University of Sydney, Department of Architectural Science, Ph.D. Thesis, Smith, P.R., The Use of Precast Concrete Structural Elements in Major Architectural Projects, with Particular Reference to the Application of Prestressing to Three-Dimensional Structures, 1962

- Federation International de la Preconstrainte, 4th Congress - Theme 3, Paper 2, 1962, Hill, A.W., Some Recent Developments In Design and Construction or Precast Structure in Great Britain, pp. 11-25
- American Concrete Institute, Committee 533, Symposium on Precast Concrete Wall Panels, Detroit, 1965
- C.I.B. Towards Industrialized Building: Proceedings of the 3rd C.I.B. Conference, 1965, Copenhagen, Elsevier Publishing Co., New York and Amsterdam, 1966
- Institution of Structural Engineers, A Symposium Held in London on 17-19 May, 1966; Industrialized Building and the Structural Engineers, London, 1966
- International Congress of Precast Concrete Industry 5th - Proc. May 21-27, 1966; Malmstrom, P.E., Jointing Problems in Facades, pp. 3-14
- Department of Industry, Ottawa, Canada, Report of the Canadian Technical Mission on Prefabricated Concrete Components in Industrialized Building in Europe, Sept. 1966
- Pratt Institute, School of Architecture, HUD Demonstration Project: Progress Report; Cost Reduction Methods for High-Rise Apartments, New York, 1967
- Ministry of Public Building and Works, Dimensional Coordination DC5-7, London, 1967
- National Research Council of Canada, Technical Paper No. 273 of the Division of Building Research, Platts, R.E., System Contractors in Europe Lead the Way in Multi-Family Housing, Reprinted from Engineering and Contract Record, (81), Feb. 1968, p. 54-59

- Cornell University, Center for Housing and Environmental Studies, Research Report No. 8, The New Building Block, 1968
- U.S. Department of Housing and Urban Development, Division of International Affairs, Industrialized Building - A Comparative Analysis of European Experience, Washington, 1968
- U.S. Department of Housing and Urban Development, Breakthrough, U.S. Government Printing Office, Washington, D.C., May 1969
- U.S. Department of Housing and Urban Development, Operation Breakthrough: Mass Produced and Industrialized Housing, a Bibliography, The Supt. of Document, U.S. Government Printing Office, 1970
- LCN Closers of Canada, News Letter, System Building/Part 1-6, Oct. 1971 - Oct. 1973
- U.S. Department of Housing and Urban Development, Office of Policy Development and Research, Wall Panels: Analysis and Design Criteria, Aug. 1976
- University of Montreal, "Overview of Industrialized Building Systems" Conference, Davisdon, C.H., Various options for the Industrialization of Building, Montreal, Oct. 1977