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United Nations Industrial Development Organization

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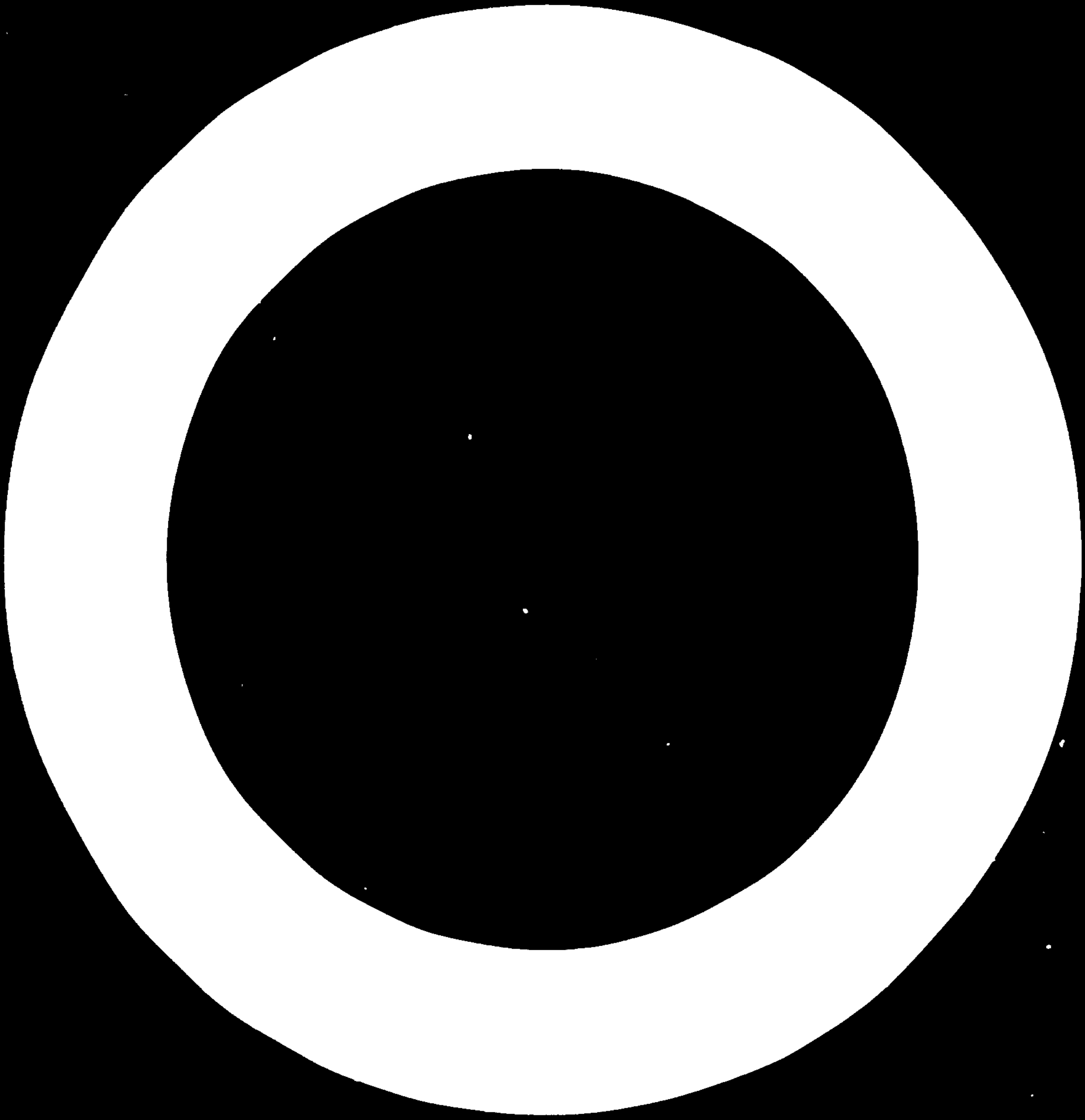


I. INTRODUCTION

Both developed and developing nations have, in recent years, been faced with severe shortages of constructed facilities. The rapidly rising construction cost, the shortage of skilled labor and materials, and the rising expectation of people for better housing have resulted in development of alternative modes of production. Innovations in and industrialization of the production process are viewed as the most promising possibilities for reducing cost, increasing productivity, and in certain cases improving the quality. The production processes are being modified in one of two ways: i) Through a procedure known as building rationalization, where the traditional building methods are retained, but the individual operations are modernized and streamlined. For example, use is made of modern construction machinery; the building progress is checked at intervals by means of network plans; and/or the construction costs are supervised by the use of modern construction accounting programs and electronic data processing techniques. ii) Through adopting a building systems concept and wholly industrialized construction process. This involves the transfer of building operations to a factory where continuous production processes can be employed. Industrialization, in contrast to rationalization, is concerned not only with selected operations but the entire construction process, from the planning stage to execution. Fully industrialized techniques have marked advantages over rationalized traditional methods only where supply and demand are mutually adopted and a body of experience has been acquired. Given these, industrialization offers many advantages over a field site for putting together a building: delays due to adverse weather are eliminated, lower costs (and often less skilled) labor can be used for many jobs, materials flow and inventories as well as the production process itself can be more effectively controlled.

However, there are certain prerequisites for industrialization to be successful. Large markets and long term commitments are necessary in order to amortize the increase in capital investment. Standardization and mass production together with functional simplicity are necessary if savings in time and money are to be realized. Finally, since the goal is to achieve an overall optimization, integration of the various building subsystems as well as integration of design and production should be achieved. In summary, therefore, the three main supports for industrialized building processes are standardization, integration, and mechanization. Standardization and integration are mandatory to permit mass production and predictability of interface. Mechanization of both muscle-power and brain power, with machinery and automation respectively, results in standardized products at a reasonable cost. The foundation of these supports is available mass market to permitthe necessary amortization of both material and management investments, necessary on the part of the system participants.

This paper limits itself to concrete prefabricated building systems. It deals with advanced prefabrication which is taken here as synonymous to industrialization of buildings. It discusses the various factors involved in the production phase of the precast industry, and reviews methodologies available for the design of precasting plants and for the analysis of their economic feasibility.

To achieve this the building systems presently in use and their suitability to different types of buildings are briefly reviewed. The functional areas of a precasting plant are identified and examined: This includes -- a description of production techniques, with related information as to their scale of output and productivity, and technical and economic considerations bearing on the choice of one process over another. Information is presented concerning the management of precasting plants.

II. GENERAL ASPECTS OF PREFABRICATION

The term prefabrication refers to a structure assembled in total or in part from factory made components.

Prefabrication implies standardization of the components and mass production. This type of manufacturing process is known to bring about so-called economies of scale, as witnessed in steel and car industries. In addition, savings in material costs, labor, and shorter construction times make prefabrication an attractive alternative to current building practice.

Savings in materials costs occur in three ways; through the purchase of large quantities and the elimination of middle men; through the decrease in dimensions of the elements, as higher quality materials provide a higher strength for the same volume; through the decrease of wasted materials.

Savings in labor are two-fold: Reduction in total man-hours resulting from the higher productivity of the factory; and the decreased amount of work required on site.

Savings through shorter construction time affects a number of items including; interest paid on borrowed capital; interest paid on working capital, increased revenues due to earlier occupation of building; and lower overhead.

In addition the harsh climatic conditions in many areas of the world restric considerably the construction process during the winter season. Factory production of components can bypass the technical obstacles, and hence regularize the volume of construction over the whole year.

2.1 Materials Used for Prefabrication

Almost all the common building materials can be used in prefabricated form. Presently, however, wood, concrete, and steel are the predominant materials.

Wood is the most widely used for single family dwellings, especially in the prefabricated mobile home industry. With an increasing shortage of timber tracts and a rising public interest in their preservation, the use of lumber in construction is becoming less frequent. Furthermore, wood-framed construction can only be used for low-rise structures. Concrete and steel are equivalent in use, and their funtions are often interrelated. In most parts of the world steel is an imported item and its use places a severe pressure on balance of payments. Its use in construction is, therefore, highly curtailed. In addition, steel and aluminum are used mostly for building frames leaving enclosures to be made of other materials. Almost all European systems use concrete, because it is readily available anywhere, it is versatile in its use, and usually cheaper than steel.

Concrete as a building material has several advantages: on a cost/unit of volume basis, it is one of the cheapest materials available. Its basic ingredients, sand, gravel and water, are natural resources found almost in any location, and cement, which transforms the aggregates into concrete, is rather inexpensive. In addition, concrete provides an excellent sound insulation, it has equally good thermal qualities, and its proper use can cut down sizeably the heating expenses of buildings. It provides all the required fire resistance in buildings, and it can be molded into any shape,and provides a monolithic structure, when properly reinforced.

2.2 Prefabricated Systems

A building system is often defined as: the method by which a variety of structural and mechanical units are assembled, erected, and installed to produce structures that will function for a specified use or combination of uses. There are two distinct categories of systems building: (1) the closed system and (2) the open system.

The closed system is characterized by components which are peculiar to one system and which cannot be combined with those of other systems. In general, the elements of such a system cannot be ordered individually but must be purchased as a portion of an entire project. Though all details are predetermined and flexibility is very limited, the closed system is appealing in that all parts for a completed system come in a single package.

The open system, on the other hand, provides a high degree of interchangeability of components from system to system and thus allows much freedom in design. One of the major problems with the open system is the development of a basic module which is a necessity if diverse components manufactured by different industries are to fit together. It is generally agreed that some kind of modular coordination is needed if construction and building design are ever to be simplified, but as yet, no standard module has been generally adopted. At this time, there are a few industrially produced building components which are interchangeable in their applications to a limited extent. Among these are the hollow core concrete slab and the single- and double- tees used as roof and floor or wall elements (see Figure 1).

2.2.1 Types of Prefabricated Elements

Prefabricated construction involves the fabrication of building components either off-site in a factory or on-site away from the final position of the components in the building. This study will be limited to prefabrication in a factory. The major cost saving factors of factory fabrication are as follows: (1) improved materials handling (e.g., quantity purchases and reduced waste and/or vandalism), (2) cheaper labor (i.e., reduction in hours needed due to efficiency, no problems with weather, and substitution of industrial labor for skilled labor), and (3) improved management, control, and scheduling and overhead

FIGURE 1

UTILIZATION OF MODULAR BUILDING UNITS IN THE U.S.

Element:	Used as:	Sold by U.S. plants:
SINGLE-TEE	a floor and roof element	by 100% of plants
	a wall element	" 36% "
	a bridge element	" 19% "
DOUBLE-TEE	a floor and roof element	by 100% of plants
	a wall element	" 50% "
	a bridge element	" 16% "
F-SLAB	a floor and roof element	by 100% of plants
	a wall element	" 20% "
	a bridge element	" 7% "
CHANNEL SLAB	a floor and roof element	by 100% of plants
	a wall element	" 16% "
	a bridge element	" 42% "
EXTRUDED HOLLOW SLAB	a floor and roof element	by 100% of plants
	a wall element	" 41% "
WET-CAST HOLLOW SLAB	a floor and roof element	by 100% of plants
	a wall element	" 22% "
SOLID SLAB	a floor and roof element	by 72% of plants
	a wall element	" 33% "
	a bridge element	" 22% "

Source: Prestressed Concrete Institute. Standardization Committee. "The National Precast Concrete Product Survey," Journal of the Prestressed Concrete Institute, Vol. 14, No. 3., June 1969.

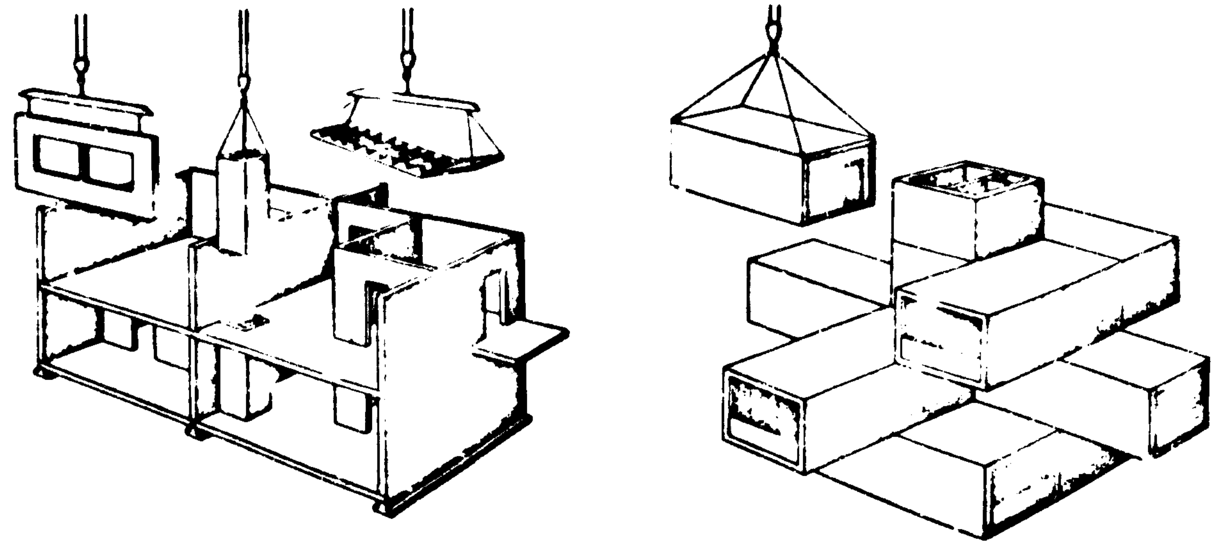
reduction. In turn, of course, these economies are reduced by the cost of transportation, need for special mechanical equipment for on-site assembly, capital recovery on plant investment, and high initial research, development, and design costs. While some prefabricators produce components essentially by traditional craft methods in a factory setting, others replace at least some of the hand labor by machines and thus avoid some of the high labor costs.

The various degrees of prefabrication are often classified into three groups: (A) beam and column, (B) panel, and (C) box. See Figure 2.

A. Post and Beam Systems: Columns and beams are fabricated off-site. The elements are transported to the working area, erected and assembled to serve as a supporting frame. The bays and floors are then covered using masonry construction or prefabricated panels.

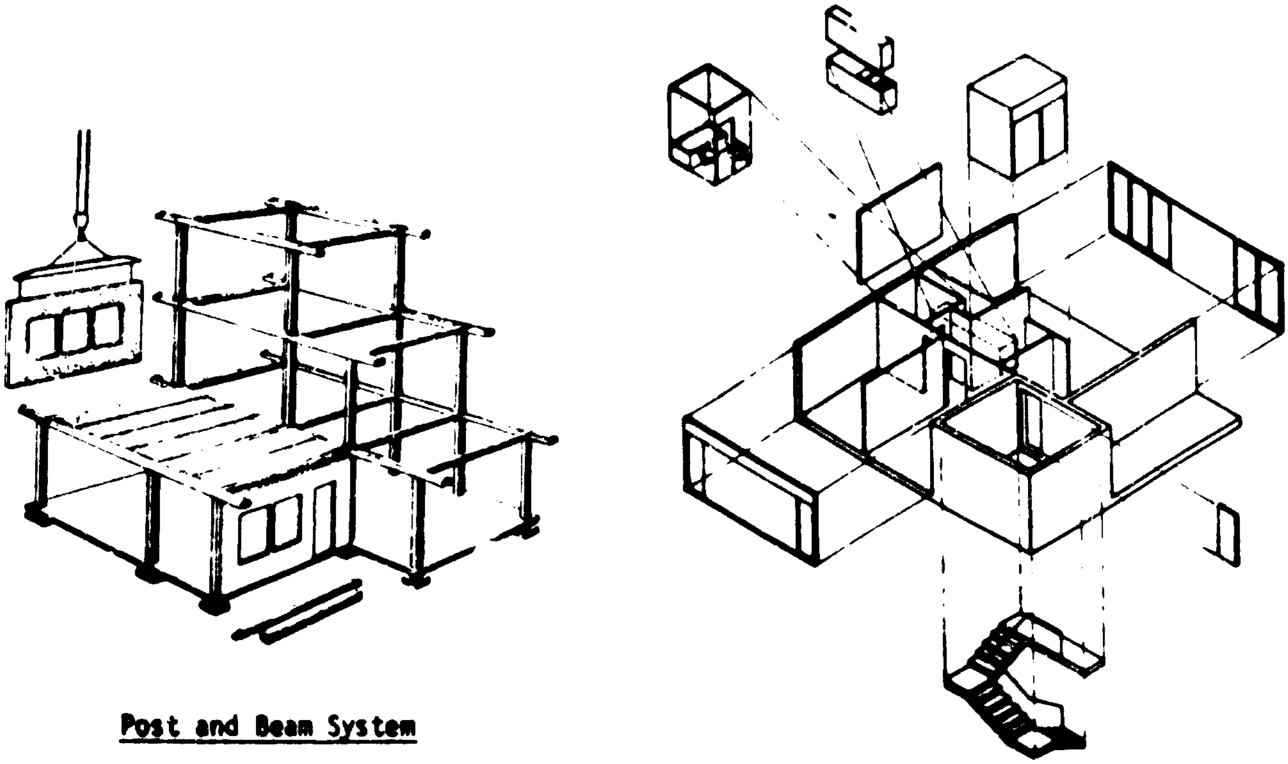
This system is the least sophisticated; it requires simple forms, usually of steel, to cast the columns and beams. A higher level of productivity is achieved by the use of long casting beds, where elements are sawn off after the concrete has set, to the required dimensions. Steel forms may or may not be provided with steam or hot water jackets to accelerate the hardening process.

Beams and columns are handled by overhead cranes, or especially equipped fork-lift type trucks. Hooks are inserted at determined positions to minimize the handling stresses in the element. For site transportation, the most common vehicle is the truck-semi trailer. Their erection is rather simple. For small dimensions, one crane is sufficient to handle longitudinal elements. Columns are tilted up with the help of spreader beams, or cable attachments to prevent the sway of the column. When large columns spanning two or more stories are erected, tandem cranes are often used.



Panel System

Box System



Post and Beam System

Combination System

FIGURE 2

BASIC TYPES   BUILDING SYSTEMS

As far as their use for housing and commercial buildings is concerned, transportation costs offset substantially any advantage of prefabrication. Since the elements are simple, the ratio of transportation cost to product cost increases rapidly to uneconomic levels. The main advantage of the system is that it requires light machinery for erection, hence reduces the investment in mechanical plant. It also provides for rapid construction, as one can fill in the floor panels immediately after erecting the precast elements, as opposed to waiting 8 or 10 days for the frame to reach its cured strength, in the conventional method of building.

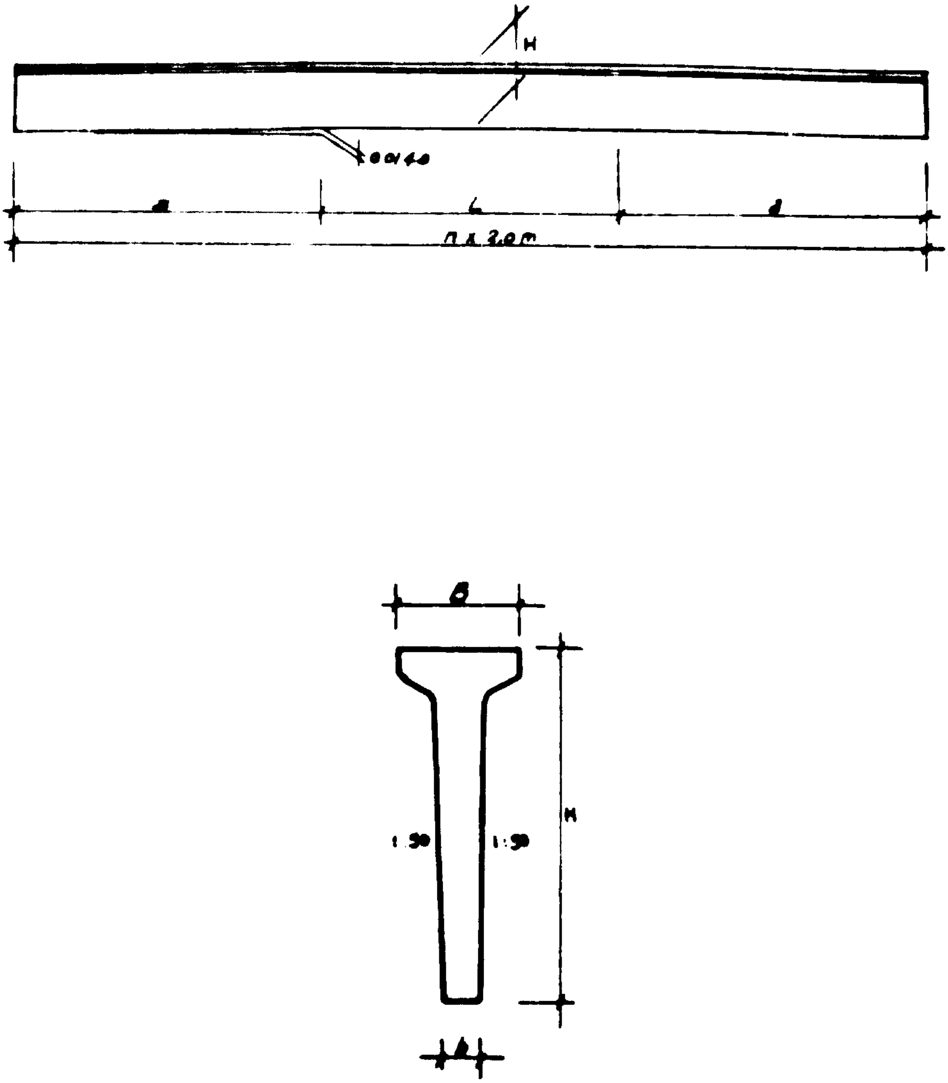
The economics of this system change substantially, once they are considered for educational and industrial buildings which usually require very large open spans. In this case, post and beam systems can be used to their fullest advantage: beams spanning 100' or more are cast in the factory, and erected on site in a very similar way to steel structures (see Figure 3). Conventional building methods cannot compete, principally because of the excessive cost of the extensive form falsework required.

B. Panel Systems: This is the most widely used system in both Western and Eastern Europe (see Figure 4). The subdivision into light and heavy panels is essential, as they differ in their economical applications. Structurally, one distinguishes three design configurations:

Longitudinal: The exterior walls are the only bearing elements. When the width of the building exceeds a limit, to be economically determined, another line of bearing walls is placed in the middle. The maximum spacing normally depends on design requirements, and in most cases, the economics of production are the constraints on maximum free span. The average length of slabs in the USA, as reported by the Prestressed Concrete Institute Survey is 30 feet. For larger spans, one might consider prestressed hollow slabs. Even then, one seldom finds elements longer than 40-45'.

FIGURE 3

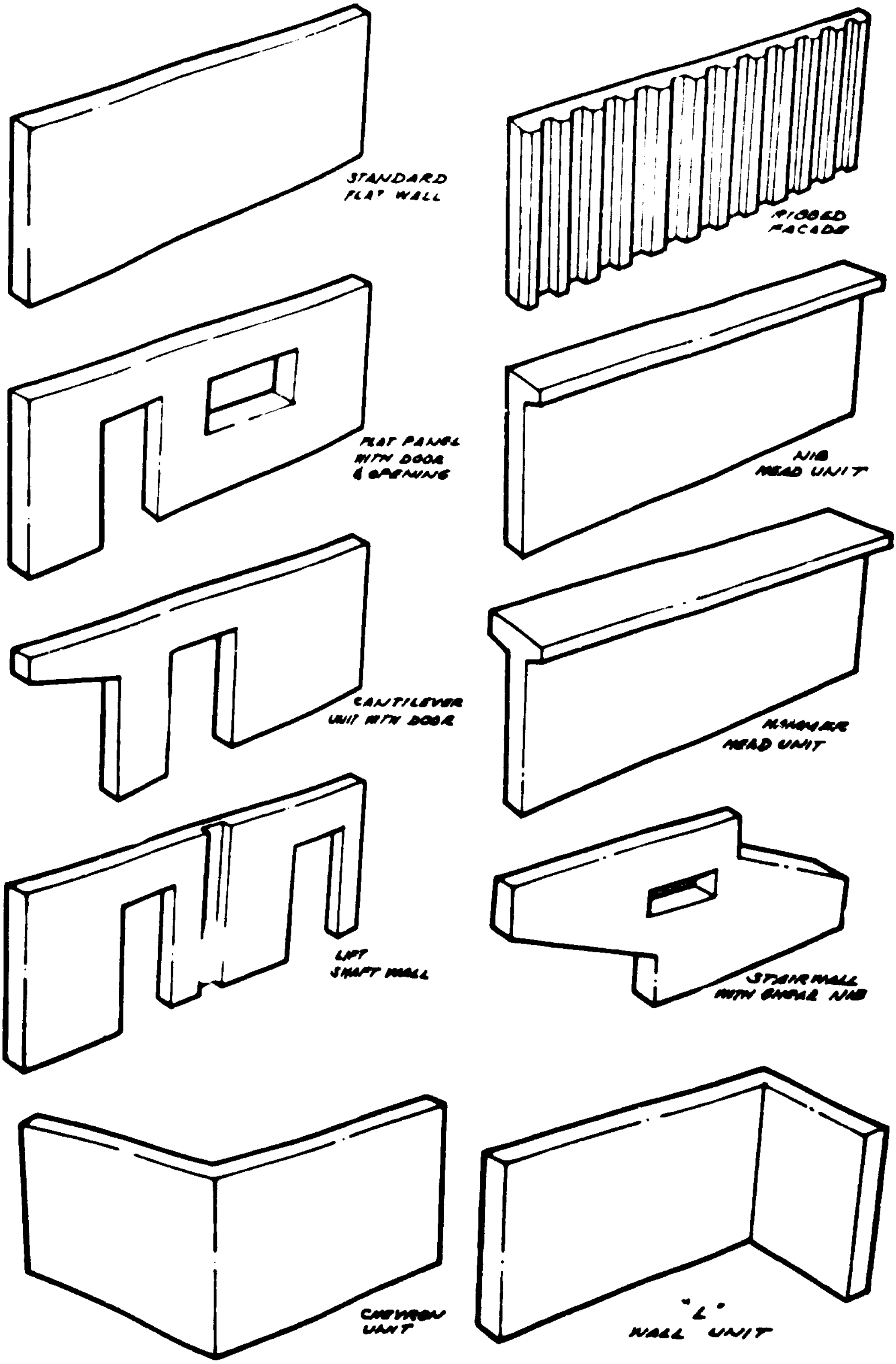
"ULTO" BEAM , SWEDEN



Source : Skanska Cementjuteriet,Malmö

FIGURE 4

TYPICAL PRECAST PANELS



Both Ways: Under this configuration, all the wall panels are bearing. This reduces the steel reinforcement required in the floor slabs and the rigidity of the structure is high in both directions. While this type of system proves very useful for housing structures, it restricts seriously the possibility of designing large open space, due to the limitation of slab dimensions.

Transverse Systems: This configuration is favored in the USA, as offering a higher flexibility in the design. Room dimensions may vary, and the spacing may be designed in such a way as to form apartment units. The transverse rigidity is maintained, while the longitudinal rigidity is normally attained by the sheer length of the building, independent of the presence of bearing walls.

Technology of Construction: The size and weight of the panel elements provides several techno-economic trade-offs which should be carefully analyzed in the selection of a system. The production process of both types is similar in the factory, with the important exception that heavy elements require more powerful handling equipment (cranes, hoists), hence a higher investment. As far as their transportation is concerned: For the same gross load, typically 30 tons, one may haul 15 or 20 light panels, vs. 2 to 4 heavy elements. Presumably, the total floor area covered is the same per load but loading and unloading times vary. Light panels do not require powerful cranes for their erection. They are also put in place more rapidly, hence immobilize the crane for a lesser time between each loading cycle. Nevertheless, lifting 15 or 20 elements takes normally more time than lifting 2 or 4, and the added cost of heavier cranes is more than offset by the reduction in erection time. Thus, heavy panels appear to be more economical.

In terms of the required connections: the higher the number of elements, the higher the number of joints and connections required. This is a disadvantage it two ways: it provides less continuity in the structure, and more possibilities of leakage or infiltration through imperfect joints. It also requires more labor on the site.

There are numerous methods of producing panel elements; they depend on the type of panel, the scale of output desired and the cost of manpower.

To increase the turnover of precasting molds, panel elements go through an accelerated hardening process (steam curing or other), and are stocked in the yard to reach their full strength. Handling these elements at the early stage requires certain care to avoid warping, cracking, or chipping of the elements.

Elements are usually erected with cranes. A variety of devices are used to avoid excessive stresses not designed for.

C. Box Systems: One further step in the concept of total prefabrication is the box--or volumetric--system. Buildings are thus designed as a stacking of volumetric elements--so-called modules. The idea behind such a system is that a larger part of the construction can be performed under factory conditions: plumbing fixtures, electrical outlets, sanitary and kitchen equipment, wall surfacing could all be installed in the plant, thus requiring a minimal amount of work on site.

This method encounters many obstacles; some are technical, such as the excessive weight of the modules, which creates problems in the handling and erecting operations:

- Within the plant, powerful, thus expensive cranes are required to move the boxes out of the production area to the stockyard.
- Road transportation is problematic: Expensive tractors of very large capacity (100 tons) are needed to haul the units. As the boxes exceed permissible dimensions on the road, special authorization from the police is necessary. Additionally, an escort must be provided, and both the itinerary and the driving hours are severely restricted.

- Very powerful cranes are needed on the site for the lifting operations.

Other problems are architectural: Stacking boxes means doubling the thickness at adjacent walls. Also, this arrangement provides little flexibility in layout. Other solutions, such as staggered box systems whereby one additional room space is provided by the exterior of four boxes require on site finishing for these "bonus" spaces, thus cancelling a good part of the advantages derived from complete finishing in the plant.

Nevertheless, the development of new lightweight concretes has allowed the reduction of box weights from 90 tons (Habitat, Montreal, 1966) to 11-15 tons (Richard Allen Villa, San Antonio, 1968).

Technology and Production: Precast concrete boxes are produced in vertical steel molds. The outer dimensions are generally fixed, while the inner plates can move to allow for varying wall thicknesses.

Reinforcement mesh is placed vertically, as in battery forms, with all ducts and inserts welded to it.

After pouring concrete and vibrating, the element is cured, and stripped off its mold. It then goes along an assembly line, supported on specially designed wheel carts. There, all the finishing operations are performed: carpeting, wall painting, installation of electrical fixtures, and, in so-called wet-molds, installation of all the sanitary and kitchen facilities.

The box is finally wrapped in a heavy plastic cover, and shipped to the site, where all connections are made without even entering the module.

At the present time, there is no full size plant in the Western Hemisphere producing these volumetric elements on a large scale basis. Box units are very heavy, which makes their handling difficult. Limitations both in dimensions and weight make the use of box units on a mass production basis rather difficult.

In addition their erection requires expensive high capacity cranes. The lifting and securing operations are delicate, and the best rate achieved until now is 10 boxes per day (Palasio del Rio, San Antonio, 1968), with 4 to 6 units being more common. A decrease in the weight of the modules would in all probability make box systems a more attractive alternative.

For these reasons, fabricators have very much emphasized the precision of the manufacture of elements. Present standards usually require finished dimensions within 1/4" or less. In turn, this requires very rigid steel frames in the factory, with tolerances of no more than 1/16". This exacting precision is one of the reasons for the high cost of precasting molds.

2.2.2 Common Problems of Prefabrication

Stability: From the viewpoint of statics the above systems (especially panel and frame systems) raise special problems by reason of the joints and other factors affecting continuity. The problem of overall stability in a prefabricated structure is that of the interaction of all components. The three generally accepted ways of obtaining stability are: (1) by means of columns fixed in or onto the foundations; (2) with the aid of frames; and (3) through slabs of shear walls.

The general construction scheme for low-rise buildings such as factories, etc. consists essentially of columns supporting a roof. The stability is derived here from the columns which are fixed in or onto the foundation. In multi-storey buildings, however, stability can be obtained by means of frames, shear walls, and floor slabs connected to the stiff cores of the building such as staircases and elevator shafts.

It is rather difficult to obtain a high stiffness by simply connecting th prefabricated members at the joints. At these connecting points the lack of space limits the possibilities of making good connections, especially when the forces to be absorbed are rather high. The usual techniques used in joints are as follows:

To solve shear and tension problems welding or strengthening of the joints by other means is used. Shear keys may be effective if the cracks formed by shrinkage are not too wide. Alternatively, post tensioning may be used to increase the friction in wall joints and thus increase the allowable shear stresses.

Tensile stresses can be supported in many ways. Generally, they are concentrated around wind bracing walls where the continuity in the tensile reinforcement can be established by welds, splices, loops, bolts, cables, etc. The problem is to find a solution which allows easy production, erection, forming, finishing and control.

Finally, the problems of stability during erection are of interest. It is important to consider the situation of each member during the whole process from the moment it is manufactured until the building is on its final state. Means for fixing auxiliary connectors, or temporary stiffness should be installed when manufacturing the elements and should therefore be considered at the design stage.

Connections and Joints: The problem of connections and joints is a feature of all precast systems. "Whoever has mastered jointing techniques has mastered system building".* Joints and connections perform different functions:

- Accomodate changes in the dimensions of structural components or differential settlements.
- Keep water and wind out of the interior.
- Provide a good thermal insulation.

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*Schmid, T., and Testa, C., "Systems Building", New York: F.A. Praeger, 1969.

- Sustain and transfer loads due to shear and torsion.
- Allow for limited movement of element, under creep, shrinkage or temperature differential.

There are two classes of joints; open and closed:

Closed: The closed joint is formed by sealing the open space between two components with some elastic material (epoxy, mortar, rubber-based plastics, etc.). The elasticity is required to maintain the watertightness even when there is a settlement or a displacement of the components. This often has created problems, and the tendency nowadays is to prefer open joints.

Open: Open joint design is based on the concept that wind along an elevation loses its pressure if it passes over a balloon-like hollow space, the decompression chamber. It has been shown, in fact, that with this kind of arrangement, driving rain can never get past the decompression chamber into the interior of the building. A typical joint arrangement is shown in Figure 5.

Connections: Connections serve structural purposes. Depending on their function, they may be rigid, hinged, or semi-rigid.

The choice of a connection type will thus depend on the load it must transfer and the type of member it connects. Designer of building systems have devoted much attention to the problem, and come up with a wide variety of solutions (see Figure 6).

Standardization: The degree of standardization is a vital question to be faced by the precast concrete industry. Reducing the variety can help to increase the demand for a standard component, but it may conflict with the user's needs: the greater the reduction in the variety of components available, the less it is likely that a particular user's requirements can be completely satisfied. Thus, for industrialization to be successful in reducing the

FIGURE 5

ISOMETRIC VIEW OF PRECAST PANEL JOINT

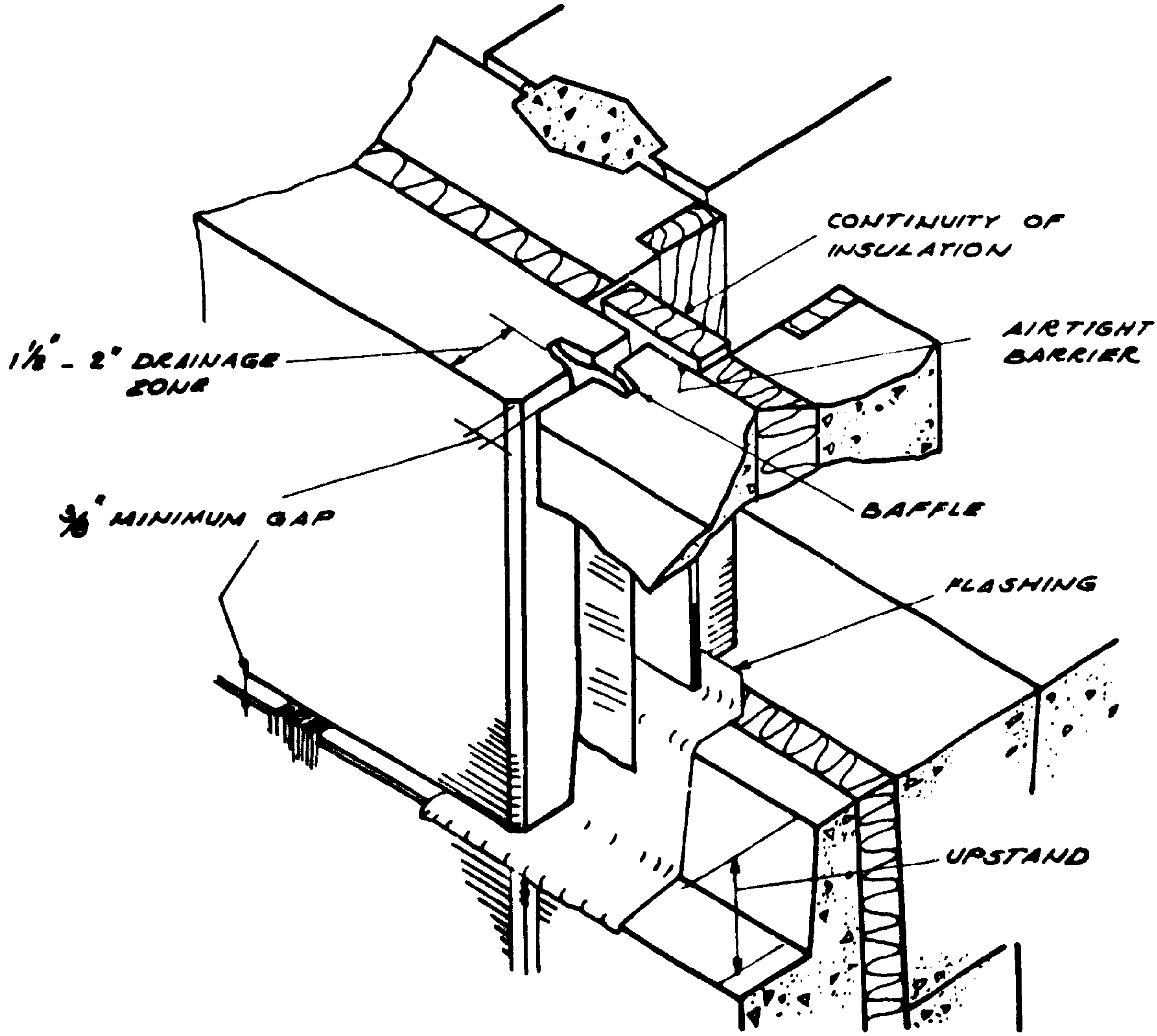
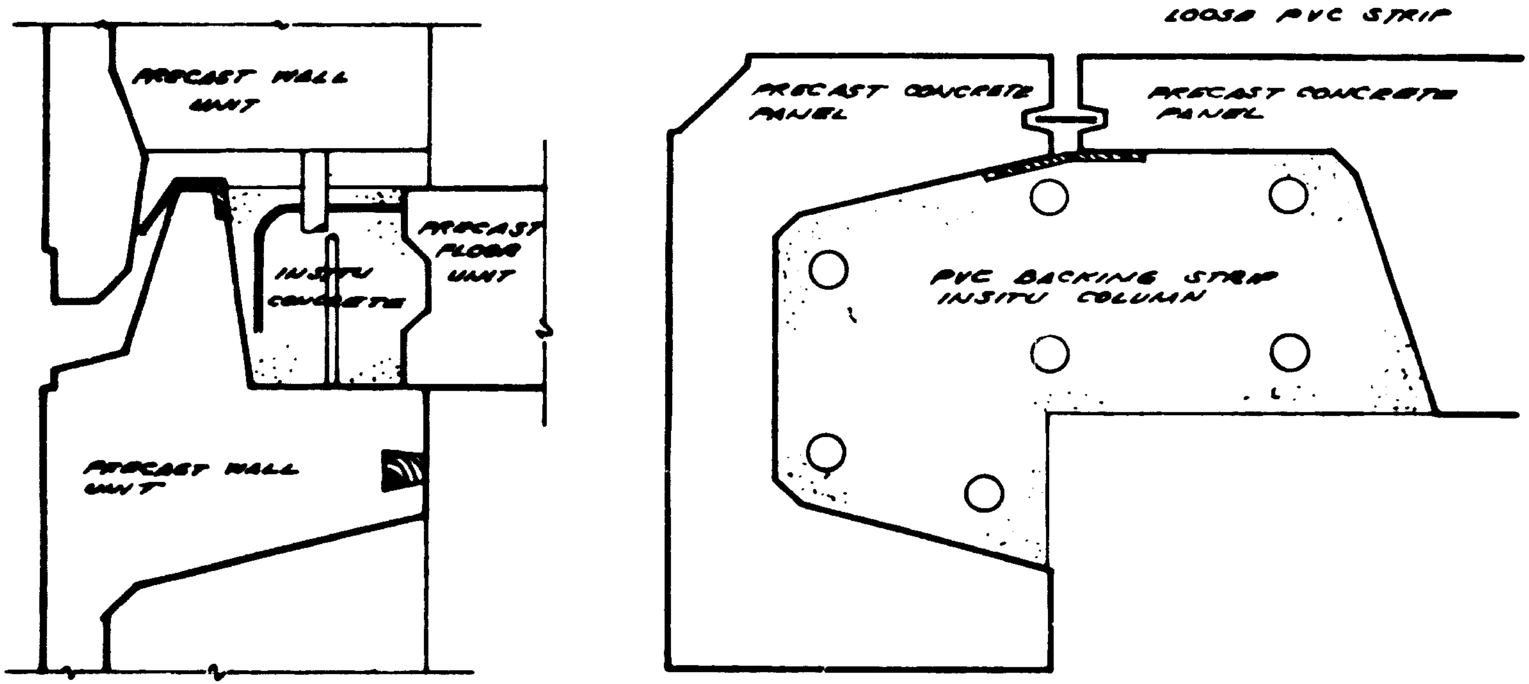


FIGURE 6

EXAMPLE OF PRECAST PANEL CONNECTION



costs of components, the number of components and their individual functions must be chosen so as to match, as far as possible, the range of conditions most frequently found.

Certain standardization is successfully adopted in Eastern Europe. Each piece of equipment and the sequence of operations are designed for a particular component. This has led to the introduction of an automated process giving high productivity and a very high output.

Dimensional Coordination: Dimensional coordination is a system that reduces the dimensions of all building components, and of buildings themselves, to multiples of one basic dimensional unit--the basic module. It is a crucial point that a basic module is devised and that the same basic module is widely accepted, especially for open systems. The module must be small enough to provide the necessary flexibility in design, but large enough to promote simplification in the number of sizes for various components.

Tolerances: In prefabricated construction it is necessary to make allowance in design for the inaccuracies that occur during manufacture and construction. Therefore, specifications on dimensional tolerances are necessary. Allowable tolerances are based on experience and there is a great need for information on the sources of inaccuracy and how accuracy can be controlled, and on the relationship between the accuracy achieved and the cost of achieving it.

III. PRODUCTION FACILITIES

Just as the various building systems and their components vary widely, their production processes are very different. The precast plant can range in size from small to large, and in sophistication from the manual production of beams and columns in outdoor plants to the manufacture of complete housing modules in an enclosed and highly automated factory. As a general rule, heavy construction plants (e.g., precast concrete plants) tend to be rather extensive and costly. In the production of basic materials and components showing a relatively low degree of prefinishing, conventional building machines can often be used, resulting in a decrease in plant costs. Components produced with a high degree of prefinishing, however, often require new types of machinery and more automatic production systems in order to be efficient. This, in turn, requires a higher initial investment. Plants may also choose to specialize in the production of only certain types of units, or they may be general purpose plants suitable for producing a variety of types of components. A certain degree of specialization is good in the plant in that it increases productivity and decreases production costs, but it is not so good at the building site where the contractor must coordinate the deliveries of various components from different factories to the site according to the erection schedule. Because this often poses serious problems, it may be preferable to establish large factories in which the various components can all be produced and shipped to the site in order and on schedule. The choice among all of these variations in basic precast plant design depends upon several factors, including projected useful life of the plant, type or types of units the plant intends to manufacture, number of units the plant intends to produce in order to meet the market demand, availability of money, and so on.

3.1 Alternative Production Procedures

The concept of a factory involves two basic production alternatives: (1) assembly point configuration and (2) assembly tree configuration.*

In the first alternative, equipment, labor, and materials move from one stationary building component under construction to the next. This approach is similar to conventional, on-site construction, except that it takes place in a factory setting. Each component is assembled in a separate area and moved only once it is completely built and ready to be shipped to the site. This type of configuration is practical only when the components vary considerably in design. It may be useful in small factories or in factories which, for some reason, require a labor intensive rather than capital intensive investment, but, at the same time, it provides little impetus to the construction workers to meet a production schedule because it is never immediately obvious to the workers that they have a backed-up queue of items awaiting processing. Furthermore, it is a highly inefficient methodology, making planning and control of production nearly impossible and completely excluding the possibility of a high level of mechanization.

The second configuration, the assembly tree, is patterned after a standard assembly line process in existence in most manufacturing plants today. The building elements move along an assembly line, and at each point along the way some part is attached to the element until the building component is complete and ready for installation. One ofthe problems with this process is that the rate at which an item progresses down the assembly line is highly dependent on what is happening to the items ahead of it. Thus, the efficiency of the whole process can be destroyed by improper allocation of men, machines, or

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*Zalewski, M.H., and Silberstang, S.D., "Design of Factories for Housing Modules," M.I.T. Department of Civil Engineering Report No. R71-9, Cambridge, Massachusetts, February 1971.

materials to any one assembly point. Similarly, each of the steps along the assembly line must take about the same amount of time in order to avoid back-ups and delays. In order to make such an operation profitable, a steady demand for large lots of similar components is required. This tree configuration has many good points as well. Since it is the components that move and since each step along the assembly line consists of a small number of repetitive tasks, the process lends itself to a high degree of mechanization and the use of less skilled labor. Pressure to maintain the steady flow rate is felt by all workers, and the production process is considerably easier to control than the previous one because it is more structured.

3.2 Production Technology

The optimum degree of automation and mechanization in the factory is of vital importance. In general, the more highly capital-intensive the technology the higher the level of output required to reach the break-even point. Therefore, before the market is secured, only centrally planned economies can afford the development of technologically up-to-date factories.

New technologies have been recently developed, such as extensive use of electrically powered equipment or new concrete heating techniques which assist in producing more complicated and serviceable components at little or no increase in cost.

Also, the development of computer controls will affect the cost of industrialized buildings. In several highly concentrated industries, such as the cement industry for example, computer controls have already been developed at all stages of production. Danish experience suggests that it may be possible by means of an automated control system in a large prefabricated plant, to produce and handle a large range of components at low cost for substantial production runs.

Although many firms attempt to maximize their profits by combining their available resources in such a way that the lowest cost is achieved, certain complications still persist. For example, industrialized building has concentrated principally on prefabrication of components comprising the structural framework, thereby substantially reducing completion time. But establishment of an optimum sized factory for the production of concrete structural components involves only one important phase of the industrialized building process. These components, however, constitute only 25 to 30 percent of total building costs. The production of mechanical and utilities equipment and finishing components also needs to be industrialized, and each of these has its own optimum scale of production. Industrialization of mechanical and utilities equipment, which require relatively expensive materials and large amounts of skilled labor, may become as important in cost reduction as industrialization of the structural systems, which requires lower cost materials and semi-skilled labor. Thus, while the optimum partial prefabrication system <u>may</u> be more efficient than no prefabrication at all, it is certainly no substitute for an optimum total prefabrication system.

3.3 Plant Development

The development of a new precasting factory is essentially dependent on the potential share of the construction market it can serve. Therefore, the first step in the feasibility study for the development of such a plant is to establish the characteristics and the trends of the construction market, as well as its functional subdivisions, taking into account competition from other producers or conventional builders. This knowledge is required to decide whether the market can support a precasting plant; if so, what mix of products should be initially manufactured, and what would the expected rate of growth be.

The necessary data required to establish the above mentioned market information are:

- Construction demand broken down by class of buildings.
- Rate of growth of demand by each class.
- Share of the market using concrete as building material by each class of buildings.
- Rate of capture of the above market by proposed system building.
- Level of competition from conventional builders and from established precasting plants, in the market area and outside its limits.
- Potential precast market for the proposed plant.

The results of market analysis influence directly the size and location of the plant, and the technological sophistication used in the production processes. In this section the organization of a precasting plant, as regards layout, requirements in machinery and equipment, materials and auxiliary services will be briefly reviewed.*

3.3.1 Physical Aspects

Location: As a rule, the precasting plant should be located in such a way as to minimize; (a) the cost of raw materials supply, (b) the shipping costs of finished components to the building sites, and (c) the land requirements for plant operation. These constraints must be evaluated, bearing in mind the necessity of: railroad siding or proximity to a major highway, availability of land for further expansion, availability of utilities (electricity, water, sewage), and availability of labor.

Sophisticated algorithms have been developed, using operations research techniques, to solve such a multi-constraint problem in an optimal way.

General Layout: The basic considerations in the layout of a precasting plant are minimizing materials handling time, and reducing nonproductive labor

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*For a detailed discussion of market analysis for the precast industry see "Precast Concrete Plant Development", Volumes 1 and 2, by Fred Moavenzadeh, M.I.T. Civil Engineering Department Reports, 1972.

movements in the plant.

Use of a "straight-through" layout is preferred to L or U shaped configurations. It is always costlier to cause a 90 degree deviation of material flow, as this requires either an additional crane, or a transit loading-unloading platform, or sharply curved tracks for cranes. In addition, the various operations centers (concreting, steel bending, placing, curing, etc...) should be installed in such a way that each center's activities take place independently of other activities.

In order to facilitate handling operations without disrupting other operations a maximum clear span in the plant should be created. Finally, within economic constraints imposed by the situation, a technology which minimizes covered area requirements should be chosen; this cuts down on initial building cost, heating, ventilating costs, and idle time of worker's displacements in the plant. A typical actual layout illustrating these rules is shown in Figure 7.

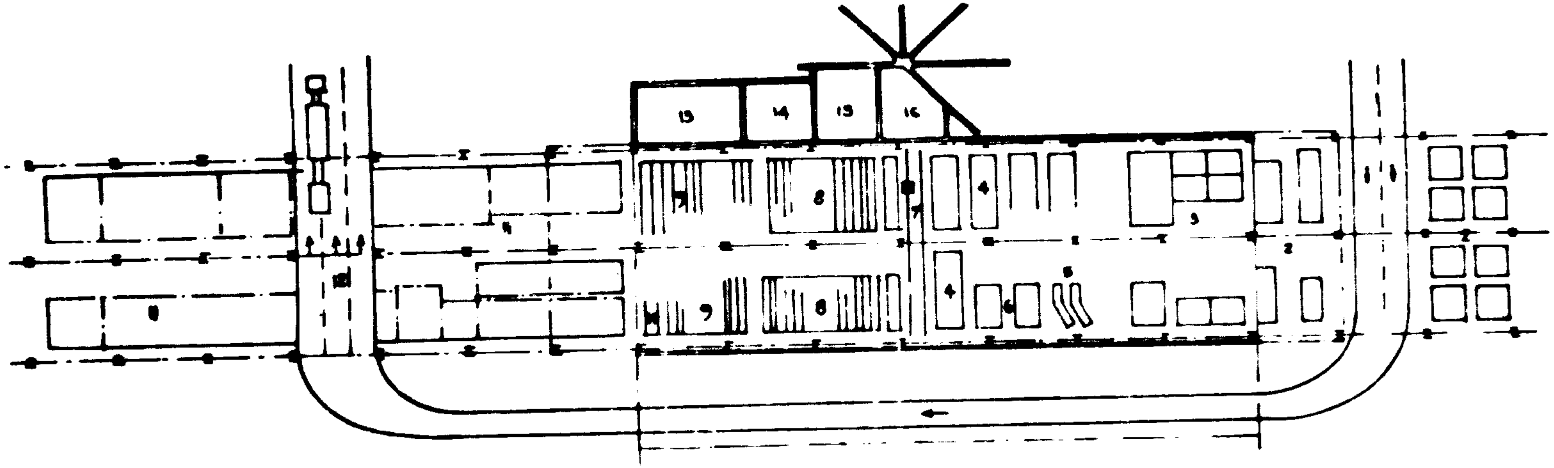
Storage Area: The design of the storage area is an important factor in the overall plant efficiency; cranes are usually expensive, and it is essential to utilize them fully, that is, maximize the number of lifting operations per day. One way of doing this is to reduce the cycle time for moving finished products from the plant to the stockyard, and back again.

This is done by allocating to the stockyard an additional crane, the function of which is to store finished components coming out of the plant, and load them on the trucks.

3.3.2 General Equipment Requirements

The various elements to be taken into consideration in the actual design of a plant are briefly reviewed in this section.

FIGURE 7



PLANT LAYOUT

FIGURE:

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 plant: 2 dwellings per day. Design: Authors' office. (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 hause, (15) compressor plant, (16) mixing plant

Source: Koncz, Tihamer, "Traite de la Prefabrication," Ed. Vander, Bruxelles, 1969.

Material Handling The handling of materials can be divided into three stages: production of concrete, production of components and handling of the finished products. To move materials in concrete production, use can be made of tractors, conveyors, draglines with buckets, monorails, rail tracks, or bridge cranes.

A variety of machinery is needed to perform the materials handling in the production areas: trucks, hoists and overhead cranes, to move steel mats, steel bars, miscellaneous formwork; these connect the steelshop and the joinery shop to the casting areas.

Another set of equipment, namely gantry cranes, and possibly rail-mounted or truck mounted cranes, are needed to move finished components to storage areas, as well as to load components on vehicles carrying these to the site. Additional equipment is needed to handle incoming supplies for both the steel- and woodshops.

In addition, other miscellaneous equipment is needed for general purpose operations. These include fork-lift trucks, dump trucks, small electric tractors, and a variety of carts and loading platforms.

Auxiliary Services: These include: a steelshop for the fabrication and maintenance of the steel molds. The shop also prepares all the reinforcement used in the casting operations. A joinery shop, for the fabrication of special forms with small run sizes, and the preparation of small inserts and embedding shapes. A laboratory, to test and control the quality of the raw materials, the characteristics of the concrete, and the strength of finished components. A boiler room, which provides steam for concrete curing. A maintenance shop, to repair and overhaul as much as possible of the plant equipment. An office area, to include administration and supervising personnel and a cafeteria and washroom facilities for the workers.

3.3.3 Panel Production Systems

They can be divided into three types

- Single production (stands, tilting tables)
- Batch production (battery, conveyor)
- Assembly line production (continuous movement on conveyor belt)

In all cases, a series of sequential operations must be performed (see Figure 8):

- Cleaning and lubrication of the mold
- Assembly of mold
- Installation of steel reinforcement and embedded parts
- Pouring of concrete, compaction and vibration
- Curing
- Disassembly of mold
- Removal of element to storage area

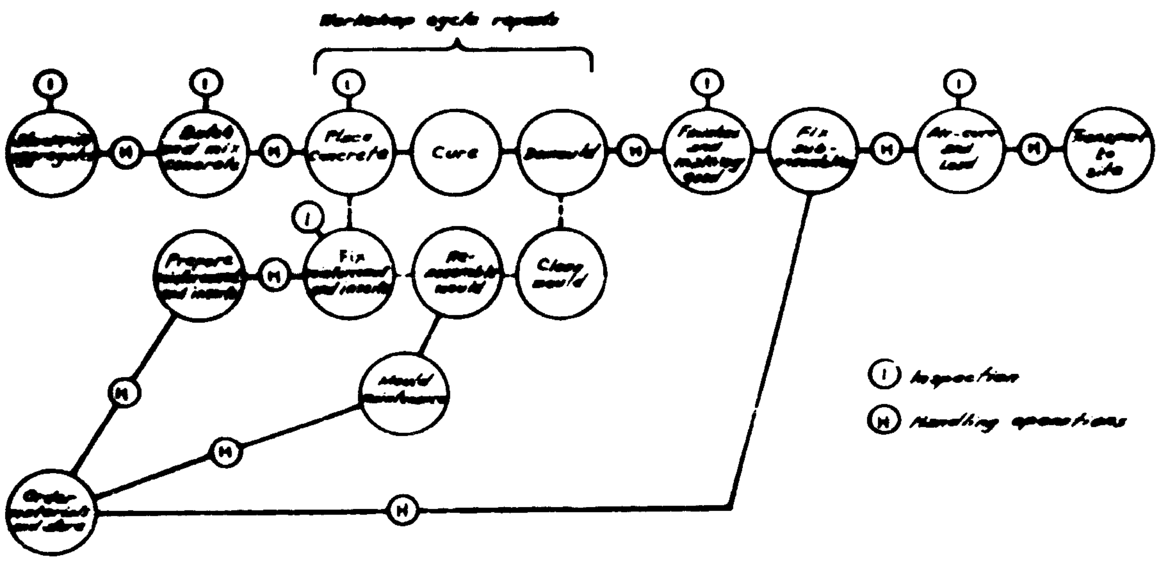
Single Production: This is characterized by the use of a stand, or a series of stands. All operations are performed in a single place by different teams of workers in a predetermined sequential order.

This method is labor intensive, and requires skilled manpower if high quality and speed are to be achieved. It is mainly used for small-scale production, or for the casting of special types of facade elements, which have architectural facings requiring care and skill to produce a good finish. It is also used for the production of sandwich elements containing plumbing and heatin fixtures or insulation materials.

Batch Production: A battery form is a special steel assembly which allows the simultaneous casting of several elements. It has been commonly used for both on-site and off-site operations. A typical battery form is shown on Figure 9. It consists of a series of vertical steel plates; the number of cells depends on the required output, with the usual values between 6 and 10.

FIGURE 8

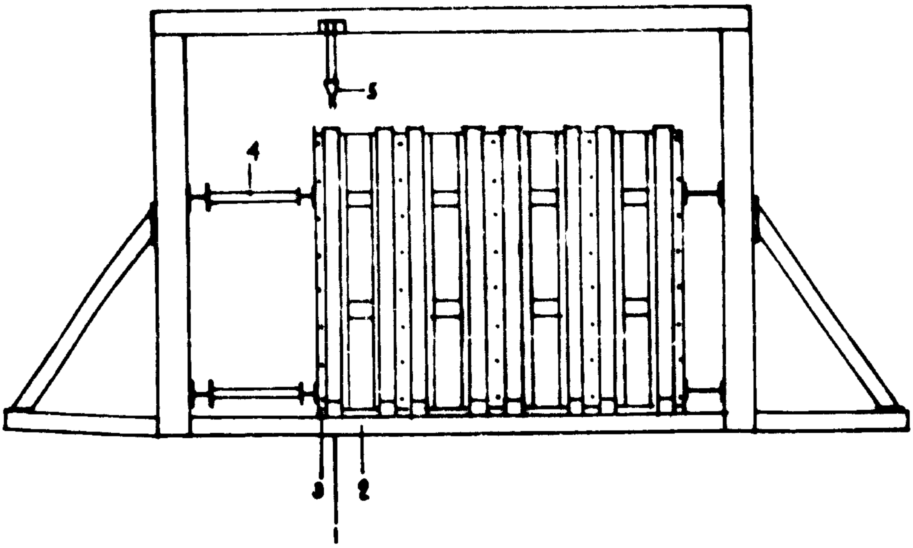
SEQUENCE OF OPERATIONS; PRECAST PANEL PRODUCTION



Source: Bishop, D., "The Economics of Industrialized Housing," Design Series 5A, Building Research Station, Garston, U.K.

FIGURE 9

Cross-section through a battery mould with heating elements and vibrating elements: the latter are each equipped with five high-frequency vibrators:
(1) frame, (2) vibrating element, (3) heating element, (4) hydraulically powered thrust props for pushing the various parts of the mould together, (5) pulley block for assembling the mould (mould type M A N and others)



Source: Koncz, Tihamer, "Traite de la Prefabrication," Ed. Vander, Bruxelles, 1969.

The advantage of battery is that concrete elements are automatically molded into their final shape; moreover, the surface finish is perfectly smooth, and does not require any further grinding or polishing. Wallpaper or paint can be applied directly, thereby eliminating plastering operations. Also, in the case of walls, since they are poured in a vertical position, an economy of 10-20% on steel is realized on the reinforcement.

Care has to be taken in the design of the steel plates. They must have a very high rigidity, otherwise, unequal quantities of concrete in two adjacent cells will develop substantial stresses, bending or warping the plate surface. This would result in twisted elements, warped surfaces, cracks and chipping at the corners. The major difficulty with the technique is lack of flexibility to manufacture panels of different dimensions and with various inserts (doors and windows, etc.).

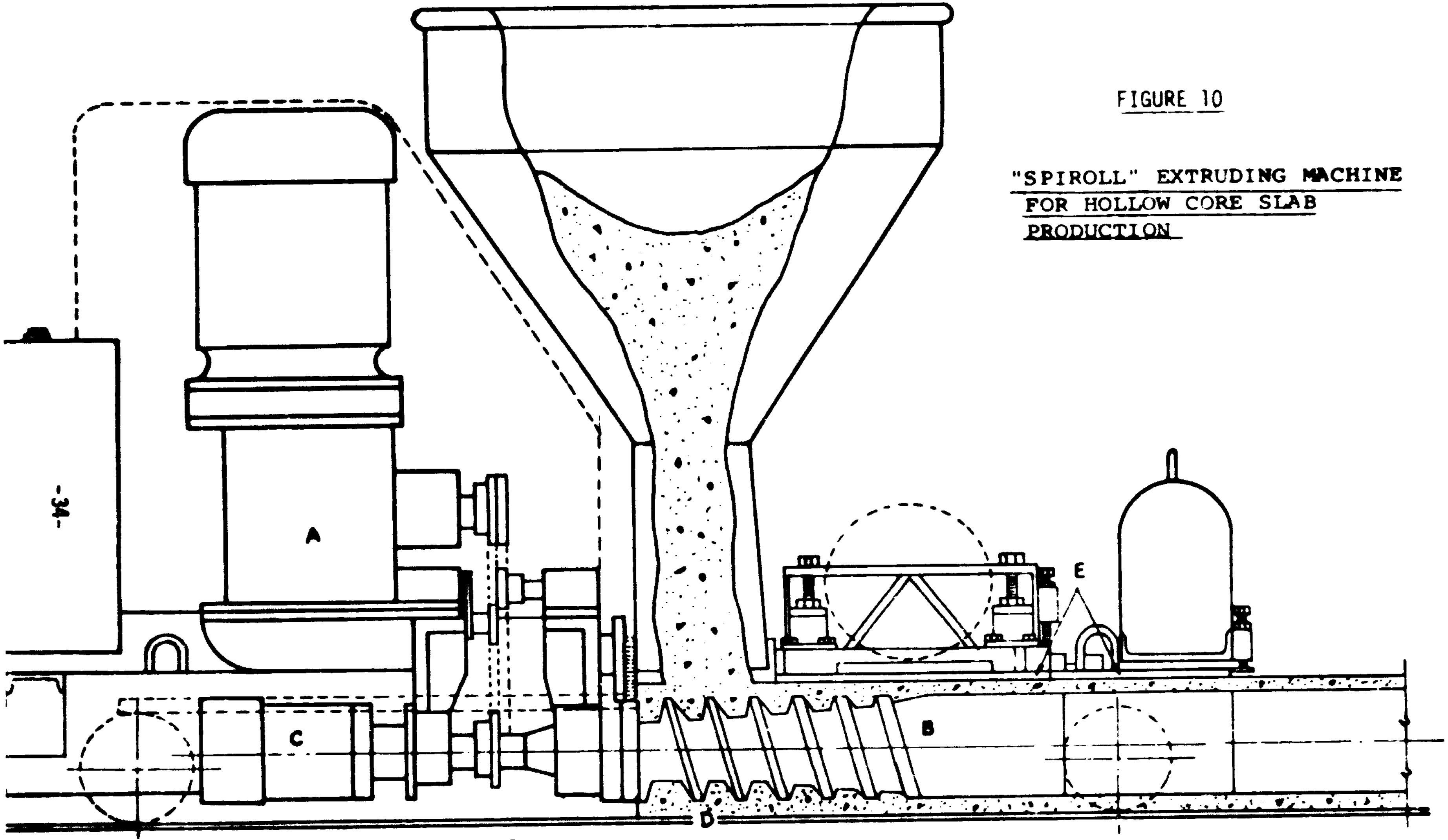
Hollow-Core Slab Extrusion: This system is a variation of the assembly line system, whereby casting operations are performed in a continuous sequence. Narrow slabs (2' to 8') are produced on long casting beds; the slabs have a series of hollow extrusions, round or oval, which result in a light weight element versatile in usage. The machine is illustrated in Figure 10. Their casting beds are between 400' to 600' long and the extrusion equipment is of a very high capacity.

Conveyor Systems: These systems can be either semi-continuous or fully continuous:

Semi-Continuous Pallet Line: In this method, concrete panels are cast on individual pallets, which move from station to station for each set of operations--that is the gangs of workers are assigned fixed positions--while the pallets are moved along the assembly line by an overhead crane, or, rarely, by roller mounted cards.

FIGURE 10

"SPIROLL" EXTRUDING MACHINE FOR HOLLOW CORE SLAB PRODUCTION



Source: Spiroll Ltd-Canada

Continuous Moving Conveyors: This method is the most automated technique for concrete production. One of the best examples is the vibro-rolling mill of Kozlov (USSR). The process comprises the following operations:

- Placing reinforcement
- Preparing concrete mixture
- Placing and thickening of the concrete mixture
- Calibration of the products
- Head treatment
- Removal of the members from the molding band.

The metallic molding band is stretched on the sprocket wheels of two drums, moving at a constant speed of about 30 meters per hour. Fixed raised metal molds, in the form of square hollow shapers are fixed on its surface, to permit the casting of ribbed elements.

Concrete is fed with a screw machine, and vibrated and compacted by a vibrating beam placed under the mold. A screen levels the concrete, which is then compacted by rollers under a pressure of up to 700 psi. The band then passes in a continuous steam curing tunnel; the element is then automatically lifted out and tilted up in a vertical position, ready for stockyard storage.

Technical aspects of the model are shown on Table 1.

3.3.4 Curing Methods

Curing is the process by which fresh concrete acquires its strength. As precast plants reuqire a high turnover of all the molds to achieve efficient productivity, curing methods hold a very significant role in the overall cycle time of production.

The three curing methods commonly used are: free air curing, temperature curing and vacuum curing.

TABLE 1

TECHNICAL CHARACTERISTIC OF VIBRO-ROLLING INSTALLATION WITH THE PPS-6 TYPE ROLLING MILL

Average operating speed of the moulding band	30	meters per hour
Maximum speed of the moulding band	60	meters per hour
Dimensions of the members manufactured:		
Width	up to 3,400	milli-metres
Length	up to 12,000	milli-metres
Thickness	from 20 to 350	milli-metres
Capacity of the vibro-rolling installation with the average width of concrete members	3	metres
Per hour	90	square metres
Per year (with the rolling mill efficiency 0.85)	480,000	square metres
Heat treatment time	2-3	hours
Dimensional sizes of the installation:		
Width (without drive)	5.0	metres
Length	94.3	metres
Height from floor level	3.56	metres
Total power of the installation electromotors	60	kilowatts
Total number of the operators	5	persons

Source: United Nations, "Report of the Workshop on Organizational and Technical Measures for the Development of Building Materials Industry", Moscow, U.S.S.R., 25 Sept.-18 Oct., 1968. ST/TAO/SER. C/123

Free Air Curing: This is the slowest method of the three. Concrete is allowed to harden under ambient temperature conditions. Whereas it normally requires a week or so to reach 50-60% of its final strength, the use of high-early cement achieves sufficient strength in an overnight period to 12 hours, to allow removal of finished elements.

Temperature Curing: This process is further broken down according to level of temperature and pressure in the curing enclosure, and means used to achieve these temperatures. They include: atmospheric curing, which may be done using steam, hot water or hot oil, or electric heating.

Autoclave Curing: This is a variant of steam curing, where the elements are cured by high pressure steam. The process is mainly used in the production of concrete blocks, but is also used successfully for precast elements. A special hermetic chamber is required, as steam pressure rises to 150 psiq, and therefore pressure losses must be avoided. This system is seldom if ever used for large dimensions.

Vacuum Curing: This is an extremely efficient system for panel curing. Here, concrete is mixed with sufficient water so as to fill completely the form when vibrated. Vacuum is then applied, which squeezes out all excess water not required for cement hydration.

The vacuum is applied by a pump connected to a vacuum mat, covering the mold under a 500 mm vacuum. The process is effective up to a depth of 30 cm, and produces marked advantages over any other curing process.

The concrete mix used must be plastic, to allow the removal of excess water without decreasing its strength characteristics.

3.3.5 Delivery, Storage and Transportation of Raw Materials

The proper utilization of a plant producing precast elements depends in a measurable extent upon the efficiency of handling and storing raw materials.

This is usually one of the most labor consuming operations and thus must receive proper care from the outset, at the design stage.

In line with the concept of minimizing materials handling, care must be taken to properly design the layout for aggregate storage. Due to the different qualities of concrete, and the various architectural finishes for facades, the plant will have a stock of a wide variety of aggregates, for which separate storage areas should be provided.

Normally, there will be a main storage area, into which incoming supplies are dumped. Following this, the concrete plant itself has a set of 3 to 8 storage bins from which aggregates are fed directly to the batching reservoir. Two problems arise in the process:

a) Transit Handling: Layout must be such as to minimize the cost of moving the aggregates from the main storage area to the mixing plant.

b) Winter Conditions: In prolonged periods of cold weather, and where snowfall is not uncommon, a special heating system must be installed to fulfill two functions; break up chunks of aggregates which impede the normal operation of conveyors and heat the aggregates to arrive at the required concrete temperature of 60 to 70 degrees Fahrenheit.

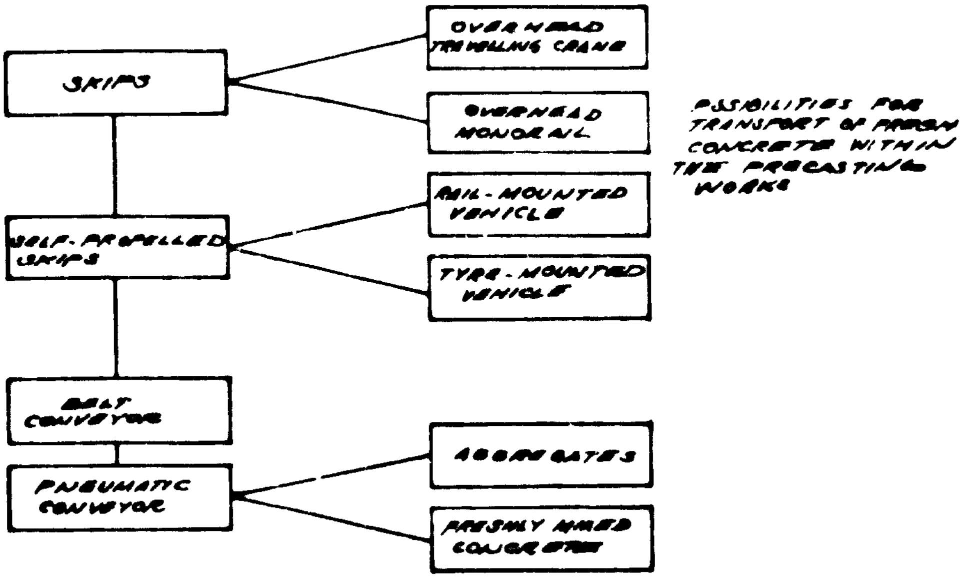
Delivery of Fresh Concrete: A precasting plant receives its fresh concrete supply in either of two ways; ready-mix, supplied by special trucks from outsiders, or mixed in-plant, at the mixing plant. We shall dwell on the latter case, as the former is seldom encountered in any sizeable plant.

Figure 11 shows the different possibilities for in-plant concrete transport. The choice of a system will depend basically on the rate of delivery required and on the distance to travel.

Storage Elements: The plant must store its production before shipping to the sites because of technical and operational constraints. Components just removed from the casting area have not yet acquired their full strength,

FIGURE 11

METHODS FOR IN-PLANT DELIVERY OF FRESH CONCRETE



Source: Koncz, Tihamer, "Traite de la Prefabrication," Ed. Vander, Bruxelles, 1969.

as curing is incomplete. An additional curing period of 10 to 15 days is normally recommended. This also allows the shrinkage effect of concrete to take place, and consequently reduces the problem of dimension tolerances for on-site erection and fittings. In addition, depending on the rate of erection, the number of projects simultaneously contracted, and the variations in the production volume, the plant must have a buffer of finished elements to ensure continuous operations on the site. This is especially true with the daily erection rate on all jobs exceeds the daily output capacity of the plant.

Thus, the storage area should be designed for a minimum of two or three weeks of production. Where climatic conditions create unfavorable construction cycles with high volume peaks, the supply period should probably be extended to six or eight weeks. The cost of working capital of the plant is thereby increased, but its ability to meet supply schedules is also improved.

The way elements are stored depends mainly on their structural function, and must be studied carefully if warping or other damage is to be avoided.

Vertical elements, such as facades, interior walls, partitions, are stored in the vertical position. The advantages are lesser space requirements, and lesser exposure to sun rays, hence lesser risks of damage due to temperature differentials between both faces of the element.

Horizontal slabs and floor panels are usually stored horizontally, or in stacks. The number of superposed elements, and their spacing are determined as a function of the type of bearing ground, the elements' weight, and handling methods.

Dispatching Equipment: There is no steadfast rule for the choice of the handling equipment; volume of output, layout configuration, and land availability are influential factors. The nature of the elements might also dictate the choice; very long elements cannot be handled in the same way as small panels for obvious reasons. In general, one can state that, for annual volumes below 10-15,000 cubic yards, a single tower crane mounted on rails represents the most economical solution. For higher annual outputs, overhead travelling cranes are the rule, often combined with the use of a tower crane. The layout in Figure 7 illustrates this point.

Two types of elements require special handling equipment, long columns or beams and hollow-core slabs. The latter are not equipped with lifting hooks, and must be handled either by vacuum pads or by fork-lifts with a special attachment to handle extra-lengths. The former are carried by a combination of two travelling cranes operating in tandem, or by similar equipment tyre mounted.

3.3.6 Productivity

The productivity of a production is a function of its cycle time, defined as the time required to complete the full sequence of production operations. The higher the output per unit time the higher the productivity.

In general, one can distinguish five phases in the process:

- Preparing the molds
- Placing the reinforcement
- Concreting operations
- Curing
- Removing

The time characteristics of each phase depends primarily on the technology used, but also on the sizes and shapes of the components produced. By increasing order of productivity, one finds the following techniques: single stand, battery, pallet conveyor, continuous casting.

The relative scale of output is indicated in Figures 12 and 13, and Table 2 demonstrates the scale of activities for various production techniques. Curing methods affect (within each technique) the scale of output. Curing is generally the slowest phase in the production. Evidently, other constraints such as capital cost and labor, skill and wage level do affect the size of output in each location. Nevertheless, one can define ranges of output for which one of the methods produces more economical results for a given set of conditions than others.

Therefore, the determination of minimum plant size can only be achieved when both the factors affecting plant production and the factors defining the market price of finished components are known.

Single Stands: Single stands are used for the production of the following elements: slabs, facades, and sandwich panels. All stands are rectangular shaped steel forms, mounted on a concrete pad. They are equipped with a hydraulic jack system to tilt up the finished element, and exterior-mounted synchronized vibrators for the compaction of the mix.

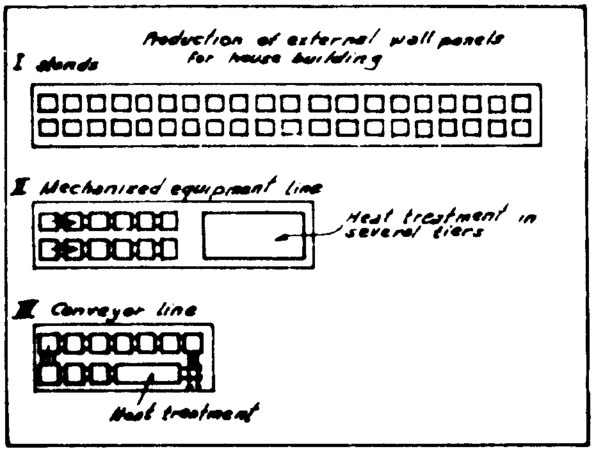
The stands are placed in line, with adequate spacing to allow provisional storage of embedded inserts, miscellanous steel bars, small tool shelves, and steel mats. Preferably, they all stand along a vehicle path; the tilting mechanism is placed in such a way as to lift the finished element towards the inside, for easier access by the bridge crane.

All operations are performed in a single location, namely the mold. Gangs of workers move from one mold to the next according to the sequence of scheduled operations.

Battery Forms: Batteries are generally used to cast solid slabs and inner walls, as it is rather cumbersome to install embedments in a vertical

FIGURE 12

RELATIVE SCALE OF OUTPUT

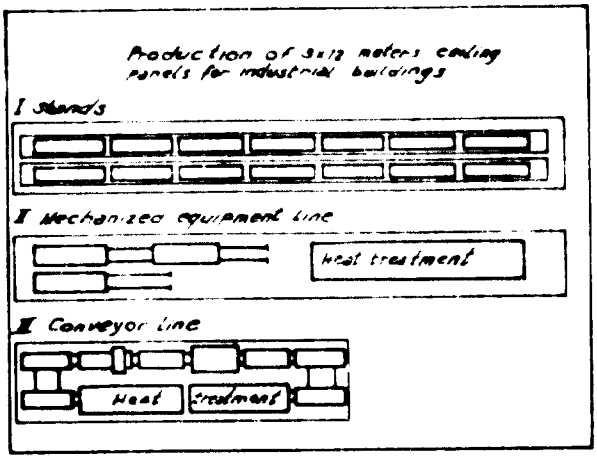


Ratings	I	II	III
1. Output per m^2 of production area in m^2 of articles per year	544	762	1500
2. Weight of equipment per m^2 of article in Kg.	0.7	0.9	1.0
3. Output per worker in m^2 of articles per year	1530	2780	7000

Source: Towards Industrialized Building: Proceedings of the Third CIB Congress, Copenhagen, 1965.

FIGURE 13

RELATIVE SCALE OF OUTPUT



Ratings	I	II	III
1 Output per m² of production area in m³ of precast reinforced concrete	12.4	13.0	18.0
2 Weight of equipment per m³ of precast reinforced concrete in kg	40.9	29.1	8.5
3 Output per worker in m³ of precast reinforced concrete	[illegible]	[illegible]	2000

Source: Towards Industrialized Building: Proceedings of the Third CIB Congress, Copenhagen, 1965.

TABLE 2

SCALE OF ACTIVITY

Method	Cycle	Normalized Scale
Site casting	weekly	1
Temporary factory	daily	6
Permanent factory		
steam curing	8 hours	15
continuous kiln	4 hours	30
continuous casting	2 1/2 hours	48
pressing	10 minutes	720

position. The main advantages of the process are low area requirements, and the production of smooth surface elements onto which wallpaper may be directly applied.

The vertical battery consists of: a scaffolding structure, which supports the individual cells; one or two rigid end plates; a series of movable intermediate casting plates, the sides of which are hinged to allow for dimensional adjustments; their position is controlled by hydraulic jacks; a set of rails with guide shoes to displace the bottom of the walls, and optionally, a steam curing installation (or hot water) embedded in the vertical steel plates.

The production cycle consists of separating the vertical plates, cleaning and oiling the inner sides of the plates; placing reinforcement, spacers, ducts, pipes, inserts; resetting the walls to required thickness; pouring concrete; setting on the external vibrators clamped on the battery; curing, striking off the molds with an overhead crane; and removing finished elements to the stockyard.

When compared to single stand production, battery forms have higher productivity, since non-productive time during a cycle is much lower in the battery process.

Cleaning and oiling go faster in the single stand process, because the working area is not confined. But the time-consuming finishing operations, that is, grinding the hardened element to a smooth level surface, more than offsets these gains. Because of its very compact shape, an eight-cell battery form requires 1/10 to 1/12 the equivalent factory area for single stand molds. This achieves substantial economies both in building costs and in plant heating costs.

Hollow-Core Slab Production: Hollow-core slabs are versatile in the end-use, as they can combine with many concrete building systems, or be used as floors to steel-framed structures--they are also very light when compared to solid slabs. One single manufacturing machine can produce up to 100,000 square meters annually, working a normal daily eight-hour cycle.

Hollow core slabs are produced on very long casting beds by a special machine, the extruder, which performs all the concreting operations (casting, forming, vibrating, compacting). Reinforcement, in the form of prestressing strands, is positioned over the bed and stressed, using hydraulic jacks, before the passage of the extruder. Cured elements are later sawn to the desired length and shipped to the stockyard.

The productivity of the hollow-core slab process is much higher than the battery and single stand processes. Given the significant capital investment associated with it (up to 1,000,000 dollars), it is essential to operate it at close to full capacity, if economic advantages are to be achieved through this production method.

Continuous Conveyor Process: This method is the adaptation of the single stand process to assembly-line methods. It achieves high productivity with very little flexibility, since one requires a different line for each type of panel.

Steel mold edges move at a constant rate (25-35 meters per hour) on a conveyor, and allthe production phases with the exception of steel placing are performed by machines. No accurate estimate of its productivity is available, and the Kozlov plant in Russia is reported to be manned by five men and produces annually 100,000 cubic meters of slabs on a line.

3.3.7 Auxiliary Services

Steel Shop: A precasting plant requires an iron-working shop to design and prepare all the reinforcement that goes into the concrete elements. Additionally, it must be equipped to handle most repair and maintenance work on the steel molds used in the production process.

Steel bars and steel mats are the two primary types of steel components entering the production of precast elements. As these in turn are produced in large runs--especially basic types of panels--it is not uncommon (in the U.S.A.) to find plants subcontracting some of their steel work to larger and better equipped specialized firms. Bars and mats are thus cut and bent according to specifications.

Since certain steel work can only be performed on the job, all precasting plants do have a steel shop. These shops are equipped with such typical machines as bar and mesh benders and cutters, steel grinders, welding equipment, and a variety of smaller tools.

Some of the points to consider when designing the steel shop areas are: easy access for the delivery of raw steel products; sufficient area to allow the assembly of long elements reinforcement; sufficient storage area for assembled cages; good layout coordination with in-plant facilities; for materials handling to minimize the transportation time from steel shop to casting bed.

Joinery Shop: Woodwork is an important element for the successful production of high-quality precast components. Wood is very often used to fabricate molds of special shapes with limited production runs (usually less than 40), and the design of these requires skill and attention if good dimensional accuracy is desired, as well as evenness in quality throughout the run. Wood is also needed for the fabrication of many inserts and embedded parts that go along with panels incorporating ooor or window openings, ducts, or other special projecting shapes.

In contrast with the steel shop activities, most of the woodwork is specialized and goes into specific jobs. Each insert, each form is normally custom-built according to the design drawings. Consequently, the joinery shop of a precasting plant must have all the facilities to produce a wide variety of products, and the investment in such a shop is quite high. Some of the pieces of equipment normally found in joinery shops are circular and rip saws, grinders, planers, drilling and boning machines, plus all the related hand operated tools.

The same consideration that applied to the steel shop layout also apply to layout of joinery shop. The woodshop can be more removed from the production area as it requires larger storage space for incoming raw materials.

Offices: For reasons of coordination, control and supervision, administrative quarters (i.e., design, management, sales) are best located at the plant. To minimize noise problems, offices are often located away from the production area.

Finishing Area: Once the elements have been cast, they must sometimes be subjected to further treatment; this includes:

- Grinding and polishing surfaces, architectural treatment, and correcting fabrication defaults.

The finishing area is normally located between the casting area and the stockyard; this allows the use of the same cranes for handling and is a logical layout corresponding to the sequence of production operations. Attention should be given to design a proper drainage system, as water consumption is very high for some finishing processes. Well-designed racks must be provided to minimize handling stresses and avoid damage to the finished elements, see Figures 7 and 8 for layout.

3.3.8 Erection of Precast Elements

Cranes in Precast Construction: The economic production of a precasting plant depends on an organizational solution to handling problems. The basic consideration of planning and standardization procedures should be to reduce handling costs to a minimum. In this respect, the role of cranes is essential, both for material handling in the plant, and erection of components on the site.

Typically, precasting plants use bridge cranes and lifting block hoists in the production area, while mobile, gantry, and tower cranes are used in the stockyard area.

On the site, erection is usually done with tower cranes, crawler cranes and truck mounted cranes.

The main advantage of bridge cranes and the like is to provide for a clear span throughout the production area. Materials and finished components may be removed to the stockyard without interrupting the work.

In the stockyards it is essential that the tower crane reaches the delivery area of the gantry. Otherwise, transit handling from one area to another by trailer or cart is required, multiplying the lifting operations, and thus increasing the handling cost.

Advantages of using a truck mounted crane in the storage area are: the flexibility to vary the location of stocks, and the substantial saving in land use, as no fixed tracks are required.

For on site operations, truck or crawler mounted tower cranes have become universally accepted as the most efficient handling crane for large jobs.

Schedule of Operations: Figure 14 shows the sequence of operations on the building site. In the case of prefabricated components, it is essential to plan well ahead the work of the production gang, so as to minimize waiting times. The goal of the schedule is to use expensive equipment to its fullest capacity, and this means erecting the maximum number of elements per working shift. On well-organized sites and with a trained crew, up to 60 elements may be put in place daily.

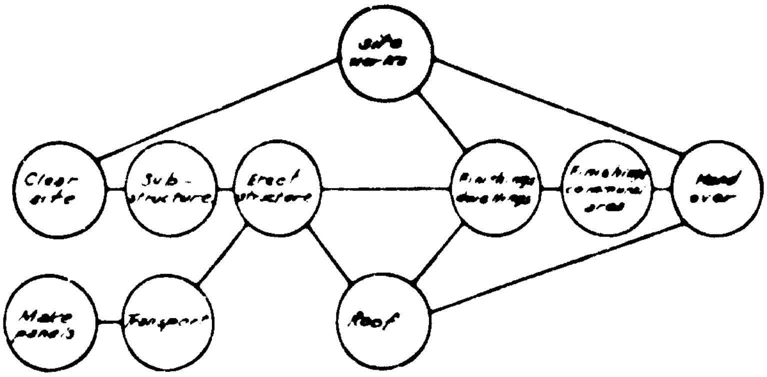
Productivity: Table (3) presents average man-hour requirements in the United Kingdom. Given the labor union requirements in the U.S., an erection crew in the U.S. may be composed of 10 men: 6 iron workers, and 4 masons, plus the crane operator.

Co-ordination on Site: It must be emphasized again that costs can only be kept down if idle time equipment is reduced to a minimum. This implies a global co-ordination between the plant and the site: Deliveries of elements to the site must be on time, while trucks shuttle back and forth, leaving the loaded trailers on the site. Whenever possible, elements should be picked up by the crane directly to their position, thus avoiding transitional handling on the site.

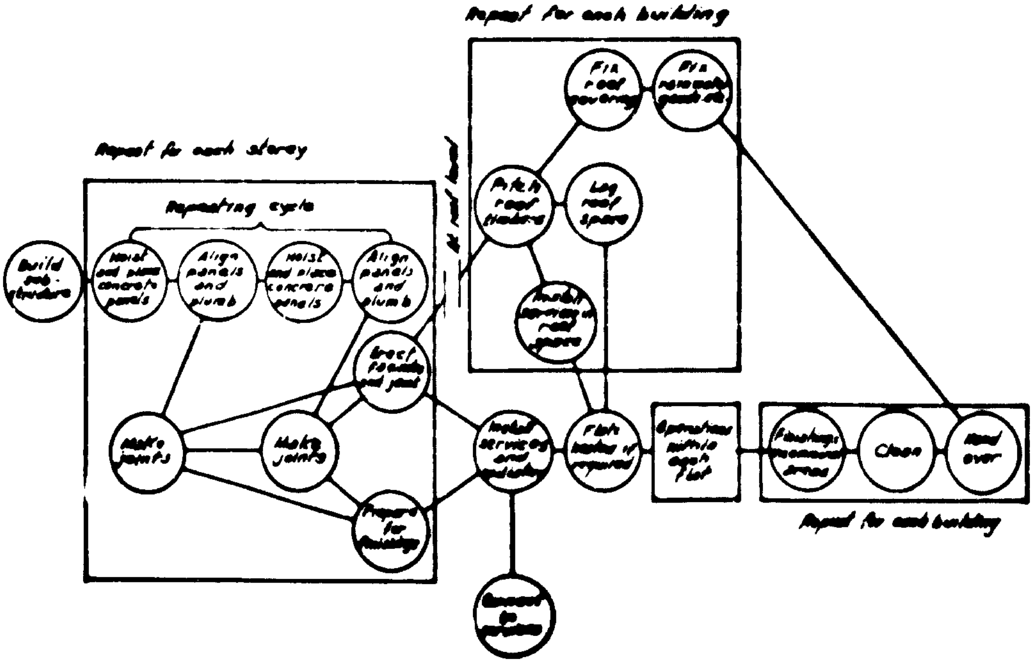
3.3.9 Transportation of Precast Elements to the Site

This is an important consideration in the prefabrication process as transportation costs may substantially affect the savings derived through mass production.

FIGURE 14



SEQUENCE OF OPERATIONS; LARGE PANEL CONSTRUCTION



SEQUENCE OF OPERATIONS FOR A BLOCK OF FLATS WITH STAIRWELL ACCESS

Source: Bishop, D., "The Economics of Industrialized Housing," Design Series 5A, Building Research Station, Garston, U.K.

TABLE 3

MANHOURS FOR ERECTION OF STRUCTURE

	A		B		C		D$^{(iv)}$		E$^{(vi)}$	
Factory	Temporary factory partial cover		Permanent factory in open		Permanent factory under cover		Permanent factory under cover		Temporay yard, alongside building under construction	
	per panel	per 100 ft^2 of panel	per panel	per 100 ft^2 of panel	per panel	per 100 ft^2 of panel	per panel	per 100 ft^2 of panel	per panel	per 100 ft^2 of panel
Place panels and align	2.9		2.3		2.8		0.65		4.1	
Jointing	2.9		1.6		3.3		0.75		5.2	
Total, erect and joint	5.8	8.6	3.9	5.1	6.1	5.7	1.4	3.1	9.3	11.9
Initial preparation for finishings		(ii) 2.9		(iii) 4.1		6.8		2.5		1.5
Total		11.5		9.2		12.5		5.6		13.4
Number of men in gang	14		12		25		17		18	
Panels per$^{(i)}$ week per crane	120		155		215		270$^{(v)}$ 540 per crane		100$^{(vii)}$	

(i) Actual rate achieved when sites established

(ii) Plastering required in addition

(iii) Plastering and lining required in addition

(iv) Excludes lightweight façade panels which were erected by another gang at a labour expenditure of 7.3 manhours/100 ft^2 of panel

(v) Two cranes employed, hence gang of 17 erected 540 panels per week

(vi) Erection geared to demoulding cycle from batteries set out alongside the building under construction

(vii) Crane also served other functions involving 70 other lifts a week including crane gantries, loading pre-packaged materials, removing debris. Labour requirements excludes this work.

Source: D. Bishop: Industrialized Building - with special reference to formwork.
Building Research Station, Garston, England
Current Papers, May 1968.
Reference 14

There are two constraints which limit the size and weight of the components produced in a factory.

- Government regulations governing the dimensions, and weights of the carriers.
- Machinery requirements for the assembly on-site. In recent years, there has been a consistent trend in the use of large cranes on sites. Larger equipment allows for the placing of bigger elements in a single operation. On the other hand, larger equipment implies heavier capital investments, and higher costs of capital recovery. An optimal balance must be struck for the economic usage of prefabricated components.

<u>Factors Affecting Transportation Requirements</u>: A building is made up of elements of different sizes and weights.

The relative number of units per haul, and their relative weight affect the efficiency of truck transportation, and hence its cost.

While the relative quantities of slabs, beams, walls and other precast components vary from job to job, it is possible to establish a probabilisitic distribution of each item.

In turn, the relative numbers of each type of element affect the average load per haul. As transportation costs per ton-mile obviously decrease for a higher load factor per haul, it is essential to determine the most probable load factor per haul. This value can then be used to set the transportation charges.

While this information alone cannot help to determine the overall transportation costs, it allows one to define a most probable load factor per haul.

Numerous transportation cost equations are available and it is possible to draw parametric curves which give the cost as a function of load factor.

Vehicle Requirements - By Function: Precast elements may be classified according to their shapes; beams, joints, columns. These require long flat bed semi-trailers, similar to those used for the transport of lumber.

Slabs: Unless designed in a special way by the addition of reinforcing steel, slabs should be transported in a horizontal position. The most common way is to use flat bed semi-trailers, with special steel abutments to maintain the stability of the load.

Walls: Walls are normally transported in a vertical position, side by side, on a flat trailer. Special attachments are used to avoid mutual contact during transportation, which could cause cracks or chipping on the concrete.

For large sizes, a frame is mounted on the trailer, so as to remain within the statutory limits imposed on overall dimensions.

Another common method is to use a specially designed low-lying flat bed trailer, with a pivoting table. The elements are loaded in a horizontal position, and the table is then tilted to reduce the transverse cross-section of the vehicle.

Volumetric Elements: There are normally little difficulties in shipping box elements. The restrictions are mainly due to the maximum allowable load, as these units are generally quite heavy (up to 30 tons).

Economic Radius of Transportation: The economic distance within which precast elements can be transported depends primarilv on the following factors:

- Cost of transportation, i.e., vehicle operating cost.
- Government laws with regard to size and weight limitations.
- Duration of one working shift.

For example, the current practice in the U.S. is for daily transportation schedules which returns the truck back to the factory at the end of an 8 hour working shift, plus a limited amount of overtime.

Cost Model: Three main approaches may be used for the evaluation of transportation costs:

1) Unit costs per ton-mile; vehicle-mile cost as given by the Interstate Commerce Commission Statistics for Motor Carriers.

These average unit costs are derived from the data of hundreds of carriers in the U.S. They are only useful as an indication of the order of magnitude of such costs, as the individual transportation characteristics of each carrier vary greatly.

2) Costs derived from an econometric model of truck transportation: these are derived on the basis of curve-fitting techniques from carrier data.

Here again, the operations of the carriers under study do not reflect the specialized aspect of prefabricated transportation. The methodology used, however, is very useful for the construction of specific models.

3) Costs derived from a semi-empirical model, such as the one used by the National Swedish Building Research.*

Figures 15 and 16 show dependency of the transport cost on load factor (expressed as percentage of maximum load Qmax), waiting time t_s and one-way distance. Note the importance of reducing waiting times at short hauls.

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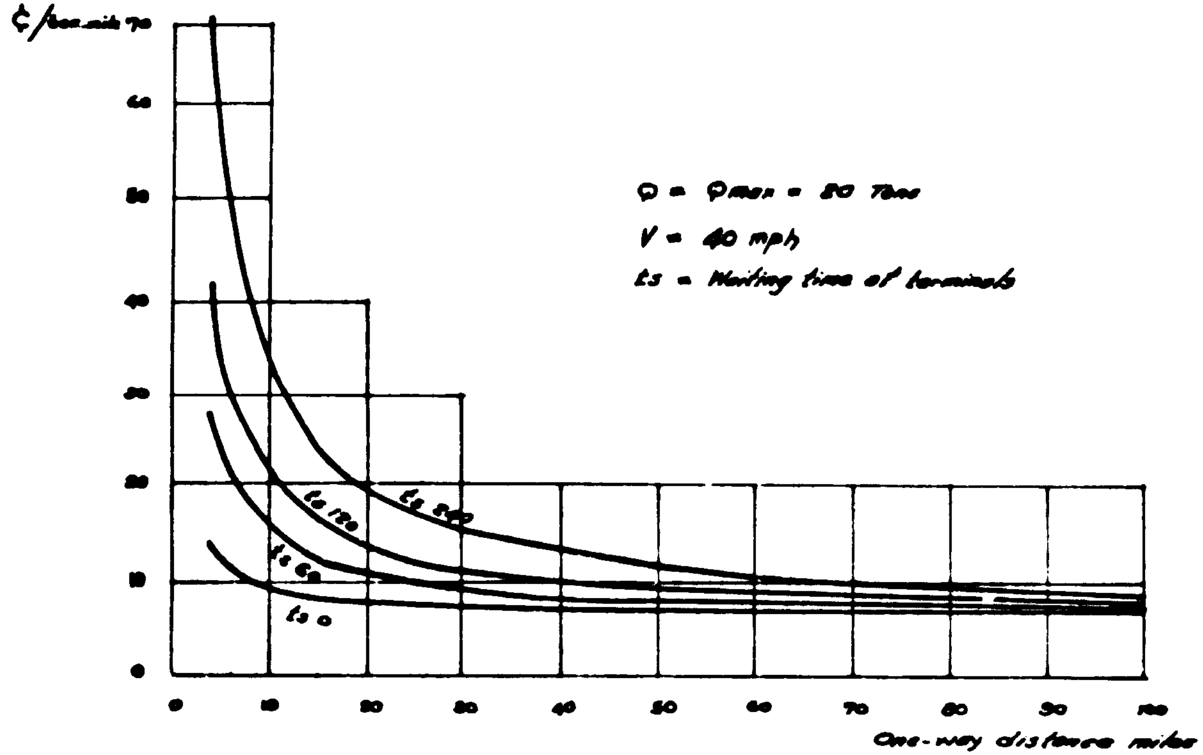
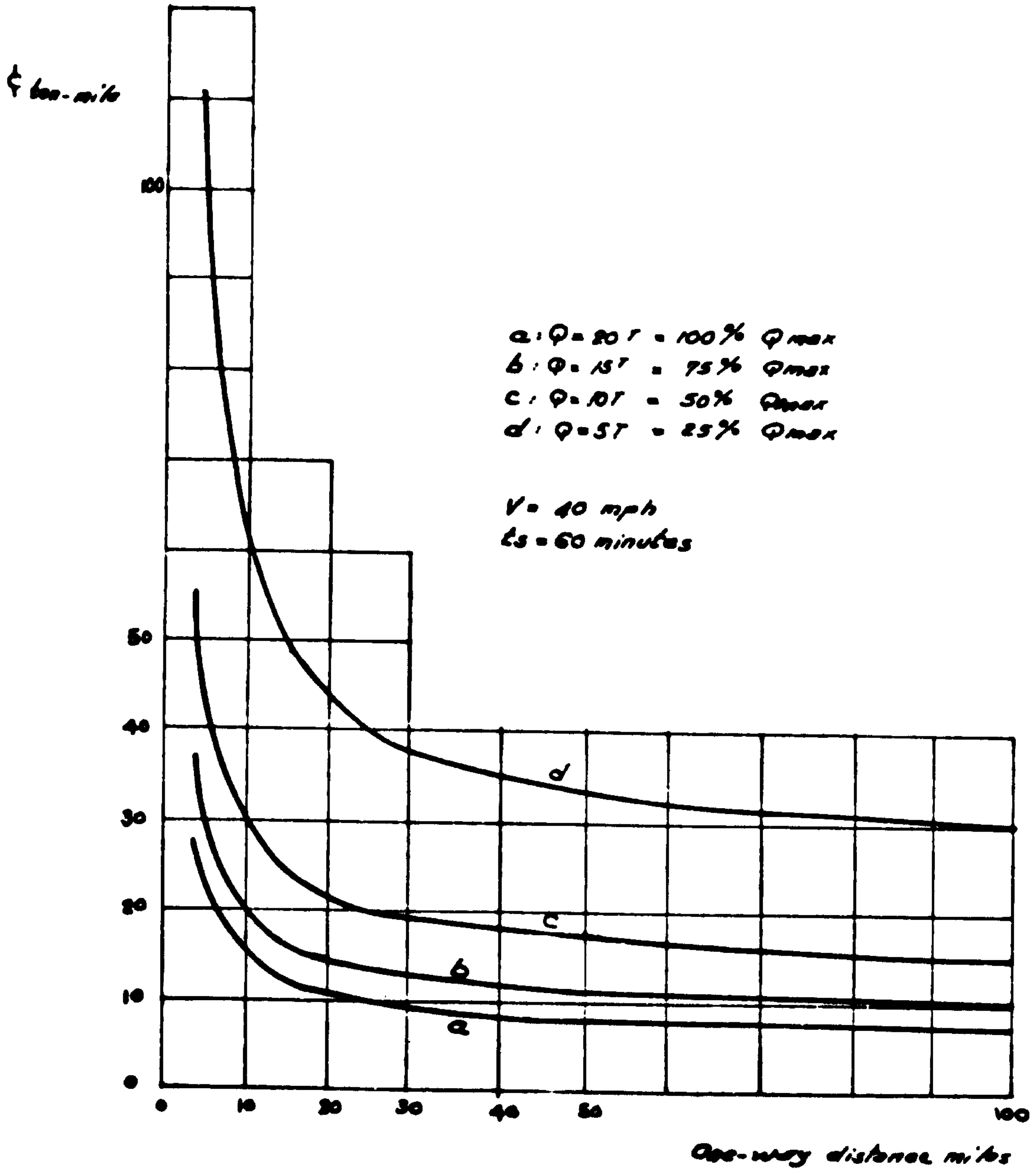
*"External Transporter av Betongelement till bostadhus," National Swedish Building Research Report No. 30, 1969.

FIGURE 15



TRANSP. COST OF PRECAST ELEMENTS

FIGURE 16



TRANSP. COST AS A FUNCTION OF LOAD FACTOR

3.3.10 Framework for Plant Design

In the process of designing a precasting plant, a set of alternatives have to be considered, and they include both natural and imposed constraints: By natural, we mean the level of technology available, the local conditions (market, competition, price level, skilled labor, etc.), and the production process requirements, i.e., factors which the designer cannot influence: By imposed, we mean the set of constraints dictated by previous choices: for example, a ceiling on the capital investment available, or the decision to consider only the residential construction market.

The following list summarizes the various factors affecting the design of the plant:

FACTORS	SOURCE
plant location plant capacity product mix shipping costs price level	construction market
rate of return equity leverage amortization debt servicing	financial market
level of automation	labor market
product characteristics labor productivity seasonality design standards	local factors

Economic Performance of Plant: In order to evaluate the feasibility of the precasting plant, it is necessary to assess its functional, technical, and economic performance. This should be based on three basic considerations:

1. The flexibility of the system to meet client needs, i.e., to satisfy user requirements
2. The technical performance of the buildings, in terms of thermal and sound insulation, fire resistance, structural integrity, and other factors such as durability, weather tightness, etc.
3. The economic performance, viewed from the standpoint of the client and the contractor.

While there are still other characteristics to consider, (ability to meet deadlines, improvement in productivity, etc.) in this paper financial performance is discussed.

Cost: The cost of a system is composed of the cost of development, overhead, capital charges, material costs, labor charges and the cost of irrecoverable items.

These costs can be classified in three groups:

a) Cost of Components Production: To include all costs borne in the process of manufacturing the elements. The basic charges which make up production costs are: Capital and labor charges, material costs, and overhead and consumable stocks.

Capital charges include amortization of the capital required to develop and establish the factory, the interest on this capital, and on working capital, and the cost of maintenance.

Labor charges are derived from the labor force required to man the process, including those responsible for supervision, administration, inspection and maintenance.

Material costs include the cost of shipping and storing the raw materials. For large orders, discounts may be expected in some cases. As material costs are independent from the production process, they are not normally included in the performance equation.

Overhead and consumable stocks represent all the expenses not directly associated with the production process -- they include advertising and promotion, telephone, travel expenses, plant heating and lighting, etc. Consumable stocks are represented by office supplies, small tools and other miscellaneous small expenses.

b) Cost of Transportation: This cost is normally computed on a separate basis. The reason is that transportation costs vary with the distance, the average load, and the cycle time. Moreover, producers tend to prefer facing higher charges in periods of little work, so as to keep the factory running at a higher rate of utilization.

c) Cost of Site Work: This represents the sum total of capital, labor and overhead, as well as materials and consumable stocks, incurred on the site. There is actually little special-purpose equipment used on the site when compared to conventional building plant; the main difference rises in the higher crane capacity required to lift heavy components.

Costs are subdivided into direct and indirect costs, with corresponding cost entries shown below. In order to provide a measure for comparison to other processes, all the costs are reduced to a unit of production basis. For the purpose of this study, a unit of 1000 square meters per day is used. Direct costs consist of: materials, and direct labor (man-hour requirements), and indirect costs consist of the following:

- Man-hours for non-productive labor, i.e., clerical, technical, administrative and other.
- Capital charges due to amortization, maintenance and interest.
- Process costs, heating, steam, lighting, and overhead including telephone, travel and advertising charges.
- Cost of working capital, i.e., interest burden.

A representative sample of the results of a cost model developed at MIT* is shown in Figures 17 and 18. These indicate the process cost of producing 100 square feet of panels under labor productivities ranging from 40 to 100 man-hours per 1,000 sq. feet, and for plant utilization factors between 0.5 and 0.9. The capital investments in Figure 17 correspond respectively to investments of $1 million, $1.5 million and $2.0 million for a plant producing annually 1.2 million square feet of panels at full capacity. Note that the process cost does not include the cost of raw materials nor the working capital charge. Figure 18 includes both these costs, but assumes a longer life of the assets, thus reducing the capital charges per unit output.

Plant Management Information System: The precasting industry is still rather young, and production, development and growth are still too often consequences of judgement decisions and empiricism. It is therefore essential that a precasting plant be considered as a manufacturing industrial plant, and to be concerned with the flow of information in four major areas:

a) Market: The potential of the construction market served by the plant should be continuously monitored in order to analyze the characteristics of the building stock, the growth pattern of its sub-classes (educational, industrial, residential buildings..), and to provide a basis for short term and long term forecasts of building demand.

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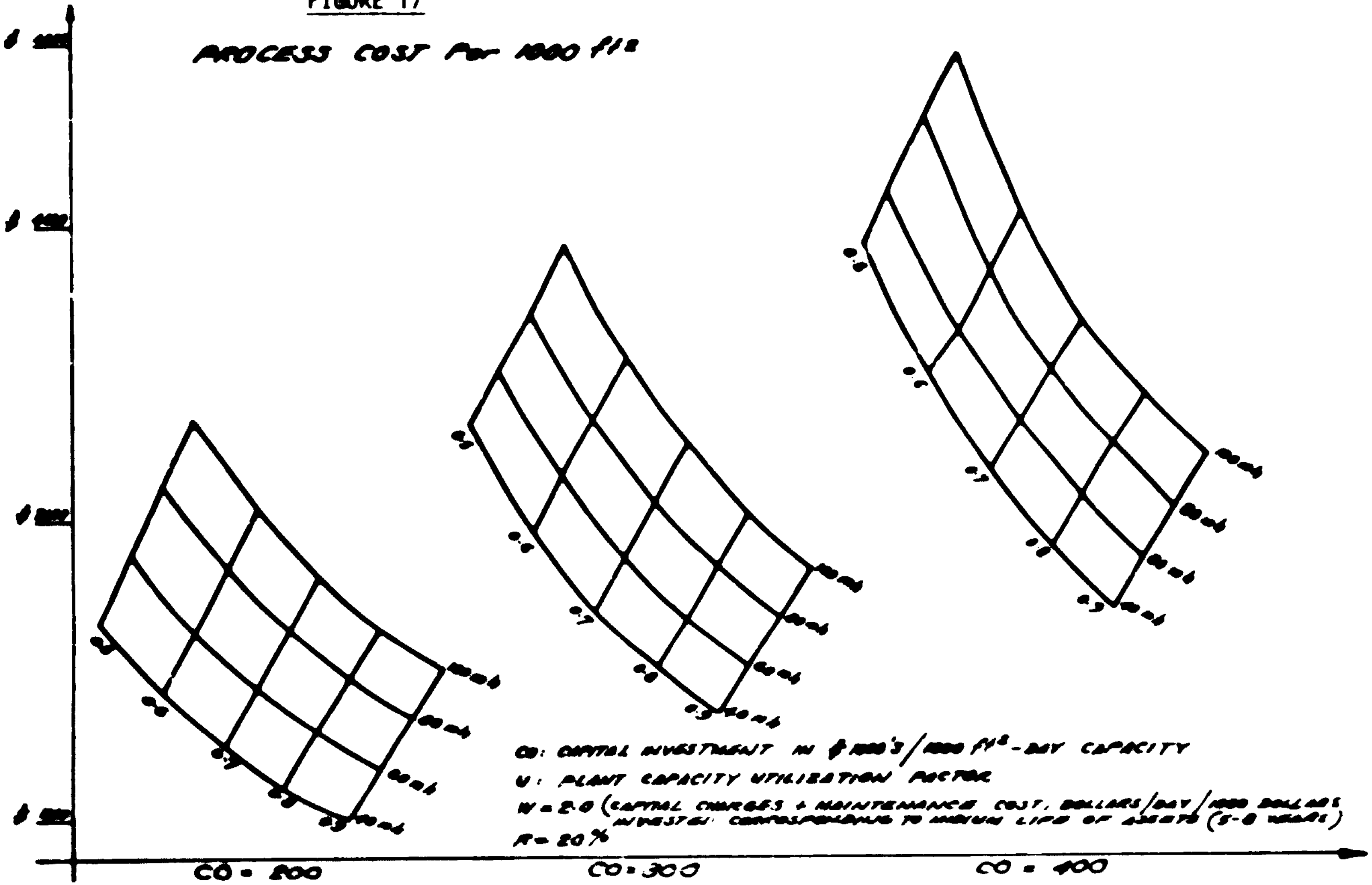
*Moavenzadeh, F. "Precast Concrete Plant Development," Vol. 2, M.I.T. Civil Engineering Reports, 1972.

FIGURE 17

PROCESS COST Per 1000 ft²



CO: CAPITAL INVESTMENT IN $1000'S/1000 ft²-DAY CAPACITY

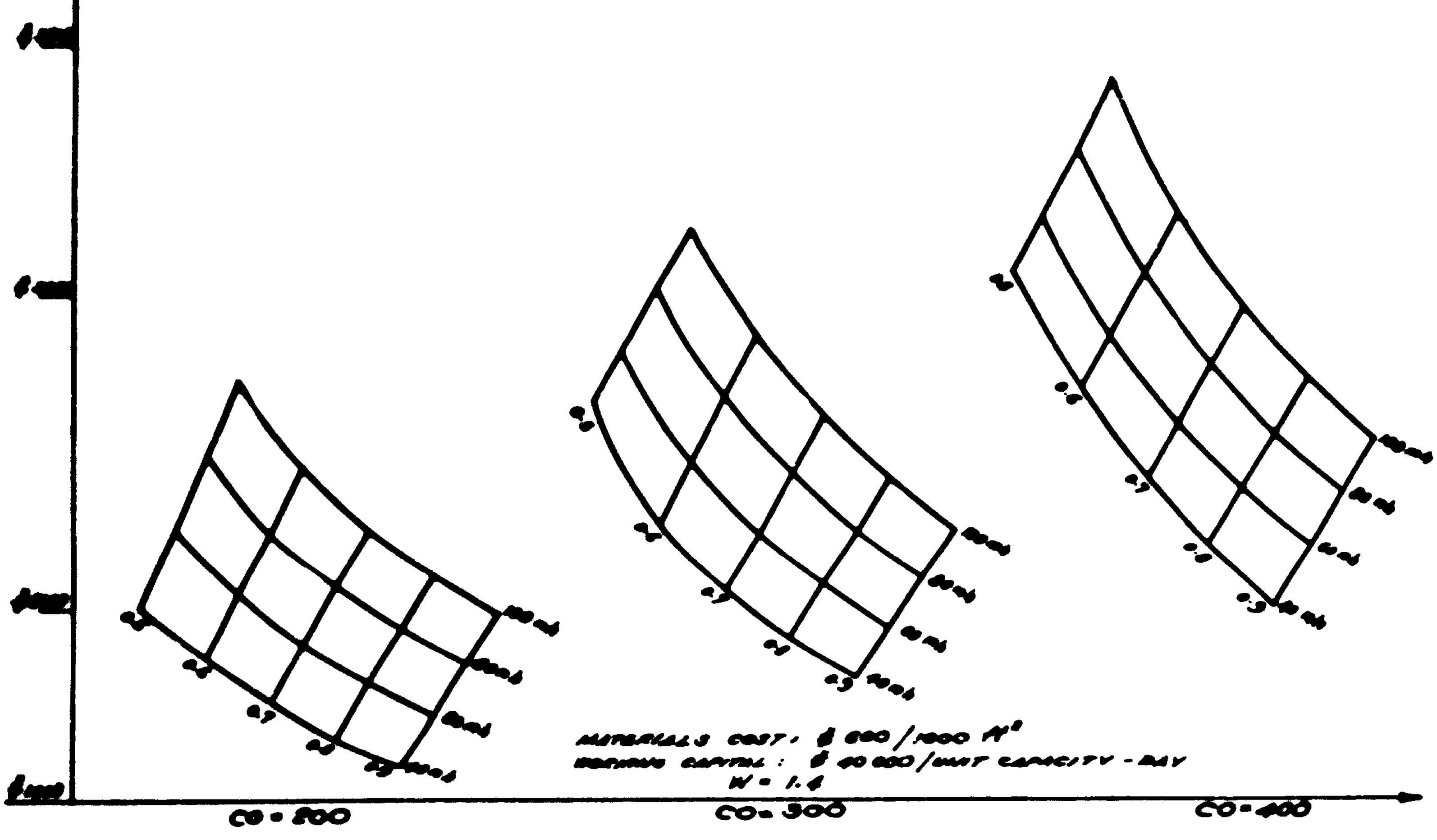
U: PLANT CAPACITY UTILIZATION FACTOR

W = 2.0 (CAPITAL CHARGES + MAINTENANCE COST, DOLLARS/DAY/1000 DOLLARS INVESTED: CORRESPONDING TO MEDIUM LIFE OF ASSETS (5-8 YEARS)

R = 20%

FIGURE 18

PANEL PRODUCTION COST



MATERIALS COST: $ 600/1000 ft²
WORKING CAPITAL: $ 40 000/UNIT CAPACITY - DAY
W = 1.4

b) Design System. Providing optimal design solutions for the range of products of the plant as a function of users' requirements.

c) Information System: Ensuring effective communication between the different responsibility centers, as well as feedback information to check the operations in the plant.

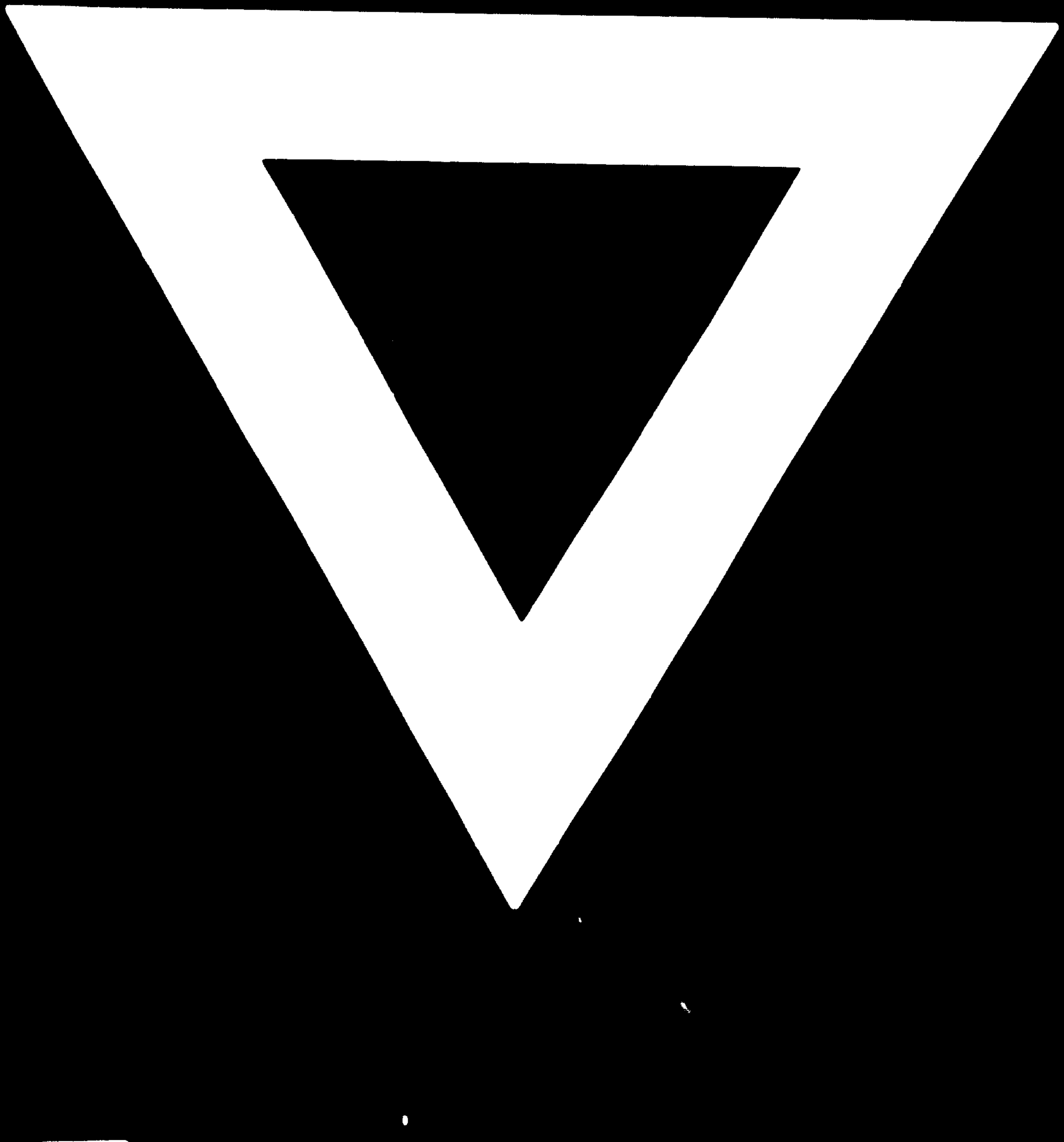
d) Production System. Providing a continuous control at the different phases of production, and the allocation of materials and manpower according to schedule.

As far as the information system is concerned, it is important that management be able to know at any instant the level of supplies, deliveries, and the timing of production orders, so as to establish cash flow schedules and minimize inventory costs. Since the precasting plant is basically the processing of raw materials into finished elements, the essential control is that of material flows. The sophistication of the information depends to a large extent on the size of the plant and on the diversity of its products.

Production System is actually an operations control system, the purpose of which is to compare on going costs with pre-determined standard costs. There are two implications in this statement:

i) That time-motion studies should be established for all production operations, and

ii) That cost control in the plant be performed on a standard cost accounting principle.



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