CONCRETE PREFABRICATED BUILDINGS

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A Major Technical Report
in
The Faculty
of
Engineering

Presented in Partial Fulfillment of the Requirements
for the degree of Master of Engineering at
Concordia University
Montreal, Quebec, Canada

September, 1976

ACKNOWLEDGEMENTS

It was during 1970, the writer first listened to Dr. Zenon A. Zielinski, then Ford Foundation Consultant, at a symposium on Low Cost Housing, arranged by the National Building Organisation, New Delhi, India. This eventually resulted in my current interests in Prefabricated Structures.

The writer wishes to express his profound gratitude to Dr. Z. A. Zielinski, professor of Civil Engineering, Concordia University, for his valuable advice, guidance, criticism and corrections which helped immensely in the preparation of this report.

The writer expresses his deep appreciation to Dr. M. M. Douglass for the care he took in checking and reviewing the manuscript and pinpointing the corrections. Thanks are also extended to Mrs. H. Stuppel for typing the final copy of the report.

My final acknowledgement is to my wife, Tripat, for her continued encouragement, interest and patience.

ABSTRACT

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A review of the state of art in the field of prefabricated concrete structures is presented in this report. Different systems of prefabrication, design concepts with a particular reference to the avoidance of progressive collapse, methods of manufacture, erection and assembly techniques are discussed.

Various reasons for the non-adoption of prefabricated construction by some industrially developed countries and also of developing countries are discussed, and the essential prerequisites for its success are enumerated. To justify the choice of prefabrication in any particular case, it is shown that the advantages must, of course, outweigh the disadvantages.

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CHAPTER I

INTRODUCTION

1.1 Industrialization

The terms industrialization and prefabrication are synonymous. Prefabrication is the basis of industrialization in the building industry. The essential features of industrialization are mechanization of labour, rhythm of production. Industrialization results in a smaller labour outlay, more efficient use of materials, and considerable reduction in the construction period. Moreover, it makes the building industry much less seasonal. In fact, non-industrialized buildings do not exist. Even the most traditional building uses some industrially made products like bricks. To assemble them many manual, i.e., non industrial, operations are required. Therefore, when we use the word industrialization, it is likely that we are calling for the industrial manufacture of more complex building components, designed to be assembled industrially.

1.2 Need

The traditional building construction methods have not produced the needed productivity and performance gains for the fast growing population. The building industry has not kept pace with developments in other producing segments of the economy. This has resulted in a dramatic increase of construction costs which resulted in a drastic reduction of many construction projects. The inability to complete most construction projects within the time frame consistent with present day demands, is increasingly calling the conventional construction methods into question. Prefabrication is the answer to the ailing traditional building practices.

1.3 Why Concrete

Concrete is an old material but its present qualities and usages characterize it as modern and versatile. As it is well known, concrete can be moulded in so many ways with a variety of surface treatments, will play a very important role in the development of industrialized approach to buildings. An even more significant advantage is that it can be simultaneously used, both structurally and architecturally and also can have cast within it practically all of the required services. This allows for greater versatility in architectural expression. Durability and fire resistance properties of this material make it ideally suitable for industrialized buildings.

1.4 Advantages of Prefabrication

Many advantages of precasting of structural reinforced concrete and prestressed concrete have resulted in the mass production of the units in nearly all spheres of architectural and engineering practice. The principal advantages are:

a) Economy in formwork and shuttering.

b) Mass production methods due to standardisation, resulting in economy in labour and increased productivity.

c) Factory production proceeds independent of weather conditions.

d) Appropriate methods of curing ensure improved and reliable products and accelerate maturing, thus increasing productivity.

e) Minimizes the need to have specialized and trained labour at site.

f) Factory production or, at any rate, under factory conditions at building site, ensures better quality control, which means higher permissible stresses in materials, thus resulting in lighter sections. Weight of the building as a whole is reduced. Prestressing further reduces the sectional size.

g) Speed of construction on site is greatly increased which results in further savings; i.e., interest on construction funds, early return of revenue.

h) Volumetric stability of precast structures is better since shrinkage of each element has already taken place before being placed in position and is largely eliminated after erection due to the multiplicity of joints in the finished structure.

i) In insitu construction a surplus of materials is usually unavoidable, but in the case of precast unit construction the transport is limited to that of the finished product.

Against this there is a problem of transporting the prefabricated components from the factory to the site, which is more difficult than transporting materials, and of erecting and interconnecting them to form the final structure. These operations associated with prefabrication entail additional cost.

Designing prefabricated structures calls for greater effort and more careful detailing than conventional construction. With prefabrication, construction time of the building becomes shorter, whereas the design takes more time. Besides, the detailing of the individual members and connections call for a great deal of skill and experience and the designer has to spend considerable time even on a small detail.

To justify the choice of prefabrication in any particular case, the advantages must of course outweigh the disadvantages.

1.5 History of Prefabrication

Records indicate that as early as 1892, a prefabricated bearing wall system was used by a French firm, "Constructions Edmund Coignet", for casino building. Concrete Ltd. of England began to manufacture precast concrete plank in 1919 but a precast system for the entire building was not developed until some years later. Several large panel systems were developed in Europe in the 1920's. Most of these did not survive. Inadequate handling capacity of the equipment was a prime handicap, and these systems could not compete economically with conventional construction. Major development in prefabricated concrete system building occurred after World War II. Many countries suffered from a severe housing shortage, especially for low income groups. There was also a shortage of skilled labour. Industrialization, it was believed, could bring about a significant decrease in the cost of residential construction. Currently, in Great Britain, Denmark, Finland and other European nations approximately 25% - 35% of all housing construction is with precast systems. East European countries generally exhibited a greater percentage of industrialized residential construction than did West European countries. The Soviet Union projects that by 1980 over 80% of its housing construction will be of precast systems.

In the United States precast concrete construction has been in use since the 1900's. But not until the late 1960's was any system developed which overcame the many constraints of residential construction while providing aesthetically and functionally flexible buildings which were also economically feasible. High labour and material costs and strong demand for residential units have finally changed the climate in favour of industrialized systems.

1.6 Prerequisites for Success

Only the work of building has been left out of the industrial miracle since the age of mechanisation began. Reason, we do not work in harmony with our scientific processes. In the past, the Master builder was a perfect human being. He was an architect, an engineer and a builder, all in one. He drew inspiration from materials, secured respect for his ideas and shouldered all responsibility. The present day Architect tends to put himself at a distance from technical considerations and even further from actual execution of the work. He is more of an administrator than an originator. Architects, Engineers, Contractors, each operate separately and their interests are too often only conflicts. This has resulted in profession deterioration. A representative of an Aircraft industry has said that if aeroplanes were produced in this way, they would not fly.

Prefabricated or industrialized housing demands that architect and engineer should be integrated into industry. An architect must accept the design disciplines of that system. He is a member of the building team, but not the leader. This is a prerequisite for success and will have the effect of changing the role of architect and engineer in the building industry. Their common concern, like that of the motor industry, should be to produce the best housing at the most competitive price. This is what spells success in industry.

Experience in industrially developed countries shows that in broad terms, prefabrication passes through a three stage evolutionary process. In the first stage, prefabrication often costs more than the conventional construction. Nevertheless, prefabrication is considered necessary and desirable to supplement traditional methods and to achieve a certain scale of production and level of technology which can reduce the total cost of construction. During this stage the local government, quasi-public housing societies, etc., must participate to assure continuity of demand and to support programs of research and production by lending loans at a lower rate and capital subsidies and special forms of contracts. Guaranteed scale and continuity of production are necessary for success. This was clearly demonstrated in Europe. The second stage is characterized by weeding out of many systems which are non-competitive and unacceptable to consumers. The successful systems are then consolidated and given further support. In the third stage, concerted efforts are made to apply scientific methods of design, production, erection and standardization of prefabricated components. Substantial economies can probably only be made under a long term comprehensive industrialization program.

Aesthetics seem to be another drawback. Architectural flexibility is not as easily obtained as with conventional construction methods. Prefabrication is most extensively used in Socialist countries, primarily because of the centrally controlled nature of their economy. With prefabrication, new forms of construction are bound to emerge. It is precisely this variety of techniques and possibilities that lends appeal to the work of the architect and the engineer. To bring about the gradual change from traditional to prefabricated construction systems, technical schools/universities should introduce one or more specialized courses of instruction on prefabrication for educating professionals (engineers, architects).

1.7 Experiences of Industrialized Countries

Industrialization of buildings in Europe occurred in three stages. The first stage, during the late 1940's and 1950's, supplemented traditional methods and attempted to raise the level of technology and scale of production. Progress continued as national and local authorities stepped in to assure continuity of demand and to support research and production.

During the second stage (late 1950's and early 1960's) many systems that were not competitive were weeded out. Successful systems were given additional support by the government, some were consolidated and refined. The third stage occurred during the late 1960's when a concerted effort was made to apply scientific methods of engineering design, production and erection for reducing the cost below the conventional systems.

The much needed increase in housing production could not have been achieved with the existing labour force by using conventional building methods. Industrialization could reduce on site labour by as much as 30-50%, and erection time could be greatly reduced. The essential features of industrialized building systems are mechanization and attainment of rhythm of production. Combined, they result in continuity and evenness of output. Box type systems in the U.S.S.R. showed even a greater reduction in on site labour, as high as 80%. The translation of man-hour savings into net building cost savings is difficult. Some European countries have claimed a clear cost advantage for large panel prefabricated systems over conventional systems, of the order of 10-20%. Several other countries, especially with highrise construction, claim a cost advantage in the range of 5-15%. A secondary aspect of cost is associated with completion time. On site construction time has been markedly reduced in most European countries. This reduction in time saves capital costs during the construction period due to reduced interest on construction funds, and advances the time for income realization. An interesting point to appreciate is that no independent British precast concrete company has survived without having a "standard" product to sell. Invariably those who only manufactured "specials" to others' designs sooner or later have gone to the wall.

In the United States, for several years, prefabricated concrete systems were only used for buildings up to four or five storeys, but in the last six or seven years, many buildings have been constructed in the range of 15-24 storeys. Habitat '67 in Montreal, Canada, created interest in the U. S. housing industry. It was an exciting architectural utilization of prefabricated modules for residential construction. About the same time, H. B. Zarchry Company developed a box-module system in San Antonio, Texas. A crash program involving the use of checkerboard pattern of modules for the 21 storey, 500 room Hilton Palacio del Rio was required. Construction had to be completed in nine months so that the hotel could be ready for the opening of Hemisfair, in April, 1968. The first module was cast on August 15, 1967, erection began on November 10th, and the final module was in place on December 20, 1967. Since then many hotels/motels have been constructed using this system. In 1969, a program to encourage industrialized housing called "Operation Breakthrough", was introduced by the U. S. Department of Housing and Urban Development. "Operation Breakthrough" was to be a total development program to resolve a multitude of problems associated with making quality housing available in large quantities. H.U.D.'s experience has shown that concrete box-module systems seem to have the most difficulty in sustaining long term success. A primary difficulty seems to be that of complexity of forming. Another adverse factor encountered with the modular system, and, to a lesser degree with the panelised system, is the tremendously high investment required for manufacturing and transportation facilities. Unless a company can be guaranteed a minimum number of components per year, it can not afford to construct an expensive factory.

1.8 Experiences of Developing Countries

Industrialized methods of construction involve higher capital investment and lower utilization of unskilled labour. Developing countries have a large surplus of unskilled labour force and shortage of capital resources. Thus, developing countries face a dilemma regarding the apparent efficiency, speed and productivity of prefabricated construction and the social aspect of providing jobs to unskilled and unemployed labourers. It is also argued by some that, although labour intensive methods of construction do temporarily provide jobs to a large number of unskilled labour, more mechanized methods provide a rapid increase in building output and capital works which, in the long term, will accelerate the economy and provide wider and more permanent employment possibilities. However, as a gradual step, the improvement of manual methods of construction with introduction of partial prefabrication is desirable. Partial Prefabrication represents a first step in the direction of industrialization. The masonry for walls is still hand laid, but many elements of the building such as lintels, floor and roof slabs, stair flights, etc., are precast away from the site, and erected as the masonry work progresses. The use of prefabricates reduces the construction time and introduces some mechanization of labour. As industrialization gets greater hold into the set-up, complete prefabrication would be automatically introduced. Partial prefabrication enables optimum utilization of human skill along with mechanized methods. To start with, partial prefabrication, perhaps, finds the best answer to meet the situation.

CHAPTER II

DIFFERENT SYSTEMS

2.1 Building Systems

A system is a co-ordinated series of industrialized building components to meet specific needs. It may be subdivided into two main categories, i.e., Open System and Closed System.

Open System.--In this system, the components from various manufacturers, catalogued, may be fitted or integrated alongside one another to form one or more building types, i.e., modular units produced by different manufacturers are interchangeable within different systems without any modification. This system requires dimensional co-ordination in the strictest sense and a high degree of liaison between different manufacturers in establishing tolerances, fittings, and joining requirements.

Closed System.--In this system the majority of components are sized and detailed for use with each other, usually by one manufacturer, and are assembled with strict uniformity of approach for a particular building system, and no interchangeability is possible.

2.2 Structural Systems

Although there are many structural systems, generally speaking all are variations of two main basic approaches: the Component approach and the Module or Box approach.

The objective of the Component approach is to achieve construction of an almost unlimited variety of buildings by using a limited number of mass produced interchangeable components like wall and floor panels, beams, columns, stairs, etc. This approach is common almost universally. It offers flexibility in production, in type and size of plant, selection of components and architecture. The extent of mechanization can be varied to suit local conditions.

The examples of the so-called Module approach include mobile houses in the United States and Box type construction. The production of modules requires high capital investment, superior infrastructure, and a higher level of mechanization than of Component approach.

The Component system is further subdivided into framed construction and slab or shell type construction. Here again systems are distinguished into shed type structures and multistorey buildings.

2.3 Industrial or Shed Type Structures

For shed type industrial buildings, solid web members are used as main beams and columns. The maximum length of span of a solid web beam concreted in one piece is ±30m. However, for spans in excess of ±30m, solid beams become too heavy for transportation and erection. Under such circumstances it is preferable to design arch frames or lattice trusses, or, if solid beams are adopted, to assemble them from small units. In this way, the need to use heavy lifting appliances can be avoided; on the other hand, scaffolding has to be provided. The economy in any particular case is a matter of relative costs.

The structural system may also consist of slab or shell type units for roofing as well as for load bearing walls.

Some of the forms of construction for single storey, single or multibay, flat or sloping roof, with or without roof lights, are shown in Figs. 1 to 8.

Grandstands.--Prefabrication is ideal for such structures. They comprise a large number of identical components, even though the ground plan is not regular. Most of the components are identical to industrial sheds. Tiers used for seating accommodation are similar to the roofing members, i.e., Single T's, double TT's, trough units, as shown in Fig. 9b, while the supporting structure and roofing structure correspond to the frame work. A typical grandstand in the United States is shown in Fig. 9a. It comprises three main types of components: inclined columns, beams with steps to support tiers, and roof beams. These components are assembled together by means of prestressing.

Montreal Olympic Stadium.--To meet an almost impossible deadline for the completion of the Montreal Olympic Stadium, post tensioned, segmental precast concrete elements combined with conventional precast, and prestressed components were used. The stadium is elliptically shaped 481.7m x 279.9m of 73,000 seating capacity. Its inward sloping mast will house both athletic and recreational facilities, and when completed, will cable support the retractable fabric canopy roof. Fig. 10

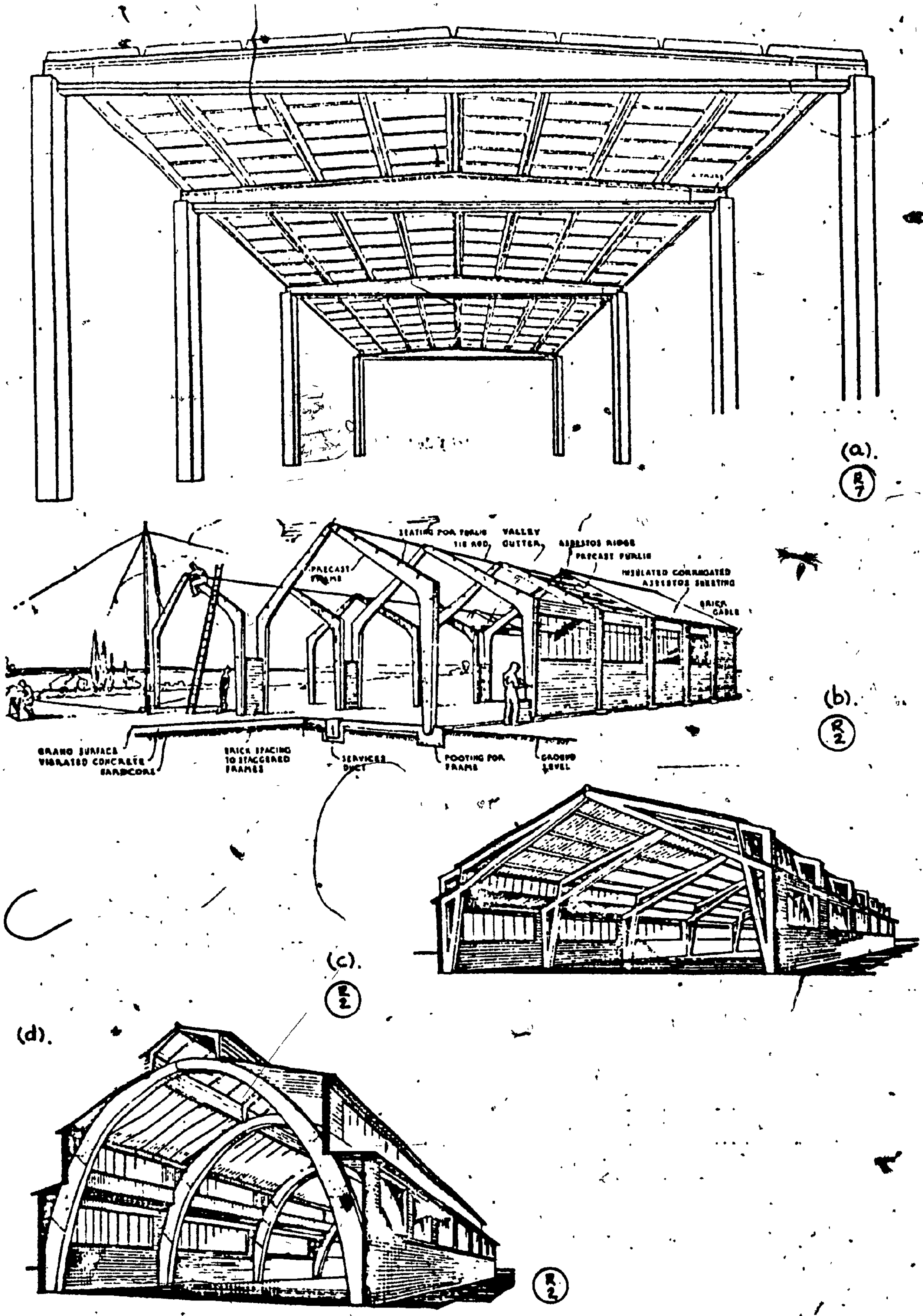


Fig. 1 - Shed Type Structure - Framed Construction

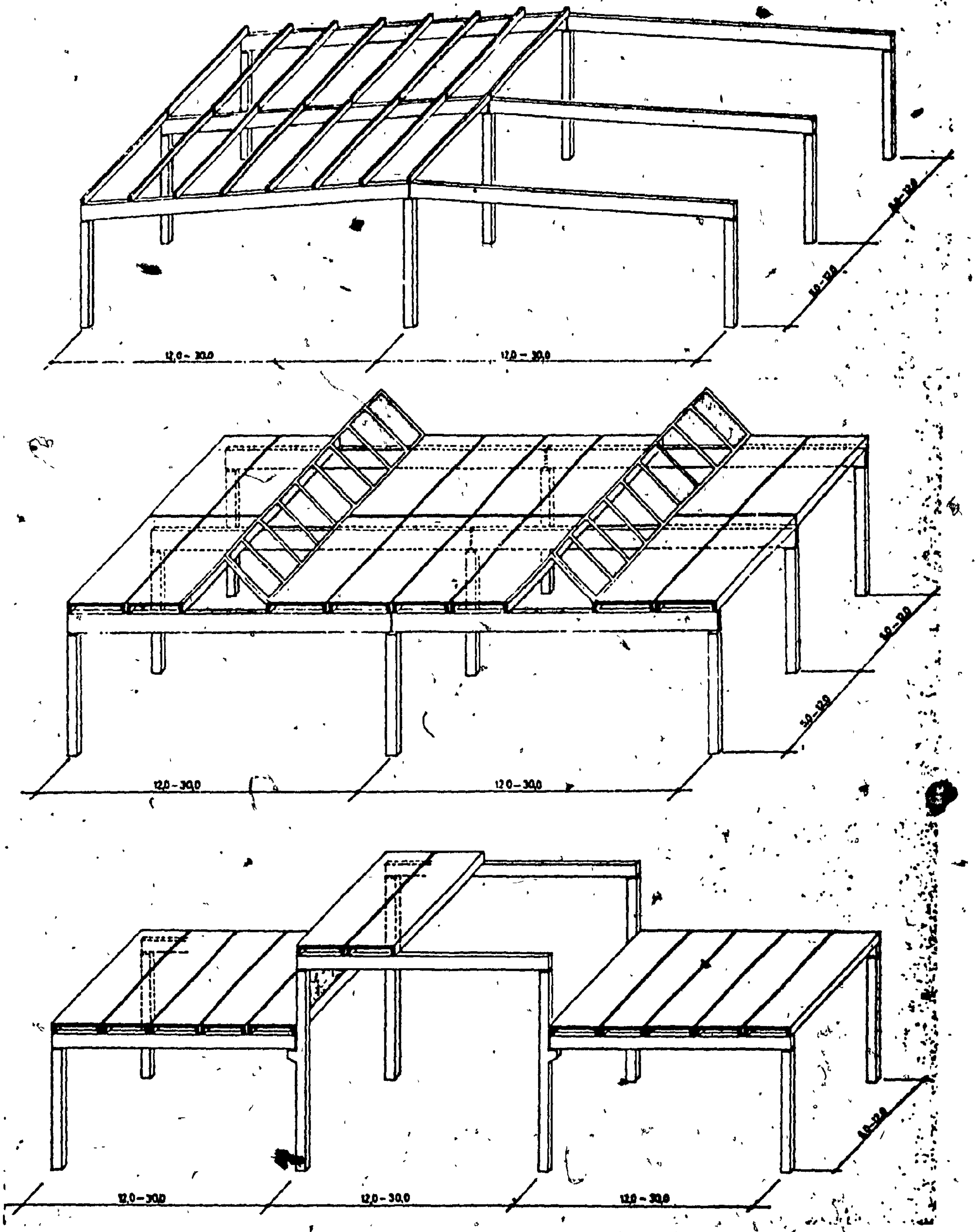


Fig. 2 - Shed Type Structure - Framed Construction

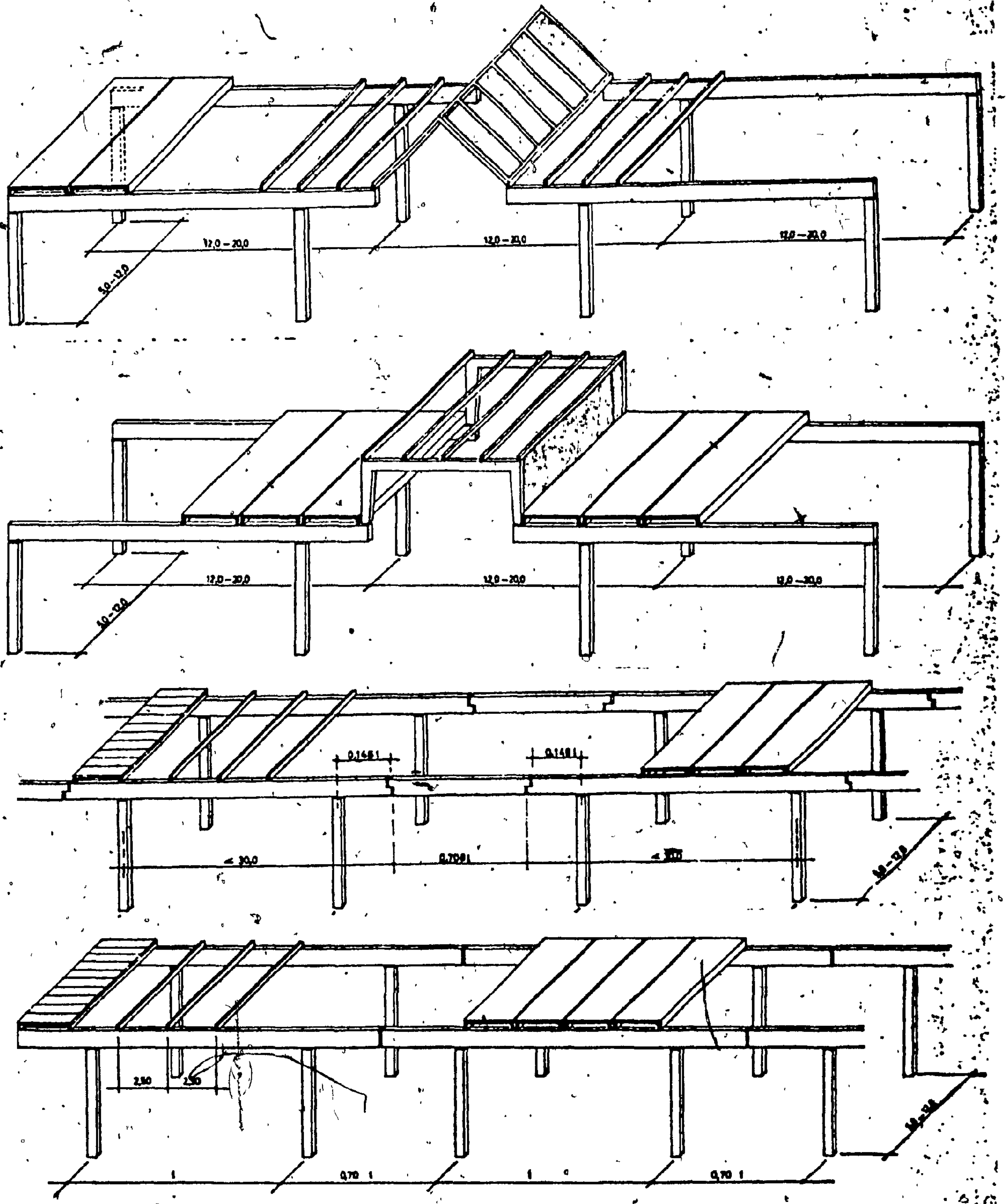


Fig. 3 - Shed Type Structure - Framed Construction

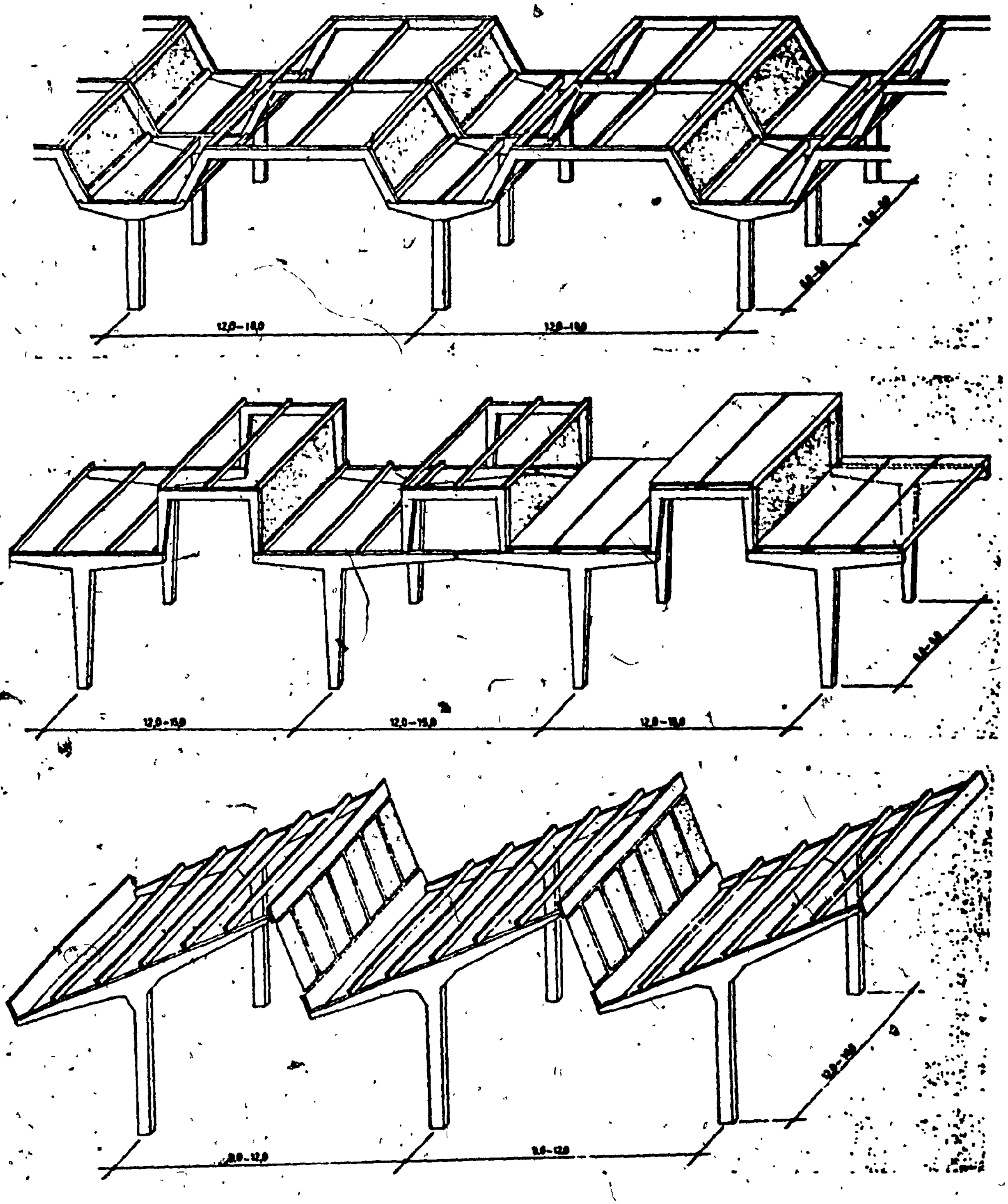


Fig. 4 - Shed Type Structures - Framed Construction (R 21)

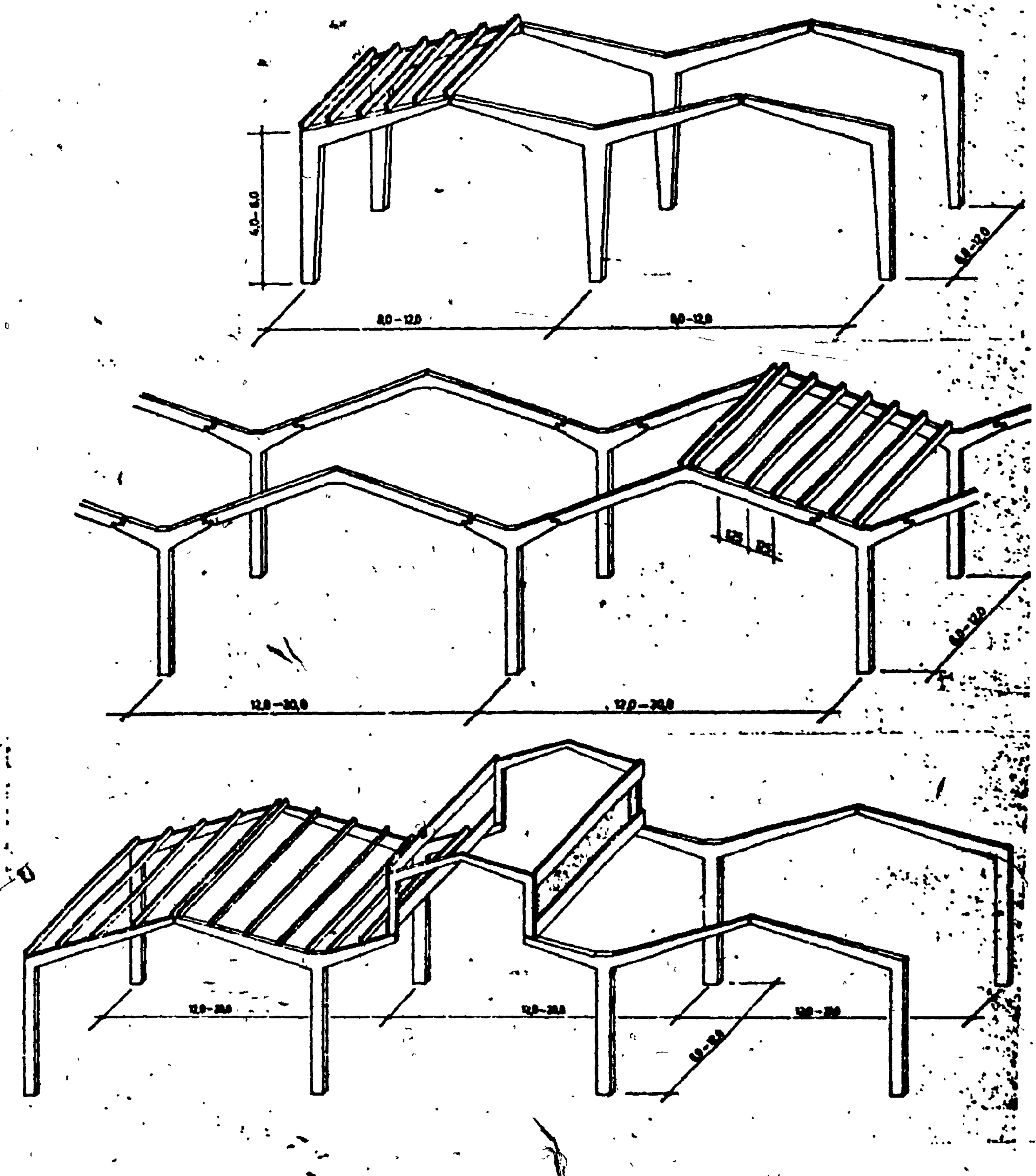


Fig. 5 - Shed Type Structures - Framed Construction (R. 21)

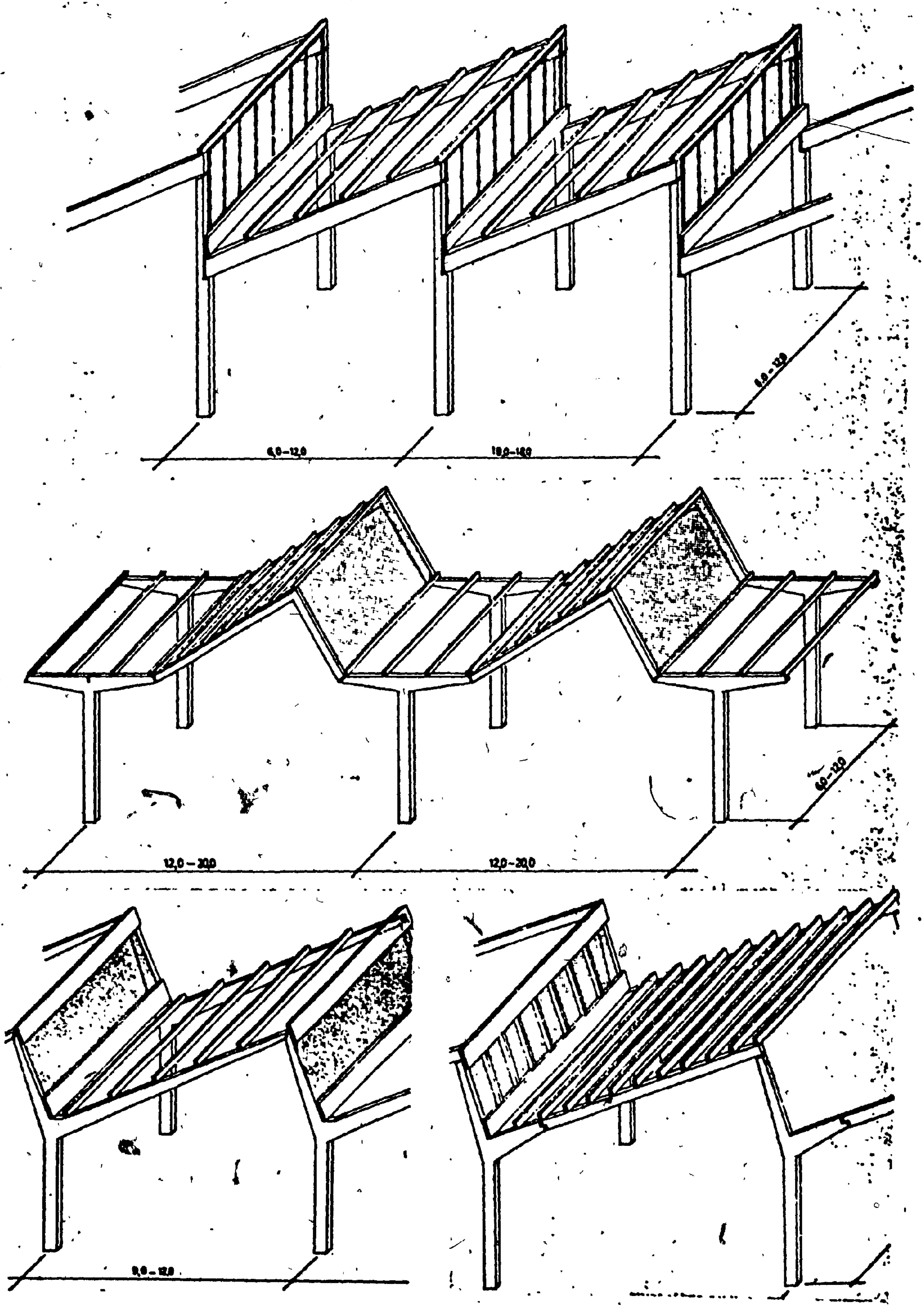


Fig. 6 - Shed Type Structure - Framed Construction (E 21)

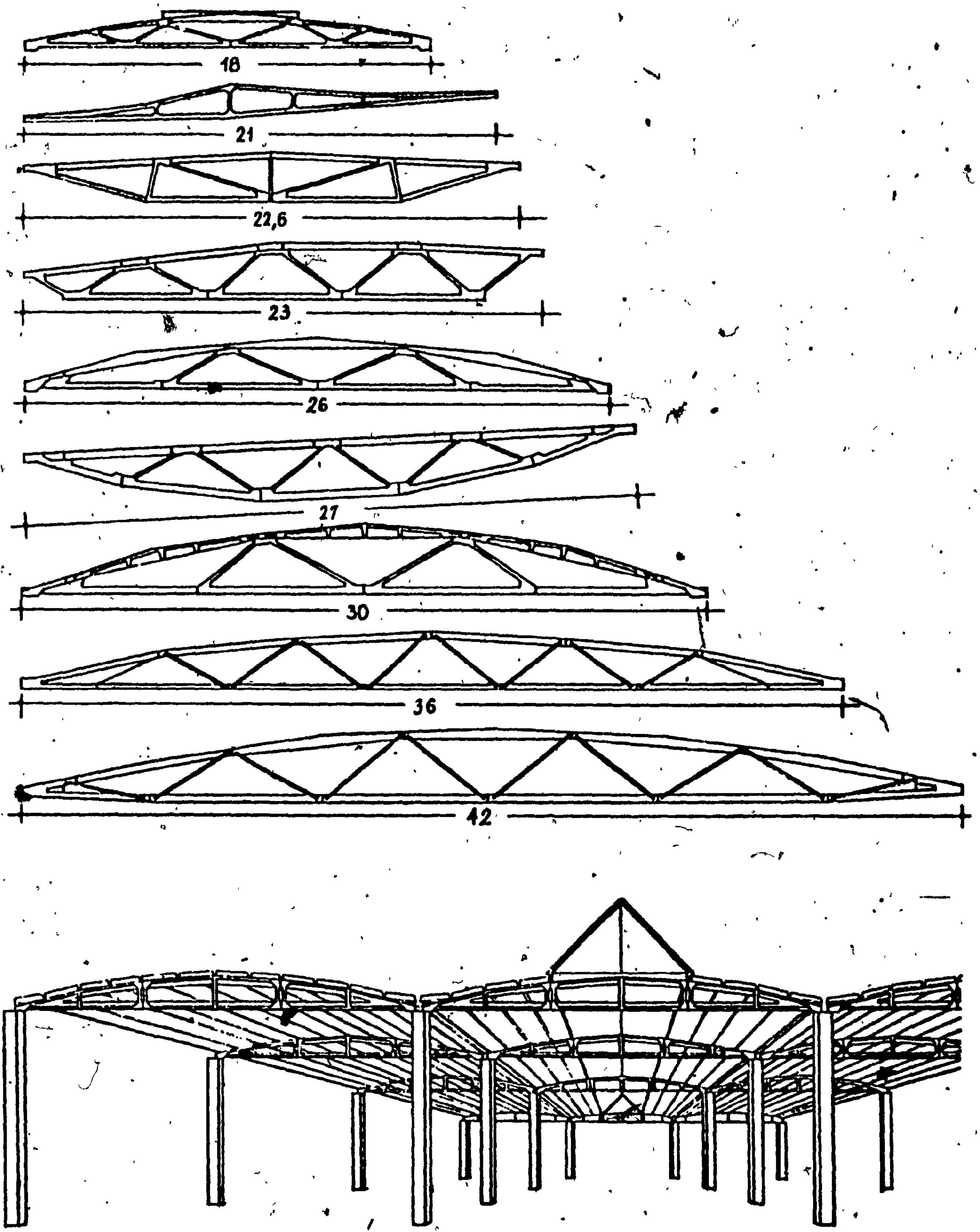


Fig. 7 - Latticed Roofing Components

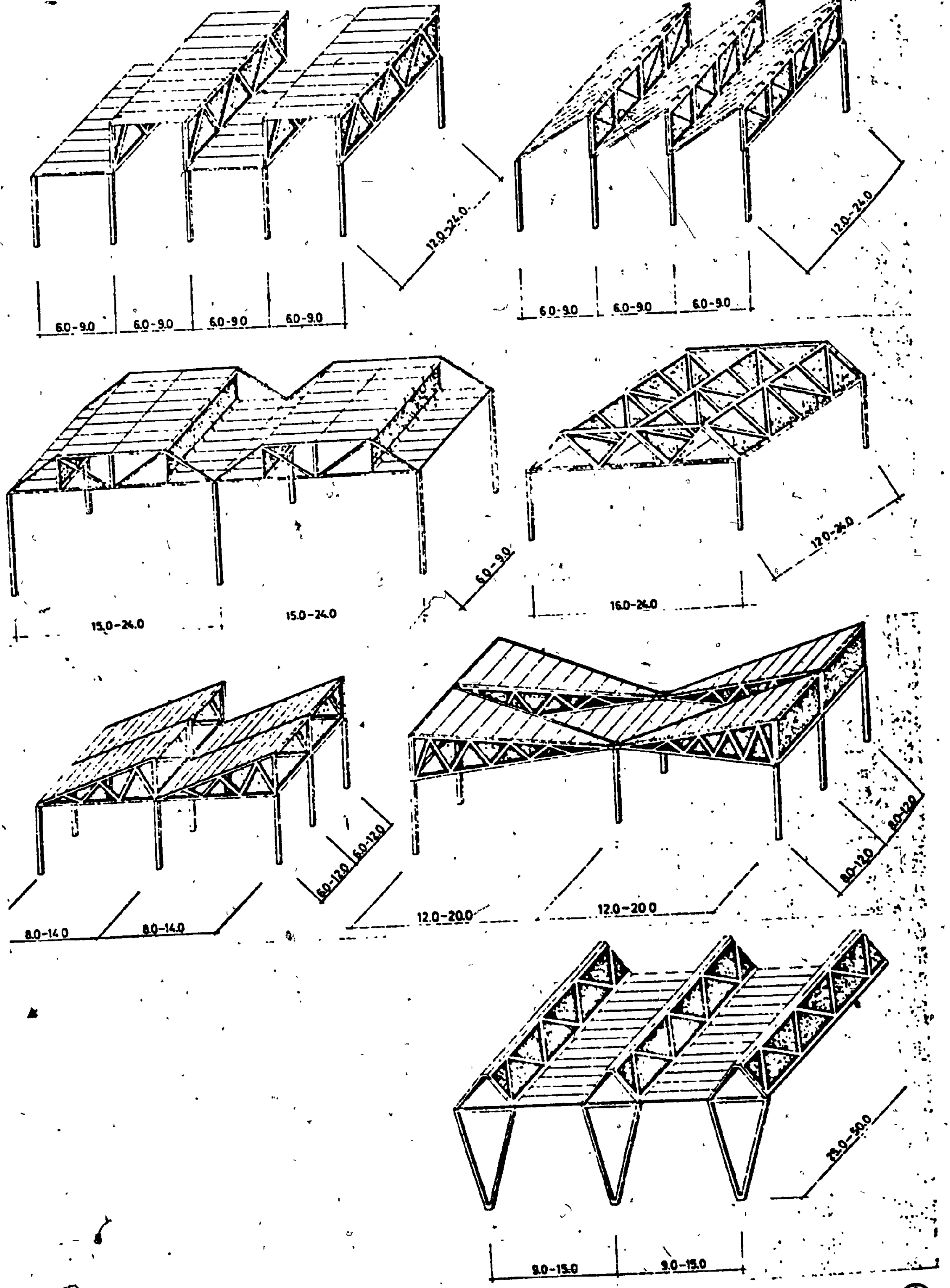


Fig. 8 - Shed Type Structures with Latticed Roofing Components

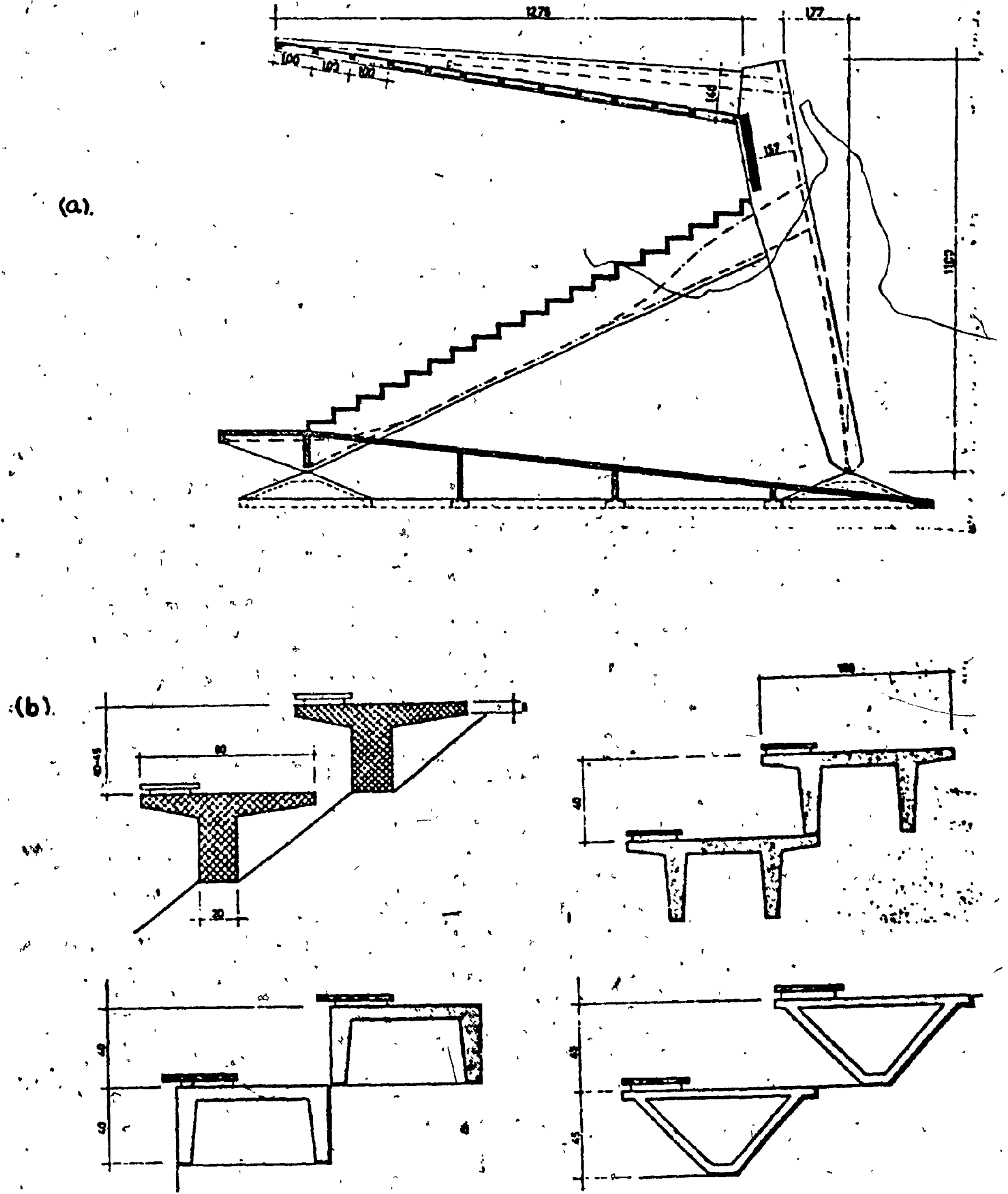


Fig. 9 - A typical Grandstand in United States
(a) Cross Section, (b) Tiers for seating accommodation

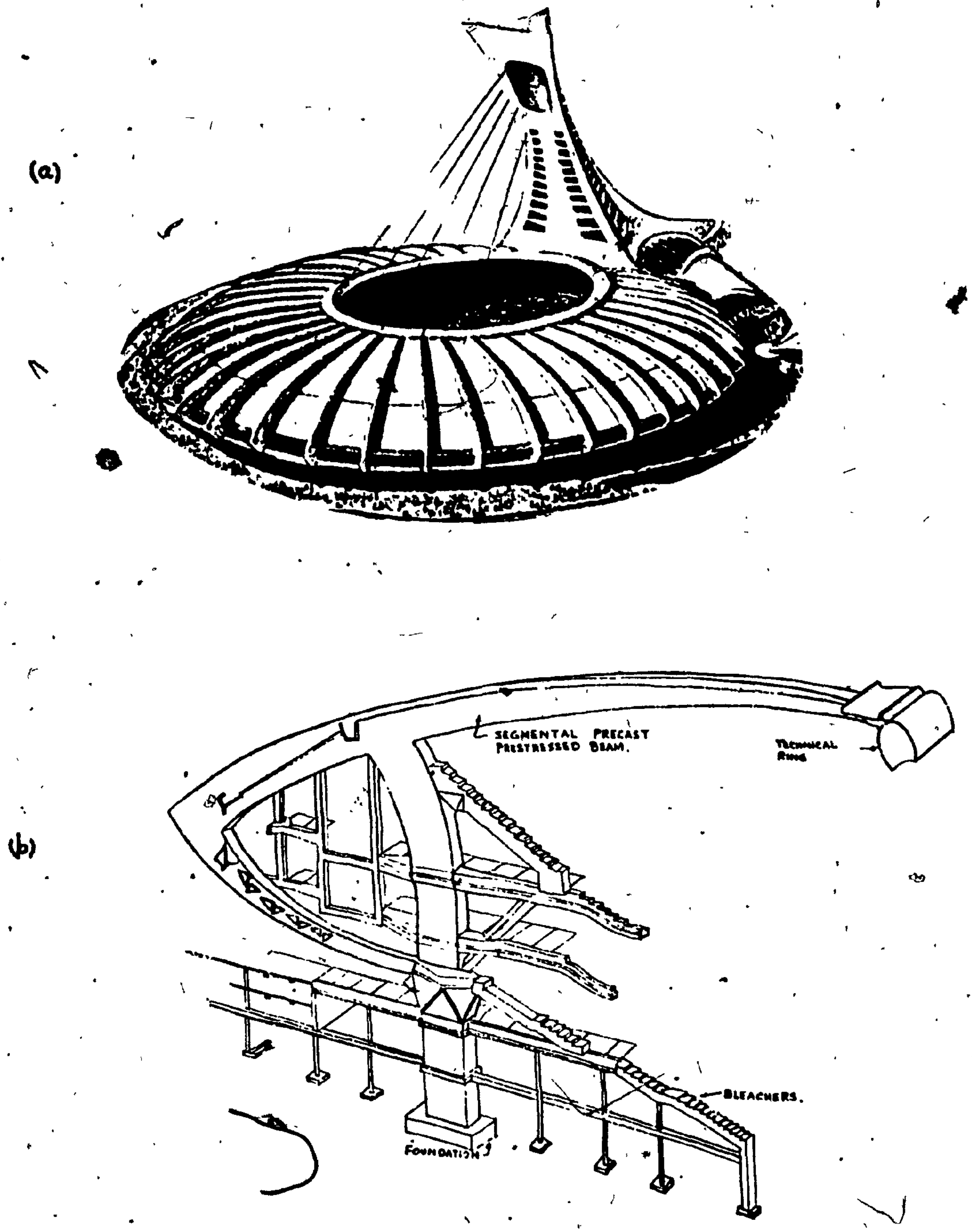


Fig. 10 - Olympic Stadium, Montreal
(a) Completed Structure
(b) Cross Section

shows the view of the completed structure and arrangement of structural members. The primary structural frames for the 50.3m high stadium are 34 pedestal mounted 'C' shaped post-tensioned, segmentally precast consoles or frames, radially positioned 19-20 metres apart around the perimeter of the stadium. They are the supports for both the six spectator and service floor levels and the permanent roof over the stands. Post tensioned precast radial beams, either cantilevered from, or partially supported by the column portions of the consoles, provide the end bearings for precast 'TT' floor slabs or bleacher slabs. The back and top portion of the consoles are connected by a series of triangular section stringers and gutter beams and covered with post tensioned precast thin shell roof slabs. A Circumferentially post tensioned, segmentally precast technical ring, containing the field lights and other mechanical services, is post tensioned to the inner boom ends of the consoles.

2.4 Roofing and Floor Units

Large individual precast units are better able to fulfill the requirements of industrialized buildings than small roofing components can. They will, therefore, gradually supersede the more conventional form of construction with small flooring units, i.e., channel, hollow cored units, and precast joist beams with filler units, which are being used only for relatively small buildings. Thus the number of units is substantially reduced, which results in a saving of manufacturing and erection time. Large flooring/roofing units generally produce a more pleasant aesthetic appearance. In multistorey buildings, the floor units account for something like 50-60% of the material requirement. For this reason and because of the very large numbers of units involved, they may be regarded as the most important structural components of all. The choice and design of floor units are affected by the following considerations:

a) the spacing of the beams that support them;

b) the superimposed loads;

c) the structural requirements, i.e., flat soffit, construction depth;

d) the possibilities of manufacture, transport and erection.

The most commonly employed types of floor or roof units are:

a) Waffle slabs composed of square or rectangular slab elements joined together;

b) Ribbed slabs with widely or closely spaced ribs;

c) Hollow floor units with circular, oval or rectangular cavities.

In housing construction, the solid 10cm to 20cm thick reinforced concrete slabs are considered to be economical floor units. For office buildings, the architectural trend towards large rooms free from columns is manifesting itself. The realization of this trend calls for large construction depths, and prestressed concrete members. In most cases it is not essential for the components to present a flat soffit, since a suspended ceiling is to be provided for air conditioning requirements.

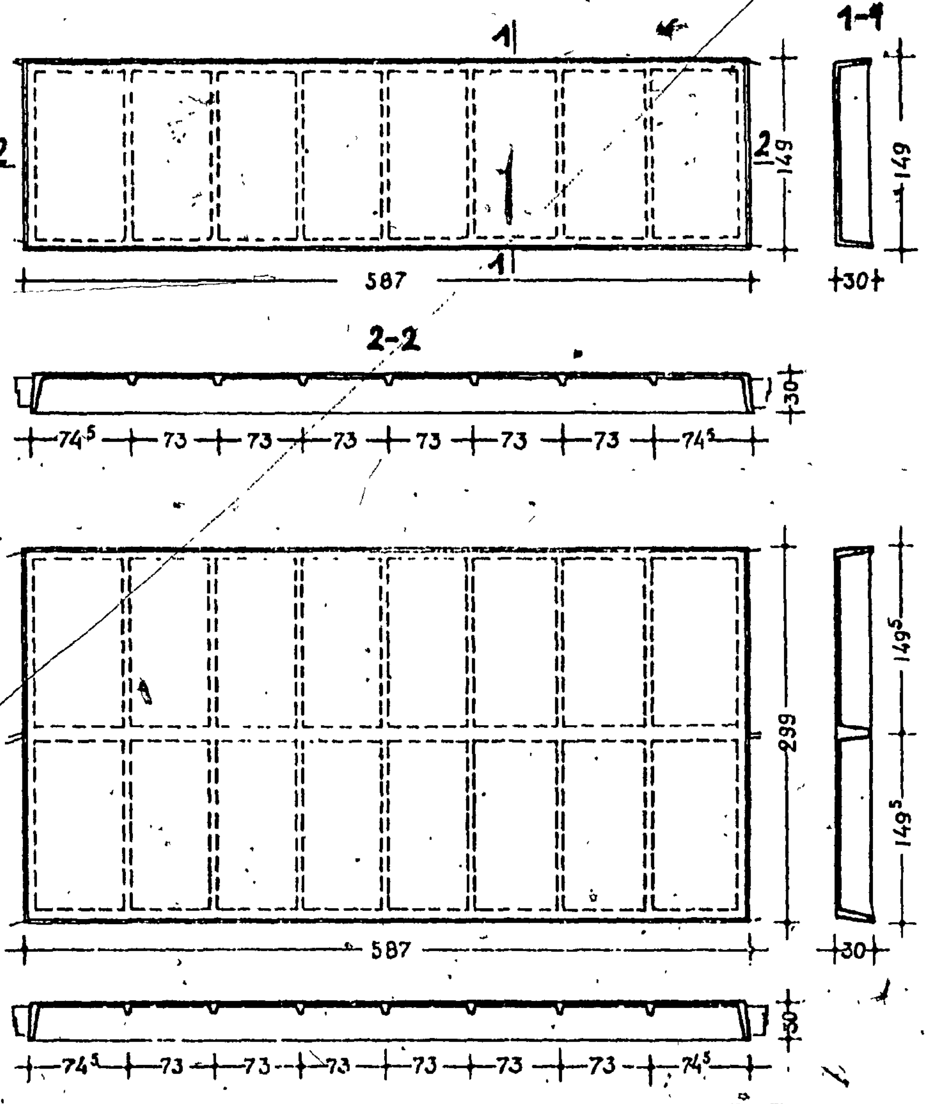
As regards prestressing, with floor units it will be necessary to exercise rather more caution than with roof units. If the prestress is given large eccentricity, considerable hogging of the units is likely to occur, especially if the superimposed load is a large proportion of the total load. In such a case it is unavoidable that certain units will develop differential hogging and therefore fail to form a level surface. The only way to prevent this is by using smaller eccentricities for the prestress which, of course, will require more amount of steel.

2.4.1 Waffle Slabs

Waffle slabs are characterized by having transverse ribs which perform a structural function and which may be so arranged as to form a series of approximately square panels with the longitudinal ribs. (Fig. 11). As a result of this, the actual slab can be made very thin. Thus they are the lightest in terms of material consumption. The width of the units range from 1 to 3 metres. The spans range from 5 to 12 metres, the corresponding depth of the longitudinal ribs being from 20cm to 65 cm. Greater depths of ribs will pose serious problems of demoulding. Transverse ribs are from 10-20cm in depth. In the transverse direction the ribs are interconnected by welding or by means of grout and bars left projecting from the slabs. The longitudinal ribs are provided with small recesses in order to function as a kind of shear key that will form joints capable of transmitting shear and thus obviate any relative displacement of individual floor units under load. Waffle slabs are economical for superimposed loads of about 500-1000kgf/m^2.

Fig. 11

Large Waffle Slabs (2/7)



2.4.2. Ribbed Slabs

In general, ribbed slab units have no transverse ribs. Therefore the slabs have to be made thicker and are thus heavier than waffle slabs. There are three main types:

a) Channel units;

b) 'T' or 'TT' units;

c) Ribbed slabs with closely spaced ribs.

Channel units or trough units differ from the waffle slab only by the omission of transverse ribs. The thickness of actual slab is 4-6 cm, the units are 0.3 to 1.2m wide and are suitable for spans of 4 to 9m with construction depths of 15 to 50 cm. These are suitable for superimposed loads up to 1000 kgf/m^2. Ribbed slabs with closely spaced ribs are suitable forms of construction for larger superimposed loads of 1000-2000 kgf/m^2.

Fig. 12

Channel Units

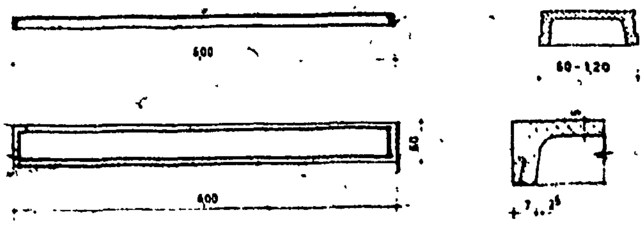
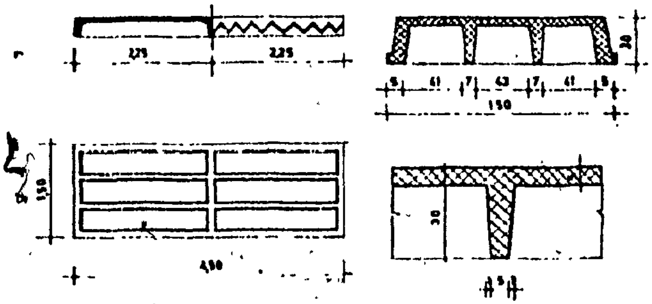


Fig. 13

Ribbed Slabs with
Closely Spaced
Ribs



'T' Units.--In order to fully utilize the compression slab and attain long spans, T-ribbed slabs have come into wide use. The units are 1.2 to 2.4m wide. The slab thickness ranges from 4-12 cm. Spans up to 36m are produced, normal spans are 12-25m. These are usually prestressed and the top flange is provided with a single layer of fabric reinforcement. Y-units are modification of 'T' units.

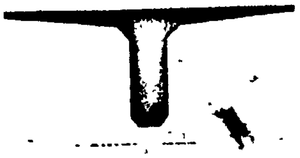


Fig. 14
'T' - Units

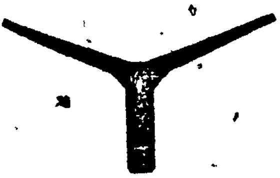


Fig. 15
Y - Units

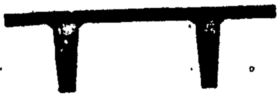


Fig. 16
'TT' - Units

<u>'TT' Units.</u>--These roofing units differ from 'T' units in that they have two ribs instead of only one and that the slab does not cantilever out so far on each side. However, the significant difference is in the method of manufacture. The moulds for 'T' units are removed side-ways, whereas the 'TT' units are manufactured in non-collapsible moulds. The depths of 'TT' units are limited to 65cm in order not to make demoulding difficult.

2.4.3. Hollow Core Floor Slabs

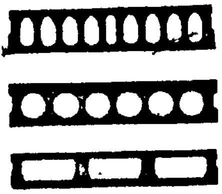


Fig. 17
Hollow Cored
Floor Units

Floor units consisting of hollow beam or slab type members are preferable in cases where a flat soffit is required. With circular performed cavities they are not so economical in terms of quantities of materials. The cavities comprise about 50% of the sectional area and units weigh nearly twice that of waffle slab units. For a superimposed load of 300-500 kg/m^2 the span of hollow units can be 6m, but prestressed units are being manufactured up to 13m.

Spancrete precast prestressed hollow core planks for roofs and floors are used in different countries. It is machine extruded on beds up to 180 metres long in one metre widths and 10, 15, 20, 25 and 30 cm thicknesses. Spancrete is then cut into desired lengths and can span up to 13 metres. The light textured surface of spancrete can be left exposed both on the interior and exterior surface or floor or ceiling material can be applied directly on it.

2.4.4. Light-weight Concrete Solid Slabs

Solid slab units of light weight concrete are being manufactured under different trade names. Siporex slabs are well known in a number of countries. Hebel aerated concrete slabs are widely used in Germany and Switzerland. Siporex is a light-weight autoclaved aerated structural material with high thermal insulation value and low shrinkage and moisture movement. It is non-combustible, light in colour and its weight is approximately one-fifth that of normal concrete. Siporex is manufactured as horizontal and vertical walling units, floor and roofing units of standard widths of 60cm and up to 6m long from 8cm to 30 cm thickness. Siporex can be sawn, cut, drilled and nailed like wood.

2.5 Wall Units

Precast concrete is now available in complex shapes which serve not only as curtain walls but combine their architectural appearance with the ability to serve as main structural members. The cross-sectional design of the wall panels will depend on the type of roof construction adopted, in combination with which they form a space structure. The basic shapes are solid slabs, ribbed slabs or hollow slabs, folded plates of trapezoidal or triangular shapes. They are normally manufactured to the same width as roofing units, and are provided with door or window openings as required. Figs. 18 and 19 show different shapes of units used for walls.

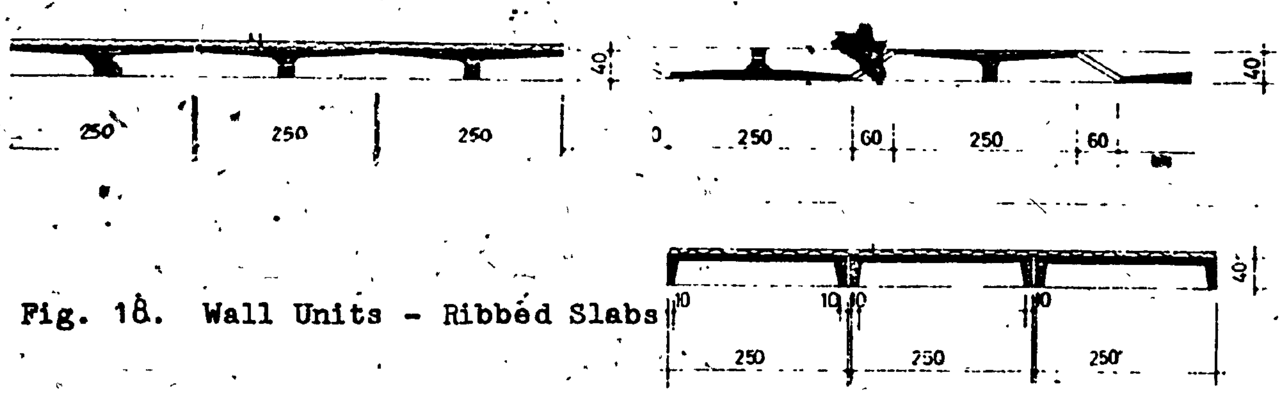


Fig. 18. Wall Units - Ribbed Slabs

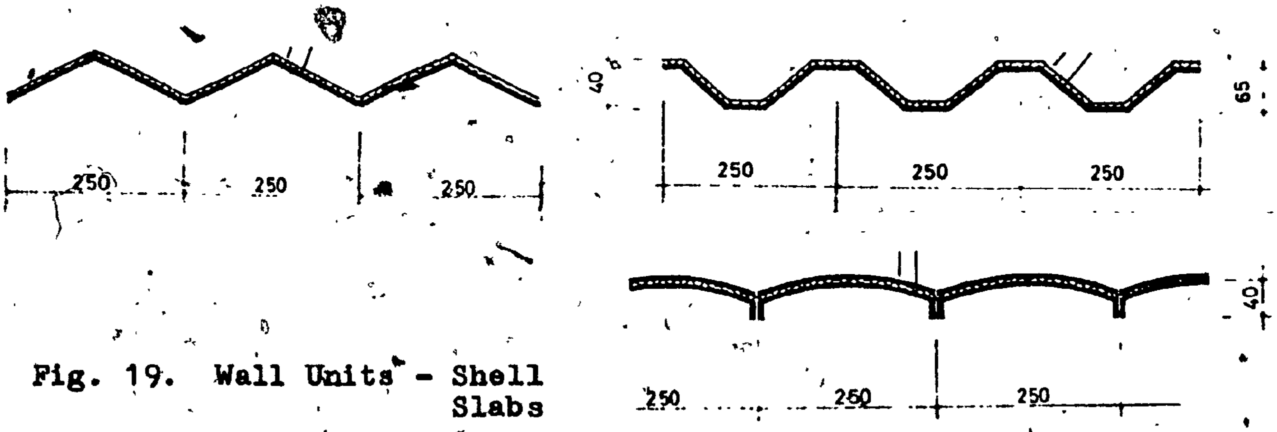


Fig. 19. Wall Units - Shell Slabs

2.6 Multistorey Buildings

Prefabrication can more advantageously be applied to multistorey buildings since the number of identical units is relatively greater, as they repeat themselves in successive storeys. Because of their large number and uniformity, the units lend themselves more readily to standardization so that they can be mass produced.

The structural system for prefabricated building should not try to imitate that of corresponding building of monolithic concrete construction. If the stability of the building does not call for flexurally rigid connections, it will be possible to take advantage of this circumstance by introducing hinged joints, which ~~are~~ simple to construct. The savings in time due to speedier erection will, in that case, offset any increased consumption of materials entailed by this simplified structure. The structural system may consist of a framed type or slab type assemblies which form floors and walls.

2.6.1 Framed Type Buildings

There are four main types of structural systems each of which allows several variations. These are:

- a) Framed structure with unspliced continuous columns;
- b) Framed structure with spliced columns;
- c) Framed structure assembled from frame units;
- d) Mushroom type structures.

The possible limits of application of the structural system, according to height of the building and span of floors

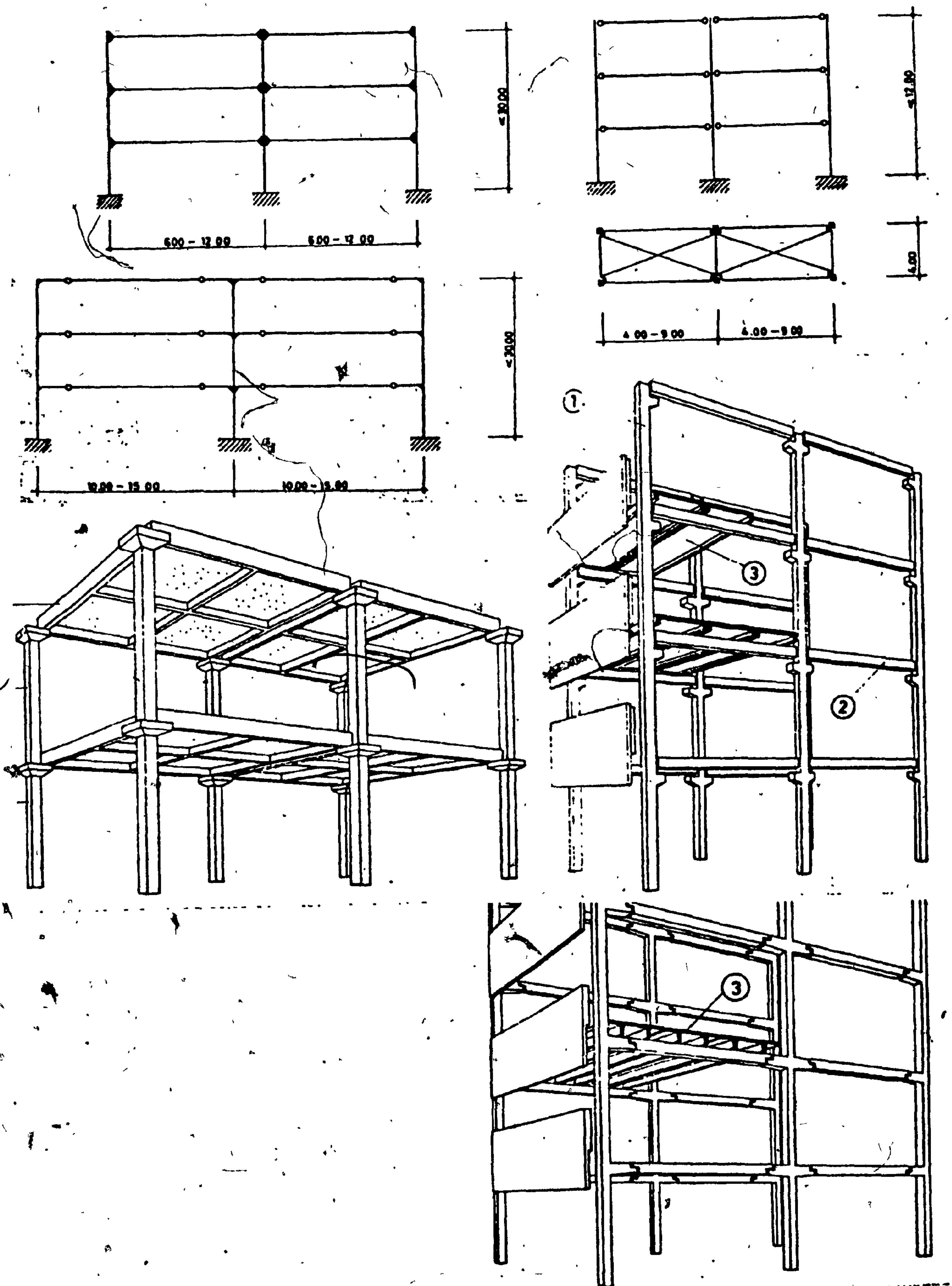


Fig. 20. Multistorey Building - Frame System
Unspliced Continuous Columns

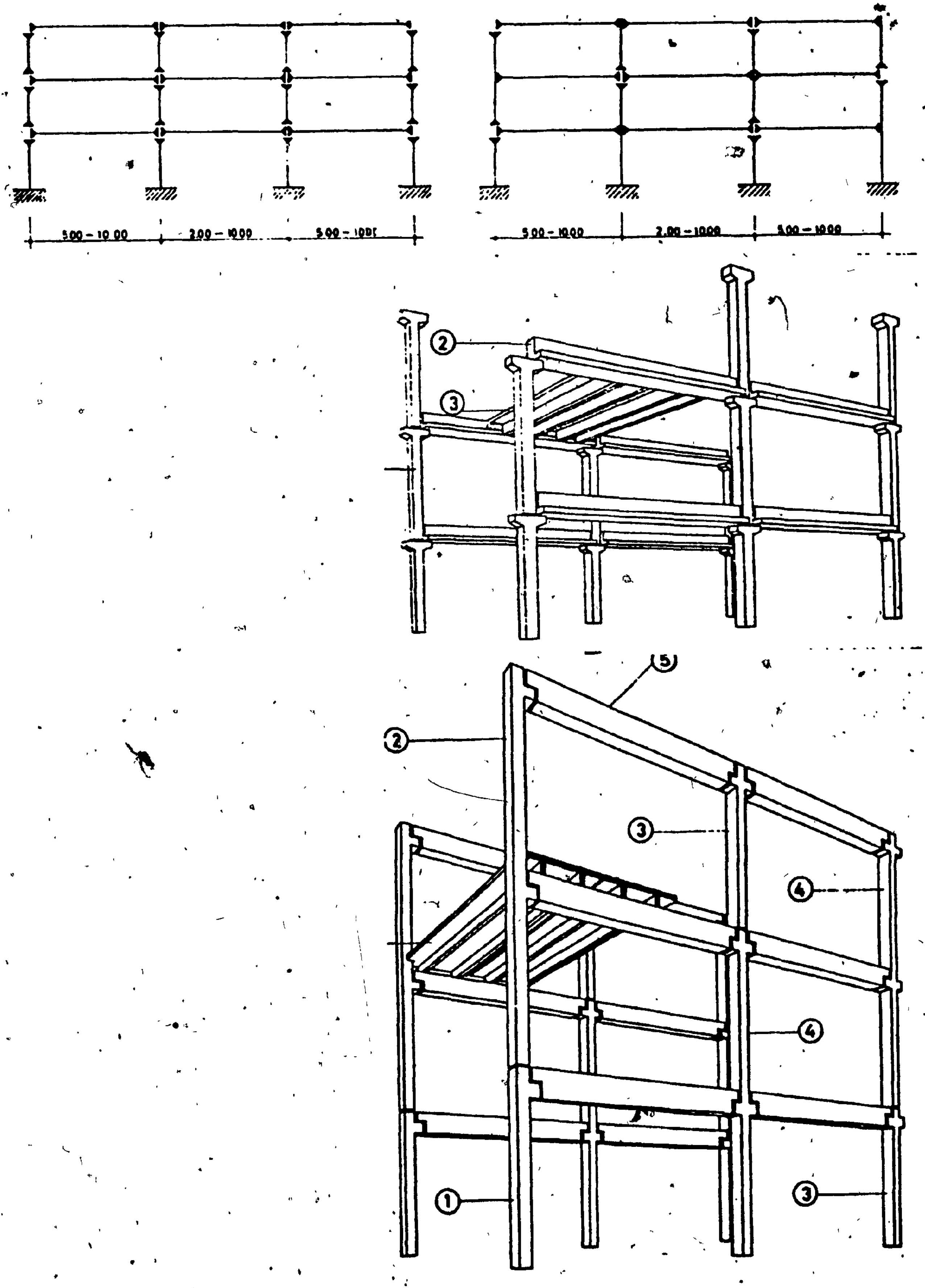


Fig. 21. Multistorey Building - Frame System Spliced Columns (R 21)

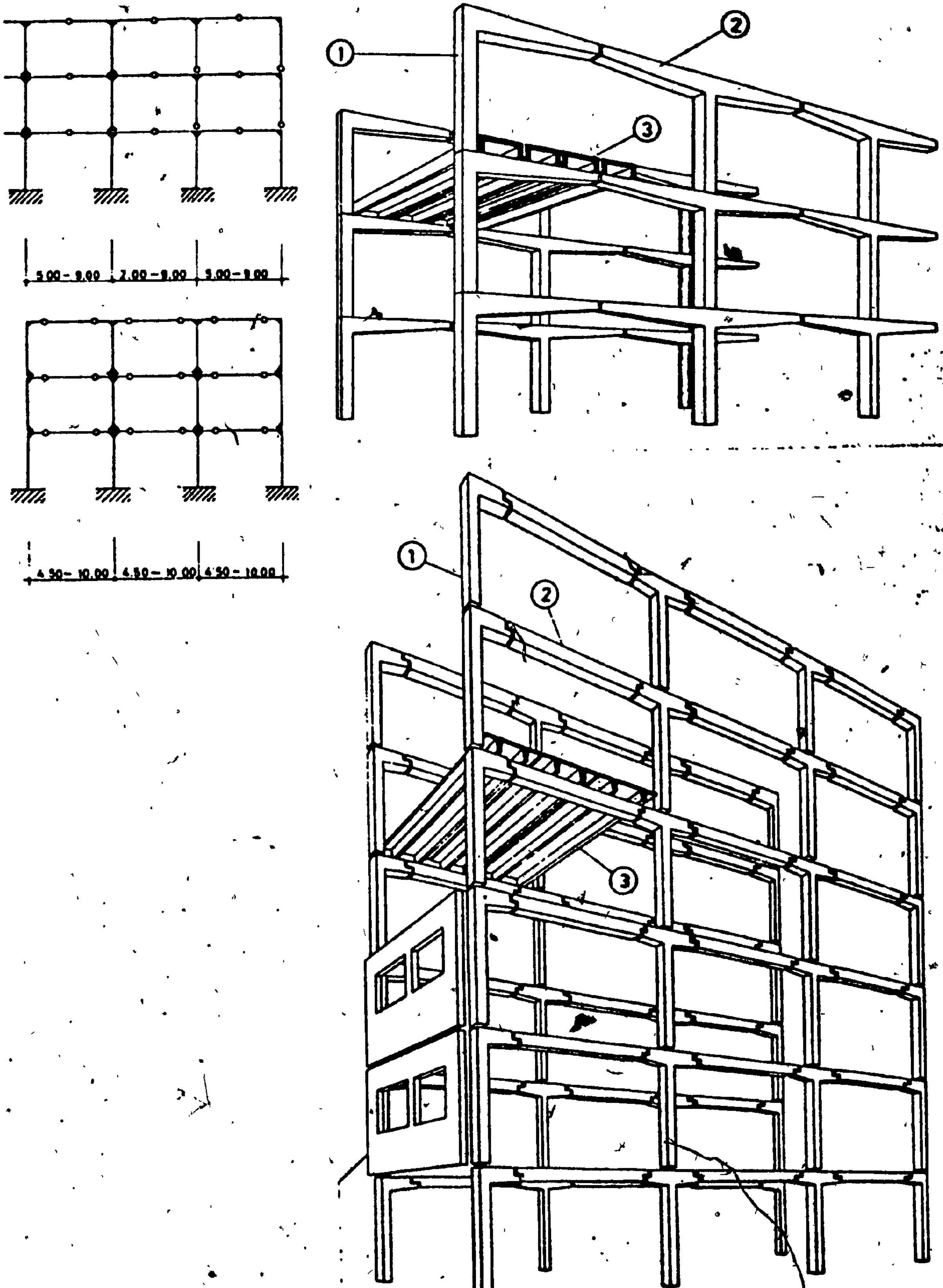


Fig. 22. Multistorey Building - Frame System
Spliced Columns

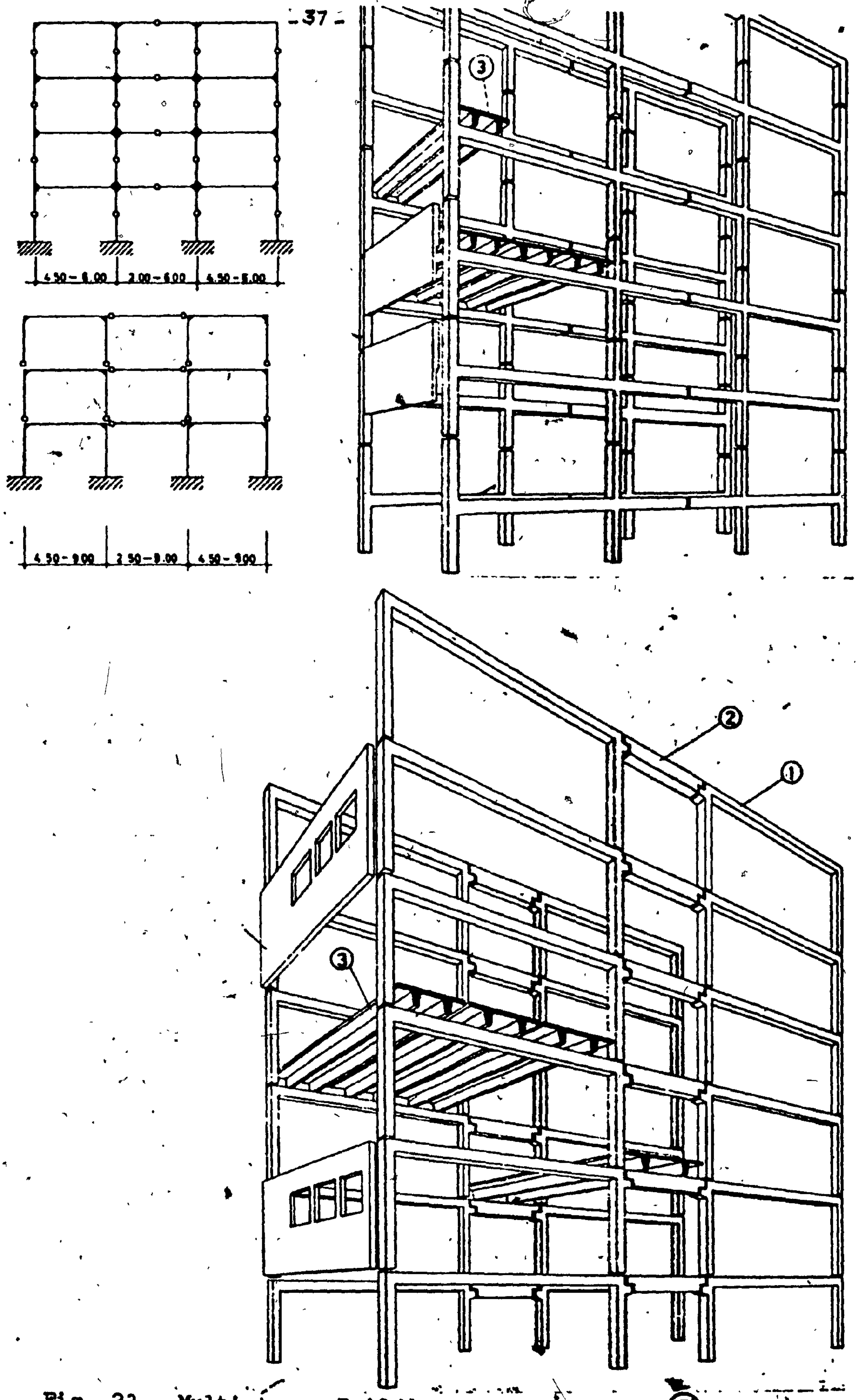


Fig. 23. Multistorey Building - Frame System Assembled from Frame Units K' 21

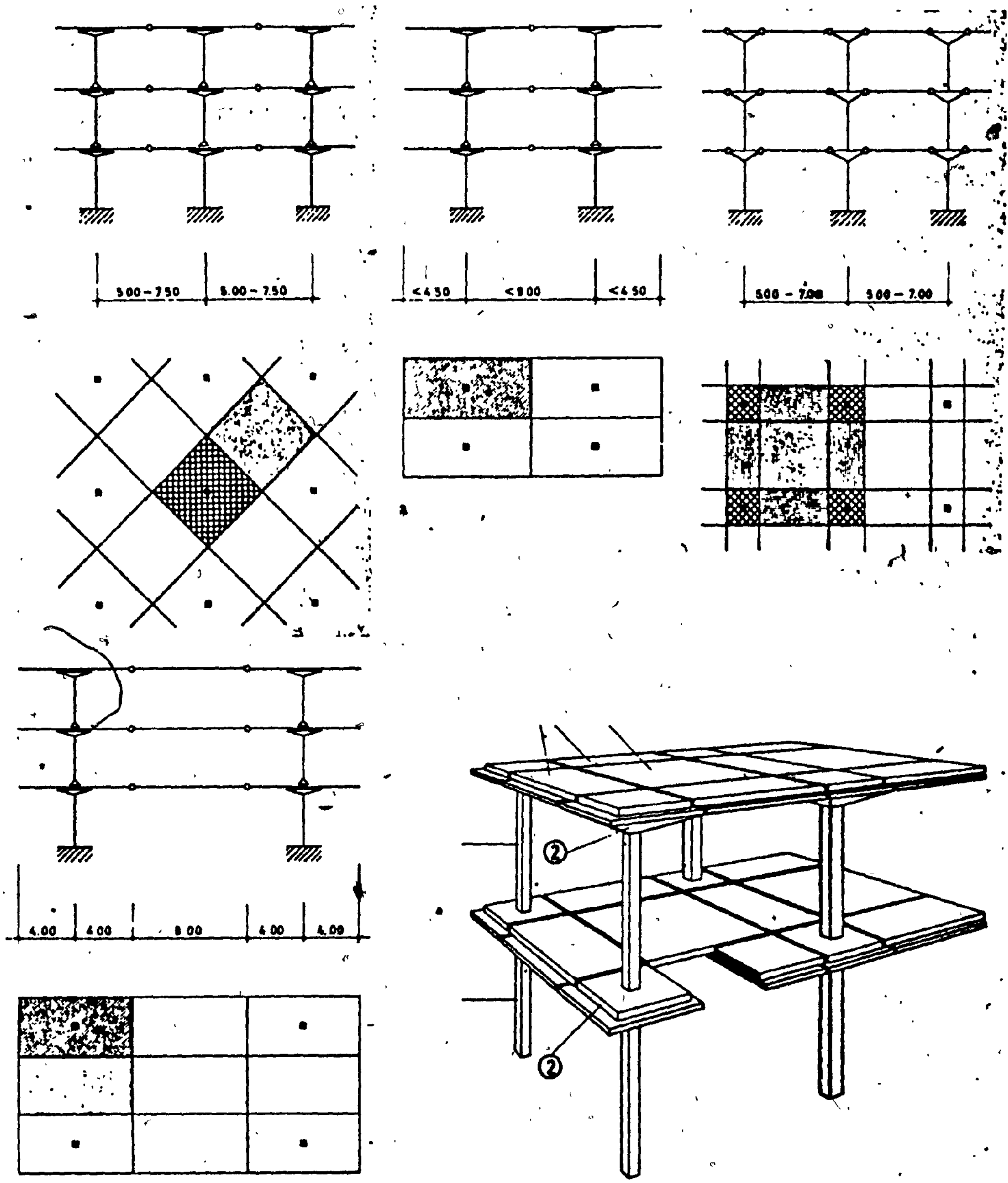


Fig. 24. Multistorey Building - Frame System (R 21)
Mushroom Structures

are indicated in Figs. 20 to 24. Choice of the system is related to the availability of manufacturing, transporting, erection facilities, and their related costs in each individual case.

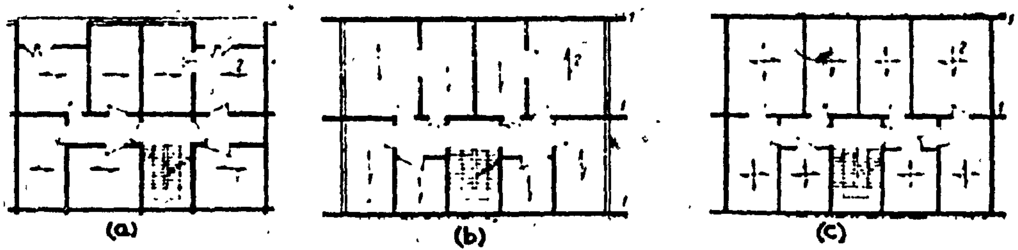
2.6.2 Panelized Buildings

Structures composed of slab or plate type components embody the solutions which conform most suitably to the essential character of reinforced concrete construction. They are undoubtedly most economical in terms of material consumption and labour costs. Their disadvantage is their limited scope for application but they are worthwhile propositions for long span structures. Three variations on the panelized structural assembly are in use:

a) Cross bearing walls and one directional floor units;

b) Longitudinal bearing walls and one directional floor units;

c) Cross and longitudinal bearing walls and two directional floor units.



(a) (b) (c)

Fig. 25. Different Systems of Panelized Structure ④
(a) Cross bearing wall system
(b) Long bearing wall
(c) Cross and Longitudinal Bearing Wall System

Architectural and structural differences in the systems are obvious and are listed below:

i) Cross bearing wall concept allows greatest flexibility since length and penetrations can be arranged at will and spacing of cross walls is only dependent on possible span of floor panels. With pretensioned hollow floor planks or multiple 'T' units, spans of up to 15 metres are possible. Front and back walls are left open to accommodate curtain wall, spandrel beam or balcony facades, according to architectural or economical requirements.

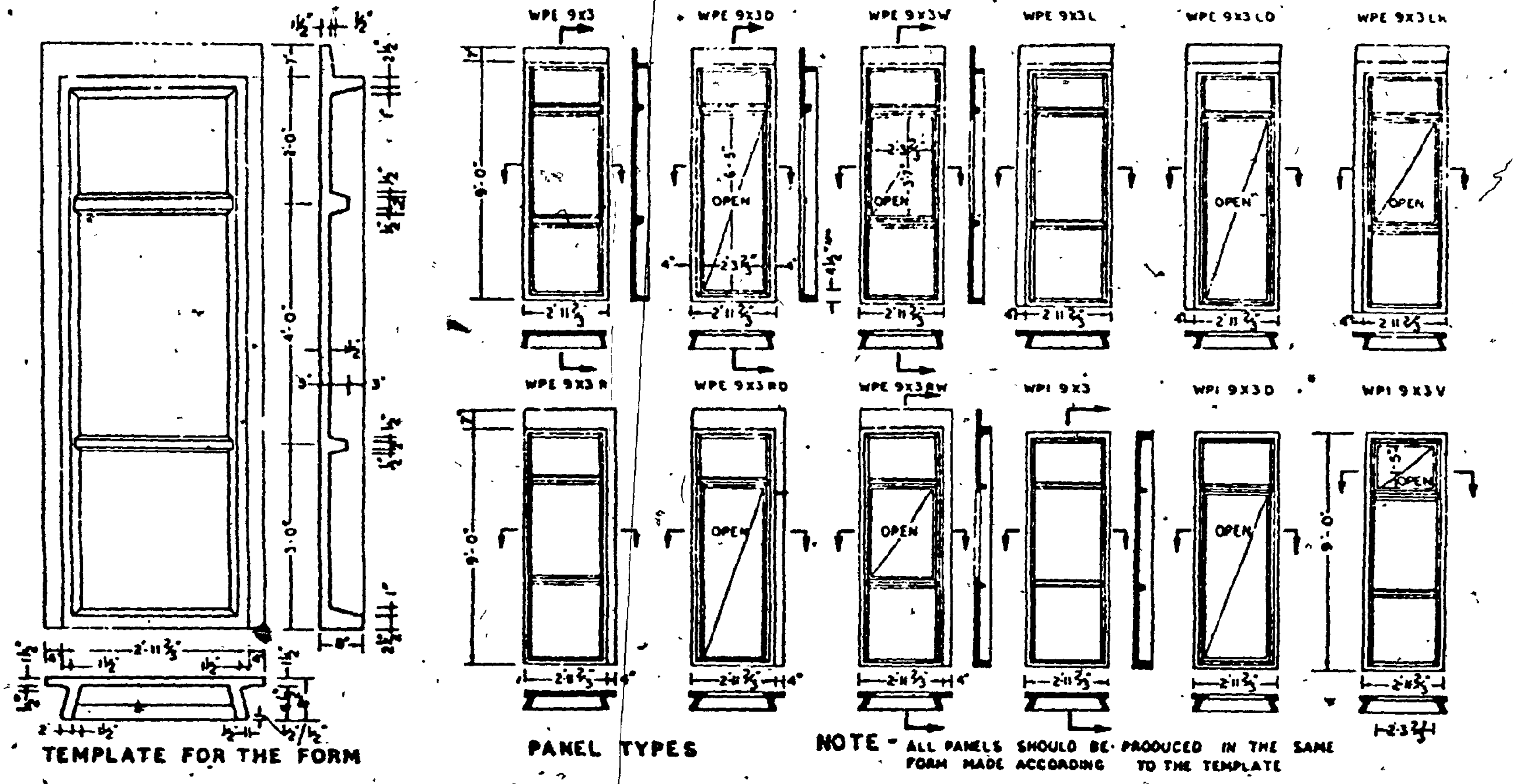
ii) At first glance, the longitudinal bearing wall concept seems to provide even greater freedom for interior planning. However, the assumed advantages decrease rapidly if production and architectural criteria are applied to it. A certain amount of uniformity for many buildings is imposed by economical considerations, hence, a rather uniform pattern of window opening results. The interior planning is often influenced by facade panel, and it is difficult to apply balconies.

2.6.2.1 Small Panel Construction

The structure may embody large or small panel construction. Small panel construction systems make use of floor and wall panels of less than room size. In general, floors and walls of the rooms in such buildings comprise joints. The construction with small panels is important in cases where prefabrication is required to be capable of execution by any contractor with the aid of ordinary handling and erection equipment.

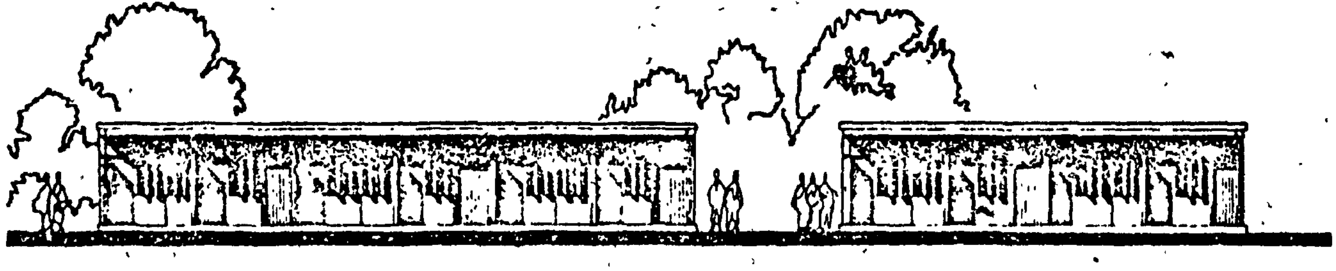
2.6.3 UCOPAN - Component Building System

Universal concrete panel building system (UCOPAN) was developed by Dr. Zenon A. Zielinski, during his four years of stay in India (1967-71) as a Ford Foundation Consultant to Calcutta Metropolitan Planning Organization. The system essentially consists of thin walled ribbed panels which are used for floors as well as for walls. Panels are made of 4cm thick concrete reinforced with wire mesh and stiffened with perimeter ribs. The consumption of materials is a minimum possible. The equivalent thickness of concrete when spread flat on ground is only 5-7.5cm. Panels can be made to any modular size depending on space requirement and availability of erection equipment. A universal single form is designed which is used for different types of walls; i.e., solid, or with openings for doors or windows. The same mould is also used for floor panels. The panels can be produced industrially or on site by unskilled labour. At places, where only tripod or pulleys are available for construction, minimum size of the panel can be 2.75 x 0.9 metres, as was done in India for low cost housing of C.M.P.O. The small size and weight of the panels (300-350 kg) permits the panels to be handled manually. UCOPAN system has been used on many projects in India and other developing countries. Cost of buildings made with this system is nearly half of the cost of buildings made with traditional materials, and so is the savings in consumption of cement and steel. Under conditions of extreme climate or in moderate climates, or when the funds permit, additional insulation can be provided to the exterior walls.

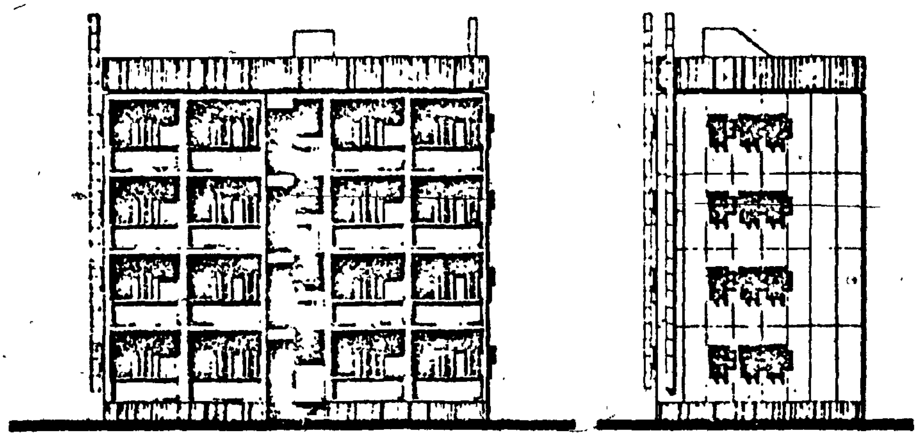


NOTE - ALL PANELS SHOULD BE PRODUCED IN THE SAME FORM MADE ACCORDING TO THE TEMPLATE

Fig. 26. UCOPAN - Different Types of Panels



(a) Single Storey Building



(b) Four-Storey apartment block

Fig. 27. UCOPAN - Typical Buildings Designed in C.M.P.O., Calcutta, India

2.6.4 Large Panel Construction

The large panel construction method is characterized by the fact that the rooms in the building have walls and floors of a single panel and therefore comprise no joints. For large panel construction, it is necessary to have special manufacturing facilities, transport equipment and erection cranes. Also, the execution of the job is to be entrusted to a specialized construction firm which has secured an adequate volume of orders, because high capital investment costs have to be redeemed and written off. Against this, the amount of labour on manufacture and erection is reduced, the construction time is shortened, and the quality of internal finishes is higher because these features can be better incorporated into large units than in small ones.

2.7 Box Type Construction

Often called module system, constitute the next step in industrialized building construction. Its main significant feature is that complete prefabrication, including all fittings and finishes is possible, just as with many other industrialized products. Further development of this construction technique is likely to come with the introduction of new transport and erection methods; e.g., helicopters, which may help this technique to achieve success. With good architecture, this form of construction presents possibilities which have so far only seldom been utilized.

Habitat Expo '67, Montreal, Canada, dramatizes the

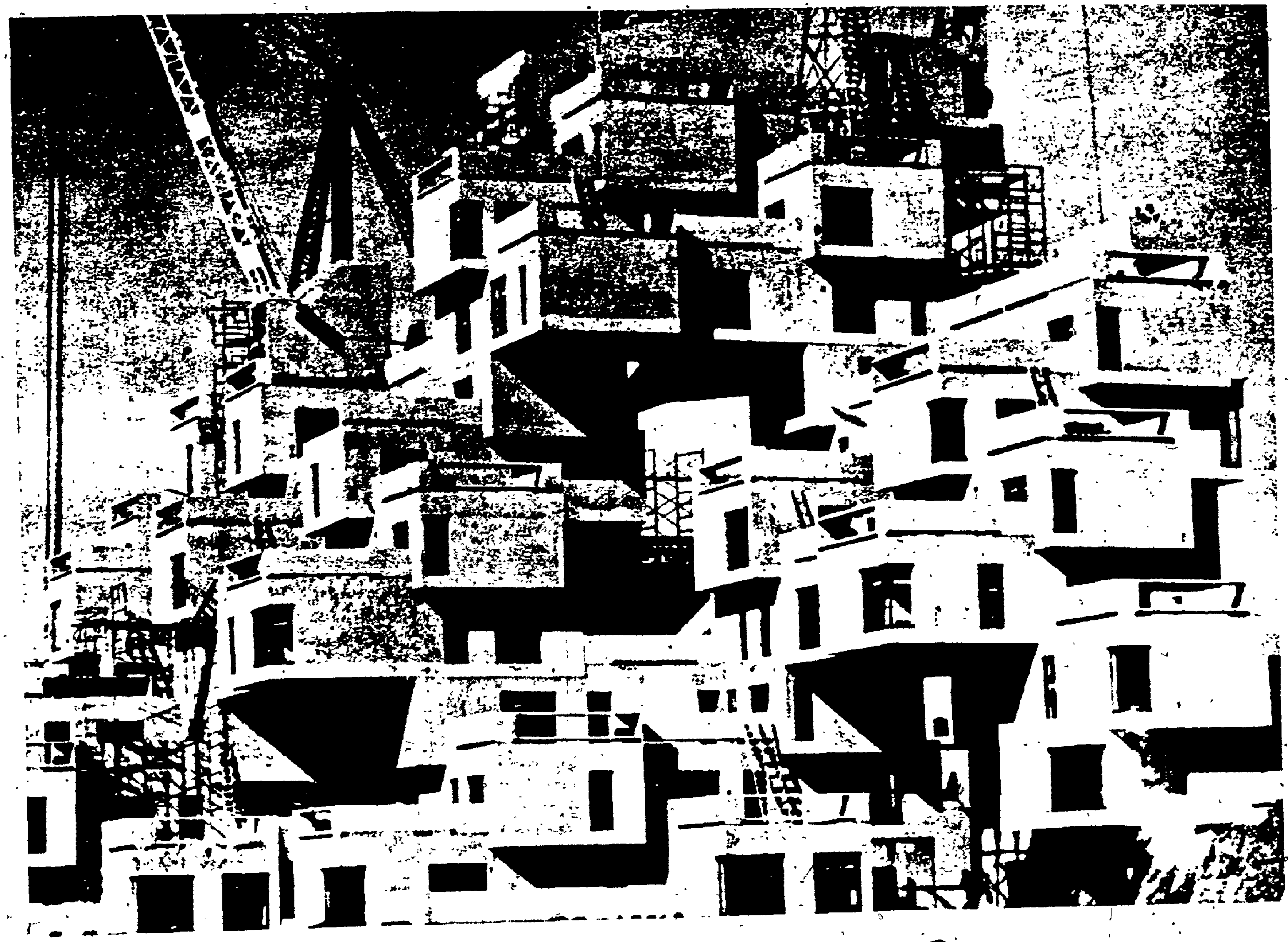


Fig. 28. Habitat Expo '67, Montreal (R29)

use of factory produced dwelling modules in a multistoreyed structure of unique configuration. The individual apartments vary in plan. One to four bedroom units are available in a total of fifteen different combinations. The modules are constructed of precast concrete near the building site. Each module is 11.6m long, 5.3m wide and 3m high and weighs 90 ton. Two cranes of 50 ton each hoist each unit into place. The units are tied by post tensioning cables inside concrete columns in the modules.

The H.B. Zarchry Construction Corp. of San Antonio, Texas, has completed construction of a 21-storey hotel containing 496 rooms, called Palacio Del Rio, in which preassembled units were used for rooms. Their construction is prestressed reinforced concrete with 5-inch thick walls and floors and 4-inch thick ceilings. The boxes are cast in a yard seven miles from the site. The modules are 9.75m long, 4.3m wide and 3m high and weigh 35 tons. The project was completed in a record period of nine months which resulted in considerable savings to the company due to shorter interim financing and early return.

Uniment concept and use of chemstress have increased the potential for the use of concrete in production of the modules. Chemstress is an expanding concrete aggregate which can greatly reduce weight and wall thickness without reducing structural strength. The modules used for Richmond project, California, U.S.A., have exterior dimensions of 11m x 3.4m, weigh only 11.5 tons. The basic difference between chemstress and ordinary concrete is that chemstress concrete aggregate, or chemically prestressed concrete, expands as it sets instead of contracting. This expansion during the setting process prestresses the steel reinforcing bars. The resulting structure produces a wall thickness of only 8cm thickness without corresponding reduction in strength.

2.8 Lift Slab Construction

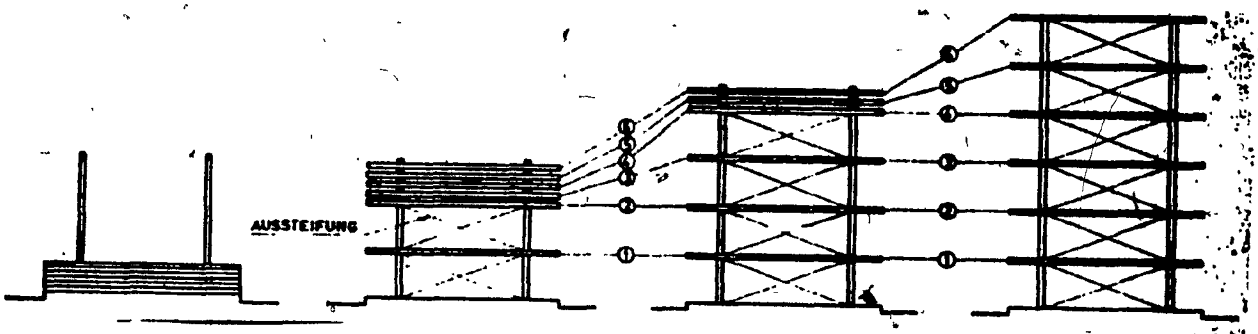


Fig. 29. Showing principle of lift slab construction. (K 21)

In this method, the floor slabs are concreted one upon the other at ground level and jacked up into position. The principle of the lift slab method is explained in Fig. 29. This method of construction can advantageously be employed on buildings of three to six storeys and where the floors are required to have flat under surfaces. Formwork and scaffolding are completely dispensed with. This system can be regarded as on-site precasting.

CHAPTER III

STRUCTURAL DESIGN

3.1 Design Principles

The principles of structural design applicable to prefabricated structures are the same as for any other structure except that there are some special problems like development of additional stresses during manufacture, handling and erection of prefabricated components, which have to be taken care of. Also, precast systems have discrete and finite joints which are absent in cast-in-place structures. If the joints are not properly detailed, the resulting structure solely depends on friction and gravity for stability and exhibits a "house of cards" behaviour.

In order to design a building, it is necessary to consider all possible forms of loading that may have structural significance during the lifetime of the building.

Large and sudden stresses are liable to occur in the course of demoulding and are due to adhesion of the precast components to the sides of the mould. The magnitude of the bond stress is dependent upon the nature and condition of the mould. On an average, the sticking force can be taken as 1 ton/m^2. Its effect must be overcome by picking up the component at a number of points. An alternative procedure is to manufacture on a tilting table.

Handling stresses in precast components are developed during transportation and erection due to the following causes:

a) The components are transported in different positions from those in which they are finally installed in the structure.

b) In the structure, the components are braced by other members, but during transport and erection they may be endangered by the absence of such bracings, i.e., in the case of slender laterally unbraced beams.

c) During transportation, dynamic stresses are liable to occur which may, in certain cases, exceed the stresses actually produced in the completed structure.

Errors or faulty practice in design or construction represents another category of loading too diffuse in nature to be quantified.

In certain circumstances it may be necessary for the designer to exercise his individual judgement with regard to the significance and the nature and magnitude of some special loads. In recent years it has become apparent, especially after a progressive collapse of a 24-storey apartment tower at Ronan Point in London, in 1969, that there are special abnormal loadings that may be structurally significant which are not specified or quantified in the most of the building codes.

Of the various types of abnormal loading that have been studied or considered in engineering buildings, three subtypes appear to be of some consequence, namely: a) gas related explosions, b) bomb explosion and c) vehicular collision. For abnormal loading, structural safety rather than serviceability is the principal design consideration.

At Ronan Point apartment building, a gas explosion on the eighteenth floor caused an exterior load bearing wall to be blown off; this initiated a chain reaction collapse upwards to the roof and then almost down to the ground as debris fell on succeeding floors. The progressive collapse was the result of the inability of the structure to bridge over the local failure, i.e., due to its lack of structural integrity. Three alternative approaches could be used to obviate the risk of progressive collapse i.e. eliminate the hazards which cause local failure; design the structure so that the hazard does not cause any local failure; and lastly, allow the local failure to occur but design the structure so that progressive collapse does not occur.

With few exceptions abnormal loads can be hardly eliminated altogether. It is technically very difficult and economically prohibitive to design residential type buildings for absolute safety without some damage. On the other hand there is no justification for constructing buildings which do not afford a certain amount of safety with respect to abnormal loading. To reduce the risk of progressive collapse, it is desirable to assume bridging of local damage while maintaining stability of the partially damaged structure by tying the components of large panel structures together horizontally and vertically. Elements and connections must distribute forces via an alternate path around the damaged portion.

Strength of the structure, regardless of the type of construction, depends upon the strength of its connections and that the full strength of the elements cannot be utilized if the connections are inadequately designed. Continuity across the connection and ductility within connections should be ensured to achieve general structural integrity. Continuity is essential to develop bridging capability for transmission and redistribution of loading through an alternate path. Ductility is important not only to sustain deformations but also as a measure of energy absorption under the effects of dynamic loading. Tensile continuity across and within the connections can be effectively achieved by providing ties as shown in Figure 30.

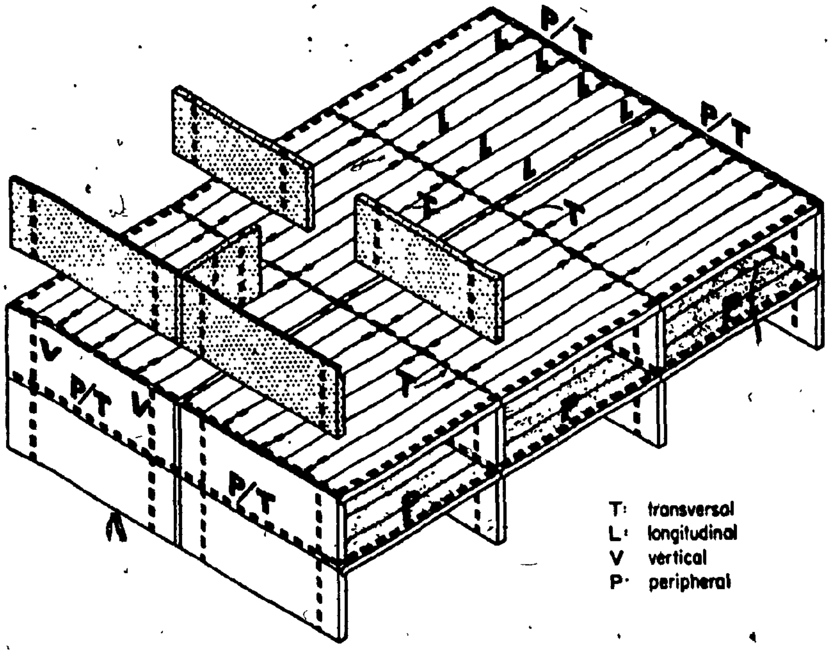


Fig. 30. Suggested system of tensile ties in large panel structure. (R16)

Excerpts from the U. S. Department of Housing and Urban Development "Provisions to Prevent Progressive Collapse" are reproduced below:

a) Buildings shall be designed and constructed so that if any one structural member is considered removed, structural failure will affect only a small part of the building. The amount of structural failure acceptable shall involve not more than three storeys, nor more than 750 square feet (70 square metres) or 15%, whichever is less of horizontal area in each storey affected.

b) As an alternative design method, failure need not be assumed to be initiated by notional loss of structural member if the structural member is capable of sustaining a load of 5 psi (3500 kg/sq.m) applied to it from any direction. This load is to be combined with dead load, plus one third live load, plus one third wind load. Debris load need not normally be taken into account.

c) Reinforcement shall be provided in all load bearing wall units for complete height of building capable of supporting in tension one storey height of wall plus one level of floor slab. Steel allowable working stresses may be increased by 75%. Connections in tension shall be of steel, either welded or threaded.

d) Horizontal connections between load-bearing walls and floors or roofs: The steel connection at top and bottom of all external load bearing walls shall be capable of resisting horizontal forces in either direction at right angles to the length of joint times 1700 plf (2534 kg/m) at top and 850 plf (1267 kg/m) at bottom, without exceeding permissible stresses.

e) Peripheral ties: At each floor and roof level an effectively uninterrupted peripheral tie, capable of resisting a tensile force of 9000 lbs., (4091 kg), without exceeding the permissible stress in steel, shall be provided within the depth of the floor or roof elements. The tie may be steel reinforced in the in-situ horizontal external wall to floor joint or steel reinforcement (prestressing tendons) in an edge beam or in edge of floor or roof construction and within 4 ft. (1.2 m) from edge of the building or its general line where there are relatively small projections in the face.

f) Internal tie: At each floor and roof level, effectively uninterrupted ties shall be provided in two directions at approximately right angles across the building and shall be anchored by welding or hooking to peripheral reinforcement at both ends. The longitudinal and transverse ties shall be capable of resisting forces of 2534 kg/m and 1267 kg/m respectively without exceeding permissible stresses.

g) To comply with this section, design stresses for both steel and concrete may be assumed as 1.75 times working stresses, except for the steel the design stress shall not exceed 95% of yield stress. Where interaction between precast units is assumed for bridging action, effective steel connections shall be provided between these units and care shall be taken to provide adequate shear resistance in vertical joints between wall panels.

CHAPTER IV

CONNECTIONS

4.1 Principles of Design

Joints are said to be the weakest points in prefabricated structures. Connections of precast components present difficult technical problems since the structure is only as strong as the joints.

The three principal design considerations are: the loads and actions to be resisted, the structural function of the joint, and last, but not least, the fabrication and erection procedures. In addition to gravity and lateral loads due to wind and earthquakes, the effect of volume changes due to shrinkage, creep and temperature, the effect of differential column shortening and settlements, and the effect of fabrication and construction tolerance errors must be considered. Tolerance errors cause variations in the location and distribution of the forces acting at the connection. Quality of workmanship in field connections introduces another uncertainty. It is, therefore, common practice to use larger safety factors or load factors in the design of connections than are used for the design of elements.

4.2 Classifications

With respect to structural function, joints may be classified as simple bearing, bearing with axial continuity, and full moment resisting capacity connections. Joints and connections may be further divided into hard and soft connections. In hard connections, the movements and rotations within the connections are limited. Such connections are normally used in rigid frames, such as beam to column, column to footing, to resist lateral forces. Most hard connections employ steel plate or rolled shapes. Soft connections permit a limited amount of movement in the connection. This is usually achieved by the use of elastometric bearing pads. In actual practice, most of the connections are neither fully soft nor fully hard. Connections can be further subdivided into two basic types: Wet Connections, and Dry Connections. Wet connections require in-situ concrete placing, curing and a certain amount of strength before the next wall panel can be placed. Dry connections are mechanical in nature and provide sufficient strength to allow continuous erection. Any grout or drypack required to complete the joint can be placed independently of erection. Scheduling of erection depends upon the type of connection. Erection progress for wet connection is in the horizontal direction and requires frequent movement of crane set-ups. Placement of insitu concrete has to be done in the open and is weather dependent. Special curing and winter protection is required. Vertical erection scheduling can be used for dry connections. Placement of panels is independent of drypack or grouting and can be done in an enclosed area. Crane moves and set-ups are also minimized. Dry connections could be welded type or bolted. Some of the salient features of mechanical bolted connections, as now being increasingly preferred for multi-storey panelized buildings are:

a) Bolting does not require skilled labour.

b) It is not time consuming.

c) The connection is dry and can be performed in any weather condition.

d) The jointing system consists of a number of connections which allows for discrete movements before ultimate load. Thus shrinkage, creep or thermal movements are conveniently controlled by friction bolting across slotted holes. When the thermal stresses exceed the ultimate slip capacity of the connection, the member simply moves. In the process of movement, a friction bolted connection has definite energy absorption characteristics similar to the plastic behaviour of ductile materials. When the tolerance slot is exhausted, the connection transforms into a bearing bolted connection of a much greater ultimate capacity but equally ductile. The exact dynamic behaviour of such a structure and its energy dissipating capacity may well have a marked influence on the building response to earthquakes.

e) Because of slotted holes, the system provides for greater manufacturing and erection tolerances. Moreover, since the connection is completed through make up pieces of plates or angles, it is much more convenient to rework, reject or replace a small makeup piece than to reject the big precast element.

f) The same connection inserts are used for the lifting and erection process.

Figures 37a to 37d show some of the friction bolted connections. Friction bolted connections have been used by M/S Descon Concordia Building Systems in the panelized buildings for "Operation Breakthrough" of H.U.D.

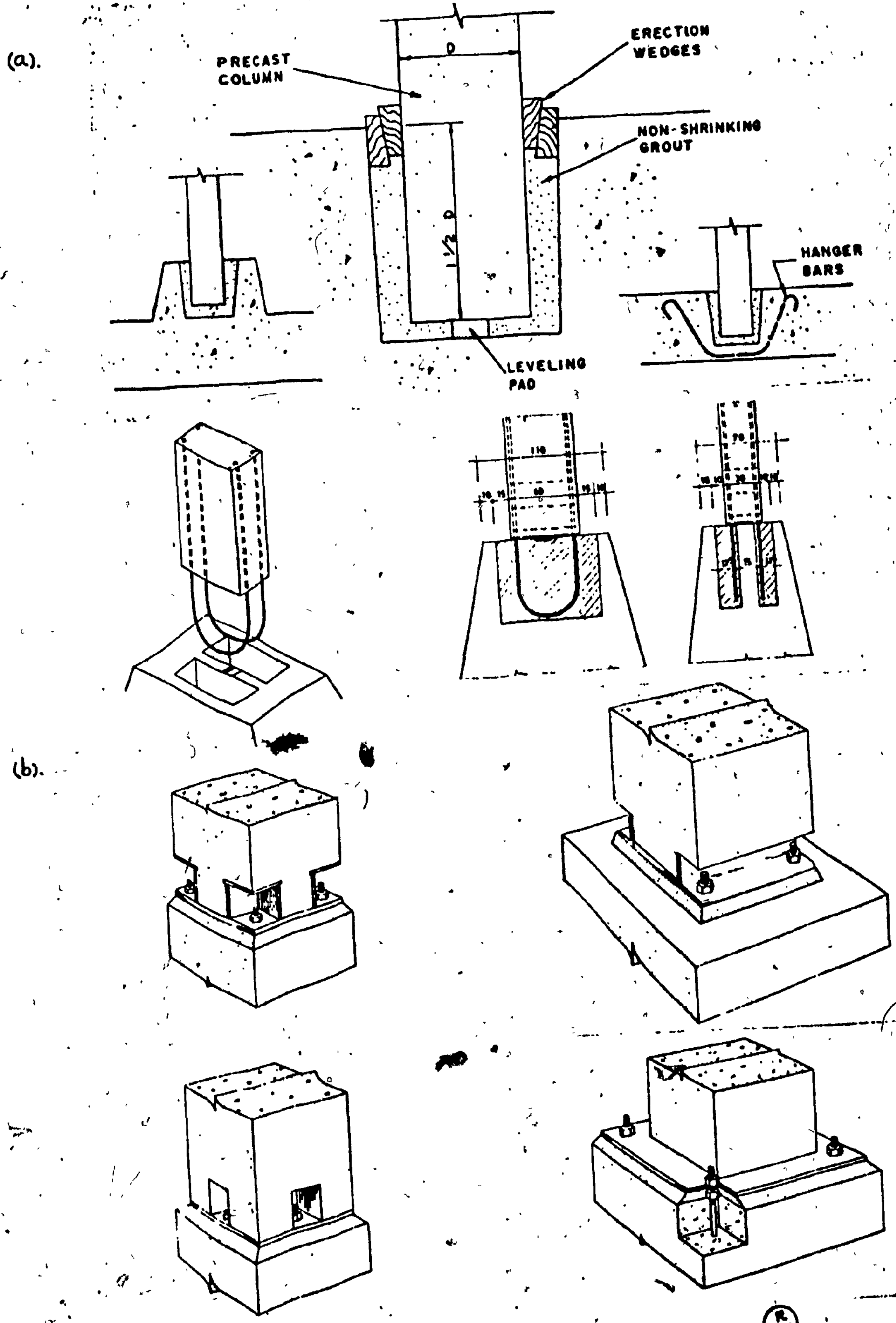
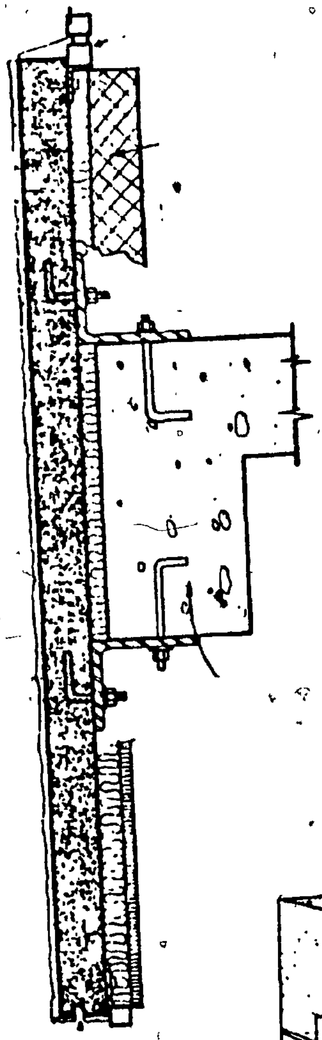


Fig. 31. Connections - Column to Base
(a) Wet Connections, (b) Dry Connections



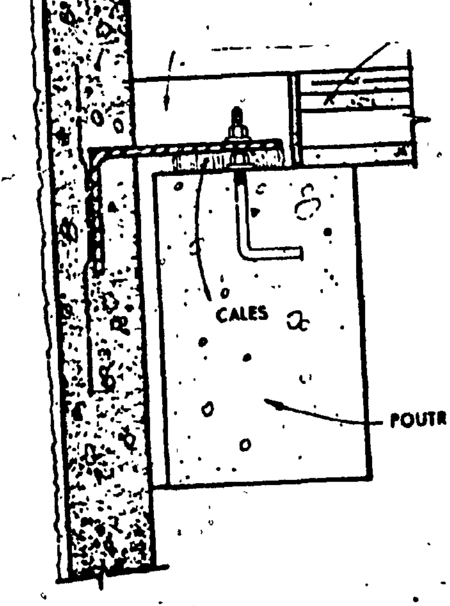
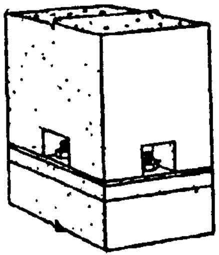


Fig. 32. Connection Non Load Bearing Wall to Beam (R 32)



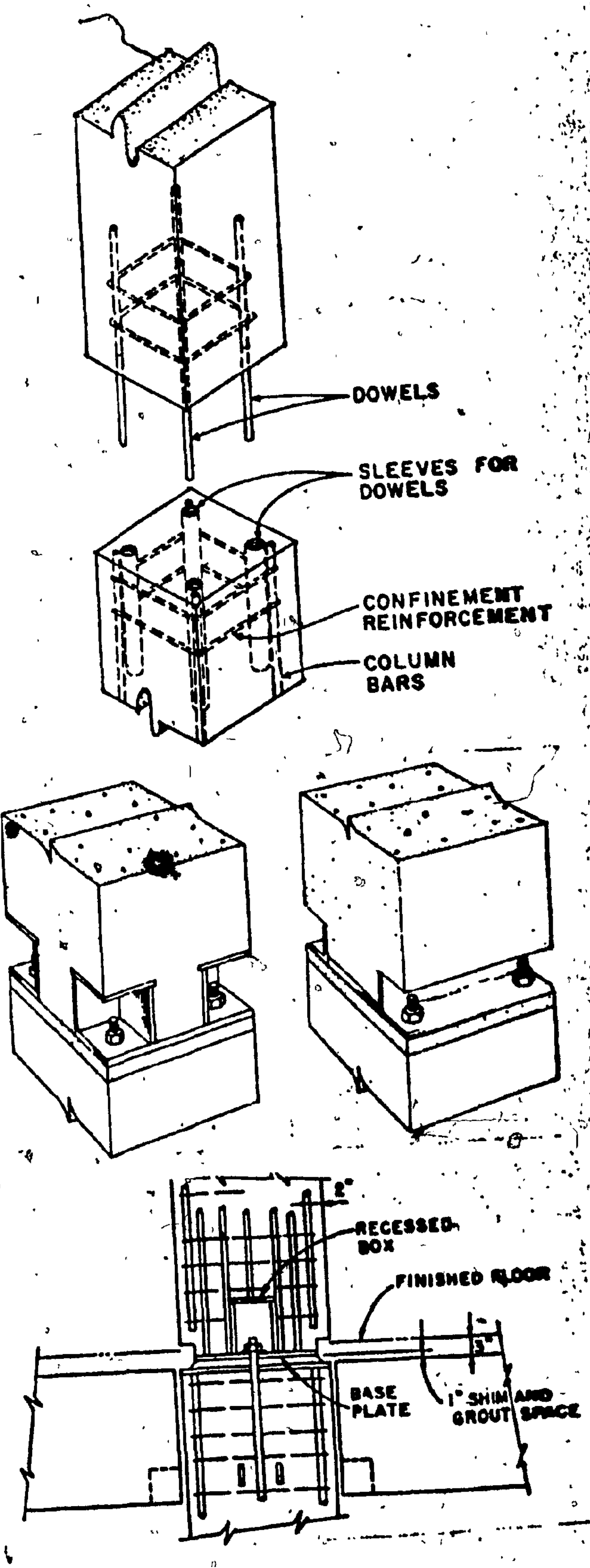


Fig. 33. Connections Column to Column (R 42)

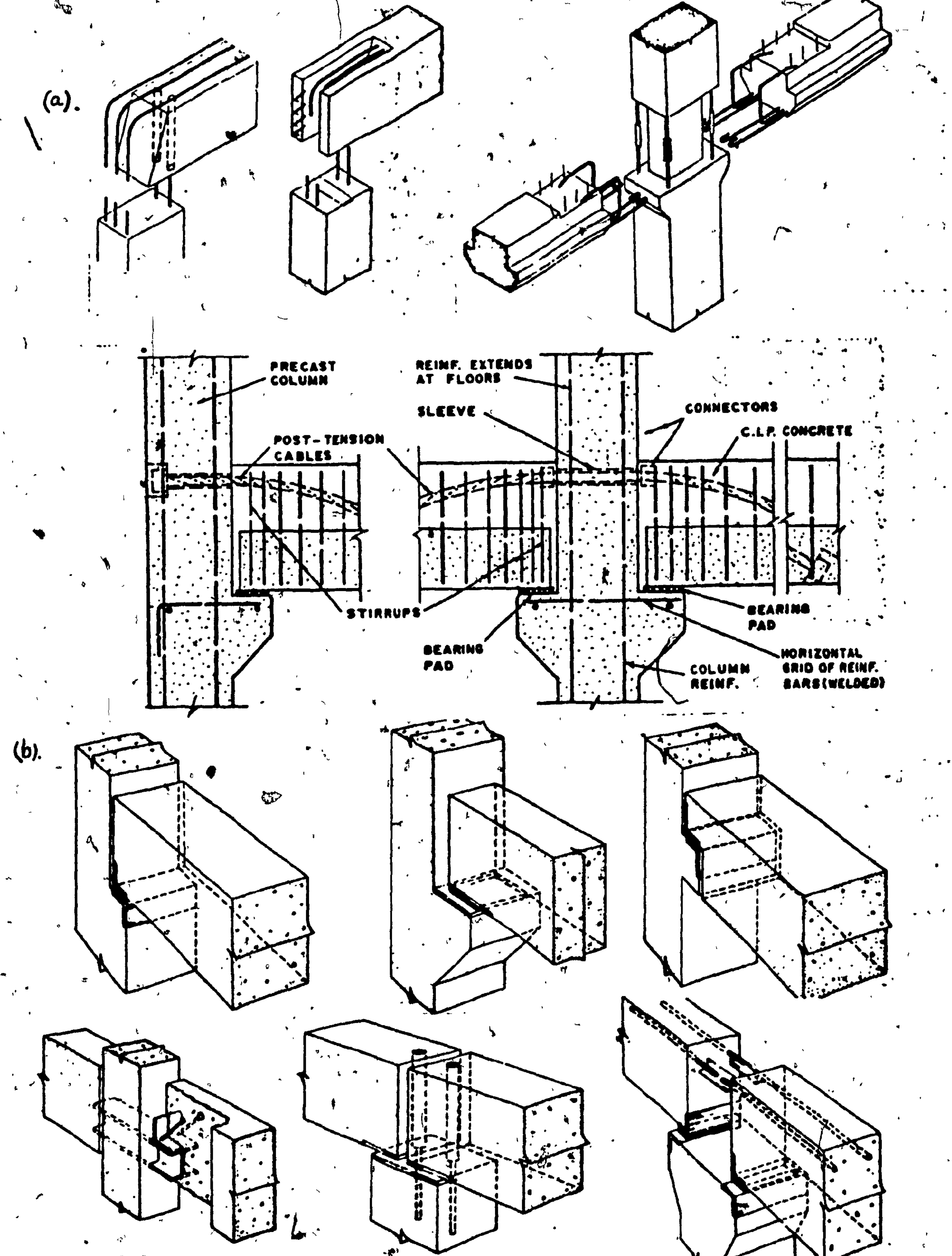


Fig. 34. Connections - Beam to Column
(a) Wet Connections
(b) Dry Connections

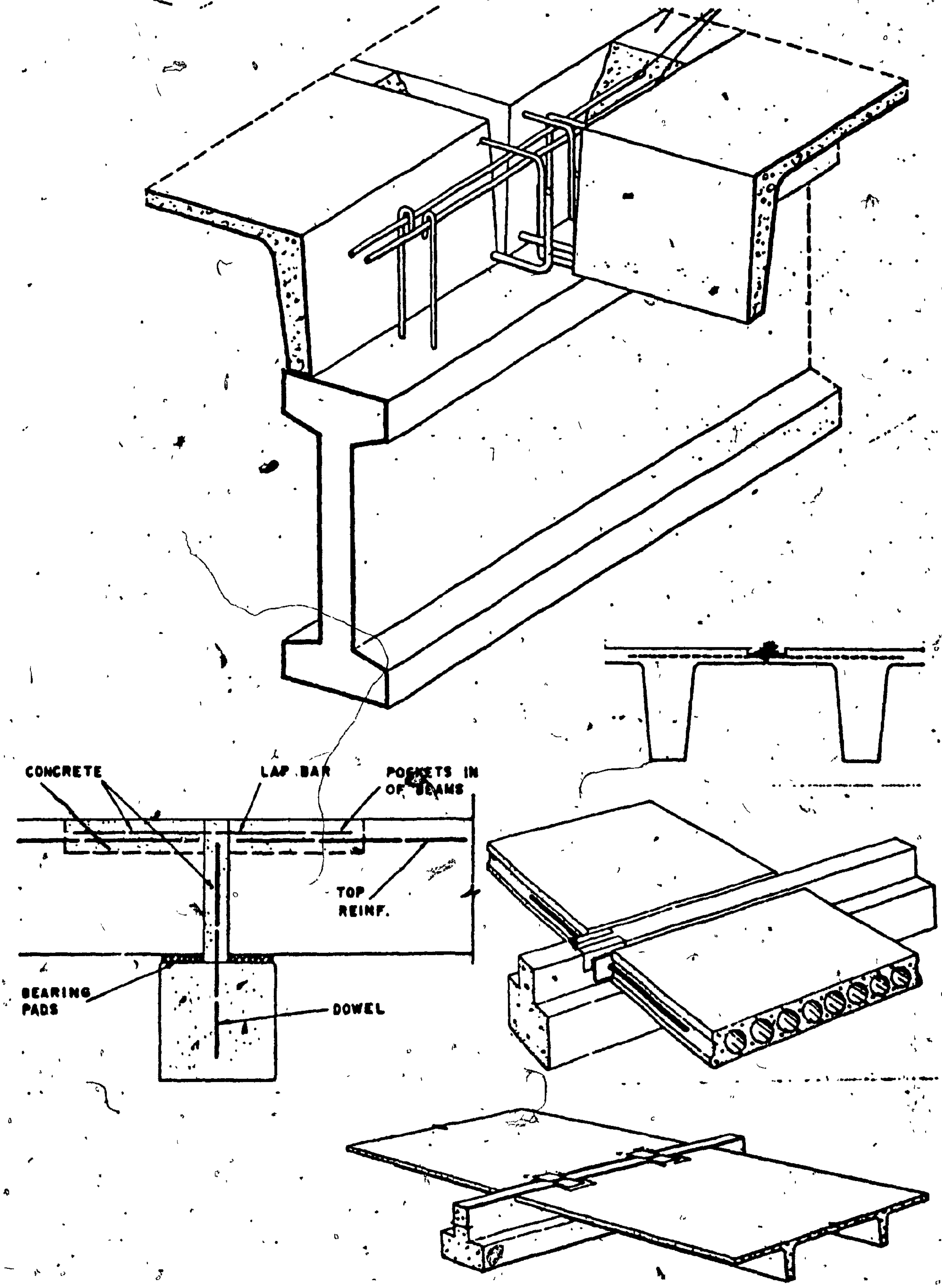


Fig. 35. Connections - Slab to Beam (7,14)

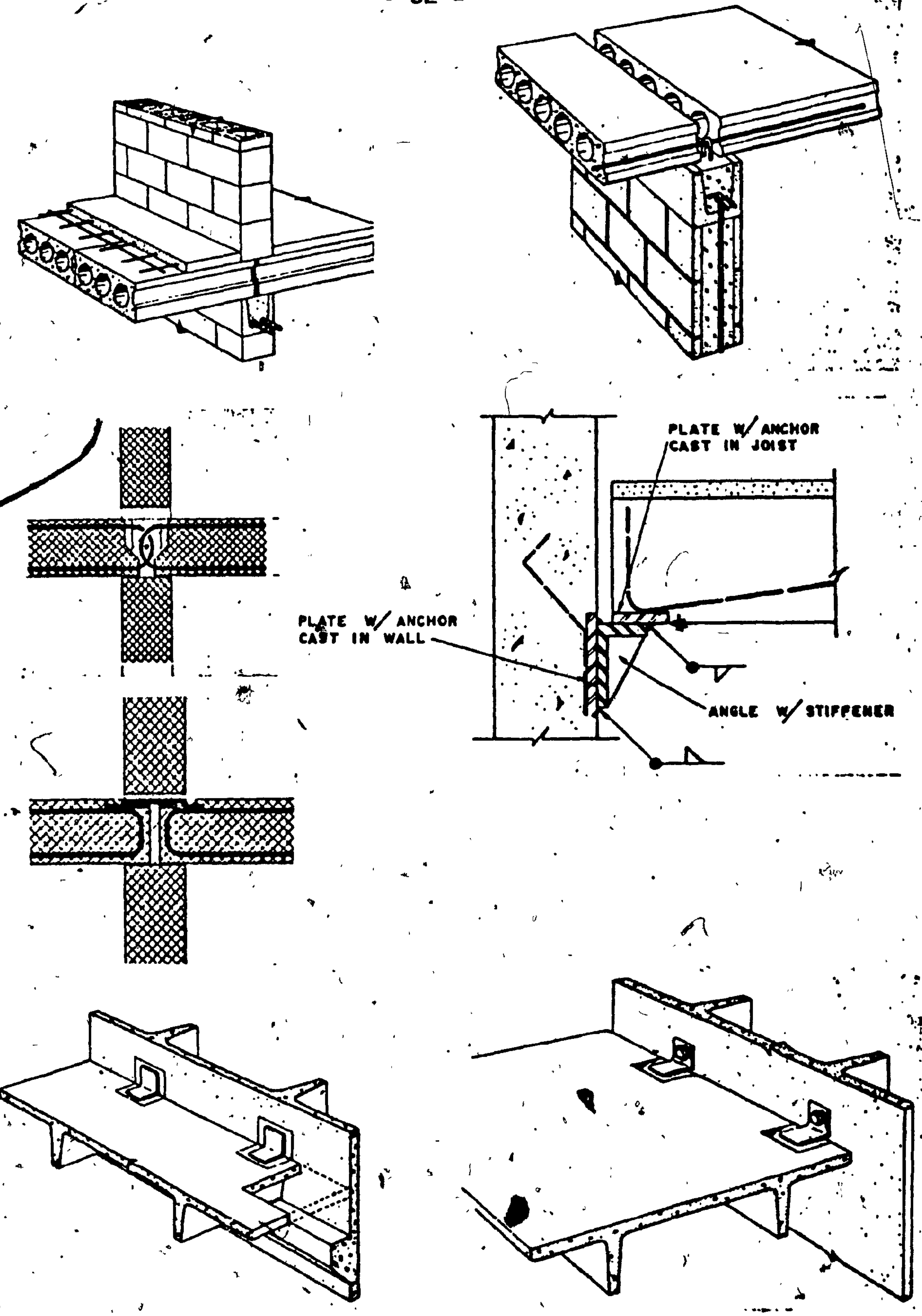
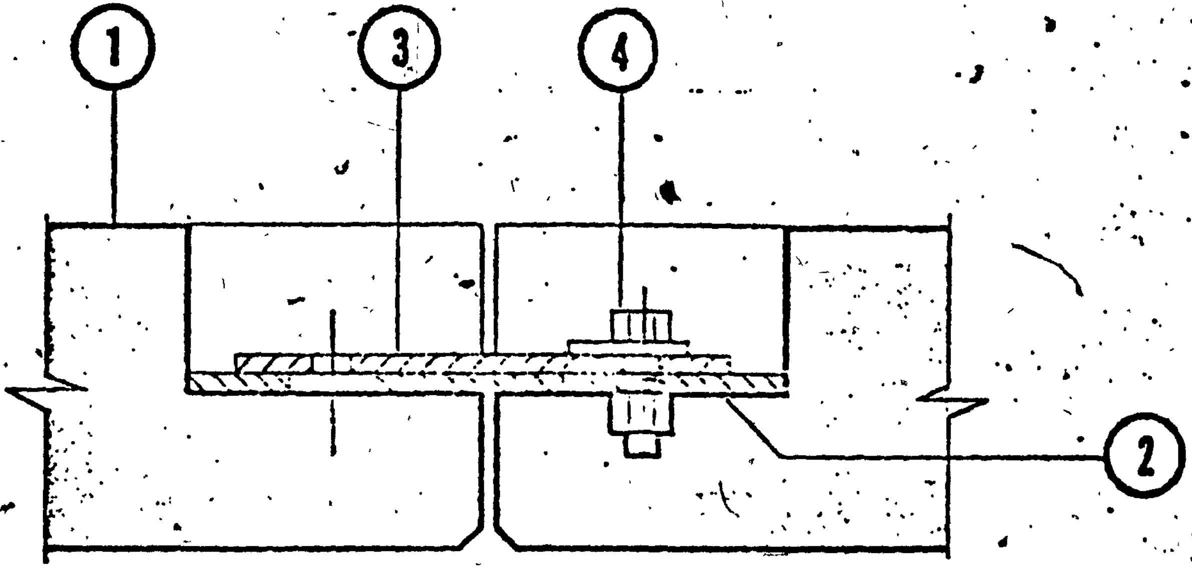
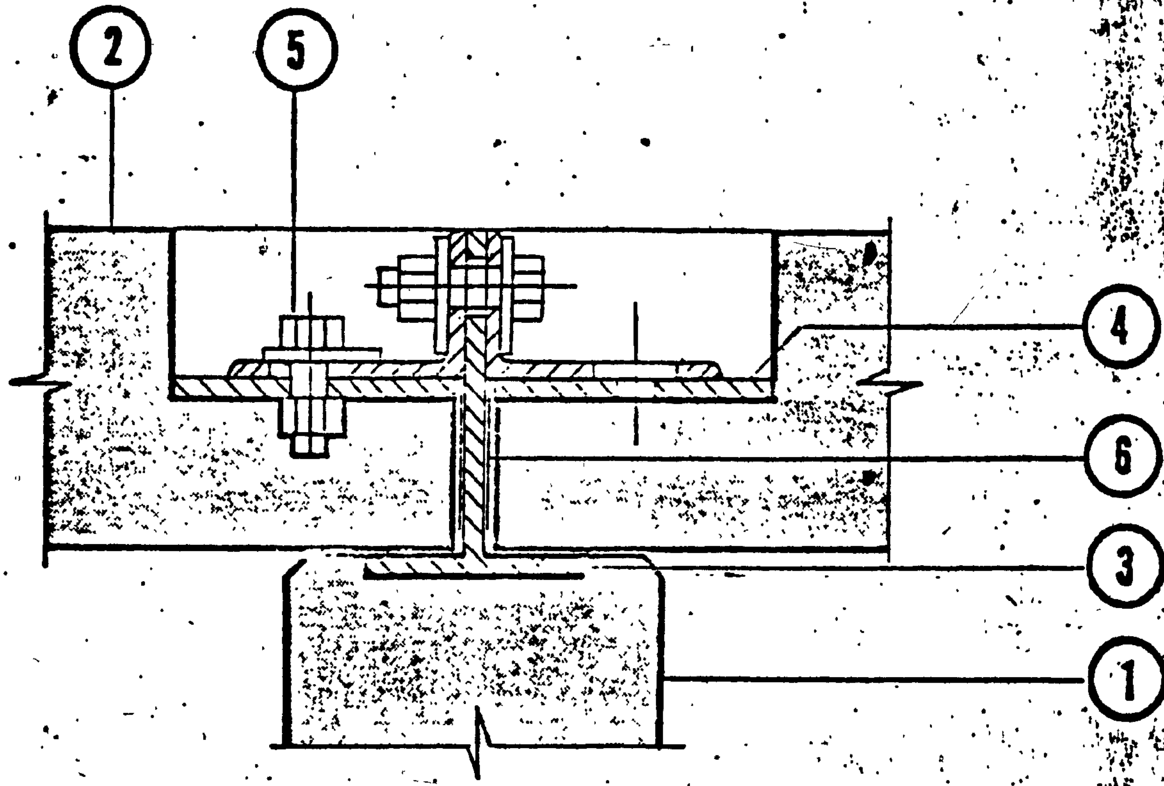


Fig. 36. Connections - Slab to Wall (R 42)



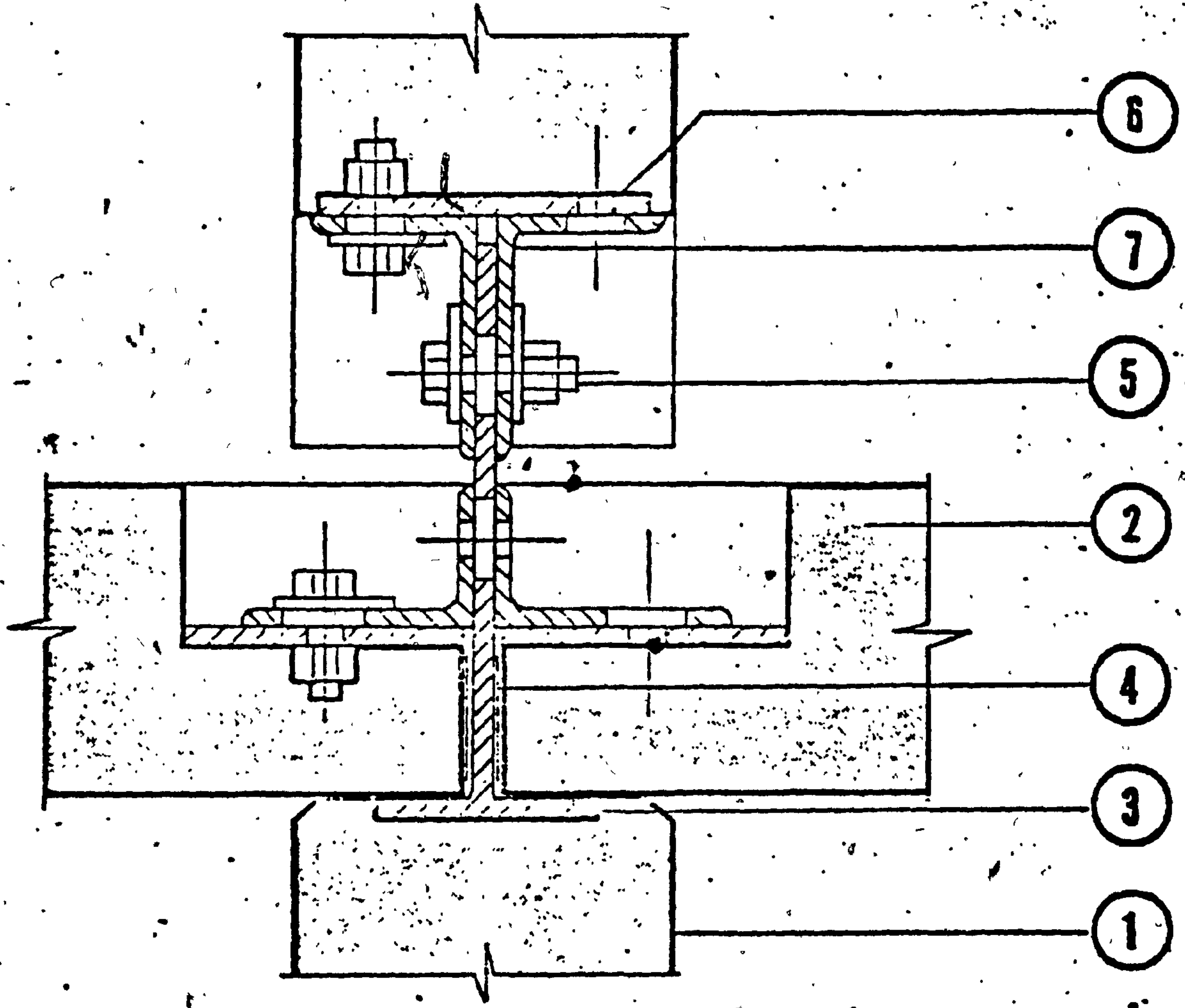
1. Floor panel
2. Embedded insert
3. Connector plate
4. Friction bolt connection

Fig. 37(a). Mechanical Bolted Connection (R. 11)
Floor/Floor Connection



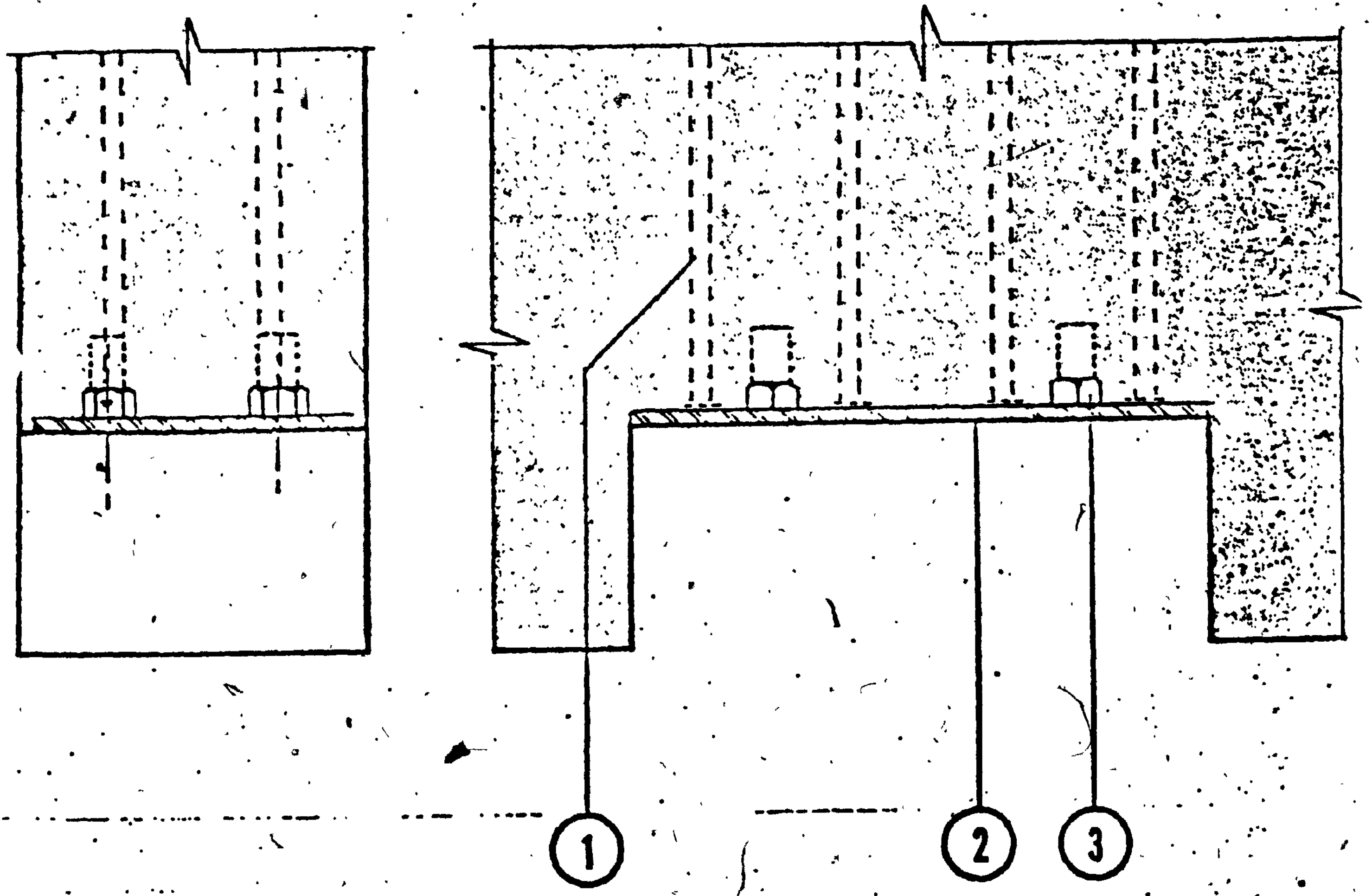
1. Bearing wall panel
2. Floor panel
3. Wall insert
4. Floor insert
5. Friction bolt connection
6. Metal shims

Fig. 37(b). Mechanical Bolted Connection ($\frac{R}{11}$)
Floor/Wall Connection



1. Bearing wall panel
2. Floor panel
3. Top of wall insert
4. Metal shims
5. Friction bolt connection
6. Bottom of wall insert
7. Standard angle connection

Fig. 37(c). Mechanical Bolted Connection
Wall/Floor/Wall Connection



1. Insert Anchors
2. Bottom of wall insert
3. Spot-welded nuts

Fig. 37(d). Mechanical Bolted Connection
Bottom of Wall Insert

CHAPTER V

MANUFACTURE, ERECTION, TOLERANCES

5.1 Manufacture

The major part of the labour involved in prefabricated building construction is with manufacture, which is between 60% to 80%. The principle of manufacture should be small amount of labour, speediest possible production and improved quality. A machine is an appropriate acquisition and its cost of purchase is justified if manual labour is saved as a result of using the machine. The object of using a machine is not only to save labour but it also aims at getting rid of the element of human error, thus ensuring constant quality. The manufacturing process of precast elements is represented in Fig. 38.

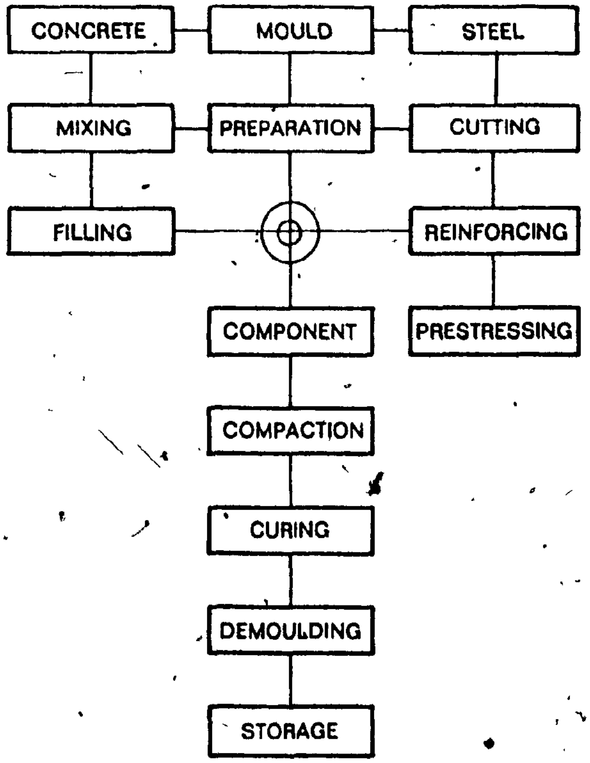


Fig. 38. Manufacturing Process

5.1.1 Manufacturing Methods

In general, the following methods of construction are in use:

a) Stationary production

b) Slip form production

c) Flow line production.

Stationary production could be classed as work-bench production or serial production. The moulds are the work-benches at which the work is done. In stationary production, the following distinction can be made:

i) Manufacture in moulds whose sides can be removed, the units being demoulded by lifting them off the mould base.

ii) Demoulding the units by tilting the moulds to the vertical position.

iii) Manufacturing in a group of moulds, i.e. battery moulds, demoulding being effected by dismantling the walls of the moulds.

For industrial buildings only the methods at (i) and (ii) are normally employed, while manufacturing of wall and floor slabs for residential construction is more suitably done by employing battery moulds.

Slipforming is a method of manufacture in which the sliding mould forming the outline shape of the unit is moved along the casting bed. The mould is vibrated, whereby the concrete is compacted. This method is widely employed for the production of flat slab like precast units.

Flow-line production is rarely practical for precast concrete members. It can be employed only if very large series have to be produced. The main snag is that with true flow-line production the same amounts of time have to be spent at each of the manufacturing stations. Combination of flow-line method with stationary production is the more likely proposition. Flow-line production can, however, sometimes suitably be used for the mass production of roofing units.

5.1.2 Choice of Manufacturing Method

The choice of manufacturing methods is affected by the following considerations:

a) the size of the series or the place of manufacture;

b) the size of the units;

c) nature and type of the units, i.e., linear or flat external walls, floors, etc.;

d) the reinforcement of the units, i.e., conventional reinforcement or prestressed;

e) the composition of the units and materials, i.e., ordinary or lightweight concrete or multilayer slabs.

Depending on these factors, one of the above methods of manufacture is chosen. The size of series, i.e., quantity of units, is of decisive importance for employment of the machinery. For fairly small size, say up to about 200 units, only stationary production will be practical. With larger series, up to about 2000 units, slipforming is a worthwhile possibility. For outputs exceeding 2000 units a year, flow-line production methods become an attractive proposition.

The size and type of units play an important part in deciding the production method. The larger linear components such as beams and columns are more difficult to be produced by

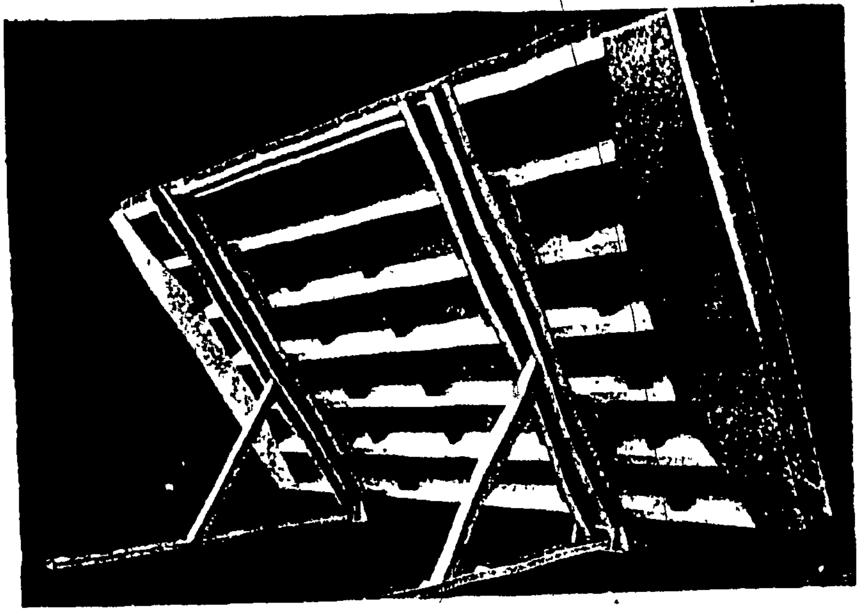


Fig. 39.

Tilting Mould
(hydraulically
operated)

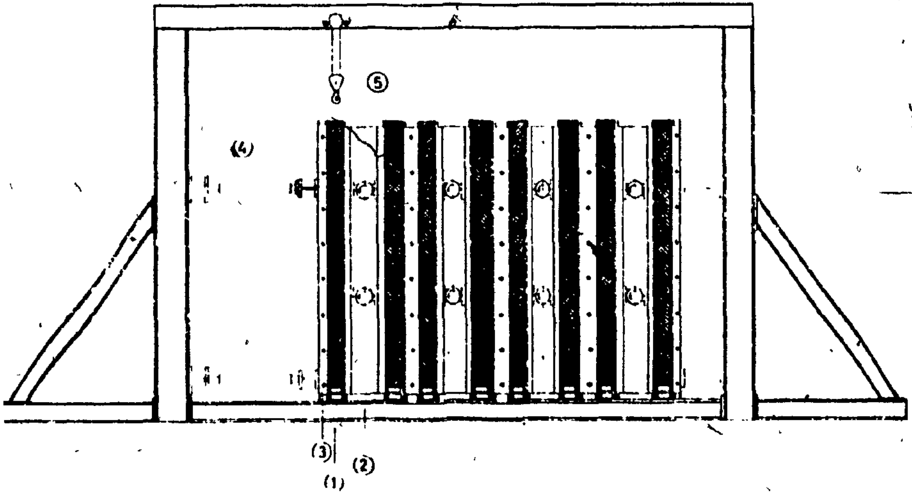


Fig. 40.

Battery Casting
Mould

(1) Frame
(2) Vibrating
element
(3) Heating
element
(4) Hydraulically
operated
props for
removing the
parts of the
mould
(5) Pulley block

any method other than by stationary production.

The reinforcement type is another factor which decides the manufacturing process. For instance, if prestressing by means of pre-tensioned wires is adopted, the members will have to be made on long casting beds on which the wires are tensioned between abutments at each end.

5.1.3 Moulds

The moulds are an important item of the manufacturing equipment of a precasting factory and their cost is a relatively high proportion of the total financial outlay. They have to fulfil a large number of requirements, since the dimensional accuracy of the units, and their quality is very largely dependent on the moulds. The materials used for construction of moulds are: steel, wood, concrete, plastics.

a) Steel moulds.--These are extensively used for precast concrete because they almost completely fulfil the requirements of a good mould. However, they are relatively expensive, and therefore it is necessary to produce very large series of components or the moulds must be so designed to enable them to be reused to produce various cross-sectional shapes. Steel moulds are suitable for solid-web beams, columns, floor and wall units. For the production of beam units, vibrators are mounted on the mould, so that the latter becomes to all intents and purposes a vibrating table. The moulds for floor and wall units are often designed as vibrating tables. For frequent reuse the moulds should be of robust construction.

b) Wooden moulds.--These are preferable for production of small series of components. However, if such moulds are constructed to the requisite standards of workmanship, they do not work out much cheaper than steel moulds. The corners of the moulds are often stiffened with steel plates or sheets. There is a considerable adhesion between wood and concrete, for which reason it is desirable to provide moulds with linings of plastic sheets, etc. Timber moulds for columns and beams may be treated with suitable mould lacquer which makes the demoulding easier and easy to clean. Wood as a material for moulds does not present the volume stability of steel and deteriorates more rapidly.

c) Concrete moulds.--These are primarily used for the manufacture of roof and floor units and for shells, folded flat structures and the like. They enable a high degree of dimensional accuracy but are not suitable for making any modification and are expensive from the point of view of maintenance as they damage easily. The concrete surfaces of the mould must be ground smoothly, otherwise it will not be possible to demould the units easily.

d) Plastic moulds.--Plastic moulds, especially those made of glass fibre-reinforced plastics, have come into widespread use. Their great advantage is the ease and freedom of shaping and low weight. Also, these moulds have good volume stability but these require more maintenance than steel moulds. The moulds have smooth surfaces, and the units cast in them can readily be demoulded.

5.1.4 Concreting

The components are cast on prestressing long beds or in individual moulds. The techniques basically applied in concreting are vibratory compaction and extraction of excess water by suction. Vacuum suction should always be applied in conjunction with vibration. Vibration of the concrete can be done by: internal vibrators or immersion vibrators; surface fibrators; external vibrators; and table vibrators. Internal vibrators are less and less frequently used for precast components except for columns and solid-web beams. External fibrators are used for the manufacture of linear components such as columns and beams. Table vibrators are suitable for producing precast slab and wall units, and enable a high rate of production to be achieved.

5.1.5 Curing

In the manufacture of precast concrete units under factory conditions, and also for serial production of components on site, it is usually necessary to employ artificial means of accelerating the hardening of concrete by appropriate curing treatments to increase the output for better utilization of moulds and of the whole manufacturing plant. The curing process essentially consists of heat treatment which can be applied by any one of the number of available means: the concrete may be heated by means of steam, warm water, warm air, warm oil, or electric current. With artificial means the required strengths, 25% to 60% of the final strength, for demoulding and removing from casting beds, can be achieved in as little as two to four hours.

5.1.6 Layout of Plant

Some typical layout of plants for manufacturing precast concrete components are shown in Figs. 41 to 43. However, the layout will differ in each individual case depending upon the size of plant and availability of land. The average cost of a prefabricating plant, capable of producing 2000 to 2500 flats per year, is between $1 to 3 million (excluding land and buildings). Most plants feel that they must produce at least 500 flats per year to break even. Many of them produce 1000 - 2000 flats per year. Economy increases with the volume of work.

5.2 Lifting and Erection

Lifting appliances suitable for the erection of precast concrete structural components are:

a) truck-mounted or crawler-mounted mobile cranes;
b) derricks;
c) tower cranes;
d) goliath cranes.

Mobile cranes are the most suitable lifting appliances for the erection of shed type industrial or low rise buildings. Such buildings generally come within the working reach of this crane. Mobile cranes are available with lifting capacities of as much as 200 ton and upwards and may be up to 80 metres high. Obviously, with such cranes, almost any conceivable industrial building can be erected without difficulty. These are relatively expensive in terms of initial cost, operation, and maintenance.

Derricks are amongst the oldest types of lifting appliance. Their main advantage is their simplicity and relatively low cost. On the other hand, they are awkward to

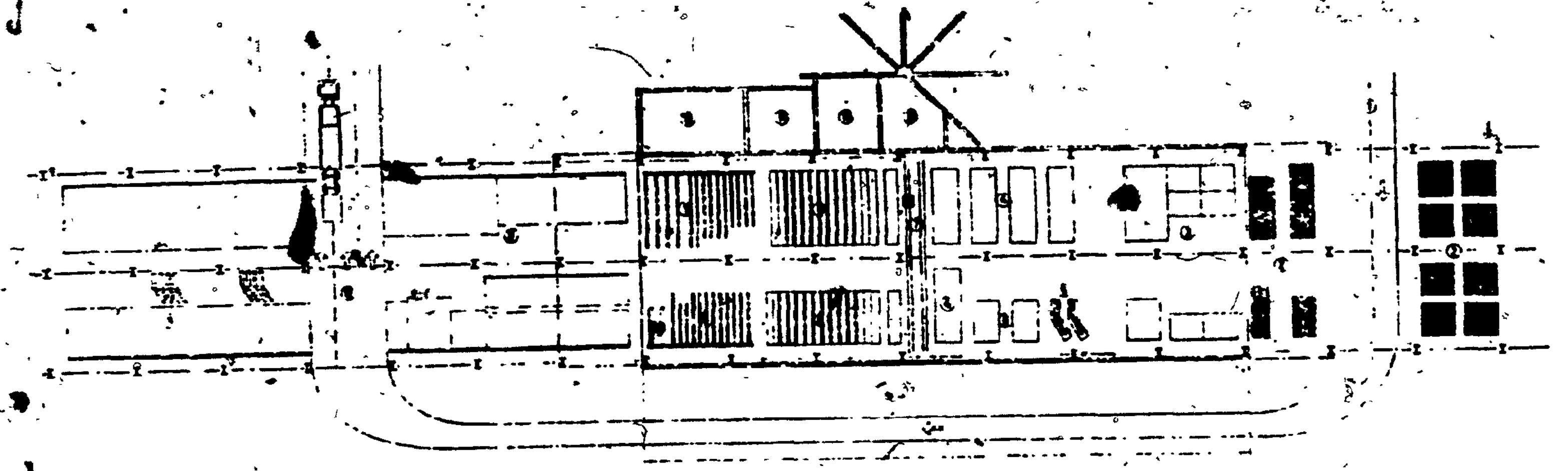


Fig. 41. Layout of manufacturing plant with combined functions in the individual bays of the casting shed: all the components for a dwelling are produced in one bay. Capacity of the plant: 2 dwelling per day. ㉑

(1) arrival of materials, (2) steel store, (3) preparation of reinforcement, (4) tilting tables for external wall units, (5) vertical moulds for stairs, (6) tilting tables for heart units, (7) transverse transport of concrete, (8) battery moulds for internal wall and floor units, (9) frames for finishing the units, (10) fitting the services (pipes, wires, etc.) into the heart units, (11) storage of the units, (12) removal of the units, (13) mechanical engineering workshop, (14) transformer house, (15) compressor plant, (16) mixing plant.

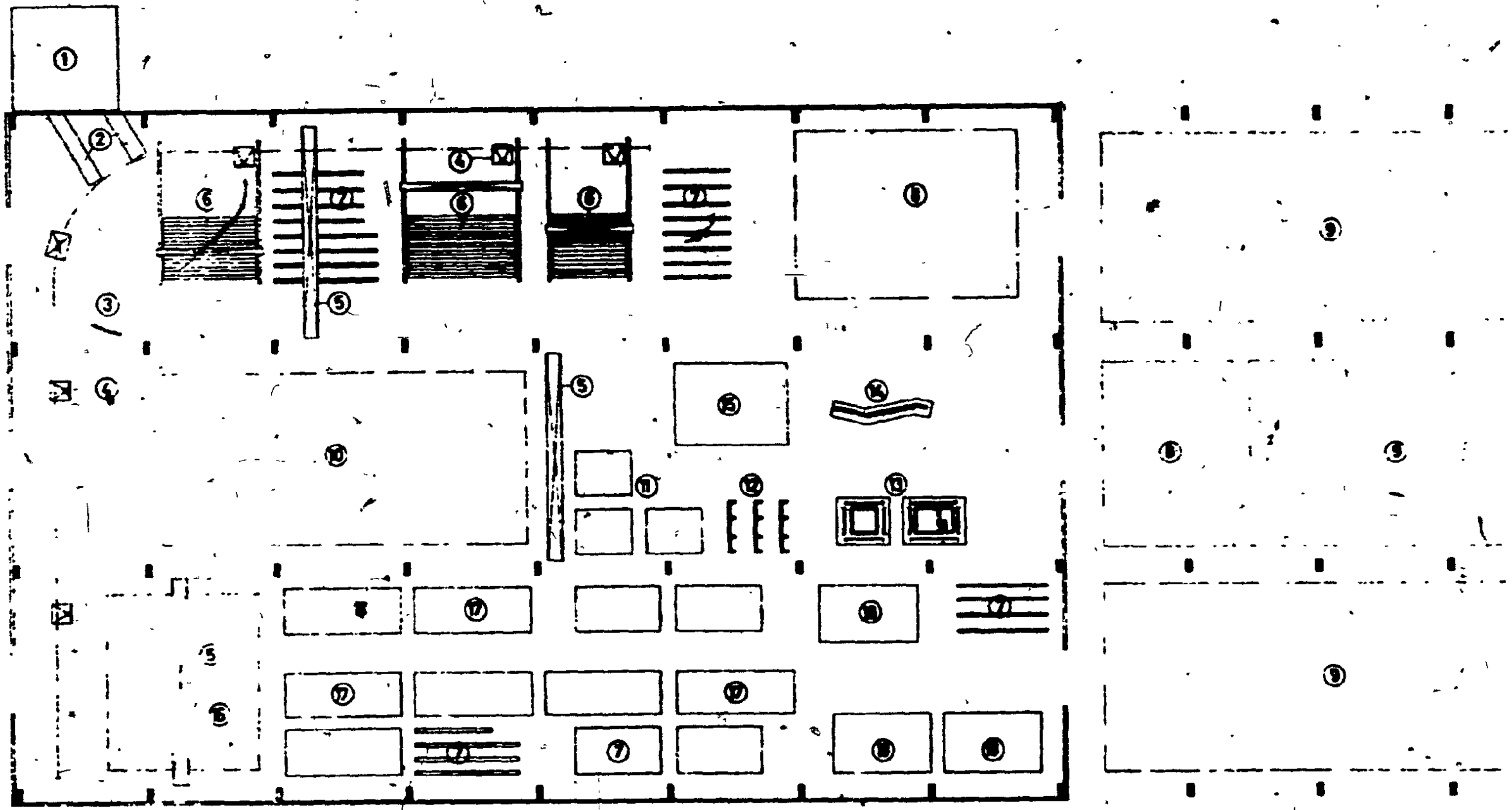


Fig. 42. Layout of manufacturing plant with separate functions of the bays of the shed: one bay accommodates only the battery moulds, while the other accommodates only tilting tables and moulds for spatial units. Capacity of the works: 4 to 5 dwellings per day.
(1) mixing plant, (2) concrete delivery point, (3) overhead monorail for concrete transport, (4) concrete delivery point for battery moulds, (5) overhead travelling crane, (6) battery moulds, (7) frames for finishing, (8) storage area for equipment to be pre-installed, (9) storage yard for finished precast units, (10) area for storage, preparation and bending of reinforcement, (11) tilting tables for wall units, (12) finishing the units, (13) box-shaped units, (14) tilting mould for stairs, (15) special units such as frames, etc., (16) preparation and manufacture of hollow light-weight concrete elements for external walls, (17) tilting tables for external wall units, (18) tilting tables for special units.

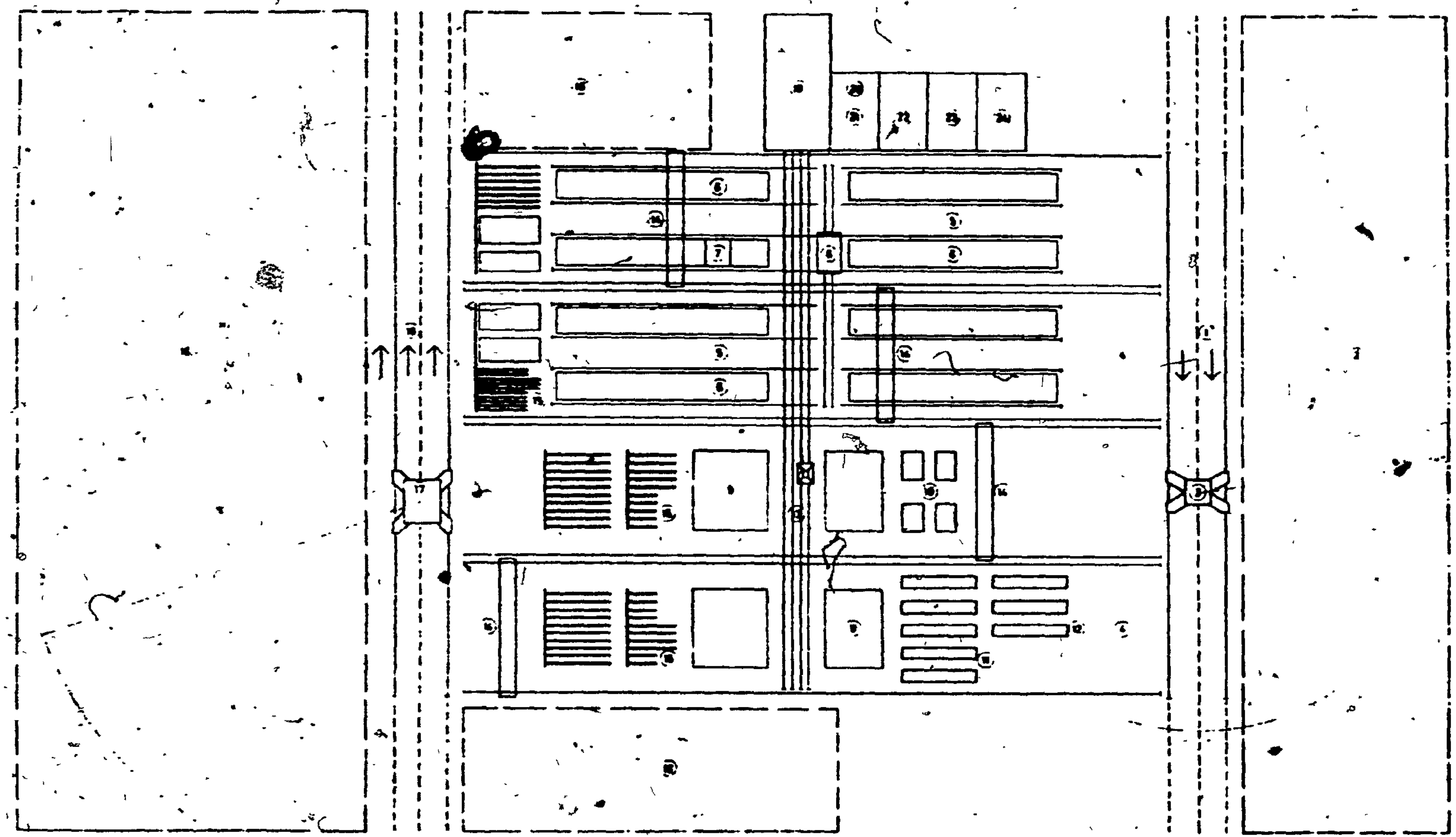


Fig. 43. Layout of manufacturing plant using slipform method.
(1) tower crane track, (2) storage yard, (3) tower crane, (4) casting bays, (5)(6) slip-forming beds, (7) slipformer, (8) hopper distributor, (9) tilting tables, (10) special units, (11)(12) spandrel panels, (13) concrete-transport, (14) overhead travelling crane, (15) frames for finishing operations, (16) materials store and storage yard for finished precast units, (17) tower crane, (18) exit, (19) mixing plant, (20)(21) mechanical workshop, (22) boiler house, (23) compressor plant, (24 transformer station.

R 21

move to a fresh working position and have only limited slewing capacity, so they do little more than hoist the components.

Tower cranes are especially suitable for the erection of multistorey buildings. They are used in the construction of prefabricated industrial buildings if the structural components are not very heavy and a large number of them can be erected by the crane moving along on one and the same set of tracks. It is most widely used appliance in building construction, including traditional buildings, because it is an economical piece of equipment. The maximum capacity of tower cranes is 200 ton-metres, i.e., a maximum of 20 ton can be lifted at a radius of 10 metres.

5.3 Tolerances

The dimensions of precast concrete units are never exactly as theoretically specified. Tolerance is the limiting value of the admissible deviation in the size or shape of the finished prefabricate from the design requirement. In practice it is impossible to make products which will have exact design dimensions. In fact, extreme precision is pointless, as inaccuracies are unavoidable during erection. As a decrease in tolerances leads directly to increased costs of production, optimum values should be established. Also, large deviations lead to waste of materials. The dimensional deviations are due to the following causes:

a) Inaccurate reproduction of the design dimensions in actual structure;

b) Inaccurate dimensions of the prefabricated components

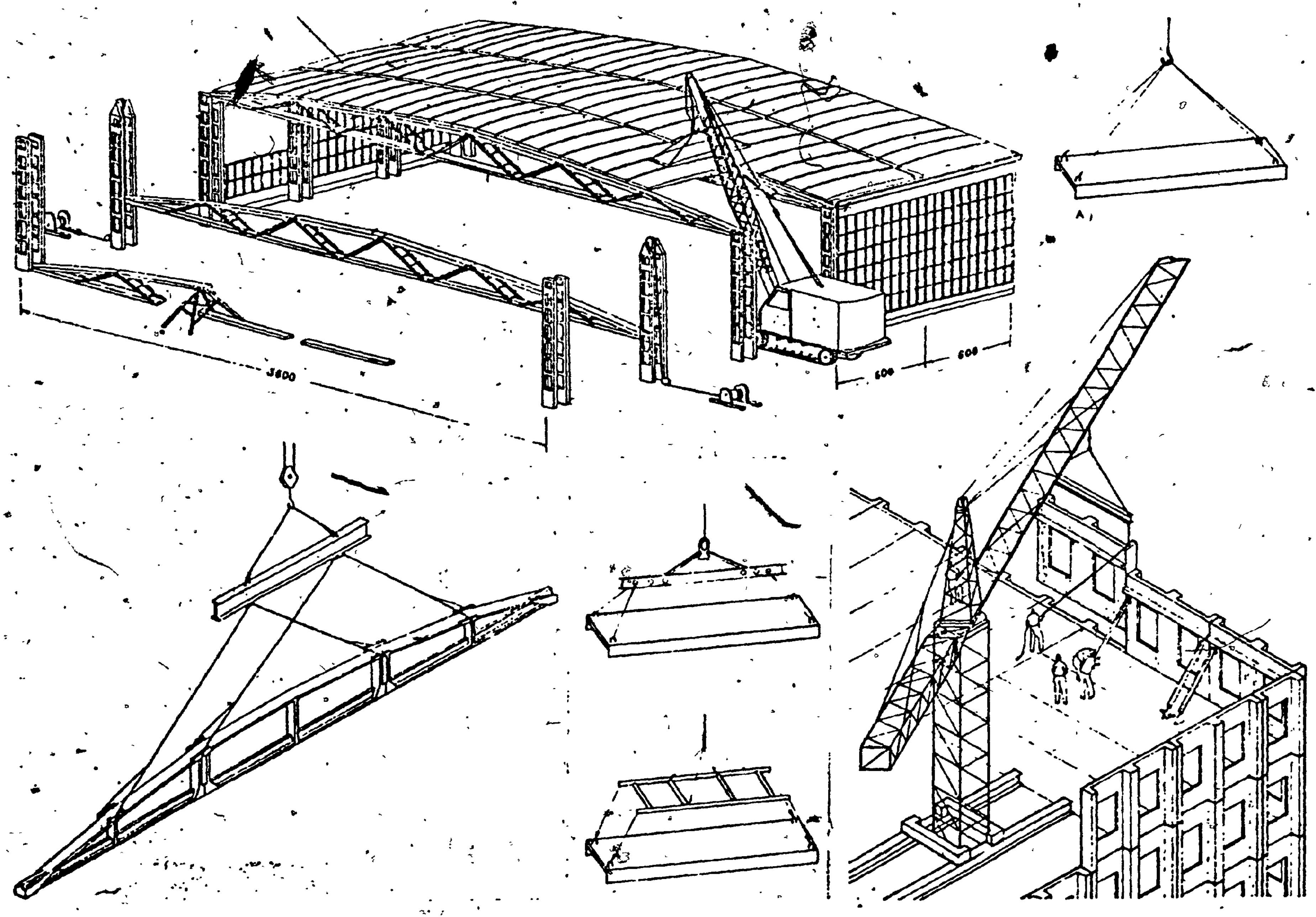


Fig. 44. Erection Techniques (R 7)

c) Inaccuracies of erection.

From a large number of measurements it has been established that the deviations in the dimensions of prefabricated structural components can be represented by a Gaussian distribution curve. Because of this conformity with the statistical normal distribution, it is possible to utilize the methods of mathematical statistics and probability analysis for determining the tolerances, as the above mentioned individual factors are mutually independent variables. The sources of the deviations can also be investigated independently of one another. The inaccuracies in the dimensions of the components are dependent on:

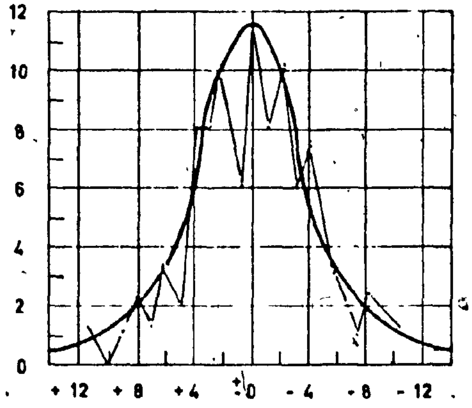


Fig. 45. Normal distribution of dimensional deviations

a) the moulds

b) the nominal dimensions

c) the nature of component

d) the position during concreting.

The deviations that arise during manufacture comprise a regular deviation and a random error. The random variations from design dimension are measured in terms of the mean deviation. The manufacturing dimensions are most affected by the moulds. It is on the condition of moulds that the accuracy primarily depends. If the deviations depending on the nature of components and their position during concreting are also taken into account, then the entire deviations associated with manufacture can be determined from individual values in accordance with Gauss's theorem:

$$\sigma_F = \sqrt{\sigma_1^2 + \sigma_2^2 + \sigma_3^2 + \sigma_4^2}$$

where σ_1 denotes the mean deviation which depends on mould, σ_2 denotes the mean deviation which depends on nominal dimensions, σ_3 takes account of the nature of components, and σ_4 takes into account of the position at the time of concreting. The inaccuracies of erection comprise three degree spatial freedom. The individual deviations in the directions of the co-ordinate axes can be determined and the resultant deviation can be calculated from

$$\sigma_M = \sqrt{\sigma_x^2 + \sigma_y^2 + \sigma_z^2}$$

Since the tolerances are proportional to the deviations, the requisite tolerances can be determined from the known deviations associated with manufacture and erection of the components. Depending on the manufacturing method and possibilities for remedying any inaccuracies during erection, the components and the structural connections can be subdivided into quality classes.

Permissible tolerances for components as set by Polish standards are tabulated as shown on page 82.

Measurements	Types of construction		
	Large-block buildings with walls thicker than 24 cm	Large-block buildings with walls up to 24 cm	Large panel buildings
Displacement of the axes of structural walls	± 5	± 3	± 3
Displacement of the axes of partitions	± 10	± 5	± 5
Displacement from the vertical of walls over the height of one storey	± 10	± 5	± 5
Displacement from the vertical of walls over the whole height of the building.	± 30	± 20	± 20
Deviation of wall from the plane withone one apartment	± 5	± 5	± 2.5
Deviation of wall from the plane over the whole length or width of the building	± 15	± 15	± 10
Deviation from the horizontal of the top surface of the wall (per metre)	± 1	± 1	± 1
Deviation from the horizontal of the top surface of the wall (in one apartment)	± 10	± 10	± 6
Deviation from the horizontal of the top surfaces of the wall (over the whole length of the building)	± 30	± 30	± 25
Deviation of floors, landings and stair steps (per metre)	± 1	± 1	± 1

(Continued on following page)

Measurements	Types of construction		
	Large-block buildings with walls thicker than 24 cm	Large-block buildings with walls up to 24 cm	Large panel buildings
Thickness of horizontal joints between prefabricates	+ 10 - 5	+ 5 - 2	+ 5 - 2
Thickness of vertical joints between prefabricates	+ 10 - 5	+ 5 - 2	+ 5 - 2
Deviation from the design height of the height of each storey height	± 30	± 20	± 20
Deviation from the design height of the total height of the building	± 50	± 40	± 40

CHAPTER VI

CONCLUSIONS

To satisfy the pressing demand and increase the efficiency and productivity of housing, and ~~also~~ for conservation of construction materials, industrialization of the building trade has become a necessity.

Governments should fully recognize the need for industrialized buildings. Having recognized this need, government and the public must wholeheartedly participate in its adoption. To start with, prefabrication is often costlier than traditional methods because of the amortization of huge amounts of capital investments in equipment and machinery. To make prefabrication a success, the governments and local housing bodies should provide incentives by financial assistance to the developers by giving liberal loans at a lower interest rate and capital subsidies; and also assuring continuity of demand.

To bring about a gradual change from traditional methods to prefabricated construction systems, technical institutions should introduce courses of instruction on prefabrication for educating professionals. Also, there are still many who are not yet prepared to accept prefabricated buildings as they feel that it represents inferior and monotonous construction. It is, therefore, apparent that a considerable amount of educating the public is required before it is fully accepted.

Prefabrication of housing also demands that architects and engineers should be integrated. An architect must accept the design disciplines of the system. He should consider himself as a member of the team and not the leader. This is an essential prerequisite for the success of industrialization of the building trade.

Developing countries have large forces of unskilled labour and shortage of financial resources, and thus face a dilemma regarding the apparent advantages of industrialized buildings. Complete mechanization is likely to create unemployment problems and huge amounts of money are required to be invested in equipment. To start with, partial prefabrication, particularly prefabricated components for roofing and flooring, along with traditional methods, is best suited for developing countries. This will pave the way for complete prefabrication as and when the conditions become favourable.

From a study of existing systems, it is noticed that component approach is better suited than module approach as it allows users need for diversification and works out cheaper as a lesser amount of money is required to be invested in equipment. However, before any particular system of prefabrication is chosen, its advantages must outweigh the disadvantages.

The current trend to the limit state design philosophy requires a better understanding of the behavious of joints and connections not only with respect to their strength but also their deformability at various stress levels. From the point of view of economy it is not feasible to design structures to resist unusual or accidental overloads without some structural damage. Enough reserve strength and redundancy should be provided so that load will not result in progressive collapse but that damage will be confined to the immediate neighbourhood of the accident.

Both theoretical and experimental research is therefore needed to develop improved structural models for predicting joint resistance and deformability and the parameters that influence these characteristics. Alternate design details should be evaluated, not only from the point of view of structural adequacy, but also the cost of fabrication and ease of construction.

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