METHODOLOGY FOR THE DESIGN

OF PRECAST CONCRETE PLANTS

by

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ABSTRACT

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The precast concrete industry has developed in the U.S.A. essentially during the past 15 years, reaching a volume of sales close to $1 billion in 1971. Whereas this is barely 1% of the annual volume of construction in the country, its share is expected to increase rapidly in the next decade, as its potential for solving the housing problem is being recognized.

Many aspects of the precast concrete industry are currently being investigated: This thesis is only concerned with the production of precast elements, and attempts to develop a methodology for the design of precasting plants, and a means of evaluating their economic performance.

To achieve this, factors influencing the design and use of precast elements were surveyed:

The market analysis showed that the minimum economic size of a plant corresponds to the precast construction market of an average Standard Metropolitan Statistical Area in the U.S.A., that is, to a population of 500,000 or more.

The present methods of production were found flexible enough to adapt to an irregular demand for precast elements.

The methodology developed stresses the importance of the continuity of production on the production cost, as the burden of capital charges increases markedly for a low plant utilization factor.

In the final part of this thesis, a case study is presented to illustrate the proposed methodology, starting with the market analysis of a defined area, and ending with the design of a plant corresponding to the expected market for precast elements.

The results obtained seem to indicate that the suggested methodology may be considered a valid appraoch to the design of precasting plants.

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I. INTRODUCTION

I- INTRODUCTION

The last few years have witnessed a surge of interest in the problems facing the Construction Industry in the United States.

On one hand, government agencies have been concerned both with the amelioration of the standards of dwelling units, and the search for cheaper and more productive methods to increase the construction output. Witness of this focus of attention are the remarkable development of the Mobile Home industry, the large scale experimental program of "Operation Breakthrough", and the multiplication of new industrialized systems of construction.

On the other hand, rising construction costs have led builders to seek new solutions to keep prices down, whence their growing interest in industrialized techniques.

While prefabrication, modular coordination, systems construction and housing in industrialization have become common expressions to the industry's vocabulary, they are usually not clearly distinguished, and their true meaning is often confused.

Industrialized construction developed rapidly after World War II in several European countries where conditions favourable to its initiation were found due to the severe shortage of housing and manpower as a consequence of the war. At the present time, prefabricated construction has become a reality especially in the housing field, and research is undertaken to analyze its past results and provide means to further improve its operations.

The precast-prestressed Concrete Industry has developed rapidly in the U.S.A. during the past 10 years. According to a survey made by the Prestressed Concrete Institute, the annual volume of sales rose from a mere $20 million early in the 1960's to close to $1 billion in 1971. Whereas this represents barely 1% of the annual volume of the construction industry as a whole, the share of prefabricated concrete is expected to increase at a fast pace during the coming decade.

The growth of the industry and its vitality came along with deficiencies characteristic of new industries: or uncoordinated research development, scattered enterprises throughout the country, and a lack of standardization in product development.

To induce a rational approach to the solution of the problems facing this new industry, and to attract venture capital so as to foster its growth, it was felt that a thorough and in-depth study should be undertaken so as to identify and analyze the driving forces of the precast construction industry.

The knowledge so acquired should provide a better understanding of its operations, and help promote the growth of the industry in an organized and structured pattern.

The interactions of the industry with its various components may be illustrated by the schematic diagrams in Figures 1 and 2. Although by no means comprehensive, it provides a feeling for the complexity of its global analysis. As the first step of a comprehensive study the ultimate goal of which is to build a model of the precasting industry, it was decided to restrict the appraoch initially to the production aspect of the industry and to try to develop a methodology for the design of precasting plants and a measure of their economic performance.

To achieve this result, factors influencing the design and use of precast elements were surveyed.

First, a broad presentation is made of the building systems presently in use, and their suitability to different types of buildings is discussed.

Next, 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. Technical and economical considerations bearing on the choice of a process over another are presented

-Some aspects of material handling in precasting plants, the storage of aggregates, the delivery of fresh concrete, and the dispatching of finished elements to the stockyard.

-The role of auxiliary services such as the steel and joinery shop, and the requirements of the plant in terms of utilities and power.

-The problem of transportation to the site: Given the importance of this item in the overall economic picture of prefabrication, a cost model, based on a Swedish study, is developed to provide a clear and precise picture of the costs involved.

-Erection of precast structures, with information relating to manhour requirements, coordination of site operations, and probable costs of lifting and securing precast elements.

After having identified the major factors influencing the operations of a precasting plant, the results are summarized in the form of a suggested design methodology, the aim of which is to provide the following information:

-Whether or not to build a precasting plant.

-How to evaluate its economic performance.

Additionally, information is presented concerning the management of precasting plants; this includes the structure of a management information system, and some considerations about a cost control system and the evaluation of labour productivity.

In the final part of this study, a case is built up to illustrate the proposed methodology, starting with the market analysis of a defined area and ending with the design of a plant corresponding to the derived precast market potential.

II- GENERAL ASPECTS OF INDUSTRIALIZED CONSTRUCTION

A. GENERAL ASPECTS OF PREFABRICATION

1 - Definition: The term prefabrication is ambiguous because it is used to describe any manufacturing process by which components are produced, such as pre-cutting, pre-finishing or pre-assembly.

Furthermore, it is difficult to differentiate between prefabrication, pre-engineering, systems building, and a host of similar terms used in the building industry nowadays.

For the purposes of this study, prefabrication will be used to describe:

- A structure assembled in total or in part from factory made components
- A component that has been factory fabricated before erection on site.

2 - Brief History: Historically, large scale industrialization building started in Europe after World War II: The housing needs were immense, the labor shortage acute, and there was a dearth of resources. France and East European countries engaged subsequently in the development of industrialized systems, with the belief that this was the only way to provide a high output of dwelling units as well as a reduction in the traditionally high costs of building.

During the early period (1950's), the cost of factory built units was often higher than conventional construction.
Research and development were pursued with the assistance of the government, and as a result, the number of systems increased

rapidly. Their value was tested in the field, and a natural selection occurred through which the successful and promising methods were adopted and further developed.

Currently, industrialized systems seem to have reached maturity, and the emphasis has shifted to advances in technology and the search for efficient methods of organization.

3 - Present Trends: In recent years, several factors have contributed to making prefabrication an attractive construction method to the building industry in the U.S.A.:

Housing: There is a definite shortage of new dwellings in the U.S.A., and the available information indicates that this trend is to continue throughout the 1970's. Figures (3,4,5,) which project household formations and housing needs until 1985 are a clear illustration of this problem.

Manpower: Concurrently, there is a serious labor shortage developing in all trades of the building industry. The projected number of carpenters, plumbers, and other skilled labor are far below the requirements of the global housing needs of the U.S.A., let alone other types of construction.

Figure (6), which is an estimate of manpower needs in the future years, show how wide the gap stands between supply and demand, for some trades.

4 - Advantages Derived from Prefabrication

Prefabrication implies standardization of the components and mass production. This type of manufacturing process is known to bring about so-called economies of scale. These are actually witnessed in most process industries such as aluminum smelters, steel mills and car factories, to cite a few.

One legitimate question, however, is wether these economies of scale also apply to the building industry. Information from past experience suggests this is also the case. The following examples in tables (1) to (4) are taken from a United Nations publication. (Ref.: (I35). to support this assertion.

Other savings associated with component prefabrication are said to include:

- Savings in materials costs: these occur in three ways:
  - i) Through the purchase of large quantities and the elimination of middle men. The values in Table (5) are taken from ref. (I03).
  - ii) Through the decrease in dimensions of the elements, as higher quality materials provide a higher strength for the same volume.
  - iii) Through the decrease of wasted materials. Typical loss values for factory and site conditions are given in table (6).
- Savings in labour, which are two-fold:
  - i) Reduction in total man-hours required: The higher degree of productivity of the factory, and the

decreased amount of work required on site bring about drastic reductions in manpower use. The higher the degree of factory prefinishing, and the higher are the savings. Figure (7) illustrates this point.

ii) Lower wage rates for factory workers: Due to better working conditions, workers in factories are often paid substantially less than their counterparts on the site. Figure (8).

- Savings through shorter construction time: This affects a number of items.

  Interest paid on borrowed capital

  Interest paid on working capital

  Increased revenues due to earlier occupation of building

  Overhead

  Some of these aspects are demonstrated in Figure (7).

- Savings in maintenance: The higher quality of factory-made components reduces the subsequent maintenance requirements. Although not yet established through hard figures, this assumption is nevertheless logical.

5 -Other Intangible Favorable Factors

In addition to the above mentioned advantages, prefabrication offers better conditions in the following areas:

- Quality: The increasing requirements for better standards of living, embodied in the Building Codes, impose products of a higher quality. Aside from the structural requirements, noise control and thermal control within living units must be improved; these results are easier to achieve in a factory environment, and are also easier to control and enforce.

- Seasonality: The harsh climatic conditions in many areas of the U.S.A. restrict considerably the construction process during the winter season. Here, factory production of components can by pass the technical obstacles (such as concreting under freezing temperature conditions), and hence regularize over the whole year the volume of construction. This fact is demonstrated in Sweden, where foundation work is often started during the fall, and erection is continued throughout the winter.

- Working Conditions: A factory environment provides a shelter against adverse climatic conditions. The output of a worker is greatly increased by the more efficient use of his time: Idle time is high on the site: The sequential operations imply that workers can move in after a given job is completed, i.e., concreters can only pour after the formwork is erected. Although idle time is not eliminated in the factory, it is significantly reduced, be it only through the repetitive type of work involved.

6 - Industrialized Building Systems:

Definition: The work industrialization has often been misused for better organization and management of building organizations. It is also often confused with factory production, or prefabrication, which actually is only part of the overall picture.

What is meant by industrilization is both mechanization of the building process and its programming.

In other words, the whole building process is considered as one entity: At one end, the mechanization of the production processes for the elements constituting a building -- At the other end, an extensive scheduling of all the operations, including transportation and erection. The path of each constituent of a building is monitored from its fabrication to its placing in the structure.

7 - Materials Used in Building Systems:

All the common building materials are used in industrialized system. At the present time, wood, concrete and steel are predominant, as shown in figure (9). Wood is the most widely used for single famile dwellings, especially in the prefabricated mobile home industry. (Table 7)

Concrete and steel are equivalent in use, and their functions are often interrelated:

Steel is used in concrete construction as the reinforcing elements.

Concrete is used in steel structures to provide fire proofing capability.

Almost all European systems use concrete, because it is readily available any where, it is versatile in its use, and usually cheaper than steel.

In this study, concrete has been chosen as the building material for the reasons given below.

8 - Selection of Concrete

Concrete as a building material has several advantages:

- On a cost/unit of volume basis, it is one of the cheapest materials available anywhere:

  The basic ingredients, sand, gravel and water, are natural resources found in any location, and in unlimited quantities.

Cement, which transforms the aggregates into concrete, is extremely cheap, being also produced from the basic constituents of the earth crust.

Moreover, its price has remained fairly constant over the past twenty years, as opposed to the continually increasing prices of other building materials.

Other advantages are:

- It provides an excellent sound insulation
- It has equally good thermal qualities, and its proper use can cut down sizeably the heating expenses of buildings.

  Table (8)

- It provides all the required fire resistance in buildings
- It can be molded into any shape, and provides a monolithic structure, when properly reinforced, an advantage in earthquake regions.

9 - Reflections on Aspects of Building Industrialization (1)

The development and use of factory-made building components depends on the equilibrium reached between two conflicting objectives:

(A) Provide flexibility in design, so that different user requirements may be accommodated and satisfied at minimum cost of dimensional and functional design.

(B) Provide substantial economics in component production, and in labor use on site, so that overall economies of building may be obtained.

Suppose we first start with a very flexible system: then the costs associated with (a) are low. As we introduce more and more standardization and rigidity in our system, the costs indicated by (a) will rise, and we obtain simultaneously more economies of type (b).

Consequently, one may define at least one optimal point on the scale of standardization for which the cumulative sum of (a) costs and (b) costs is minimum.

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(1) Reference 20

Going further into the decomposition of the problem, one may study buildings classified by type, and identify for each class of buildings an optimal level of standardization, that is, an optimal number of standard elements for each type of building.

On the other hand, excessive decomposition leads to sub-optimization if we do not realize that standardization of components should also be such as to maximize their use for the different categories of buildings: Standard elements for one building type which do not apply to other building types lead to a detrimental increase in the number of standard components.

To summarize, it is necessary to integrate the "vertical" component decomposition obtained by building class categories with the "horizontal" decomposition obtained by component functional uses.

10 - Limits to Industrialization Imposed by the Market

The building industry may be regarded as consisting of two parts:

- One concerned with the supply of raw materials and finished parts
- One concerned mainly with assembly

The first group operates from fixed factory sites, while the second moves from job to job, on a site basis.

We are presently dealing with the first group, as it applies to the prefabrication industry.

Its degree of industrialization depends on the effective market size, and on its geographical location. The market, in turn, is subdivided into three main activities:

- Improvement
  Repairs and Additions to Existing Buildings
- Construction of New Buildings

For all practical purposes, the last item is the only one to consider when establishing the market for precast products.

Demand for New Construction: The effective demand may be broken down into functional classification. V. A. Jennings has suggested the following method of market determination: (Ref.55).

$$E = D_V(D(R(F \times L)))$$

Where:

E = Market Size

L = Classification by location

F = Classification by function

R = Requirements for facilities

D = Major demand factors (economic relationships)

D_V = Variable demand factor

This allows the grouping of constructions by type and by region, from which the size and evolution in time of each class may be determined.

Location of Market: Once the elements of construction demands are established it is equally important to determine their geographical location; The density of demand in a given area will influence the location of the plant.

If we assume that supply of raw materials is assured at a constant cost within the limits of an area, plant location will be governed essentially by its proximity to the weighted center of construction activity: High density urban zones normally provide the greater part of construction orders in a region, and factories will tend to choose a location as close as is feasible. (Land costs and zoning regulations are constraints which have to be considered at that moment).

B Characteristics of Systems

1. Introduction

Concrete building systems are generally divided into three main categories:

- Post-and-Beam Systems
- Panel Systems
- Box Systems

A more detailed break-down, suggested by Schmid and Testa, is the following: (Ref.: 109)

- Heavy Panel Systems
- Light Panel Systems
- Heavy Skeletal Frame Systems
- Light Skeletal Frame Systems
- Heavy cellular Systems
- Light Cellular Systems
- Ready-made structures

One can further distinguish between: closed systems, whereby only the components of a given system can fit together, with the exclusion of any other system. Open systems, whereby different manufacturers can combine their products into one system.

While it is not our purpose here to evaluate and compare all the existing systems (there are more than 100 of them), we shall however attempt to identify characteristic features associated with each of these categories.

2.. Systems Classification

a. Post and Beam Systems

i) - Description: 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.

ii) - Technology and Production : This is the least sophisticated type of system: 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.

iii) - Transportation and Handling: 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.

iv)- Erection: 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. For a good description of the techniques employed, the reader should refer to References (77) and (115).

v) - Economics: Let us distinguish the use of post and beam in two areas:

a) Housing and commercial buildings.

b) Educational and industrial buildings.

For case a) the following can be said:

Transportation offsets substantially any advantage of prefabrication; as 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 saves on the investment in mechanical plant; furthermore, it 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.

For case b), the economics differ substantially:

The type of structures considered usually require very large open spans. In that 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. Conventional building methods cannot compete, principally because of the excessive cost of the extensive form falsework required.

As an example, the Sweedish Company Skanska has developed a special long-span beam under the trade-name ULTO, which is currently produced for spans up to 120'.

See Figure (10)

Typical Connections of members are shown on figures (11) and (12).

b . <u>Panel Systems.</u>

i) <u>Description</u>: This is the most widely used system in both Western and Eastern Europe. The subdivision into light and heavy panels is essential, as these differ in their economical applications,(typical shapes,fig.(13) Structurally, one distinguishes three design configurations:

<u>Longitudinal</u>

Here, 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: Past a certain length, slabs show unacceptable deflections. These can be corrected by increasing the steel reinforcement, or using thicker elements. In other words, 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 (90), is shown on Table (9). A similar survey in Sweden appears on table (10).

For larger spans, one might consider prestressed hollow slabs. Even then, one seldom finds elements longer than 40-45': The large moments induced at the junction with the exterior bearing walls require heavy reinforcement, special connections, and hence reduce the savings attained by the use of prefabrication.

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 spaces, 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 (Ref.: 161). The transverse rigidity is maintained, while the longitudinal rigidity is normally attained by the sheer length of the building, independently of the presence of bearing walls.

ii) Small versus Large Panels

The difference arises mainly from the size and weight of the elements:

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. The trade-offs arise in the following areas:

- Transportation: 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: For light panels, one requires 15 loading cycles and 15 unloading cycles, vs. 4 for the heavy panel.
- Erection: Light panels do not require powerful cranes, do not require special lifting devices to avoid excessive handling stresses. 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

- Connection: The higher the number of elements, the higher the number of joints and connections required. This is a disadvantage in 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.

To summarize:

- At the production stage and on the site, a higher investment in equipment is required for handling heavy panels.
- Light panels require longer loading and unloading times than heavy panels.
- Light panels are secured faster than heavy panels.
- Light panels require more on-site labor than heavy panels, due to the increase in the number of joints and connections.

iii) Technology and Production.

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. A detailed evaluation of them is found in chapter (III).

iv) Transportation and Handling

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. Table (11) illustrates the principal causes of damage.

v) Erection

Elements are usually erected with cranes. A variety of devices are used to avoid excessive stresses not designed for. As an example, some of the methods used are illustrated in figure (14)

Vacuum lifting is probably the best way to handle panels: Covering a large area of the element, it reduces the handling stresses quite effectively.

The advantages are:

- Higher turnover in the production, as elements may be handled at lower concrete strength level.
- Ease in securing the panel, as element may be tilted vertically by the vacuum lifter.
- Ease in handling for elements where lifting hooks cannot be inserted (hollow-core slabs)

The drawbacks are: - Device is expensive

- It takes more time to secure the element, as vacuum must be made each time before lifting. (20 to 70 seconds)
- It implies that all handling operations in the factory are done with the same procedure, since no lifting hooks are cast in the element.

vi) Economics:

Panel systems are widely used building systems for residential construction. They provide a higher level of industrialization than post and beam systems, especially where plumbing and electrical fixtures are embedded in the panel at the factory.

Their use is limited to small spans, as larger dimensions require an over-design of the element, an increase in the capacity - hence the cost - of handling equipment.

C. Box Systems

i) -- Description

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 basic idea behind such a system is that a larger part of the construction can be performed under factory conditions: Plumbing fixtrues, 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 (250 ton capacity, versus 90 for panels). Even then, it is not possible to go above 12 or 15 floors with box weights in the vicinity of 40 -- 50 tons.

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 4 boxes require on site finishing for these "bonus" spaces, thus cancelling a good part of the advantages derived from complete finishing in the plant.

Other problems yet are related to labour, as much resistance is met by the labour unions who see in it a decrease in job opportunities for site workers.

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).

ii-- Technology and Production

Precast concrete boxes are produced in vertical steel moulds. 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 mould.

It then goes along an assembly line, supported on especially designed wheel carts. There, all the finishing operations are performed: carpeting, wall painting, installation of electrical fixtures, and, in so-called wet-modules, 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, we know of no full size plant in the Western Hemisphere producing these volumetric elements on a large scale basis: the probable reason is the numerous legal and technical constraints mentioned above.

One of the most successful examples is the "Heart" unit in Sweden produced by the Skanska Group; the box is the so-called wet module, which includes all the fixtures and equipment of the bathroom and the kitchen. Fixtures and outlets are so designed that the unit is installed on the site without having to enter it. It finds its application in both single-family units and multi-family structures, and seems to be competitive with traditional building methods.

iii) <u>Transportation</u>

Box units are very heavy, which makes their handling difficult. The "Heart" units weigh 10 to 12 tons, whereas suggested systems in this country call for 30--40 tons, whereas suggested systems in this country call for 30--40 ton modules, when using normal concrete, and 12--16 tons with the techniques now under development (Chemstress, for example, using a self-stressing concrete, has reduced wall thicknesses from 8" to 2")

Limitations both in dimensions and weight make this solution rather difficult to use on a mass production basis at the present time.

iv) Erection

Whereas lifting 10--15 ton modules is quite feasible, lifting 30--40 ton boxes 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 quite attractive.

v)-- Economics

At the present, box systems have not overcome their inherent constraints: Maximum allowable loads on highways limit their weight to 30-40 tons. Traffic regulations limit their width and height, as well as driving hours, and the lifting operations on site are quite expensive. These systems provide however the highest degree of off-site industrialization, and it is expected that in the coming years, when most of the building code and traffic regulation constraints are solved, box systems will demonstrate the full advantages of total prefabrication.

d-- Common Problems of Prefabrication

i-- Dimensional Tolerance.

Because panels are transported to site in finished form, it is very important that all components fit together perfectly during assembly. It is extremely costly to correct a defect, because this implies:

- Disruption of the assembly schedule
- Disruption of the production schedule

Hence a considerable loss of time and money on and off-site.

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 moulds.

ii) 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:

1--Accommodate changes in the dimensions of structural components or differential settlements.

2--Keep water and wind out of the interior.

3--Provide a good thermal insulation.

A connection serves structural purposes:

1--Sustain and transfer loads due to handing, shear and torsion.

2--Allow for limited movement of element, under creep, shrinkage or temperature differential.

Joints: 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, mortor, 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 on 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

Typical joints illustrating these concepts are shown in figures (15) to (20).

Connections: As was mentioned previously, 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. These are illustrated in Figure (21) to (23).

III- MARKET ANALYSIS

MARKET ANALYSIS

A. Introduction

The implantation 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 trends of the construction market, as well as its functional subdivisions, taking also into account competition from other producers or conventional builders.

B. Purpose

The precasting plant requires market information to:

(1.) Decide whether the market can support a precasting plant.

(2.) Establish the following initial conditions:

- Initial mix of products
- Initial yearly output for each product
- Best adequate technology to provide this output

(3.) Establish a long-range expansion schedule:

- New types of products to be added
- Rate of increase in production by component type
- Capital expenditure scheduling

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

(1.) Construction demand broken down by class of buildings

(2.) Rate of growth of demand, by class

(3.) Share of the market using concrete as building material, by class of buildings.

(4.) Rate of capture of (3) by system building proponents

(5.) Level of competition from:

(a) Conventional Builders

(b) Established Precasting Plants, in the Market area and outside its Limits

(6.) Potential precast market for the proposed plant

C. Construction Demand

1. Classification by Building Function

To follow the trends of construction, 6 main groups of buildings are recognized.

- Residential: Includes one and two-family houses - apartment buildings, hotels-motels, dormitories, and other shelters.
- Commercial: Includes stores, warehouses, office and bank buildings, commercial garages and service stations.
- Educational: Includes schools and colleges - laboratories, libraries and museums.
- Manufacturing: Includes manufacturing plants; manufacturer-owned laboratories and warehouses
- All Other Non-Residential: Includes hospitals, public buildings, religious buildings, social and recreational buildings.

- Public Works and Utilities: Includes streets, bridges, dams, sewarage systems, power, heating, communications systems, airports facilities etc..

2. Market Demand by Building Type

Due to their different functions, these types of buildings do not equally lend themselves to precast concrete construction. Wood or steel may have competitive advantages, or the architectural requirements are such that standardization and repetition of components are not possible.

We may consequently expect a varying percentage of market capture for each building class.

Moreover, the factors affecting the markets of each group are not the same.

- The public works and public buildings markets is solely dependant on Government spending policies.
- The residential buildings market to a large extent depends on demographic expansion, migration, income and savings.
- The commercial and manufacturing building market is more subject to variations in the state of the country's economy: it is mainly an investment venture.

Thus, one needs to prepare a market demand forecast to each type of buildings.

Vast amounts of literature have been devoted to this subject: (ref.26,27,36,44,68.98,106), and we are little qualified to dwell into the intricacies of the methods and models developed for such market studies. In the following paragraphs, we briefly summarize some of the components of each type of market, as an indication to the complexity of the problem.

3. Residential Market Analysis

Area: It is usually defined as that region where dwelling units are linked by a chain of substitution. Topography and transportation usually define the boundaries; commuting time and labor employment area also influence its limits. Therefore it is quite difficult to draw exact influence lines for a market, and quite often administrative delineations, such as standard metropolitan statistical areas are used (SMSA).

Classification: The four main types of classification of a market into subdivisions are:

- Locational
- By Types of Rights of Tenure
- By Price or Rental Class
- By Physical Quality (Single Family - 2,3 - Multiple)

The choice of a classification depends on the purpose of the research. For example, if the potential of demand for equipment items is required, locational submarkets have little significance. If the purpose is to project the number of new dwelling units, locational submarkets are of greater but not significant interest. If the purpose is to evaluate the prospects of a large real estate development, then local segmentation by price and rental class is most significant.

Periods: Two periods are distinguished in market analysis: Standing Stock Period: This relates to price determination when the housing stock remains constant. Construction Period: This relates to price determination when the size of the stock varies. It has no relation with the physical construction period of buildings.

Demand Factors

One distinguishes between short and long run factors.

Short-Run:	Monthly Cost of Ownership Short-term interest rates
Long-Run:	Net Household Formation Growth Income Growth in Liquid Assets (Savings)

Supply Factors

Short-Run:	Monthly Mortgage Costs Maintenance Costs Insurance Costs Real Estate Costs
Long-Run:	Rate of New Construction Construction Costs Mortgage Rate of Interest Mortgage Supply

Rate of Construction

The factors influencing the rate of construction are:

- Rents and building prices relative to other prices
- Vacancy rates for apartments
- Ratio of demand to supply for single houses

- Number of speculative builders, and distribution of their assets.

- Total amount of assets in the community, and risk preferences of the owners.

- Level of building and operating costs

Forecasting Techniques

The main types are:

- Based on analysis of opinions, expectations and intentions.

- Based on historical and statistical patterns: these include:

  The simple projection, assuming no change

  The trend, assuming continuous change along a mathematical path.

  The periodicity, assuming events repeat themselves in a given cycle

  The correlation, which is a derivation of simple or complex mathematical relationships based on past statistical data.

- Based on indicators or indices

4. Non-Residential Market Analysis

The factors influencing the growth of non-residential construction differ sensibly from those of the residential market: Both compete for scarce capital resources, but non-residential construction is essentially affected by the state of the economy as a whole. Office buildings and manufacturing plants represent capital investments, and as such, are subject to the patterns of the financial market.

Some of these influencing factors are:

- Cost of capital
- Mortgage interest rate
- Level of employment
- Growth of the GNP
- Technological changes

In other words, the basic consideration is to evaluate the necessary capital input to achieve a given level of output of goods.

Localized economic factors also play a role in determining the pattern of growth. Among these are:

- Pattern of growth or decline of various industries
- Age and condition of existing plants
- Government sponsored projects
- Changes in zoning regulations
- Incentives

A more accurate analysis will divide non-residential construction into functional categories such as mentioned in (3) Then, each type of industry is evaluated as regards its growth, its employment requirements, its projected output of goods, and forecasts of construction demand are made in line with these findings.

These forecasts will express the expected demand in terms of dollar volume of construction, or in floor space of buildings.

In turn, these figures provide the potential precaster with a basis from which he will determine the types of precast elements required and the volume of production needed.

D. Precast Concrete Market Share

Once demand forecasts have been established with regard to construction level of the different classes of buildings, the next step is to determine for each class what share of the market precast construction may capture.

This will depend on:

- The suitability of precasting for a given type of building: (See for example Table 12)

  As mentioned in the general discussion on Prefabrication (Chapter), prefabrication requires repetition of design, and large series of identical elements, if full economic advantages are to be obtained from such a method.

- The competitive edge of precasting over conventional building methods: (Table 13) to (15))

  This means that prefabrication will normally prevail only where total construction costs are below those of conventional building methods. In some cases, however, availability of labour, or the necessity of a short completion time may impose prefabrication even at a higher cost.

- The competition of other building materials:

  Steel, brick, wood and gypsum among others compete with concrete as building materials: Their suitability to various construction types are illustrated on figure; thus precasting will succeed best when concrete is mostly used. See figures 9 and Tables 7 and 17.

- The promotion effort of precasters at the level of architects and designers: Table (18)

  Given the relative newness of precasting techniques, precasters must strive to impose their products and make their usages and possibilities known to promoters of new construction. They must thus develop close ties with architects and engineers to make them familiar with these new techniques and to increase their willingness to use precast construction. This involves a continuous feedback process through which the precaster will develop new products to satisfy the needs of his clients, and the designers will adapt their plans to suit better the precasting techniques.

E. Competition

Competition comes from two sources:

- Conventional Builders
- Other Precasting Plants

and is also affected by "intangible factors" which we shall discuss.

1. Conventional Builders

The relative shares of the precast and conventional construction market will depend very much on the price advantages of each type. Some of the elements to consider in such a comparison are:

- Ability to meet supply schedules
- Ability to meet user requirements, that is, flexibility in design, variety of components, adaptability to architectural needs etc.

- Ability to complete construction in shorter time intervals, thus cutting down on the cost of interim financing, and allowing earlier returns through earlier occupancy.

- Ability to produce and build at competitive unit prices.

While most of these criteria are not known until the plant is actually built, they do influence largely the choice of production processes, labor and capital intensiveness, and plant capacity.

2. Other Precasters

Competition here may come in two ways:

- From local precasters

- From precasters outside the market area who ship their products

Local Precasters: These have already established a market for their own products; before entering the business, the newcomer should evaluate:

- The number of plants, and their location

- The capacity of the plants, and their range of products

- The share of the market captured by these plants

- The price level of their products

Once these elements have been determined, they must be weighed against the present and expected future construction market of the area. To do this, the growth of total construction volume, and the growth of the precast market must be estimated.

This enables the newcomer to decide:

- Wether or not there is a residual precast market for his proposed plant, and what is its expected trend in the future.

- Given there is a residual market, wether it is large enough to absorb the output of an additional plant.

Outsiders: These producers ship their products from a factory which is situated at a non-negligible distance from the market under consideration.

Therefore, they must bear the added cost of transporting their products to the construction site. This provides the local precasters with a shipping cost differential advantage which must be tempered by the possible higher efficiencies, hence lower production costs, of these "exporting" plants.

The case might also be that these "exporters" provide the market with types of components not produced by the local manufacturers due to special circumstances which should be investigated (for example, the market for concrete foundations piles is too small in the area, but much larger in another market location, hence the export to the non-producing area).

3. Intangible Factors

- The delivery schedule: In slack periods, a factory may well dump its products in neighboring markets to keep the utilization factor high.

- The goodwill associated to the names of each company: A high reputation or a solid tradition are considerable advantages not so easily overcome by a new competitor.

On the other hand, the local plant could at least in theory - compete on reciprocal terms in the other producer's markets: if producer A is ready to ship his products to the market of B 100 miles away, B would also be ready to ship his products to A's market.

Without going into the economic analysis of oligopoly behavior, or, for that matter, monopolistic competition, one might reasonably assume that - under normal market conditions, each producer will act as a monopoly in his own circle of influence. Whereas this does not hold for a big market such as Boston, which no one competitor can control, it probably holds true for the smaller markets which could be dominated by a 1, 2, or 3 producers.

F. Determination of Product Mix

1-Purpose Once the demand for precast products has been evaluated, and a sufficient market exists to justify the construction of a plant, a breakdown by component types must be established to determine the production processes required to meet these needs.

2 Residential Construction

Panel systems are the most widely used systems for housing as rooms have manageable sizes in terms of panel dimensions, i.e. weight and area. The possibility of providing thermal and sound insulation with one single element, as well as the ability to produce flat surfaces ready for painting or carpeting are additional factors favoring panel construction over composite systems like post and beam. As long as the constraints impeding the use of room-sized precast boxes exist, panel systems are assured to maintain their domination of the housing construction market.

Tables (19) and (20,21) suggest the percentage breakdown by panel types for dwelling construction. A common rule of thumb used by the industry is the 2 to 1 ratio of wall to floor panels.

From these figures, it is then possible to know how many square feet of panels must be produced for a given floor area demand.

Applying the percentages provided in Table (19) or (21) will then enable the precaster to design for the number and size of each production unit (single stands, battery forms, etc..)

3. Non-Residential Construction

We have been unable to find some quantitative information regarding the proportions of each type of precast element used in the construction of warehouse, manufacturing plants or otherwise.

Whenever large clear spans are required, it seems that the commonest structural design is a basic frame (columns and beams) with either concrete or steel being the building material. Bays and floors are then installed in a variety of ways: Masonry blocks, bricks, gypsum, or precast flat elements.

As industrial and manufacturing buildings usually have large floor areas (that is, when compared to a dwelling's room size), one might expect the floor areas to be greater or equal to the wall areas.

In the absence of more specific information, a 1 to 1/2 ratio of floor to wall areas will be used.*

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* This estimate is somewhat academic: In all probability, floor areas can only be made of precast concrete slabs, while there is little chance to see them used as infills for wall bays; Parking garages for example have open bays, whereas office or commercial buildings would tend to use light partition walls inside, and brick masonry blocks or light steel sandwich panels for exterior walls. Consequently the actual floor space demand constitutes in itself the only certain requirement for precast elements. Whatever comes above this amount is rather hazardous to estimate, and although welcome, should not be accounted for in base estimates.

IV. THE PLANT

A - PHYSICAL ASPECTS

From the market analysis and the evaluation of the local factors we know the annual output required. This influences directly the size and location of the plant, and the technological level used in the production processes.

We shall now review the organization of a precasting plant, as regards layout, requirements in machinery and equipment, materials and auxiliary services.

1.--Location

As a rule, the precasting plant should be located in such a way as to:

--Minimize the cost of raw materials supply.

--Minimize the shipping costs of finished components to the building sites

--Minimize the land requirements.

These constraints must be evaluated, keeping in mind the necessity of:

--Railroad siding or proximity to a major highway

--Availability of land for further expansion

--Availability of utilities: Electricity
Water
Sewerage

supplemented by in-plant production of Steam
Compressed Air

--Zoning Regulations

Sophisticated algorithms have been developed, using Operations Research techniques, to solve such a multi-constraint problem in an optimal way. (Ref. 42,58,69,101,121,126).

2.--General Layout

Some basic considerations guide the layout of a precasting plant:

--Minimize materials handling time.

--Minimize nonproductive labor movements in the plant.

In cold regions, such as the Northeast, one additional factor is to minimize heating, hence overall factory dimensions. The implications of these premises are straightforward:

--Use a central batching plant to feed all production units:

This is so because any duplication of the concrete mixing plant entails duplication of storage bins, hoppers, handling facilities, aggregate storage, etc... It is much cheaper to increase the capacity of the existing plant by increasing the batch volume, or by installing a second mixing equipment in the direct vicinity.

--Use a "straight-through" layout rather than L or U-shaped configurations to avoid altogether changes in direction: it is always costlier to cause a 90° deviation of material flow, as this requires either an additional crane, or a transit loading-unloading platform, or sharply curved tracks for cranes.

--Install the various operations centers (concreting, steel bending, placing, curing, etc...) in such a way as to have each center's activities taking place independently of other activities.

--Create a maximum clear span in the plant, to facilitate handling operations without disrupting other operations--this also increases the safety of the workers.

--Finally, within economic constraints imposed by the situation, choose a technology which minimizes covered area requirements: this cuts down on:

initial building cost

Heating, ventilating costs.

Idle time of worker's displacements in the plant.

Some actual layouts illustrating these rules are shown in Figures (24) to (26).

3.--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 those components on the trucks which haul them to the building site.

The savings in idle time and increased productivity are two-fold:

--The immobilization of haul-trucks is reduced to a minimum, which is many cases increases the daily tonnage of components shipped to site.

--The schedule of production operations in the plant progresses smoothly (lifting reinforcement, lifting concrete buckets, etc.)

B - GENERAL EQUIPMENT REQUIREMENTS

The discussion here will merely identify the various elements to be taken into consideration in the actual design of the plant--A more comprehensive review is found separately in subsequent sections.

1.--Material Handling

Three types of operations are performed through materials handling

a) Concrete Plant

--Tractors are required to move aggregates from the main storage area to the mixing plant. Alternatively, conveyors may be used.

--Draglines with buckets, or conveyor belts, to feed the aggregate to the holding bins of the batching plant.

--Monorails, rail tracks, or bridge cranes, or tractors, or a combination thereof, will handle ready-mix concrete to the different production areas.

b) Production Process

A variety of machinery is needed to perform the materials handling in the production areas:

--Trolleys, hoists and overhead cranes, to move steel mats, steel bars, miscellaneous formwork; these connect the steel-shop and the joinery shop to the casting areas.

c) Storage

Another set of equipment, namely gantry cranes, and possibly rail-mounted or truck mounted cranes, 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.

d) Miscellaneous

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.

The specific requirements of the plant will be studied in greater detail in the next chapter.

2.--Auxiliary Services

These include:

--A steelshop for the fabrication and maintenance of the steel moulds. 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 administrative and supervising personnel.

--A cafeteria and washroom facilities for the workers.

C - 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:

- Cleaning and lubrication of the mold
- Assembly of mold
- Installation of steel reinforcement and embeded parts
- Pouring of concrete, compaction and vibration
- Curing
- Disassembly of mold
- Removal of element to storage area.
  Refer to Figure 27

1. 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.

Characteristics: This method is labor intensive, and requires skilled manpower if high quality and speed are to be achieved.

This method 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 heating fixtures or insulation materials.

Typical methods are shown in figure (28)

Description of Operations

a. Mold Preparation

The actual design of such stands varies greatly: The bottom can be made of steel, or of plain concrete with a smooth surface or wood, or fiberglass. In both cases it has to be cleaned and oiled to prevent adherence of the cast element. Whatever the precautions, the force required to lift off the element is usually greater than its own weight.

Side forms are made of steel, sometimes of wood. The joints at the corners must be designed with great care to avoid leakage of the concrete which results in chipped corners or irregular surface.

b. Placing of Reinforcement.

The steel reinforcement comes normally in the form of a mat, ready-made at the steel mill or at the reinforcing workship of the factory.

It is placed manually, or with the help of a small hoist travelling on a gantry.

Workers then place the mat in its correct position, install spacers, lifting hooks, stirrups if required, and embed inserts if special holes or apertures are needed.

Of all the operations, reinforcement placing is to date the least mechanized phase of the production cycle, regardless of the method used.

c. Vibration.

Vibration is done in either of two ways:

- Workers handle stick vibrators which operate in the concrete mass.
- Stationary external vibrators, powered by electricity, fuel or compressed air, vibrate the whole stand. In that case, the form has to be well isolated from the floor so as to minimize vibration losses transmitted to the ground.

The power and frequency of the vibrators, as well as vibration duration, depend on the consistency of the concrete and its volume in the mold.

d. Curing.

Curing methods depend on the required output:

- Elements can be allowed to harden in the normal atmosphere (3-4 days minimum).
- The molds can be heated by a coil system in which steam, hot water or oil circulate (3-7 hours).
- The mold can be removed as is and placed in a curing chamber (steam-curing) (3-5 hours).
- Vacuum method can be used: This actually decreases the water to cement ratio, and provides at the same time very smooth finished surfaces (20-40 minutes).

A general discussion of curing methods is found in Part D.

e. Removal of Element.

The finished element is removed by a travelling crane or a hoist. It is then transported directly to the stockage area, or placed on a trailer which, when filled up, is in turn driven to the stockyard.

2. Batch Production

Battery Technique

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.

Description: A typical battery form is shown on figures (29,30)

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.

The advantage here 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.

a. Mold Preparation

The shields are moved apart, one by one, and cleaned and oiled by one or two gangs of workers. When oiling is well applied, cleaning operations can go very fast.

b. Reinforcement Placing

Steel mats are placed in each cell, and secured to the plates Electrical conduits, ducts inserts are then fitted to the mat. Next, the shields are rolled back to the design thickness, and secured tightly by some suitable mechanism.

c. Concreting - Vibrating.

Concrete is poured in the cells by an overhead bucket, or a special pouring-vibrating machine, or fed from below with concrete pumps. This depends on the sophistication of the battery, and on its relative elevation: In some plants, the battery is below ground level, to allow for concreting directly from buckets.

Vibration is normally done with externally mounted vibrators which are clamped to the steel frame.

d. Curing.

The castings are normally submitted to a heat treatment:

Hot oil or water, or steam circulate in coils which are contained within the shields. Sometimes, the heating agent is simply injected into the hollow of the shield.

e. Removal.

The shields are moved away one by one, and the elements lifted out in a vertical position, and transported to the stockyard.

Three types of battery installations are employed:

- Shields are hoisted out individually after each cycle, cleaned and oiled on special stands, and then returned and fastened to the frame.
- Shields swing on hinges which hold them on the frame, to allow cleaning, oiling, and reinforcement placing.
- Shields are moved by hydraulic jacks or electric winches along guiderails mounted on the frame.

The third type of battery is recognized as the better of the three: it does not require the constant use of a crane to dismantle and replace the shields, and takes less place in the factory.

Other Limitations of Single Stand and Battery Processes.

One useful asset of any production process is its flexibility to adapt to user requirements. This is especially true for element dimensions. One cannot expect all building designs to use similar components, and a rigid system would entail costly set-ups and modifications to suit each different production run.

The PCI survey showed the range of sizes for fabricated panels:

A median of 10' x 35'

with 7 ft. and 50 ft. being the extreme dimensions. (Refer to Table 9)

For batteries, limitations are very much the same: A quick look at manufacturer catalogs shows the most common sizes to be:

Width: 6' to 10'

Length: 20' to 30'

As fabrication is done in molds with fixed maximum dimensions, any production run with components of smaller sizes does not fully utilize the process capacity.

Moreover, mold dimensions cannot be increased indefinitely: To solve the increased problems of buckling, torsion deformation, and dimensional accuracy in very large molds becomes rapidly a very costly solution.

To minimize these problems, an optional size must be struck, based on some weighted average of component sizes used in building construction. Such an analysis is to be found in the latter part of this report, for the Case Study.

3. 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 lightweight element versatile in usage. The machine is illustrated in Figure 31.

a. Bed Preparation

The casting bed, 400 to 600' long, is cleaned and waxes in its entire length.

b. Steel Placing

Prestressing strands are laid to both ends, and stressed by hydraulic jacks to the required level. Additional transverse bars may be placed manually or by the extruder.

c. Concreting--Vibrating

The extruder performs the casting operations in one continuous motion. Concrete is laid, formed, vibrated and compacted, and acquires such a strength that a worker can step on it immediately after casting.

d. Curing

A compound is sprayed on the bed to ensure good curing conditions. When the concrete has reached 65 to 70% of its strength, the slab is cut to lengths by a circular saw which moves along the bed.

e. Dispatching

There is one particular problem to dispatch hollow-core slabs: they do not have hooks or inserts cast in them. Consequently, they must be carried out by a special forklift truck, or by vacuum pads attached to an overhead crane.

4. Conveyor Systems

a.-- 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 carts. (Figures 32,33,34,35,36)

(1)-- Mould Preparation

Individual pallets are cleaned and oiled in sequence as the finished element is removed. Normally, empty pallets return to the beginning of the line before being prepared for the next run.

(2)-- Placing Reinforcement

This is done in a similar fashion, that is, mats are fixed to the mould at a determined station by a gang of workers.

(3)-- Concreting--Vibrating

Concrete is brought by a monorail, hopper, or by pneumatic concrete pumps, and quite often the operations of pouring, vibrating and compacting are performed by a single machine.

(4)-- Curing

Pallets are removed from the assembly line and stacked in a curing chamber. This latter phase often proves to be the bottleneck of the line, as curing time is at least three hours.

b--<u>Continuous Moving Conveyors</u>

To date, this is the ultimate in automation of precast concrete production. One of the best examples is the vibro-rolling mill of Kozlov (USSR). (1)

The process comprises the following operations:

--Placing reinforcement.

--Preparing concrete mixture.

--Placing and thickening of the concrete mixture.

--Calibration of the products.

--Heat treatment.

--Removal of the members from the moulding bond.

The metallic moulding band is stretched on the sprocket wheels of two drums, moving at a constant speed of about 90 feet per hour. Fixed raised metal moulds, 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 band. 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 a vertical position, ready for stockyard storage.

Technical aspects of the model are shown on table (21)

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(1) Ref. no. 144, page 40--44.

D - CURING METHODS.

Curing is the process by which fresh concrete acquires its strength. As precast plants require 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 are:

- Free Air Curing
- Temperature Curing
- Vacuum Curing

1. Free Air Curing: This is the slowest method of the three. Concrete is allowed to harden under ambiant 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 of 12 hours, to allow removal of finished elements.

2. 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. We shall briefly review these

a. Atmospheric Curing

i) Steam Curing.

The principle is to accelerate the hydration of the cement, a phenomenon which occurs better when temperature is elevated. The complete cycle goes as follows:

-- Pre-set: The finished element is allowed to set for 15-20 minutes before steam is applied.

-- Rising Temperature: Heat is applied to raise the temperature at a rate of 20 to 60°F., which depends on size and type of element (and concrete).

-- Constant Temperature: The curing compound is held at constant temperature while elements reach the desired strength.

-- Cooling: The elements are allowed to cool back to atmospheric temperature - gradually.

Curing cycle lasts from 6 to 12 hours, depending on the characteristics of the element, the strength required, and the steam quality and temperature.

ii) <u>Hot Water, Hot Oil Curing</u>

The principle and procedures are the same as in (i) but the heating agent is oil or water circulating in jackets. The choice of steam, oil or water is a function of the relative costs of heating by each of these processes in the region considered.

iii) <u>Electric Curing</u>

In this method, the formwork is heated by passing a current through the steel frame. Extreme care must be taken to avoid accidents and short-circuits. Producers in the Northeast claim this method cuts down their curing costs by 30% when compared to steam curing.

Another technique which was pioneered in the USSR apparently, but is also used elsewhere, is the heating of the reinforcement itself, which also is said to decrease curing costs.

Both these methods need an elaborate control system, as the electricity requirements vary with strand elongation, temperature increases, and conducting characteristics of the circuit.

Temperature is commonly controlled to $\pm$ 2° F., and is continually monitored. As concrete develops internal heat when curing, this allows for a progressive decrease in electric heating as curing progresses.

. 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 psig, and therefore pressure losses must be avoided. This system is seldom if ever used for large dimensions.

3. <u>Vacuum Curing:</u> This method seems to be little used in North America, although it is extremely efficient 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 mould under a 20-inch vacuum. The process is effective up to a depth of 12 inches, and produces marked advantages over any other curing process:

i) Three-day strength is increased 100%, while 1-year strength increases an average of 30%.

ii) Shrinkage is reduced (less water in the concrete).

iii) The finished surface is smooth, requiring no further grinding or plastering on the site.

iv) An economy in cement up to 25% is possible with no reduction in strength.

v) The elements can be stripped off the mold and shipped to storage immediately following the vacuum process.

vi) Curing time is reduced to a nominal period of 10 to 20 minutes, as compared to 3-4 hours by the fastest other process.

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

E - DELIVERY, STORAGE AND TRANSPORTATION OF RAW MATERIALS

1. Introductory Remarks

The proper utilization of a plant producing precast elements depends in a measurable way on the efficiency of handling and storing raw materials. This is usually one of the most labour consuming operations, and thus must receive proper care from the outset, at the design stage.

A simple example illustrates the importance of the point: 1 cubic meter of reinforced concrete contains on the average 0.9 m^3 of coarse aggregate, 0.45 m^3 of sand, 250 to 300 kg of cement, and 100 kg of reinforcing steel. Its weight is approximately 2.5 tons.

A medium size factory, producing annually 30,000 m^3 of concrete products, will receive in the course of the year 30,000 x 2.5 = 75,000 m^3 of raw materials, which is the equivalent of 5,000 large dump-truckloads or 1,500 fifty-ton railway carloads.

2. General Aspects

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 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^{o}F.

3. Raw Materials Storage Layout

There are two main layouts for the storage of aggregates; depending on the capacity of the mixing plant and the number of aggregate varieties.

For large volumes, a main storage area in the shape of a rectangle, with concrete walls creating enclosures for each variety. (Figure 37).

For smaller volumes, a radial layout whereby each compartment in the shape of an arc of circle contains one variety. A dragline mounted on the top then feeds the desired type into the silos of the mixing plant. (Figure: 37)

a) Cement Storage

Cement is usually stored in steel silos, as its properties are adversely affected by atmospheric moisture and carbon dioxide.

Under the best storage conditions, cement is likely to lose up to 30% of its strength in 3 months, and nearly 40% after one year ([1]). Consequently, prolonged storage of cement should be avoided; otherwise, it should be tested for strength before usage.

b) Aggregate Storage

A precasting plant should expect to use 10 or 12 varieties of aggregates: While most of the consumption will originate from two to four grades of aggregates, architectural finishes of facade elements will require the plant to store special varieties of aggregates which differ in colour, weight and strength.

4. Unloading

a) Cement: A plant will receive cement in bulk shipments, or in barrels. The material is transferred to the storage silos by pneumatic pumping. When a slight slope exists between the receiving and the storage points, airslides can be used very efficiently: They operate on the principle that light aerated masses of fine material flow easily on slopes as little as 3 to 4%. The velocity of the flow is 2 to 5 feet per second, and the transfer capacity goes up to 150 tons per hour in very large installations.

* (1) Ref: 32

b) <u>Aggregates:</u> The layout of the main storage area depends on the supply method.

Where aggregates are discharged from railroad wagons, the most efficient handling is through the use of bottom-dump wagons discharging directly in underground storage pits.

Alternatively, especially designed dragharrows can rack the contents of the wagons in storage boxes along the railroad track. This implies either a discontinuous forward motion of the train, or the use of special equipment to move the cars at a very slow preset rate. Special problems are encountered when aggregates have frozen in the wagons, forming large chunks of frozen material. These have to be broken down, an operation which is time-consuming and often costly.

Where aggregates are delivered by truck, the most common method is to dump them directly into the corresponding aggregate pit.

The mode of delivery depends essentially at the annual volume shipped, and of the transportation facilities available nearby.

For large volumes (100 000 cubic yards and over), boat delivery at aggregates is probably the cheapest, if applicable.

Next comes railroad delivery, which is as a general rule more economical than truck transportation. As the conomics of shipping depend largely on the location of the supply source, and on the connecting transportation network, this brief discussion cannot be taken further than the generalities quoted above.

5. Transit Handling

a) Cement: Cement is normally directly transferred from its silo to the batching scale. Here also, pneumatic pumps are often used for the transfer. As cement increases in bulk when stored, due to the compaction brought about by the overlying weight, it has a tendancy to consolidate and does not flow freely. To maintain its fluidity, special aerators are installed at the bottom of the silo, which inject compressed air (28-40 psi) to loosen up the material.

b) Aggregates: Aggregates must be transferred from their pits to the auxiliary storage bins next to the mixing plant.

In very large installations, a series of conveyors feed individually each type of aggregate to the mixing plant. This implies large turnover of aggregates, and high capacity plants (100,000 cubic yards and above).

In the medium range (40 - 100,000 cubic yards), a blade tractor or a power shovel transfer the aggregates from their individual enclosures to a single conveyor, which in turn distributes the aggregates in bins located next to the batcher.

In the smaller range (10 - 40,000 cubic yards) radial layout of aggregate storage is preferred. Trucks dump their loads directly into the corresponding enclosure, and the dragline feeds the bins according to requirements.

For even lesser annual volumes, serious consideration must be given to the substitution of the mixing plant by transit-mix concretes in the event of a close-by producer.

6. Concrete Mixing

One distinguishes 5 main types of concrete-plant mixers covering a range of capacities:

Mixer Type	Rated Capacity (cubic yards)
Single compartment two-opening, non-tilting	1 to 7
Opening Tilting-Type, mixing angle 15^{o}/horizontal	2 to 13
Two-opening, front or rear discharge	1 to 13
Vertical-shaft type	1 to 7
Horizontal-shaft type	1 to 3

These mixers meet the whole range of types of concrete normally used, and the choice of one system depends on the concrete type as well as the mising time requirements. Short mixing times are essential in precasting plants, where large amounts of concrete must often be supplied in a short period of time.

Typical characteristics are shown in tables (23) and (24)

As mentioned earlier, vertical-shaft mixers are considered the best suitable for precast plants, as they have the two important characteristics of:

- Short cycle time (65 to 120 seconds), thus quick delivery capacity.
- Accomodation of no-slump or low slump concrete, which is the typical concrete for precast products.

7. Winter Conditions - Concrete

Minimum concrete temperature for delivery is 60^{o}F., and when temperatures are below freezing, this may go up to 80^{o}F.

As aggregate bins are not usually stored under cover, and in most cases are actually stored in open air, they acquire the ambiant temperature.

A special heating system must be used to raise the temperature of the mix to the required conditions. We shall now briefly describe some of the techniques used to solve this problem.

i) Heating Bin: This bin stands between the main storage area and the mixing plant. Frozen aggregates are fed into the bin, which is heated by any suitable method (steam, hot air, hot water or oil, gas burners, etc.) This procedure is unefficient, as it implies additional handling of the aggregates, and periodic replenishment of the bin, and is very expensive, as the heating volume is large.

ii) Revolving Drum: When gas is available cheaply, a stream of aggregates is fed into the drum; at the contact of the heat from the gas burners, the materials heat evenly and gradually. The rate of heating will depend on the revolving speed and the quantity of gas burned. On the average, 2,000 cubic feet of gas (2 million BTU) are required to heat one cubic yard by 60 to 90° F.

iii) Bulk Heating: In very large plants, the following procedure is used (*): Shallow chases are sunk into the storage ground, and steam pipes 2.5 to 4 inches thick installed within. Perforated compressed air pipes are then run below the steam pipes. The air, heated by the steam pipes, penetrates the overlying material and thaws it. * Ref: 32

iv) Conveyor Heating: In this method, the conveying mechanism is heated by the means of a steam pipe network installed below the moving surface. Alternatively, the conveyor has a roof structure to which infra-red heaters are suspended. Aggregates are thus heated in the short time of their transfer from silo to batcher.

v) Transit Heating: This is a combination of the conveyor and drum technique: To cut down on the heat losses, aggregates are heated along a short passage of the conveyor: Powerful infra-red heaters, or steam pipes coupled with compressed air perforated pipes are placed on each side of the conveyor, over a distance of 3-4 yards.

These heating methods are illustrated in figures (38) (39).

8. 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-plan, at the mixing plant. We shall dwell on the latter case, as the former is seldom encountered in any sizeable plant, unless it happens to be located next door to a ready-mix producer: In that case, trucks deliver their concrete directly to the casting mould, with the help of an orientable chute, or they dump their load into skips and buckets which are picked up by cranes to the casting area.

Modes of Delivery:

Figure (40) 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 cover. Their suitability is discussed briefly below; the wide variations in prices for the some equipment do not allow for a thorough general economic discussion and would be applicable only to a specific plant layout.

- <u>Overhead Monorail</u>: Often used in conjunction with a self-tipping bucket, is most suitable where large amounts of concrete are poured, such as vertical battery-moulds. For long distances, exceeding 1000 feet, the overhead monorail appears more economical than conveyor belts. The monorail requires a large headroom, as overhead travelling cranes must pass above the monorail trucks.
- <u>Conveyor Belts</u>: These are especially suitable where concrete is to be distributed uniformly on horizontal surfaces. (pallets, slipform lines) The delivery distance should not exceed 300' or so - one important asset of such a system is that it minimizes segregation of concrete during transportation.
- <u>Fork-lift Trucks and Wheel-mounted Skips</u>: The advantage of this method is of being independent of crane operation, thus freeing it for other handling activities. The system is applicable to all ranges of delivery distances, but has the drawback of operating at floor-level; this means using up floor space, especially if tracks are reserved to it for fast delivery - moreover, this method does not offer significant advantages over the crane-transported bucket.
- <u>Pneumatic Conveying</u>: This method is said to combine all the advantages of the other systems: high delivery rate, little space requirement, flexibility in use, and no segregation of concrete. Its operation is delicate and requires experience, otherwise conveying lines become plugged by hardened concrete residues: special tampers

must be fed through the pipe, under pressure, to remove all traces of concrete, after utilization, and the line should be oiled to case the concrete flow.

9. <u>Storage Elements</u>.

a) <u>Purpose</u>

The plant must store its production before shipping it to the sites because of technical and operational constraints:

- Technical: Components just removed from the casting area have not yet acquired their full strength, 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.
- Operational: Depending on the rate of erection, the number of projects simultaneously contracted, and the variations in production volume, the plant must have a buffer of finished elements to ensure continuous operations on the site. This is especially true when the daily erection rate on all jobs exceeds the daily output capacity of the plant.

Thus storage area should be designed for a minimum of 2 or 3 weeks of production. Where climatic conditions create unfavorable construction cycles with high volume peaks, the supply period should probably be extended to 6 or 8 weeks. The cost of working capital of the plant is thereby increased, but its ability to meet supply schedules is also bettered.

b) Storage Methods:

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 fasades, 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, floor panels are suually stored horizontally, or in stacks. The number of superposed elements, and their spacing are determined in function of the type of bearing ground, the elements weight, and handling methods.

c) 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 the same way as small panels for obvious reasons.

On a broad level, one can however state that:

For annual volumes below 10-15000 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 layouts in figures (24) (26) illustrate 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.

F - PRODUCTIVITY

1. General Remarks

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 periods the higher the productivity:

On a broad level, one distinguishes five phases in the process: (Ref. I25)

--Preparing the moulds

--Placing the reinforcement

--Concreting operations

--Curing

--Removing

The time characteristics of each phase depend primarily on the technology used, but also on the sizes and shapes of the components produced: A finer focus on these operations would show two groups:

(a) Operations Independent of element characteristics:

--Lifting

--Hooking

--Removing

(b) Operations function of element characteristics:

i) Function of Area:

--Cleaning

--Oiling

--Placing reinforcement

--Curing

ii) Function of Volume:

--Concreting

--Vibrating

--Compacting

2. <u>Relative Scale of Output</u>

By increasing order of productivity, one finds the following techniques:

--Single Stand

--Cassette (i.e., battery)

--Pallet Conveyor

--Continuous Casting

The relative scale of output is indicated in Tables 25,26 Furthermore, curing methods affect within a technique the scale of output, as curing is generally the slowest phase in the production. The relative increase is indicated in Table (27).

3. <u>Minimum Scale of Output--Plant Size</u>

For each level of output, there exists an optimal technique for the factory production. Evidently, other constraints such as capital cost and labor, skill and wage level do affect the size 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.

Therefore, the determination of minimum plant size can only be achieved when both factors affecting plant production and the factors defining the market price of finished components are known. This evaluation is discussed thoroughly in Chapter (IV).

4. Single Stands

Single stands are used for the production of the following elements:

--Slabs

--Facades

--Sandwich Panels

Description

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.

Layout

The stands are placed in line, with adequate spacing to allow provisional storage of embedded inserts, miscellaneous 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

Production Cycle

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

Sequence of Operations

The complete production cycle consists of the following:

--Set form dimensions to required size

--Clean and oil sides

--Clean and oil bottom

--Bring in steel mat, place, position spacers, tie up bars, cut out extra length--install inserts, pipes, misc--hooks

--Bring concrete and pour.

--Vibrate.

--Cure by vacuum process, or steam, or free atmosphere

--Finishing: Grind, sharpen edges, etc.

--Remove

Total Production Requirements

Table (28) indicates average values of man-hour requirements for various types of panels in residential construction.

A more accurate value is derived on a job-to-job basis from the series of graphs in Appendix (A), which break down the process in its different phases.

To make comparison with Table (28) possible, the following panel dimensions are assumed.

Surface:	4.2 x 2 meters
Thickness:	15 centimeters
Weight:	3.0 tons (metric)

The corresponding values are:

Bottom Form Cleaning:	32 minutes
Side Form Cleaning:	11
Steel Placing:	30
Concreting	12
Vibrating, Vacuum, Curing, Finishing	45
Total	130 minutes

Normally, 28 to 33% of factory labour time is considered non-productive. Correcting for this yields:

1.3 x 130 = 170 minutes

With two men on the job, this amounts to 5.6 manhours/100 ft^2 (170 x 2/60)

<u>Comments</u>

Assuming then 180 minutes per complete cycle, that is, including tilting the table and removing the finished element, a gang of 2 workers can handle 4 separate castings in a normal working day, assuming vacuum curing is used throughout.

This alone ensures a maximum annual production of:

100 x 4 x 250 = 100,000 ft^2; at full utilization of capacity

Obviously other factors must be taken into consideration.

i) This example assumes one type of element, with no special features, while actual demand will vary as far as sizes and shapes are concerned.

--Facade elements with special surface treatment need much longer times--also many panels require embedded elements (pipes, windows, etc.)

--If all workers are assigned one stand, they will have high idle times, as concrete workers will stand still while iron workers do their job, and vice-versa.

Thus, the next step is to determine the expected requirements as far as number of moulds is concerned, and the scheduling of worker operations. This aspect of operations planning is emphasized in the Case Study.

5. Battery Forms

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

Description

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

--Optionally, a steam curing installation, (or hot water) embedded in the vertical steel plates.

Production Cycle

--Separate the vertical plates, clean and oil the inner sides of the plates

--Place reinforcement, spacers, ducts, pipes, inserts.

--Re-set the walls to required thickness.

--Pour concrete, by overhead bucket, or concrete pumpt (20--30 cubic yards, in one hour or less)

--Set on the external vibrators clamped on the battery.

--Cure.

--Strike off the moulds with an overhead crane, and remove finished elements to stockyard.

Table (28) indicates overage man-hour requirements for various types of panels cast vertically.(see also Tables 29,30)

Also, using figures (5) to (6) in Appendix (A), and the same representative panel, one finds:

Cleaning, Oiling Moulds	62 minutes
Steel Placing	21
Concreting, Vibrating	18
Total	101 minutes

Using the same non-productive time factor (1.3) this yields: 135 minutes.

For an 8-cell battery: $135 \times 8 = 1080$ minutes,
or, 18 hours

A crew of three men, can thus produce more than 800 square feet of panels per day, in one shift.

Where high early strength cement is used, in conjunction with high temperature curing, 2 production cycles are easily achieved in one 8-hour working day.

Assuming one cycle per day, the maximum annual output is:

$8 \times 100 \times 250 = 200{,}000$ ft^2/year, at full capacity utilization.

Comments

--The figures considered here for the production time are somewhat minimum numbers, as any special casting requirement, such as window framing or special end joints increases the cycle time substantially.

--When compared to single stand production, Battery Forms show a gain in productivity. This is understandable, as 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 8-cell battery form requires 1/10 to 1/12 the equivalent factory area for single stand moulds. This achieves substantial economies both in building costs and in plant heating costs.

6. 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 1,000,000 square feet annually, working a normal daily 8-hour cycle.

Description

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.

Production Cycle

--Clean and wax casting bed.

--Place longitudinal strands, and prestress.

--Pass the Extruding Machine

--Spray the slab with a curing compound.

--Cut off to desired lengths.

--Remove.

Man-hour Requirements

Labour requirements and production sequence analysis, as suggested by a large manufacturer are shown on Figure(41) and figure (42).

From these, one derives that total production requirements for labour amount to: 0.4 man-hours/100 ft^2 of slab.

The daily production is in the range of 2,000 to 4,000 square feet, depending on the number of casting beds in use; this amounts to:

500 to 1,000,000 square feet/year.

Comments

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

7. Continuous Conveyor Process

Description

This method is the adaptation of the single stand process to assembly-line methods. As mentioned in Chapter (II), it achieves high productivity with very little flexibility, as you require a different line for each type of panel.

Steel mould edges move at a constant rate (70--100 ft/hour) on a conveyor, and all the production phases with the exception of steel placing are performed by machines.

Man-hour Requirements

To our knowledge, no such plant exists outside the USSR. We have been unable to determine quantitative figures concerning the process.

The Kozlov plant is manned by 5 men (1), and produces annually 1,000,000 ft^2 of slabs on a line.

Another indication is given by Table (22), which shows this process to output the equivalent of 1300 flats annually.

(1) Ref. no I4I page:44

G - AUXILIARY SERVICES

1--Steel Shop

a) Function

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 moulds used in the production processes.

b) Capabilities

Steel bars and steel mats are practically the only two 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 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.

The tradeoff is largely dependent on economies of scale: Higher prices for out of plant work versus higher equipment investments for in-plant production. Here, the volume of output, and the variety of product sizes and shapes will decide on what course to follow.

Whatever the choice, there still remains a basic amount of work that can only be performed on the job. Consequently, all precasting plants include a steel shop with such typical machines as bar and mesh benders and cutters, steel grinders, welding equipment, and a variety of smaller tools.

c) Layout

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 steelshop to casting bed.

2 --Joinery Shop

a) Function

Woodwork is an important element for the successful production of high-quality precast components. Wood is very often used to fabricate moulds 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 door or window openings, ducts, or other special projecting shapes.

b) Capabilities

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 there are circular and rip saws, grinders, planers, drilling and boning machines, plus all the related hand operated tools.

c) Layout

The same considerations that applied to the steel shop also apply here. The woodshop can afford to be more removed from the production area as it requires larger storage space for incoming raw materials, and because handling small inserts and shapes is easily done and does not require special moving equipment. A Forklift truck can carry with no problem the largest wood form.

3- --<u>Offices</u>

The assumption made at the beginning of this study was to consider the precasting plant as an independant entity. 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, and in such a position as not to interfere with the movement of vehicles and goods flowing in and out of the plant.

Space requirements and office equipment correspond to normal needs for any such enterprise, and this subject will not be dwelt upon further here.

4--<u>Finishing Area</u>

a) <u>Purpose</u>

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

- Grinding and polishing surfaces to obtain a smooth finish where required: e.g. surfaces onto which wall-paper, carpeting or paint are applied.
- Architectural treatment: The concrete surface may be sand-blasted, or an expose-aggregate finish is desired, whereby cement is expelled with the use of powerful jets of water and air. Alternatively, bricks are pasted to the outer surface: This is done by using a retardont in the concrete mix of the outer layer, when casting. After the panel is removed from the mould, workers place the bricks (usually half-bricks) into the plastic concrete mixture.
- Correcting fabrication defaults: A leak in a mould, or excess air in the concrete mixture create

respectively protuberonces or cavities in the surface. These are eliminated by grinding the excess concrete or posting a fluid mortor mix into the holes, then re-polishing the surface.

b) Location

The finishing area is normally located between the casting area and the stockyard; this allows to use the same cranes for handling and is a logical layout corresponding to the sequence of production operations. Case is taken 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. (refer to figures (24) and (25) for layout).

H - ERECTION OF PRECAST ELEMENTS

1. 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.

With this respect, the role of cranes is essential, both for material handling in the plant, and erection of components on the site.

Crane Capacity: The choice of a capacity is critical if operations are to be efficient:

--Ideally, all precast units should have the same weight. A single very heavy element is decisive for the choice of an expensive crane.

--Many light, small units cost the same to lift per unit as one single bigger unit.

--Should the capacity be excessive, then investment and operating costs become a substantial burden on the cost of the component.

--Should the capacity be too low, then the expenditures for repair and overhaul increase disproportionately, and the deficiency in lifting capacity might cause bottlenecks in a tight schedule of operations.

Crane Selection: 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. (See Fig. 43,44) Materials and finished components may be removed to the stockyard without interrupting the work.

Gantry and Tower cranes are used in open-space stockywards:

--The gantry overspans the stocking area with its bridge.

--The tower crane is mounted on rails along the outside channel formed by the bridge column supports.

It is essential to properly design the layout of both cranes to make sure the tower crane may reach 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.

--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.

Their versatility is their merit:

--They do not require large ground areas to operate, nor fixed tracks.

--They are easy to mount and dismount.

--They are easy and quick to move from site to site.

These advantages tend to disappear in any of these conditions:

--Hi-rise construction, requiring excessive height, or reach

--Erection of very heavy elements.

These conditions tend to make the crane unit cumbersome and heavy, as counterweights increase. Also, mobility is affected, and the tires transmit very high pressures to the ground.

----

2. Schedule of Operations

Figure [45,46] 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 creation 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. Present figures are 1500-2000 square feet created per working day, and this should reach 3000 to 3500 square feet under good working conditions.

3. <u>Productivity</u>

Table (31) represents average man-hour requirements in the United Kingdom. Given the union requirements in this country, an erection crew here must be composed of 10 men: 6 iron workers, and 4 masons, plus the crane operator. Table (32) is an indication of monthly crane rentals for various capacities.

On the basis of these figures, and assuming 2000 square feet erected daily, with an average hourly labour wage of 8 dollars, panel erection costs amount to $0.55 to 0.60 per square foot.

With the following assumptions:

82 Ton crane.

10 men crew, 8 hours per day, $ 8/hour

22 working days / month

2000 Square feet erected daily.

The panel erection cost amounts to $0.55 to $0.60 per square foot.

Co-ordination on Site: It must be emphasized again that costs can only be kept down if equipment idle time 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.

The effect of different patterns of site organization on the cycle time for panel erection is illustrated on the bar diagram of figure (46).

The work organization and the manhour requirements for the completion of the superstructure are respectively shown on figures 47 and 48 (the latter being valid for U.K. conditions).

J--- COST MODEL FOR THE TRANSPORTATION OF PRECAST ELEMENTS TO THE SITE

1. Analysis of Requirements

a) Introduction

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

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

- Federal and State regulations governing the dimensions, and weights of the carriers. Presently, in the state of Massachusetts, they are as follows:

  Width: 96"

  Length: 55'

  Height: 13' 6"

  GVW: 72,000 lb. (Gross Vehicle Weight)

- Machinery requirements for the assembly on-site In the past years, there has been a consistant trend in the use of large cranes on sites; On one hand, 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.

b) Factors Affecting Transportation Requirements

A building is made up of elements of different sizes and weights.

The relative number of units per haul, and their relative weight both 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 probabilistic distribution of each item, To this intent, one may refer to a study made by the National Sweedish Building Research, as well as on other published information.(References (35) and (36)). See also fig.48

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 probable load of each haul; Again referring to the Sweedish study, it is possible to establish a most probable load value. This value is then used to set the transportation charges Figure.

While this information alone cannot help determine the overall transportation costs, it allows us to define a most probable load factor per haul. From the transportation cost equation providing established, it is then possible to draw parametric curves which give the cost as a function of load factor. This will be done after the operating costs of the carriers have been evaluated.

c.) Vehicle Requirements - By Function

Precast elements may be classified according to their shapes; beams, joints, columns. These require long flat bed semi-boilers, 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 site, 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 especially 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).

d) Economic Radius of Transportation

The economic distance within which precast elements can be transported depends primarily on the following factors:

- Cost of transportation, i.e., vehicle operating cost
- Federal and State by laws enforcing size and weight limitations.

- Duration of one working shift.
- Driving conditions on the road network - Cycle time

Neglecting momentarily the interrelationship of these factors, in spite of the fact these factors are inter-related, we shall focus here on the two last points: These in turn allow us to define the maximum distance.

i) Working Shift

To comply with U.S. accepted usage, daily transportation schedules must be such that the carrier is back to the factory at the end of an 8 hour working shift, plus a limited amount of overtime.

ii) Driving Conditions - Cycle Time

The driving cycle is decomposed as follows:

t_L: loading time & stoppage

t_F: driving time, loaded

t_E: driving time, empty

t_u: Unloading time, & stoppage

t_o: idle times unforseen

Let T be the cycle time, V_1 the full load speed V_2 the non-load speed.

Then $II = (t_L + t_u + t_o) + \frac{L}{V_1} + \frac{L}{V_2}$

and if Q = working shift period, then we must have:

$Q = N.II$, when N is a full number

the resulting cycles are shown in Figure (49,50,51)

From then on, it is possible to determine the fleet size, in function of the daily tonnage of hauls and the average cycle time of delivery.

2-.-- Cost Model

a) Methodology

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

- Unit costs per ton-mile, vehicle-mile as given by the Interstate Commerce Commission statistics for the Motor Carriers. (ref 148)

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

- Costs derived from an econometric model of truck transportation: these are derived on the basis of curve-fitting techniques from carrier data. (ref 88)
  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.

- Costs derived from a semi-empirical model, such as the one used by the National Sweedish Building Research. (ref 36)

For the purpose of this tudy, we shall use the latter solution, applying to it relevant information pertaining to U.S. costs.

b) Cost Elements

Transportation costs (c), can be subdivided into two classes;

- Costs which are function of the mileage, M
- Costs which are a function of time, T (Fixed costs)

Then : $C = M + T$

i) Mileage Dependent Costs

$$\dot{M} + V_V + V_T + R_F + R_L + R_R + S_u + S_a + S_m$$

where

V_V = loss in vehicle value

V_T = loss in tire wear

R_F = fuel cost

R_L = lubricant cost

R_R = repair and maintenance costs

R_u = unforeseen costs

S_a = administration-overhead costs

S_m = marginal costs

$$V_V = \frac{K_V - K_R}{m_V} \quad \text{cents/mile}$$

$$V_T = \frac{K_T}{m_t} \quad \text{cents/mile}$$

$$R_R = P \frac{(K_V + K_T)}{100 \times m_V} \quad \text{cents/mile}$$

where;

K_V = purchase cost of vehicle - U.S. dollars

K_R = residual value of vehicle - U.S. dollars

K_T = purchase cost of tires - " "

m_v = life of vehicle (miles)

m_t = life of tires (miles)

P = percentage factor

S_a, R_u, S_m are expressed as percentagesof the aggregate cost M. The formula then becomes:

$$M = \left(\frac{K_V - K_f}{m_v} + \frac{K_T}{m_t} + R_F + R_L + P\frac{(K_V+K_T)}{100 \times 5\, m_V}\right) \left(\frac{R_u+100}{100}\right) \left(\frac{S_a+100}{100}\right)$$

$$\left(\frac{S_m+100}{100}\right) \text{ cents/mile}$$

ii) <u>Time Dependent Costs</u>

$$T = A_T + A_I + A_o + A_u + I_W + I_C + B_a + B_m$$

where;

A_T = tax on vehicle

A_I = insurance cost

A_o = other costs - garaging, communications, tools, etc.

A_p = driver's wages

A_u = unforeseen costs

I_C = interest cost of rolling stock capital recovery

I_W = interest cost of working capital

B_a = Administration, overhead costs

B_m = marginal costs

$$I_C = \frac{r(K_V + K_T + K_R + A_o)}{100} \quad \text{dollars/year}$$

$$I_W = \frac{r.q(K_V + K_T)}{100 \ . \ 100} \quad \text{dollars/year}$$

r = interest rate

q = ratio of working capital to investment capital

A_o = fraction other costs, related to fixed costs

A_u, B_a, and B_m are expressed as percentages of the aggregate cost T. The formula then becomes:

$$T + \left((A_T + A_I + A_o) \left(\frac{A_u + 100}{100}\right) + A_D + \frac{r(K_V + K_T + K_R + A_o)}{200} + \frac{rq(K_V + K_T)}{100 \ . \ 100}\right) . \left(\frac{B_a + 100}{100}\right) . \left(\frac{B_m + 100}{100}\right) . \ \frac{100}{T_u} \quad \text{Cents/minute}$$

where T_u = vehicle utilization, minutes/year.

c)-- Application - Results

For a given transport distance, the costs are expressed as:

$$C = 2d.M + (td + ts).T \text{ cents/haul}$$

$$td = 60 \times \frac{2d}{V} \quad t_s = t_L + t_u$$

where;

d = one way distance in miles

td = driving time minutes

ts = terminal time minutes

V = velocity miles/hour

t_L = loading time, including stoppage minutes

t_u = unloading time, including stoppage minutes

Now, let q = ton/load:

Then

$$C = \frac{2d.M + (60. \ 2d/V + t_L + t_u).T}{d.9} \text{ cents/ton-mile}$$

The corresponding cost curves derived from these equations are found in figures (52) to (57) and the supporting cost data is presented in Appendix (B) .

V. FRAMEWORK FOR PLANT DESIGN INITIATION

FRAMEWORK FOR PLANT DESIGN INITIATION

A--Design Approach

1. Analysis

In the process of designing a precasting plant, a set of classes of alternatives have to be considered. In other words, the design process has an iterative, hierarchical structure (Ref. I63).

Starting with a large number of alternatives in each class, the designer, by matching these choices to a set of defined objectives must reduce their number to one per class.

Once a decision is made between alternatives of a same class, the designer may wish to repeat the process to find a better solution; or, as the design progresses, evaluation criteria may be modified. In each case, the designer need not start back at his initial point: rather, he returns to a decision point where classes of alternative solutions may be found.

The choice of alternative is not unlimited: they are bound by natural and imposed constraints:

By natural, we mean the level of technology available, the area conditions (market, competition, price level, labour skill..) 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 next step in the design process is to order the classes of alternatives according to a hierarchical scale. At each step of a scale, a decision must be taken, which eliminates a set of alternatives from further consideration.

This is somewhat an ideal situation, as in reality, many of the choices are inter-related, whence the iteration process mentioned at the beginning.

2. Constraints

We shall analyze here the natural constraints defined by:

(i) Construction Market Characteristics

(ii) Financial Market

(iii) Labour Market

(iv) Regional Factors

and leave aside imposed constraints which are not derived from the above, as these will vary according to the objectives of the potential producer.

3. Decision Flow Chart

Each of the above mentioned classes can be subdivided into a network of sequential decisions. These, in turn, specify the constraints imposed at the next level of the design process, until a final plant design has been established. The decision sequence is illustrated in figures.(58,59,60,61)

B ---Plant Design

1. Natural Constraints

Part I of the analysis identified the exogenous information processing required to take the initial Go No go decision of building a precasting plant (Figure: 58). Part B of the analysis is concerned with the compatibility of the constraints specified by the four major variables, namely Capital, labour, Market and local factors--that is, given the present state of these elements, how to determine a set of feasible conditions which accommodate all the constraints and still provide us with an economically viable answer.

Let us first summarize the various factors affecting the design of the plant and which were specified by the analytical framework of Part A

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	labour market
product characteristics labour productivity seasonality design standards	local factors

2. <u>Factors Influencing Plant Capital Investment Requirements</u>

For each production process, there exists a set of constraints which affect the initial cost of the plant. These constraints derive mainly from the equipment needs, area requirements, labour force strength, supervision level, and rhythm of output. A schematic diagram (Figure: 62) illustrates these factors.

3. <u>Factors Influencing Plant Operating Costs</u>

Once a production process has been chosen, a number of related factors are specified. These include manpower, inventory level, and scale of output. As the fixed costs of the plant have to be allocated to the output, it is clear that the level of operations deriving from the choice of a production process will directly affect the burden level of the fixed costs (Figure: 63).

4. <u>Compatibility of Constraints</u>

We have presently analyzed the decision-making chain to determine whether or not a plant should be built. Next, factors which influence plant initial cost, and plant operating costs were identified.

The problem now is to provide the potential producer with a methodology which will allow him to assess the merits and limitations of various plant design alternatives.

To do this, natural as well as imposed constraints must be included in the analytical model. Part C will develop the framework within which such an evaluation is made possible.

C --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 made on three basic considerations:

First - The flexibility of the system to meet client needs, i.e. to satisfy user requirements

Second- 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.

Third - The conomic performance, viewed from the standpoint of the client, the community and the contractor:

Community and client are both interested in long term assessment, that is, the demand of the system for resources--capital, material and labor--for a given output.

Client and Contractor are both interested in short term assessment, that is, cost of the output, as this reflects the viability and competitiveness of the system.

While there are still other characteristics to consider, (ability to meet deadlines, improvement in productivity....) we shall be concerned here only with the assessment of financial economic performance.

1. Demand for Resources: Cost

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

These costs can be classified in three groups:

i) Cost of Component Production: To include all costs borne in the process of manufacturing the elements.

The basic charges which make up production costs are:

Capital and Labour charges

Material Costs

Overhead and consumable stores

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.

Labour charges are derived from the labour 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 (refer to table: (5). As material costs are independent from the production process, they shall not be included in the performance equation.

Overhead and consumable stores 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 stores 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. (Refer to Section J of Chapter III)

c) Cost of Site Work

This represents the sum total of capital, labor and overhead, as well as materials and consumable stores, 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.

2 -------- Factors of Economic Performance

Before analyzing the relative influence of the variables affecting performance, let us briefly summarize the essential items:

i) Capital

Total Investment Capital:	Includes development costs, fixed assets of plant, temporary assets, and working capital

Investment per unit Production Capacity:	This is a measure of the capital intensity of the process.
Investment per unit at Minimum Output:	Defines the minimum investment required.

ii). Materials

This is done by comparing material costs for similar building types, and takes into account bulk purchasing, discounts and the like.

iii). Labour

Total Manhours, in factory, on site	Determines the level of productivity

Degree of skills required.

3 ------- Methodology (1)

Costs are subdivided into direct and indirect costs, with corresponding cost entries shown below. So as to provide a measure for comparison to other processes, all the costs are reduced to a unit of production basis. This may be square feet, tons, dwelling units, or any other defined measure. For the purpose of this study, we shall use a unit of 1000 square feet per day.

Direct costs consist of the following:

--Materials

Re: (1) The methodology use here is drawn directly from the work of D. Bishop, at the Building Research Station of Garston-England.

--Manhour requirements, direct labour only.

(Utilities and consumables are included in the indirect costs.)

Indirect costs consist of the following:

--Manhours for non-productive labour, i.e. clerical, technical, administrative and other.

--Capital charges due to amortization, maintenance and interest.

--Process on costs, heating, steam, lighting, and overhead, to include telephone, travel and advertising charges.

--Cost of working capital, i.e., interest burden.

a) <u>Cost Identification</u>

i) <u>Capital</u>

The cost of capital is broken down in several entries:

C_1 : Cost of Development:	Includes design, testing and all costs associated to pre-production period.
C_2 : Cost of fixed assets:	Includes buildings, equipment, vehicles (except for site transportation), site preparation and all other items related to the construction of the plant.
C_3 : Cost of Working Capital:	This represents in the case of precast plants the cost of keeping an inventory both of raw materials and finished goods. In practice, it is expressed as a percentage of the turnover of the plant. Published figures suggest it is in the range of 2-3%; we shall use 10% here, to provide for probable slack periods of production, especially in winter.

For all practical purposes, C_1 and C_2 are grouped together under C_0, that is,

$$C_0 = C_1 + C_2$$

ii) Capital Charges

Capital charges include amortization of the investment, capital recovery including profit necessary to show a return which will attract capital, and maintenance charges.

Amortization. A distinction has to be made between the various assets composing the plant: Buildings are normally depreciated over a long period of time, 30 or more, whereas process equipment such as compressors, cranes, and the like have much shorter useful lives. The Internal Revenue Service publishes guidelines to the permissible rates of amortization, which are used in this study to determine the aggregate amortization charges.

Maintenance. This includes plant maintenance, equipment maintenance and operation and general maintenance. These costs are usually expressed as percentages of initial investment costs.

Capital Return. A higher rate of return than average should be expected, as this industry is presently considered a risk capital. In order to attract financing, higher rates must be secured.

A general equation can now be established for the capital charges of the system:

$$C_{co} = \frac{1}{no}\left(1.31C_1 + WC_2 + 0.041r \left(C_1 + C_2\right)\right) + 0.041rC_3$$

where:

C_{co} = Capital charges per unit of output

n_o = maximum daily output (1,000 square feet units)

C_1 = development cost

C_2 = fixed assets cost

W = amortization and maintenance, aggregate cost per \$1,000 invested

C_3 = working capital

0.041 = charge per working day per \$1,000 invested, for a rate of 1%, i.e.:

$$0.041 = 1{,}000 \times 1\% \times 1/245$$

r = interest rate required to cover debt servicing costs and provide a return on the invested capital.

iii) Labour Costs

Direct. These include all the labour costs incurred directly in the production process. Their expression is: ld.wd, where: ld is in man-hours (8 hours per day, 5 days per week): wd is the corresponding hourly wage, to include bonuses, insurances, taxes, paid holidays and all fringe benefits.

Indirect. These include clerical, technical and managerial personnel. The more the plant is industrialized, and the higher the ratio of indirect to direct employment. Using the same functional definitions as for direct labour, total cost is:

$$L_i . W_i$$

Another approach is the following:

Let p be the ratio of the number of indirect to direct employment, Let q be the ratio of earnings of indirect to direct labour. The product pq is then a measure of the cost of indirect labour relative to direct labour. As suggested by D. Bishop, this value is around 0.35 for the system building industry.

Then:

$$C_L = ldWd\ \left((1-s) + \frac{1}{u}(s + pq)\right)$$

where:

C_L = Labour cost

ld = Direct labour man-hours, expressed in man-hours per unit of output

wd = Corresponding hourly labour wages, including all costs borne by the company (fringe benefits, taxes, insurance . . . . . .).

s = Proportion of direct labour considered as indirect, i.e., function of production rate

u = Plant capacity utilization factor

p = Proportion of indirect employees

q = Ratio of earnings of administratives to earnings of direct labour.

iv) Process On-Costs, and Overhead

These include all utilities and consumable stores expensed in the production process.

To this, we add overhead costs due to advertising, telephone charges, and all other general expenses.

These amalgamated costs can be expressed in dollars per thousand dollars of capital investment; g

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b)----- <u>Production Cost Function</u>

The cost function of the production process then becomes the sum of labour cost and capital cost: As explained previously, material costs are not entered in the equation, since they are not affected by the production process, hence do not influence the performance of the plant.

Then:

$$C_p = ld.Wd\left((1-s) + \frac{1}{u}(s + pq)\right) + \frac{C_o}{u}(W + 0.041r + g) + 0.041r\ C_w$$

Where:

C_p = Production process cost/unit of daily capacity

ld = Direct labour manhours, expressed in manhours/unit of production

wd = Corresponding wages, including taxes and benefits, per hour.

C_o = Development cost of system + Capital investment in plant $(C_1 + C_2)$

W = Amortization and maintenance/1,000 dollars invested.

C_w = Working capital/unit of production - day, in \$1000's

r = Interest rate.

pq = Ratio of indirect to direct wages, aggregate, expression.

U = Plant capacity utilization factor.

By varying capital investment, plant utilization rate, interest and amortization charges, we may establish the sensitivity of the process to each of the factors determining economic output.

c) Results

A representative sample of the resulting "carpet graphs", is shown in figures (64) and (65). These indicate the process cost of producing 1,000 square feet of panels under labour productivities ranging from 40 to 100 manhours per 1,000 sq. feet, and for plant utilization factors between 0.5 and 0.9. The capital investments "CO" in figure (64) 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 (65) includes both the above mentioned costs, but assumes a longer life of the assets, thus reducing the capital charges per unit output.

D. Plant Management Information System

The precasting industry in the U.S.A. is barely coming out of age: Production, development and growth are still too often consequences of judgment decisions and empirical methods of operations control.

It is therefore essential to consider a precasting plant specifically as a manufacturing industrial plant.

In any event, the focus of any system is to concentrate on the flow of information in the planning, design and construction process. This is further sub-divided into 4 main areas of application:

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

b. A Design System: Providing optimal design solutions for the range of products of the plant, in function of user requirements.

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

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

The two first sub-systems are really independent in their operations, and do not affect directly the production process. We shall dwell consequently upon the two last sub-systems which together provide a basis for optimal performance of the manufacturing process.

1. Information System: It is important that management be able to know at any instant the level of supplies, deliveries, and the ageing of production orders, so as to establish cash flow schedules and minimize inventory costs. As 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. Table (34) is the schematic representation of such an information system for a large precasting plant in the U.S.S.R.

2. Production System: This 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--studies have been established for all production operations.

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

The schematic information flow of physical date is illustrated in table (35).

The concepts and requirements of time study and cost accounting are discussed in the following paragraphs:

3. Time-Studies and Productivity:

Time studies fulfill two needs in the plant:

- Establish a control of operations, and an evaluation of labour productivity.
- Provide information for billing and pricing purposes.

The basic procedure to determine time rates are illustrated in figure (66).

It is most important to have several different persons measure the same operations, so as to eliminate biases and achieve a sound base rate. A suggested method is shown on table (36).

Time studies of technicians A, B, C, D, for various operations are recorded on one sheet, and the means and dispersion calculated.

Additionally, each technician receives a performance coefficient Ø, to indicate the direction of his bias in time measures.

From these time studies, learning curves may be established, which allow for the increase in productivity for the performance of identical tasks in large numbers.

4. Cost Control

It has been suggested to divide precast-unit works into so-called "Cost centers" and "cost places", which allows the evaluation of exact cost rates for the calculation, as full costs and morginal costs. The method is described in detail in Reference (99), and we present here a brief outline of the principle:

The plant is first divided into functional areas to which a major account number is allocated. An example of this division is shown in table (37). These divisions are the so-called "cost centers". They represent an aggregate collection of accounts attributable to a same type of activity.

Next, each cost center is divided into "cost places", a sample of which is given in table (38), for cost center No. 51.

This is equivalent to the creation of responsibility centers, whereby the performance of each gang of workers may be evaluated through the use of cost places, while the relative costs of each plant function are determined from the cost center accounts.

VI- ANALYSIS OF THE SPRINGFIELD - CHICOPEE - HOLYOKE SMSA CONSTRUCTION MARKET

1. Introduction

The purpose of this chapter is to illustrate the principles enunciated in previous sections, as applied to a specific area defined below. An evaluation is made of the trends in building construction subdivided into functional classes (residential, commercial, institutional etc.). The potential market of precast construction is then assessed for each class, and competition is taken into account to determine the expected market share of the proposed plant.

a. Geographical Location

The construction market as defined in this study consists of five cities and fifteen towns in Hampden, Hampshire and Worcester counties, where the three major cities are Springfield, Holyoke, and Chicopee, and is situated 85 miles west of Boston. This area had an estimated population of 541000 in 1970 (Table 39).

b. Source of Information

The main source of information for data collection were published documents. A brief list of the major sources is found at the end of this chapter.

c. Market Breakdown by Functional Classes of Buildings

Two sources are used here to establish a breakdown of the total market into its different functional classes:

- A percentage distribution for the entire United States, shown in Table (40)
- A survey of contract awards, for the Springfield S.M.S.A. which is shown in Table (41)

The last column in Table (41) is the average of the 6 preceding years, and will be used as a basis for the market breakdown in the Springfield area.

2. Residential Buildings

a. Trends

One important aspect in the residential construction market is the distribution between single-family and multi-family structures. Because of its constraints, the precast industry cannot compete with traditional building methods for single family homes, or low-rise 2-3 family units. Hence the only interesting information is the number of multi-family structures, and the average number of dwellings per structure. That information appears in Tables (42) and (43). We see that the annual number of dwelling units built over the past 10 years shows little consistency: a high point of close to 3000 units in 1965, followed by a low of 2500 in 1967. 1971 seems to be well above the 4000 mark, if the trend of the first six months continues. (Table 42). These figures appear to be consistent with two other sources:

- An FHA study (Ref: 38), made in 1969, for the Housing market of Springfield: it projected an annual demand of 2800 units, 1400 of which in multi-family structures for the years 1970 and 1971.

- A private study , dated 1968, predicting an annual demand of 4000 units by 1972, half of which in multi-family structures.

With respect to the SMSA population, the ratio of new dwellings to inhabitants seems to stabilize around 8 units per 1000 inhabitants.

This ratio is the same as that existing in southern Sweden (1), where for the past 8 years, the new housing starts have maintained a constant ratio to population. This is probably an indication of a mature market in a non-dynamic area. This same ratio is also to be found in a survey of the construction trends in 17 European countries (Ref: 138)

An indication of the geographical distribution of the housing units is given in Table (43). It stresses the importance of the three main cities, Springfield, Holyoke and Chicopee, which alone account for over 50% of the housing units. When single family units are removed, the ratio is increased to 72%, and is probably significantly higher if only multi-family structures are considered. The latter information is unfortunately not available.

b. Market Growth

The Springfield area is characterized by a substantial degree of stability: the economic base is rather steady, as can be shown from the employment level variations:

From 1960 to 1969, the sharpest drop was 1%, (1962-63), and the sharpest increase was 3.4% (1965-66) (Ref: 92). The demographic base is also quite stable, as can be seen in Table (44).

A declining birth rate was compensated by a decrease in out-migration, and the number of households is increasing at the rate of 1850 per year, for a total of 170000 in the SMSA.

Table (44) indicates population forecasts for the next ten years. These confirm the conclusions of the FHA study of a small growth in household formation.

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(1) Personal Communication: Skanska Cementjuteriet, Molmo, Sweden

c. Market Forecast

The materials presented above supports the following four points:

- The number of new dwelling units annually introduced oscillates around 3000, with an indication that the market should stabilize at level 4000. (Corresponding to a ratio of 8 units/1000 inhabitants).

- The demographic and economic base of the SMSA are rather stable, and no extraordinary growth may be expected in the near future.

- The share of multi-family units is close to 50% of the housing market.

- A high proportion of multi-family housing is concentrated in the three main cities of the SMSA.

Based on the above information, three estimates are made of the expected market for multi-family units, based on three possible growth rates; for the 1972-1980 period (See Tables 40 and 45).

Low: 2%, corresponding to a stagnant economy, and construction growth equivalent to low household formation.

Expected: 5%, corresponding to an estimate made by extrapolating historical trends from Table (41): The 1972 construction level is 2.05 higher than the 1959 level. This corresponds to an annual compound growth of 6.2%, taken conservatively as 5%. It is in line with other predictions made on a nationwide basis (Table 40).

High: 8%, corresponding to an accelerated turnover of the housing stock, due to renewals and amelioration of living standards. This figure is a judgment estimate reflecting the historical trends mentioned above, where the year 1967, which was an unusually bad year for the economy nationwide, is not taken into consideration in the annual growth calculations.

Projected Number of New Dwelling Units

Springfield SMSA

Year	Low	Expected	High
1972	3000	4000	4500
1976	3300	4800	6100
1980	3600	5900	8500

d. Market for Precast Products

If we accept that 50% of the total units are multi-family structures, and use as base estimate the expected market, the equivalent annual number of new units is: 4800 units of which 2400 units in multi-family structures (based on 1976 forecast).

These values correspond to the median of annual new construction projections at the expected growth of 5%, that is, the annual construction level for the year 1976.

From Table (42), the average number of units per structure is approximately 20, with variations from 16 to 24.

The problem now is to determine what share of the market is going to be using concrete as building material, and how much of it is precast construction:

In housing construction, concrete faces competitors at two levels:

- For low to medium rise apartment buildings, brick structures, steel framed brick structures and brick gypsum structures are commonly used.
- For high-rise buildings, steel seems to be the sole competitor, where high-rise means buildings more than 8 storeys high.

Given the inherent unsuitability of concrete construction for small buildings (1) one should expect different proportions of concrete utilization in low-rise buildings.

Ideally, each class of buildings should be analyzed individually to determine the percentage of concrete structures in each category.

(1) Refer to chapter II

However, in the absence of further decomposition of the data, we have little means to identify correctly the relative shares of concrete in multi-family construction.

Therefore, in the following derivation of the market forecast a conservative approach is used to establish a minimum market base:

In 1970, less than 1% of total housing construction was factory built, excluding mobile home type units (1). In 1972, this share is expected to rise to 5%, then 9% in 1973, and reach equilibrium in 1974 with approximately 30% of the market, which ratio is predicted to remain constant throughout the rest of the 1970's.

These percentages have been calculated from the figures shown in Table (46).

We may then consider three probabilities of precast market capture: low, 5%, corresponding to the 1972 figure. Expected, 15%, corresponding to one-half the predicted equilibrium level. High, 30%, corresponding to the predicted equilibrium level.

Translated into annual number of dwelling units, this represents:

120 Dwelling Units per Year - (Low)

360 Dwelling Units per Year - (Expected)

720 Dwelling Units per Year - (High)

These three numbers are obtained by multiplying the expected median value of annual construction of multi-family units, derived previously, by the respective ratios of market capture (5, 15, 30%).

The average floor area per dwelling unit is taken as 1000 square feet.

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(1) Refer to Tables 46 and 47.

Then, converting the projections of dwellings into area amounts to:

Low: 120,000 square feet

Expected: 360,000 square feet

High: 720,000 square feet

In later sections of this chapter, the floor areas will be converted into annual requirements for precast elements of various types (floors, walls, partitions...). The spread of these projections may appear unreasonably wide, with a high forecast six times greater than the low forecast. This range is justified however when taking into consideration the uncertainties of the market response to the introduction of precast construction.

3. Industrial Buildings

a. Trends

The bulk of the market study is derived from an industrial survey of the Springfield area made in 1956 by C.R.P. (Ref: 92).

As mentioned previously in our review of demand analyses, forecast for industrial buildings demand is a function of investment attractiveness in the area, and employment projections. These do not follow the criteria used to establish the residential market demand.

b. Market Growth

Table 48 is an inventory of industrial floor space in the Springfield area, as of 1964, classified by type of industry.

Based on this information, and on a field survey of building conditions (Ref: 92) established a 15 year forecast of construction demand for industrial buildings. These estimates are shown on Table 49.

In the absence of better information, these estimates will be used as a basis for projecting future annual demand.

c. Market Forecast

The allocation of total demand to a uniform distribution over the 15 years covered by the projection is unrealistic to the extent that new construction is a step function: additions to industrial space are discrete values, and it is quite improbable that the increase be uniformly spread over the years.

From Table 49, the 15 year demand is shown to stand at 2,234,500 square feet of building space, which is roughly 20% above the 1965 level of 10,262,000 square feet.

This represents an equivalent annual increase of 150,000 square feet, or 15 ft^2 per 1,000 installed square feet.

To try to corroborate this forecast, usage was also made of projections developed by the National Planning Association (Ref: 79) which analyzed the growth of construction for different classes of buildings on a nation-wide basis: (Table 50).

Average Annual Growth Rate (1967 to 1980)	
Industrial Buildings	5.37%

This rate corresponds to a doubling of construction in 12 years, but does not indicate what the amount of construction is, as we do not have a reference year during which construction of industrial space is known.

In the absence of better information, we shall use the C.R.P. projections in Table 49.

d. Market for Precast Products

Given the lack of factual information as regards the annual increase in industrial floor space, and the uncertainty of our predictions, we shall proceed in a simplified way to arrive at an expected demand. Consequently, the values derived below should be considered as judgment values which represent our best market estimate.

To arrive at an annual figure for the precast market, we proceeded as follows:

- The average floor space per plant was determined from Table (48), to be 58,000 square feet.
- This figure is then considered to represent the annual expected market for industrial buildings:

In other words, we expect to be able to bid successfully for one industrial building every year, and we assume its floor area to be the average floor area per plant as quoted above. (58,000 square feet)

Supporting Remarks:

- Data shown on Table 49, relate to the Springfield area only, whereas the market under consideration also includes two other cities, namely Chicopee and Holyoke.
- While 58,000 square feet represent close to 40% of the expected annual construction of industrial buildings, in the Springfield area, (150,000 square feet per year). This ratio might well represent only 10 or 15% of the total market for industrial buildings in the SMSA, which is in line with previous estimates of the share of precast products.

4. Other Building Categories

a. Trends

This group includes institutional, educational religious and commercial buildings. Although a finer classification is required if the market structure is to be thoroughly investigated, the lack of available information makes it pointless to go to further distinctions.

We shall, therefore, use another approach to evaluate the order of magnitude of the market. To do so, we shall first list the elements of information available, then analyze them.

b. Market Growth

For Hamden County, Massachusetts, the breakdown for contract awards is shown in Table (41).

The average values of the dollar volume distribution is used to predict the share.of each class of buildings in the future years.

It should be noted that:

- Contract awards represent approximately 88% of total construction

- Hampden County does not cover the whole area of Springfield SMSA.

Additional fragmented information was obtained through private sources, concerning total contract award, for the first 9 months of 1970 and 1971:

	Dollar Volume (1000's)		Construction Footage	
	1970	1971	1970	1971
Hamden County	56,544	49,365	2,743,000	1,581,000
Hampshire County	15,117	8,091	487,000	469,000
	71,661	54,456	3,230,000	2,050,000

Note: These two counties do not cover exactly the Springfield SMSA, but are probably representative of the magnitude of the construction volume: they overlap the SMSA market area, but they are to some extent larger than the actual SMSA.

c. Market for Precast Products

Excluding residential and manufacturing buildings already accounted for in the preceding paragraphs, we are left with roughly 50% of the total dollar volume of construction which amounted to $105 million in 1967 (Table 41).

To arrive at an estimate of the precast concrete market the following is done:

- The annual total construction volume is taken as $100 million which corresponds to year 1967.
- 50% of that volume is allocated to non-residential, non-manufacturing building construction; that is: $50 million.
- Superstructure costs of buildings are taken as 20% of total building costs; that is: $10 million.
- The share of precast concrete is taken as 10% of the total superstructure cost, that is: $1.0 million.
- Finally, the cost of precast concrete elements is taken as $8 per square foot (1). This yields an annual amount of: 125,000 square feet of covered floor area.

Given our estimate of 60,000 square feet for industrial building construction, the total figure of 125,000 square feet appears to be reasonable if we consider the relative shares of total construction for each class of buildings as given in Table (41).

Applying to that figure a growth rate of 5% annually (which is slightly below the projection indicated in Table (50)), the corres-

(1) From Reference (107), the range of cost per square foot of precast elements for industrial construction is $1.00 to $3.50. From personal communications with contractors, it appears that the cost of precast industrial buildings ranges from $5 to $9 per square foot of covered area.

ponding market for 1976 would stand at:

$$125{,}000 \times (1.05)^9 = 195{,}000 \text{ square feet}$$
$$\text{say } 200{,}000 \text{ square feet}$$

5. Individual Market Share of Proposed Plant

So far, we have been concerned with identifying the nature of the construction market, its trends, and its sub-divisions.

Furthermore, we established some quideline estimates as to the aggregate share of the market for precast concrete products.

It remains now to evaluate what portion of this market can be captured by a single plant which would specifically serve that market.

Competition: As far as could be established, the major producers of precast concrete are located as follows:

Producer 1: 85 miles

Producer 2: 50 miles

Producer 3: 105 miles

Producer 4: 85 miles

Producer 5: 10 miles

Assuming our future plant to be located in the direct vicinity of Springfield, all other things being equal, it should enjoy a transportation differential advantage over any of its competitors, with the exception of producer 5.

As far as could be established, producer 5 specializes in the production of architectural elements, that is essentially facade panels and exterior wall cladding. This does not represent a direct competition for a precaster whose objectives are to supply complete concrete superstructures, as such a producer can only complement the production of other precasters. (1)

As regards the existing supply of precast elements from producers outside the SMSA, we have already expressed our views on the subject in Chapter (III). Given the differential transportation cost advantages of a local producer, outsiders will tend to avoid inter-market competition under normal circumstances (this may be considered an optimistic view!)

We shall therefore assume that the proposed new plant will actually serve the totality of the SMSA precast market.

6. Summary

The preceeding market analysis has established the following expected annual demand for precast concrete products in 1976:

Residential construction	360,000	square feet
Industrial Buildings	60,000	"
All Other Buildings	200,000	"
TOTAL	620,000	

Where all areas represent actual covered floor space areas. It is also apparent that:

- Residential construction is the most important single market, with a little more than 50% of the total precast market.

- Non-residential construction has a substantial potential for precast products, which is however difficult to establish quantitatively on a reliable basis.

In view of these remarks, the safe procedure for such an investment venture is to base the feasibility study on one defined market, residential construction - and provide sufficient flexibility in output to meet the expected demand from other sectors of the construction market.

7. Breakdown of Elements by Type

Using the percentage ratios (r) in Table (19), the breakdown of panel elements for a demand of 360,000 square feet of floor area is shown in Table (51).

Note: Most partitions are not made of precast elements, but rather of lighter materials. The figure of 984,000 square feet represents the actual expected annual requirement for precast panels. This point is further discussed in the section on plant design.

b. Non-Residential Construction

The covered floor space demand is taken to be the area of precast elements required (i.e., floor elements only).

Thus, total demand is:

260,000 square feet of floor space

c. Other Products

In addition to the precast market for the above-mentioned components, another set of precast products could be manufactured. These include:

- Septic Tanks
- Manholes
- Foundation Piles
- Canal Linings
- Stadium Seats

We have focused in our study only on building components geared primarily to residential, commercial and industrial building needs. Given a large project from the Public Works or Sanitation Department, for example, the precaster can easily determine whether or not to propose a precast construction. As all the ancillary facilities are already present in the plant, the only significant additional cost is that of the specific moulds required for such miscellaneous products. We shall, therefore, not consider them in our feasibility study.

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VII- PLANT DESIGN

1. Preliminary Remark

- Seasonality of Construction: Climatic conditions in this part of the United States do not allow for a year-round constant level of construction. During the cold months of the year, temperatures are often at or below water freezing point, and this creates difficulties on the sites:

- Technical: Concrete must be poured at a temperature of 40 to 60° F. and it is extremely difficult and costly to maintain such temperature levels on the site: moreover, this level must be kept during the curing process which lasts from three days to one week, depending on the structural role of the element. The use of prefabricated elements greatly reduces this problem, but there always remains a certain amount of concreting to be performed, such as jointing, grouting and coulking, let alone foundation work.

- Human: Labor productivity under harsh winter conditions is low, thus increasing construction time and the costs associated to it (mortgage, interim loans, working capital, etc.....).

This results in an irregular output for construction, concentrated mainly in late spring and summer.

As a result, the precaster must design his equipment to meet peak demand, especially since maintaining his deliverv datelines is an important asset to the company.

2. Choice of Production Processes

The annual target output for different precast products was established in the Market Analysis,
Clearly, the major client is residential construction, with 984,000 square feet of panels, whereas non-residential construction amounts to 260,000 square feet.

a) Non-Residential Construction

The only suitable production methods are of the single stand type, as continuous casting processes achieve an annual output exceeding the market potential of the area:

For example, Appendix (D), which evaluates the economics of hollow-core slab production, shows that a minimum of 240,000 square feet must be sold annually just to cover the costs of production, and with no allowance for profit, under full capacity operations. At 70% capacity utilization, and allowing for a reasonable profit, the required annual sales are more likely to stand around 350 - 400,000 square feet.

Moreover, it is quite unrealistic to assume a market coverage by one single type of product. Most plants (if not all) use a variety of precast elements; this is evident from the Prestressed Concrete Institute Survey of precasting plants, made in 1968, and the results of which are shown in Table (52).

Beams, joists or columns are cast in individual moulds.

The cost of a single steel mould varies from $50 to $125 per lineal foot, depending on such things as possibilities of dimensional adjustment, curing pipe system and shape. Thus the investment in 300 feet of forms would amount to approximately $30,000, including auxiliary casting equipment. Another $80,000 would probably be required for handling facilities (crane, skips, trucks, etc..).

Given the importance of the investment, it would seem preferable not to include such equipment in the initial plant design. Should the opportunity for such a production arise from the successful bid for a large job, it would be a relatively easy procedure to install these facilities, if the possibility is accounted for in the plant layout.

Another factor bears favourably to this solution: for production runs of 40 to 50 units, wooden forms stiffened by steel channels, or possibly fiberglass may present a cheaper solution. Four or five such moulds could handle the requirements of any single job with a lesser capital immobilization than steel forms.

b) Residential Construction

Initial output of panel elements was established in the market analysis, and is summarized in Table (51). It corresponds to an annual production of 360 dwelling units.

The corresponding number of panels will depend on the building systems used for construction. Given the trend in large panel construction in the U.S.A., this number should oscillate between 7 and 11 panels per dwelling, whereas small panel systems comprise 16 to 25 elements per dwelling. (Table 53)

The present tendency in the U.S.A. is to use large panels (8' x 30 - 35') for load-bearing walls, and hollow-core planks for the floors, rather than solid slabs. The former are said to provide better structural characteristics, that is, smaller deflections for large spans. Nevertheless, European systems adapted to U.S. conditions seem to continue using solid slab floors.

As hollow-core slab production was ruled out in the initial stage due to insufficient market potential, we shall proceed with the assumption that a European-type building system is being used in the plant.

Assuming an average of 9 panels per dwelling the required number of elements for 360 units is:

360 x 9 = 3,240 annually.	Range:	2,520 (7 panels/D.U.)
		3,960 (11 panels/D.U.)

Before going further, let us emphasize here that such an output is generally considered as the minimum scale to justify a precasting plant. Hence, all efforts must tend to reduce the capital investment to a minimum -- at least in the initial stage.

For such reduced outputs, 3 processes are possible:

- Vertical Battery
- Tilting Tables
- Pallet Line

As their productivities were found to be in the same range (refer to Chapter), the choice of one process over another will depend on local factors: In our particular case, severe winter conditions favour compact production methods which will reduce plant heating costs, as well as initial building costs.

Vertical Battery production is thus a first choice. This must be completed by another process for the fabrication of facade elements and sandwich panels: The cost of altering the battery moulds to suit each design is prohibitive, both in labour productivity and in the fabrication of the inserts.

Moreover, sandwich panels and facade elements can seldom be cast in vertical batteries, as they require two separate castings.

The choice between a pallet line and fixed tilting tables is essentially based on expansion possibilities and initial investment ceiling.

With the projected output, a set of eight horizontal tilting tables provides adequate capacity up to 1,960 panels annually, assuming 1 cycle per day (8 x 245 = 1,960).

Above this capacity, two or more tilting tables may be added (or heat curing used with 1.5 -] shifts/day), but the economics of production are gradually changed:

(1) Distances increase sharply the non-production time of workers moving along the line.

(2) The area requirements for the plant are increased, as well as the associated costs.

(3) An additional crane is probably required, as handling cycle time increases for all units.

The cut-off point may be approximated as follows: Assume an initial design of a 12 cell vertical battery operating in conjunction with 8 fixed tilting tables, on one cycle per day:

With one cycle per day, the annual output is:

20 x 245 = 4900 panels.

If temperature curing is used in conjunction with high early strength cement, thus allowing two cycles per day in the Battery, the annual output is increased to:

32 x 245 = 7840 panels

or : 1,960,000 square feet (250 ft^2 panels)

This amount is well above the initial expected output of 984,000 square feet. It corresponds to approximately 700 dwelling units, i.e. our highest expected market capture.

Consequently, and following our conservative approach to the problem, tilting tables will be used for the initial plant design.

In any event, should a mechanized pallet line become necessary in further stages, it is a relatively easy matter to switch from stationary to on-line production: Some manufacturers of horizontal moulds have standardized their equipment in such a way that it may be used in both processes.

Alternatively, two shifts per day could also be used, thus further increasing the plant capacity by another 400,000 square feet.

The choice of methods of future expansion will thus depend on the economic trade offs between shifting to pallet-line production, or working double-shift.

Summary

Initial equipment purchase will provide capacity for residential construction only -- this includes:

-- 1 Battery of 12 cells

-- 8 Tilting Tables.

This capacity corresponds to an annual output of 4,900 pounds, or approximately 540 dwelling units, for a utilization rate of 1 cycle per day, 245 days per year. That capacity is 50% higher than the initial expected market, but is justified on the grounds that seasonality of construction will require peak production during a limited period of the year. Moreover, should the initial market turn out above our conservative estimate, then the plant should have adequate capacity to meet the demand. (High market estimate is 720 units per year.)

Plant layout will provide adequate floor space to include additionally:

--] Staircase forms

-- 1 Elevator shaft form

-- A limited number of longitudinal casting beds (beams, columns......)

3. Concrete Plant

The choice of the concrete mixer capacity is based on the peak demand of the plant; that is, casting operations are not uniformly spread throughout the day, and the mixer must thus provide it daily output within a shorter time period. In the morning, cured elements are struck off their moulds. After cleaning and oiling the moulds, and setting the reinforcement, concreting takes place throughout the plant.

With a daily production of 20 panels, the maximum amount of concrete required may be estimated at 125 cubic yards, assuming average panel area of 250 sq. ft., and a thickness of 8 inches. (75 cubic yards to the battery, so to the tilting tables.)

Using a 4 cubic yard skip would thus require 16 to 20 lifts to the battery, and 12 to 15 to the Tables. (maximum load)

From data in Appendix (A) one may estimate that 5 to 8 minutes are required to pour 4 cubic yards of concrete. The Battery would thus require approximately 90 - 120 minutes to be filled, and the tables 60 - 80 minutes. This represents 125 cubic yards in 2.5 to 3 hours, or an hourly capacity of 45 cubic yards. (peak demand)

With mixing cycles in the range of 30 - 65 seconds for vertical-shaft paddle mixers, a blender capacity of 1 cubic yard should be adequate. To minimize, however, filling time of the 4 yard skip, it is suggested to use a 2 cubic yard mixer, in conjunction with a smaller mixer for miscellaneous jobs (such as white cement concrete).

4. Storage Area Requirements

Average curing time is normally 15 days; other local constraints, such as peak demand, slack in winter conditions, require the buffer period to be larger. Conservatively, 2 months of production should be provided for. This represents 800 to 1000 elements to be stored.

The corresponding required area is approximately 25,000 square feet, and is derived as follows:

According to Reference 60, storage area requirements vary between 5 and 15 times the daily floor area output. With a capacity of 1.5 dwelling per day (i.e. 1500 square feet) the corresponding figures are 7500 to 22,500 square feet.

5. Plant Layout

Two possibilities were considered here: a "straight-through" layout, such as illustrated in Fig. (67) or a "T" layout, such as illustrated in Fig. (68).

The main criterion being minimum initial capital outlay, the second layout was preferred, as it requires only two cranes to operate (one in-plant, one for the stockyard).

The choice reduces to a certain extent the flexibility for future growth, as above 700 - 900 dwellings per year handling equipment and production areas will become insufficient.

Given the initial expected output of 360 dwelling units annually, limit capacity will not be attained until the late 1970's, according to the market analysis forecast.

6. Man Power Requirements

i) Direct Labour:

Casting Areas:	Battery:	5 Labourers
	Tilting Tables:	6 Labourers
	Finishing:	2 Labourers

Steel Shop:	4 Iron Workers
	2 Plumbers
Joinery Shop:	2 Carpenters
Concrete Plant:	2 Labourers
Concrete Distribution:	1 Labourer
Cranes:	2 Labourers
Stockyard:	2 Labourers
Maintenance:	2 Labourers
General Plant:	2 Labourers
Supervision	1 Foreman

ii) Indirect Labour

Administration, Supervision and Sales :	1 Head Engineer
	1 Production Technician
	3 Design Engineers
	2 Draftsmen
	1 Accountant
	1 Salesman
	1 Secretary

B PLANT CAPITAL COST

1- Buildings and grounds

a - Building : Covered floor area is 13.000 feet square for the production area and 2.000 feet square for auxiliary services, a total of 15.000 Sq.Ft.

The structure is assumed to be a concrete frame type, with precast panel infills, or possibly tilt-up walls.. Assuming a 24' spacing of the columns to meet bridge requirements for the crane, the cost of the building is estimated at 8 dollars per square foot;

Thus : Building : $ 8 x 15,000 120,000

b - Land : Land cost is assumed to be $ 0.25/Sq.Ft.

The requirements are:

Plant:	15.000 Sq.Ft.	3,750
Stockyard:	20.000 Sq.Ft.	5,000
Access and misc.	20.000 Sq.Ft.	5,000
Future Expansion:	25.000 Sq.Ft.	6,250
Total:	80.000 : Cost	20,000
Add site clearing and preparation:		10,000
	Total Cost	150,000

2. Storage Area

The only equipment needed in the storage area is a series of racks and supports for the concrete elements.

The cost of these fixtures has been estimated at: $5,000.

3. Production Area

a) Vertical Battery Forms

- 1 12 cell battery (1)	165,000	
- Installation thereof	18,000	
- Wooden gang-plank installation	2,500	
- Intermediate side walls, hinge extensions, turn buckles, mould cutouts.	12,000	
- Electric Vibrators, high frequency, adjustable force, base plate and clamps, at $400 each 32 units:	12,800	
- 15 KVA, 440/220 volts, 3 phase 60 cycle transformers, at $750 2 units:	1,500	
Installation:	500	
- Steam line connections, electric cable installation, switches	1,200	
- Monorail track with 4 cuyd hopper	34,500	
TOTAL:		$248.000

(1) See separate attachment in Appendix for Battery description.

b) Tilting Tables

- Steel mould (1)	14,500	
Heat pipe system	500	
Tilting mechanism	3,500	
Installation	1,500	
Sub-total	20,000	
8 units		160,000
- 15 KVA, 440/220 V, 3-phase, 60 cycle transformer, at $750		
2 units		1,500
Installation:		500
- Electrical wiring, switches, cable installation		2,500
- Electric vibrator, high-frequency, adjustable force, base plate, clamps, at $400 each		
16 units:		6,400
- Intermediate side moulds, miscellaneous parts.		8,500
TOTAL:		$179,400

(1) See separate attachment in Appendix for Table description

c) Miscellaneous Forms

- 2 staircase forms		10,000	
Installation thereof		1,500	
- 1 Elevator shaft form		12,000	
Installation		1,800	
	Sub-Total		25,300
- High frequency external vibrators, adjustable force, base plate, clamp, at $400 each, 12 units:			4,800
- 15 KVA 440/240V, 3 phase, 60 cycle transformers, at $750 each, 2 units:			1,500
Installation			250
	Total:		$31,850

4 - Batching Plant.

- 40 cubic yards per hour capacity, including:

Aggregate partitions	
350 bbl cement silo	
Aggregate and cement hopper	
Semi-automatic controls	
Water measuring tank	
Aggregate scraper	
Electric wiring	
Air piping	85,000
Installation thereof	25,000
20 BHP boiler	
50 gpm pump	
Steam pipe	
Return headers	
Water tank	8,000
Installation thereof	7,000

TOTAL $125,000

5 - Material handling equipment

a) Cranes:

In-plant bridge crane, 15 ton 60' span, floor controls		28 000	
2 x 250 feet electrified track, 15/LF		7 500	
Beam and base plate, 24' centers, installation		7 500	
	sub total		43 000
Storage portal crane, 15 ton, 60' span, cab controlled		55 000	
2 x 400' track, installed at 2/LF		1 600	
installation of controls		900	
	sub total		57 500

b) Concrete handling:

4 cuyd skip at $4,500 each		18 000	
2 cuyd buckets, at 1,500 each, 4 units		6 000	
electric carts, at 3 000, 2 units		6 000	
I fork lift truck		7 000	
misc hoists		7 000	
	sub total		44 000
	TOTAL	$144,500	

6 - <u>Auxiliary Services</u>

a) Heating:	For a maximum temperature differential of 60°F, heating requirements are estimated at 100 BTU/hour per square foot of covered area. This amounts to: 100 x 15,000 = 1,5 MBTU/hour for the plant.
b) Curing Concrete	Heat requirements in a vertical Battery Form amount to 120.000 BTU per cubic yard, for a difference of 110°F (1). This is equivalent to: 120.000 x 75 = 9 Million BTU at full capacity. The proposed tilting tables require each 1.8 Million BTU for the same temperature differential when fully loaded. This represents: 1.8 x 8 = 14.4 Million BTU. Total Heat Required: 23.4 Million BTU.

(1) From manufacturer's specifications.

Evidently, curing of elements does not occur simultaneously and at all times, and the boiler capacity need not equal the maximum heat requirements, as the amount of heat is spread over 3 - 5 hours.

Also, heat generated by the concrete curing process reduces gradually the excess heat needed in the Battery, and except for the coldest months of the year, heat curing for the tilting tables is not needed, as they operate on one cycle per day.

From discussions with manufacturers, a boiler capacity of 10 MBTU per hour was considered sufficient.

The corresponding costs are as follows:

1 50 HP Boiler (1.6 MBTU)	4,500
30 radiating fin sections, 10' each at $ 20/ft, installed:	6,000
Boiler installation	2,500
1 300 HP Boiler (10.04 MBTU)	13,500
Steam pipes, return header, installation	7,500
TOTAL	$34,000

c) Light : For an illumination level of 30 lux/sq.ft. and using suspended mercury vapour lamps 35' above floor level, total requirements are :

15.000 x 30 = 450.000 lux

with a reflection loss factor of 2.0, 30 units of 700 watts each are required.

The corresponding costs are:

30 lamp units, 700 W, installed, at $ 250 each:	$ 7,500
Electric installation, junction boxes, starters, etc.	7,500
Total	15,000

d) Power : The required installed power is broken down as follows:

Batching Plant	:	150 KW
Steel Shop	:	20 KW
Joinery Shop	:	10 KW
Cranes	:	35 KW
Vibrators	:	25 KW
Miscellaneous	:	10 KW
Total		250 KW

e) Compressed air : Compressed air is required for some shop tools, and for finishing operations on the precast elements (cleaning, sand blasting, etc.) It is also needed to operate the mechanical parts of the concrete plant. Total requirements have been estimated at a peak of 200 cubic feet per minute.

The corresponding equipment costs are:

1 200 cfm Diesel air compressor:	12,000
Piping, couplings and installation: (including compressed air tank)	8,000
Total:	$20,000

f) Steel Shop

The required equipment and corresponding costs are tabulated below. They represent normal requirements for a small precasting plant, and are sufficient to take care of most of the routine maintenance work.

1 Bender (max. size 1.5" Bar)		1,800
1 Cutter (max. size 2" Bar)		1,800
1 Mesh Cutter (max. size 1/8" wire)		2,500
1 10 KW Welder		400
3 portable steel grinders, $150 each		450
1 fixed stand steel grinder		750
3 benches, at $250 each		750
1 Stand Drill (max. 0.25")		400
1 Electric Saw		850
Misc. small tools		800
	TOTAL	$10,500

g) Joinery Shop

1 Band Saw		750
1 Planar		1,500
1 Stand Drill		750
1 Circular Saw		750
1 Bench		250
Misc. Tools		1,500
	Total	$5,500

h) <u>Laboratory Equipment</u>

Sieve Shaker, complete with accessories:	500.00
Curing Box (40 cylinders)	700.00
Slump Test Outfit	40.00
Portable Beam Tester	600.00
Air and Pressure meter (2 sets)	400.00
1 20 Kg Balance	150.00
1 Double Beam high sensitivity balance	150.00
Moisture Tester and accessories	300.00
1 Laboratory Oven	100.00
2 Electric motors (110V, single phase, 60 cycles)	300.00
1 Concrete cylinder press	3500.00
Miscellaneous Equipment	1500.00
	8240.00

Say: Total $8500.00

j) Office Equipment

6 office rooms are needed to accommodate the administrative personnel of the plant. The equipment and furniture required are common to typical offices, and the breakdown below is merely a tentative outline to establish the order of magnitude of the overall cost of office equipment.

6 Desks	3,000
6 Wheel chairs	950
6 Cabinet Files	1,500
3 Closets	1,500
8 Chairs	400
2 Typewriters	2,000
1 Adding Machine	500
1 Desk Calculator	1,000
Misc. Furnishing	1,000
Office Supplies (1 yr.)	3,650
Total:	$15,500

k) Miscellaneous Equipment

2 way communication system	10,000
Telephone installations	10,000
Sanitary installations	5,000
Cafeteria	5,000
Unaccounted for	20,000
TOTAL:	$50,000

7 - Summary of capital costs

Land	30,000
Building	120,000
Stockyard	5,000
Production	459,500
Batching plant	125,000
Handling equipment	144,500
Laboratory	8,500
Offices	15,500
Boilers	34,000
Light	15,000
Compressed air	20,000
Steel shop	10,500
Joinery shop	5,500
Miscellaneous	30,000
Unaccounted for	20,000
Start-up, I month	80,000
	$1,123,000

C -- ANNUAL PLANT COSTS

1--Procedure

The cost of owning and using equipment in a plant is often subdivided into 4 categories:

Ownership Cost:	Includes depreciation, maintenance, insurance, taxes and storage.
Transportation Cost:	Includes the shipping costs from "ex works" to site, with all the handling associated to it.
Erection, Dismantling Cost:	Includes labour and material costs incurred to set machine in plant, test, and adjust before operations. Dismantling is the cost of removing the equipment from the plant.
Operating Cost:	Includes fuel, oil, grease, steam, small parts and minor repairs on the machine. It excludes operator wages, taxes, insurance and other miscellaneous expenses alreadv cited in ownership costs.

In this study, Transportation and Erection Costs are lumped into Initial Investment, as they usually are included as assets on the Balance Sheet of the company.

Operators and other associated labour are accounted for in Manpower Requirements and Cost analysis, and are not considered here.

Maintenance:	Is taken as a percentage of initial capital investment. The values used are derived from mechanical plant survevs, and published figures in the literature.

Insurance, Taxes:	A lump sum percentage of initial capital investment is applied to all the machinery, regardless of function and use. While this may not reflect working conditions in the real world, the discrepancy is believed to be much lower than uncertainties inherent to investment cost figures.
Operating Costs:	Depending on the available information, operating costs are expressed either as a percentage of initial investment, or as a cost per unit working period. In both cases, expenses are scaled back to an annual total.

Ownership costs represent a fixed sum of expenses allocated to equipment usage. In other words, insurance, taxes and maintenance are largely independent of the rate of utilization of the machinery during the year.

Operating Costs do vary with utilization ratio of the plant. They are directly related to number of hours of usage and level of capacity usage.

The procedure of cost allocation depends on the type of cost considered:

Depreciation: Depreciation expense for any given year is function of equipment life, initial and salvage value, and method used for depreciation allowance.

All through this study, the following guidelines are used:

--Initial Cost to include transportation and erection.

--Salvage Value is zero.

--Life estimate is in accordance with Internal Revenue Service Guidelines, except where special conditions are met.

--Straight-line depreciation is used. (although in financial accounting accelerated methods would certainly be used to provide a greater cash flow in the first few years of operations).

2--Capital charges

Financing: This most important aspect of economic performance is actually impossible to evaluate on purely hypothetical grounds: the financing method, the source of capital and a host of other related factors determine the capital charges on the investment.

Generally speaking, the following may be stated:

- In the case of an independant compnay wishing to enter the market, i.e., start a precasting plant, there is little chance that it might raise the necessary capital through loans from commercial banks. Insurance companies and government sponsored agencies will not support such an enterprise financially. The only source of capital available (besides owner's equity) might originate from investment oriented financial companies, which do provide venture capital. In exchange, they require a share of the stock, a voice in the management, and more often than not, maintain a tight control on the company's operations--
- In the case of an established company wishing to extend its activities to the precasting field, the availability of capital will depend on:

- The relative size of the proposed venture with respect to present assets
- The solidity of the parent company as assessed by the lenders
- The risk level of the proposed venture
- The overall state of the financial market

In any event there is little likelihood that such a new enterprise achieves a leverage much superior to 0.5, that is, the promoters will probably be required to put up at least one half of the initial capital outlay.

In veiw of these brief considerations, it becomes evident that actual capital charges will depend on the specific nature of the proposed company.

For the purpose of this Case Study, it is assumed that 50% of the initial investment is provided by commercial banks through a 5 year laon repayable in five equal payments, at an interest rate of 8%.

Working capital is assumed to be in the form of an overdraft at the same 8% interest rate.

Keeping in mind the assumptions made above, the annual costs of running the proposed precasting plant are exposed in the next paragraphs.

Debt servicing: Initial capital investment was set at 1,123,000 dollars. Of this amount $500,000 is assumed to come from a 5 year bank loan at an interest rate of 8%.

The equivalent annual repayments amount to \$ 125,000 (capital recovery factor = 0.25046). To facilitate the presentation of a financial statement,interest and repayments will be computed separately.

Working capital: Annual turnover is in the range of \$ 2.4 million, that is 800,000 sq. feet x \$ 3.00. Using a ratio of 5 %, slightly higher than the 3% suggested by D. Bishop (1), the working capital amounts to: 2,400,000 x 5% = \$ 120,000. As this amount is assumed to be in the form of an overdraft, the annual cost of the working capital is:

120,000 x 8% = \$ 9,600

(1) Formerly Head of the Building operations and Economics Division of the Building Research Station,Garston,U.K. -personal communication

3- Depreciation

	Life in years	Annual depreciation
Buildings	20	6,000
Production equipment	5	92,000
Concrete plant	5	25,000
Handling equipment	7	20,500
Boilers,compressor	10	7,000
Shops	5	4,000
Miscellaneous	10	9,500
	TOTAL :	$ 164,000

4- Materials

The cost of materials in the production of precast elements is difficult to estimate precisely given the diversity of products which are used: this holds true evan for the basic components of concrete, i.e aggregates, cement and steel. The price of the aggregate depends on the type of rock (quartz,limestone,basalt,marble...),that of cement on its properties (high early strength,normal,slow set...)

In addition to these basic constituents, wood,electric wirings, ducts, pipes, fittings etc are used in the fabrication of panels for such things as doors, windows, sanitary and plumbing fixtures.

Keeping in mind all these factors of uncertainty, the following procedure was used to arrive at an estimate of materials cost:

annual panel production	360 units x 9 panels/unit = 3,240	
average panel area	250 ft. sq.	
average thickness	8"	
annual concrete volume	3,240 x 250 x 8 / 12 x 27 =20,000 cuyd	
average steel reinft	1 %	
annual steel weight	20,000 x 0.01 = 200 cuyd x 6.75= 1350T	
average cost of concrete	$ 20 / cubic yard	
average cost of steel	$ 250 / ton	
annual cost of concrete	20,000 x 20 =	400,000
annual cost of steel	1,350 x 250=	337,500
	sub-total	737,500
	(*)add 25% misc. item	184,250
	Total	922,250
	SAY	$ 925,000

(*) judgment estimate to cover costs of inserts within panels (doors, wirings,fixtures etc.)

5- Labour.

a) Production:

32 labourers @ $ 8,000	256,000	
1 foreman @ $ 10,000	10,000	
sub-total		266,000

b) Management:

1 head engineer	20,000	
1 Production technician	14,000	
3 Design engineers @ $ 15,000	45,000	
2 Draftsmen @ $ 10,000	20,000	
1 Salesman	12,000	
1 Accountant	11,000	
1 Secretary	8,000	
sub-total		130,000

c) Social costs:

insurance, taxes, paid holidays, @ 15 %		59,400
TOTAL :		$ 455,400

6- Power-utilities

a) Electricity

		annual consumptiom in kwh	
Light	20 KW, L.F. 1.0	40,000	
Shops	30 KW, L.F. 0.5	30,000	
Cranes	35 KW, L.F. 0.7	49,000	
Concrete plant	150 KW,,L.F. 0.4	120,000	
Vibrators	25 KW, L.F. 0.2	10,000	
Misc.	10KW , L.F. 0.8	16,000	
	sub-total		265,000
	Transmission losses, 10 %		26,500
	total		291,500
	SAY		300,000

Average electricity cost$ 0.025 / Kwh

Annual cost: 300,000 x 0.025 = $ 7,500

b) Fuel

Concrete curing:	8 MBTU x 8 hours x 140 days	8,960
Plant heating :	2 MBTU x 8 hours x 140 days	2,240
	sub-total	11,200
	Losses,25 %	2,800
	TOTAL	14,000

Average fuel cost: $ 1.0/MBTU

Annual cost : 14,000 x 1.0 = $ 14,000

c) Water

-concrete plant: assuming an average of 500 lb. of water per cubic yard of concrete (this includes water used for heating), the annual consump--tion amounts to :

20,000 x 500 lb x 1 gallon/7.48 = 1,335,000 gallons

-steam curing : assuming 200 lb of water per cubic yard of concrete, a high but conservative figure if recirculation of water is used, this amounts to:

20,000 x 200 lb x 1/7.48 = 535,000 gallons

Total annual quantity of water consumed is thus:

1,870,000 gallons--say 2,000,000 gallons

Average water cost: \$ 0.20/ 1,000 gallons

Annual water cost : \$ 400

d) Summary.

Electricity	\$ 7,500
Fuel	14,000
Water	400
TOTAL	\$ 21,900
SAY	\$ 22,000

7- Maintenance

Production equipment	460,000 x 10 %	46,000
Shops	15,500 x 25 %	3,875
Boilers-compressor	34,000 x 25 %	8,500
Handling equipment	144,500 x 10 %	14,450
Concrete plant	125,000 x 25 %	31,250
Other equipment	100,000 x 20 %	20,000
General plant	@ $ 1.50/ sq.ft.	22,000
	TOTAL:	146,075
	Say	$ 150,000

8- Overhead

Telephone	6,000
Postage	4,000
Travel	12,000
Insurance-general	12,000
Advertising	30,000
Small tools	24,000
Taxes (1)	10,000
Misc. items	12,000
Total	$ 110,000

(1) to cover miscellaneous municipality and state taxes.

9- Summary: Annual costs

Depreciation	164,000
Materials	925,000
Labour	455,400
Maintenance	150,000
Overhead	110,000
Power-utilities	22,000
TOTAL	$ 1,826,400

Debt servicing: $ 125,000

10 - Economic Performance

a) System evaluation: The procedure used here follows the methodology developed in Chapter(V),where the evaluation of the production system was established by:

$$C_p = m + W_d . L_d \left((1-s) + 1/U(s + pq) \right) + C_o/U \left(W + 0.041r + g \right) + 0.041r' \times C_w$$

where:

C_p : selling price per unit of output, \$ / 1,000 sq. feet

m : materials cost

W_d : direct labour wages, \$/hour, including social costs

L_d : manhours of direct labour, per 1,000 sq. feet

s : proportion of supervision and maintenance operatives

U : Utilization rate of plant

pq : ratio of earnings of administrative personal to direct labour

C_o : capital investment, 1,000's of dollars ,per unit capacity

W : amortization and maintenance cost, \$/day per 1,000 invested

r : interest rate sufficient to cover debt servicing costs and provide desired rate of return on capital

r' : interest rate on working capital

g : process on-costs, \$/day per 1,000 invested,to include overhead,utilities,power,consumable stores

C_w : working capital, \$ 1,000's per unit capacity per day

0.041 : \$charge per working day(245 days / year), resulting from a \$ 1,000 loan at 1%

i) Capital charges: C_c.

$-C_o$:Initial capital investment was set at \$ 1,123,000
Daily production: 20 panels
Average panel area : 250 sq. feet
Daily panel area produced: 250 x 20 = 5,000 sq. feet

Then $C_o = 1,123/5 = 225$

$-W$: From section (9)

Depreciation	: \$ 164,000	
Maintenance	: \$ 150,000	
Debt repayment	: \$ 100,000	(excluding interest)
Total	: \$ 414,000	

Then $W = 414,000/1,123 \times 245 = 1.50$

$-C_w$:Working capital was estimated at \$ 120,000

Then $C_w = 120/5 = 24$

$-r, r'$: Two interest rates are distinguished here:
8%,cost of borrowing capital
20%,desired return on equity,before taxes
As \$ 500,000 are borrowed an equivalent rate must be computed for the total investment.The derivation follows:

8% on 500,000 = 3.56% on 1,123,000 (cost of loan)
20% on 623,000 = 10.11% on 1,123,000 (profit)

Then $r = 13.67\%$, $r' = 8\%$

$$C_c = 225(1.50 + 0.041 \times 13.67) + 0.041 \times 8 \times 24$$

$$C_c = \$\ 465$$

ii) Materials, m :Materials costs were estimated at \$ 925,000 for 3,240 panels 250 ft.sq. each.
The cost per 1,000 sq. ft. amounts to:

$$m = 925,000/3,240 \times 250 = \$\ 1,140$$

iii) Labour , C_L :

W_d = \$ 4.60 (\$ 4.0 direct, 15% social costs)
L_d = 66 manhours (33 workers, 8 hours/day, 4,000 sq. ft.)
s = 0.10 (3 indirect labour/30 direct)
pq = 130,ooo/266,000 = 0.49

Then $C_L = 4.60 \times 66((1-0.1) + (0.1 + 0.49))$

C_L = \$ 455

iv) Overhead and consumable stores, g : From section (9)

Overhead :	\$ 110,000
Power, utilities	\$ 22,000
Total	\$ 132,000

Then $g = 132{,}000/1{,}123 \times 245 = 0.50$

At full capacity the plant will thus be able to sell its products at a cost of :

$C_p = m + C_c + C_L + C_0 \times g$

C_p = 1,140 + 465 +455 112 = 2,172 dollars per 1,000 sq. ft

Or : \$ 2.17 per square foot

Naturally this represents ideal conditions which are seldom if ever approached in reality. For example, assuming the plant is producing at an annual output corresponding to the expected market of 360 dwelling units this is equivalent to a plant utilization rate of:

Panels for 360 units: 9 x 360 = 3,240
maximum annual output 20 x 245 = 4,900

Then U = 3240/4900 = 0.66

The corresponding value of C_p , using the same equation then becomes : C_p = 2.68 dollars/sq. ft.

The results for varying plant utilization rates and labour produvtivity are shown on figure (69).

b) Classical evaluation: This take s the form of a hypothetical Income Statement after one full year of operations.As interest paid on borrowed capital is an expense deductible before income taxation, we assume here that the \$ 500,000 loan is repaid in 5 annual payments of \$ 100,000 each, and the interest is paid on the balance. The Statement below corresponds to the third year of operations, where outstanding debt is \$ 300,000 , and annual output is 360 dwelling units :

Sale of 810,000 sq.ft. @ \$ 2.70/ sq. ft.		\$ 2,187,000
Materials	925,000	
Labour	455,400	
Maintenance	150,000	
Overhead	110,000	
Power-utilities	22,000	
Sub-total	\$ 1,662,400	
Depreciation	164,000	
Interest on loan	24,000	
Interest on W. capital	9,600	
Sub-total	197,600	
TOTAL	\$ 1,860,000	
NET INCOME BEFORE TAX		327,000
Income tax @ 50 %		163,500

NET INCOME AFTER TAX	$ 163,500	
Debt repayment	100,000	
NET AVAILABLE INCOME	$ 63,500	
AFTER TAX RETURN ON EQUITY	10.2 %	(63,500/623,000)

D- Future Growth

1- Date of Limit Capacity

The initial plant design was based on an number of assumptions and derivations which are summarized below :

- -Production to serve the market as of 1976
- -Initial production geared to residential construction
- -Maximum annual output of 540 dwelling units, assuming 9 panels per unit, 1 casting cycle per 8 hour day.
- -Annual growth rate of the market = 5 % (probable value)
- -Precast market share = 15 % ot total construction (1976)

With the same labour force,it is difficult to achieve more than one casting cycle per day. However,using 2 shifts per day, it is possible to obtain 2 castings per day in the Vertical Battery and in the Tilting Tables, when high early strength cement and temperature curing are used.

The equivalent output for the latter conditions is 40 panels per day (2x12 in the Battery and 2x8 in the Tables).This corresponds to 9,600 panels in 245 working days per year,or 1,060 dwelling units.

Our most optimistic forecast predicted a market for 720 units in 1976, and a growth of 8 % annually:This represents 980 units in 1980, and corresponds to thirty per cent of the residential market by then.

In contrast, our"expected"marketforecast calls for a 5 % growth annually,starting with 360 units in 1976:This amounts to 440 units in 1980, well below full capacity of the plant running one cycle per day.

We may thus safely conclude that the present plant design is adequate to meet any demand for residential construction until the early 1980's.

There remains two aspects of the precast market to tackle:

-the non-residential market,which was considered too small initially to justify a permenant investment in production facilities.

-Hollow core slab production,which could serve both the residential and non-residential markets, and greatly increase the flexibility of the plant with regard to the use of different competing building systems.

2- Hollow core slab production

The market analysis for the Springfield SMSA showed a potential for 260,000 square feet of non-residential construction in 1976,using precast elements.By 1980, and assuming a growth rate of 5 % (Table50) this amount becomes 340,000 square feet. Appendix (D),which evaluates the feasibility of producing hollow core slabs, indicates that a minimum od 240,000 square feet must be sold annually just to recover the production costs, under full capacity utilization-(i,000,000 square feet).Thus, at first glance it would seem premature to plan for such a facility early in the 1980's.Let us remember however that a very conservative approach was used to estimate the market for precast elements in non-residential construction: only floor areas were considered then, excluding elements for walls.If we assumed a wall to floor ratio of 1 to 4 , this would add another 85,000 square feet of precast elements to the market estimate of 340,000 sq. ft. (by 1980): the outlook for a hollow core slab plant becomes then brighter.

The decision to go on with the production of hollow core slabs depends thus essentially on the validity of the market forecasts, for the period 1976-1980:

The actual net cash flow of the company operating the precasting plant is the best indicator of the possibilities for future expansion. Capital scheduling under uncertainty is a complex problem in itself and cannot be dealt with here.

VIII-CONCLUSION

CONCLUSION

In this thesis we have restricted ourselves to the study of the manufacturing processes of precast concrete as applied to industrialized construction. We have attempted to identify and evaluate the various factors which influence the development and performance of precasting plants, and suggested a systematic approach for the design of such facilities. From these considerations, the following conclusions may be drawn:

a) The precast concrete industry represents a small fraction of the construction industry in the United States as of 1971. Its growth has been very rapid in the past ten years, and one may expect its share of the market to increase by the end of this decade, especially in the field of residential construction.

b) From the information at hand, the precast concrete industry seems to have grown in a haphazard and dispersed way: There are no signs of a general policy for the standardization of components such as may be found in some European countries. There appears to be no general pattern of development and no concerted action for research and marketing.

c) The industry has solved most, if not all, of the technical problems associated with the production and erection of precast elements. Actually, its level of technology is more advanced than its achievements in marketing and promoting its products.

d) The decision to establish a new precasting plant obeys the same criteria which apply for any new manufacturing venture: the major pre-requisites are:

- a sufficient market size to absorb the output of the minimum economic size plant. This market was found to be equivalent to that of an average SMSA (Standard Metropolitan Statistical Area).

- a continuous and sustained demand for precast products: it is more important for the plant to have a sure market over a period of years than to operate part of the time at peak capacity, and the rest of the time remain almost idle--the main reason being the high capital charges resulting from the heavy initial investment in plant facilities.

- flexibility in the types of elements produced, so as to compete successfully for different types of projects and meet the requirements of the architects. This increases the production costs of components, especially for small runs of 50--60 units, thus reducing to a certain extent the advantages derived from mass production.

e) Given the newness of precasting in this country, hence the uncertainty of the market for precast products in a given area, and considering the flexibility of output that may be achieved by using accelerated methods of curing, for example, a potential precaster should design his plant for the minimum economic output initially, and then expand if market conditions permit. The penalty of idle capacity is too severe to be acceptable for any substantial period of time, when initial capital immobilizations are so high. It follows that an independent precasting plant is presently considered a risk venture: To cushion the impact of market uncertainty, such plants should be linked to companies operating in related fields, such as Real Estate development, or the building materials industry (cement, aggregates, ready-mix, etc.)

f) Looking towards the future, panel systems will probably continue to lead in the field of residential construction, until box systems come to maturity. These alone allow up to 90% in-plant completion, drastically reducing the manhour requirements on-site, and achieving substantial economies in the overall construction cost of buildings.

TABLES

TABLE: 1

EFFECT OF CHANGES IN OUTPUT ON PRODUCTION TIME PER UNIT

Production time	Annual output			
	15 000m^3	30 000m^3	75 000m^3	150 000m^3
Workers of the production line:				
Hours/panel	1.02	0.89	0.76	0.73
Hours/m^3	1.16	1.02	0.88	0.85
All workers:				
Hours/panel	6.4	5.7	4.9	4.6
Hours/m^3	7.4	6.5	5.7	5.9

Source: Reference No: 135

TABLE: 2

EFFECT ON UNIT COSTS OF CHANGES IN CAPACITY OF PRE-CAST CONCRETE COMPONENT FACTORIES IN THE UKRANIAN SSR[1]

Indicators	Annual capacity in cubic meters			
	20 000	40 000	60 000	10 000
Cost of basic equipment..	100	147	184	204
Number of workers	100	138	181	225
Output per worker	100	145	166	196
Cost per cubic meter of output	100	87	82.5	75

1/ United Nations, Economic Commission for Europe, Cost, Repetition, Maintenance: Related Aspects of Building Prices (Geneva, 1963), P. 32
Reference 134

TABLE: 3

EFFECT ON REP ON COST - U.N.

VARIATION OF UNIT COST WITH DIFFERENT MODEL SIZES: CONCRETE FLOOR PANELS (DENMARK)

Length of element, m —	4.80	4.50	4.20	3.90	3.60	3.30	3.00	2.70	2.40
Cost of materials, Kr/m^2...	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
All other costs, Kr/m^2.....	18.75	20.00	21.43	23.08	25.00	27.27	30.00	33.33	18.75
Production cost, Kr/m^2.....	28.75	30.00	31.43	33.08	35.00	37.27	40.00	43.33	28.75

Note: Kr. = Kronor,Danish currency

Source: Reference No.135

TABLE: 4

INFLUENCE OF ANNUAL OUTPUT (SIZE OF PLANT CAPACITY) ON COST PER M^3 OF FLOOR PANEL

Elements of cost	Unit cost, Kčs per m^3 of panel for an annual output of: (in 1000's of m^3)				Unit cost as percentage of total unit cost for a basic output of 15,000 m^3 and for an annual output of: (in 1000's of m^3)			
	15	30	75	150	15 (%)	30 (%)	75 (%)	150 (%)
Materials	207.5	200.0	195.0	190.6	51.4	49.6	48.3	47.2
Direct wages	20.8	18.4	16.1	15.4	5.2	4.6	4.0	3.8
Fuel & power	14.1	13.3	12.1	11.3	3.5	3.3	3.0	2.8
Workshop overheads	125.2	97.7	80.8	62.3	31.0	24.2	20.0	15.4
Factory overheads	19.7	17.4	14.1	11.7	4.9	4.3	3.5	2.9
Spoiled work	3.1	2.8	2.0	1.6	0.7	0.7	0.5	0.4
Form wear	2.8	2.8	2.8	2.8	0.7	0.7	0.7	0.7
Sales cost	10.6	10.6	8.1	7.3	2.6	2.6	2.0	1.8
Total unit cost	403.8	363.0	331.0	303.0	100.0	90.0	82.0	75.0

Note: The standard floor panel with dimensions 530 x 100 x 21.5 cm has a volume of 0.6 m^3.

Source: Reference No: 135

TABLE: 5

VOLUME DISCOUNTS

Material	Retail Cost In Small Quantities	Retail Cost In Carload Lots
Gypsum board	1	0.75-0.85
Plumbing fixtures	1	0.93
Lumber	1	0.86
Shingles	1	0.98
Appliances	1	0.92
Doors	1	0.95
Kitchen cabinets	1	0.77
Insulation	1	0.92
Electrical fixtures	1	0.95-9.97

Source: Reference No. 30

TABLE: 6

COMPARATIVE SAVINGS IN

MATERIALS LOSSES

Item	Site construction	Precasting Plant
Cement	6 %	1 %
Aggregates	4 %	negligible
Steel	3 %	3 %

Source: reference 103

Note: Cement represents approximately 60 % of the cost of concrete A saving of 5 % on cement corresponds to a saving of 3 % on the cost of one cubic yard of concrete. For an annual output of 20,000 cubic yards @ $ 20/cuyd, this equivalent to a saving of $ 12,000 annually.

TABLE: 7

MATERIAL USE BY TYPE OF STRUCTURE IN BUILDING SYSTEMS

Hi-Rise up to 8 floors:	Wood :	12%
	Concrete:	22%
	Steel :	13%
more than 8 floors:	Wood :	---
	Concrete:	20%
	Steel :	8%

PERCENTAGE OF FACTORY BUILT HOUSING WITH RESPECT TO TOTAL CONSTRUCTION (EXCLUDING MOBILE HOME TYPE)

1970:	less than 1% :	approximately 22,000 units
1972:	less than 5% :	approximately 100,000 units
1973:	less than 9% :	approximately 250,000 units
1974:	less than 30% :	approximately 550,000 units annually until 1980

Source: Ref. No: 65

TABLE : 8

THERMAL CHARACTERISTICS
OF
SOME BUILDING MATERIALS

MATERIAL	density lb/ft^3	thermal conductivity $\frac{BTU\ in/ft^2}{h\ ^oF}$	heat absorption $\frac{BTU}{ft^2\ h\ ^oF}$ approx.
reinforced concrete	156	10.7	2.70
asphalt concrete	131	7.2	2.87
pine	34	1.2	0.74
aluminium	169	1420.0	
glass	156	5.2	1.98
mineral wool	12	0.4	0.16
plywood	37	1.2	0.77
steel	490	403.2	22.20

Source: Reference 115

TABLE 9

PANEL DIMENSIONS IN THE U.S.A

Wall Panels (Solid) Based on 149 plants producing

Width	Average: 10' 6"
	Range: 7' 6" min. to 30'0" max.
	Largest panel reported: 30'0" x 30'0"
Length	Average: 35'0"
	Range: 10'0" min. to 60'0" max.
Thickness	4", 5", 6", 8"
Weight	Average: 20 tons
	Heaviest panel reported: 80 tons

Source: Journal of the PCI, Vol. I4,no3, page 14 +
reference: 90

TABLE : 10

Swedish Survey

Slab Panels* based on all plants producing

Width	Average: 18' 0"
	Range: 12'6"--30'0"
	Largest Panel Reported: 30'0" x 32'0"
Length	Average: 23'4"
	Range: 15'0"--43'3"
Weight	Average: 6.6 tons
	Range: 1.3--11.2 tons

*Including hollow-core slabs

Source: National Swedish Building Research, Document No. 1, 1969. (Element Building Systems in Apartment Blocks) Reference 35

Remarks

There is a clear difference in average weight per element, essentially due to the inclusion of hollow slabs in the Swedish data.

Extreme lengths are much longer in the U.S.A., owing perhaps to better transportation facilities.

The average Swedish panel is rather square (18' x 23'), whereas the U.S. panel is definitely rectangular (10' x 35').

The covered area, however, is larger for the Swedish panel (414 ft.^{2} vs. 367 ft.^{2}), but not significantly so (11%).

TABLE: 11

COMMON DEFECTS IN PANEL PRODUCTION

Damage	Cause
Warping:	Excessive stacking, or incorrect or insufficient lifting points during handling.
Cracking:	Excessive temperature during curing process. Shock or vibration due to transportation on carts with steel wheels, on irregular floor surfaces.
Chipping:	Leaking forms at the corners. Excessive reinforcement density which prohibits concrete to fill the voids. Incorrect stacking in stockyard. Insufficient protection against shocks when secured on trailers.

TABLE: 12

SYSTEM PREFERENCES IN THE U.S.A., 1970

HUD Study:	Modular :	50%
	Panel, Skeletal:	45%
	Other :	5%
LCA Study:	Modular :	54%
	Panel, Skeletal:	20%
	Other :	26%

% Output by type of structure

Single Family :	38%
Garden Apt :	37%
Medium Rise :	15%
Hi-Rise more than 8 floors:	10%

Source: Ref. No: 65

TABLE: 13

TOTAL CONSTRUCTION COSTS

CONVENTIONAL BUILDING METHODS

	Low	1st Quartile	Median	3rd Quartile	High
Elderly Housing (Mainly Massachusetts)					
without overhead & profit	$ 10.40	$ 19.25	$ 22.45	$ 27.75	$45.00
with recommended 25% O & P	13.00	24.05	28.05	34.70	56.25
Public Housing Projects					
without overhead & profit	9.15	13.30	15.05	18.40	33.00
with recommended 25% O & P	12.45	16.60	18.80	23.00	41.25
Apartments					
without overhead & profit	7.20	12.15	15.00	18.00	28.00
with recommended 25% O & P	9.00	15.20	18.75	22.50	35.00

Source: Means, Building Construction Cost Data 1970.
Reference No.75

TABLE: 14

COST PER SQUARE FOOT OF BUILDING

	Labor cost, shell	Material cost, shell	Total cost, shell	Total direct cost building
Conventionally built (average 2 New York projects)	$3.67[1]	$2.40[2]	$6.07	$14.07
Industrially built	2.02[3]	1.76	3.78	11.78
Difference	1.65	.64	2.29	2.29
Savings (per cent)	45	27	38	16[4]

"High-Rise" New Haven Apartments - 16 Stories, 915 Sq.Ft./D.U.

[1] As the cost breakdown for the conventionally built New Haven shell was not available, average figures of projects of similar New York construction were used. Man hours per sq.ft. of shell are : 0.51.

[2] Includes labor cost for mixing concrete.

[3] Using the ratio of factory to site labor and the above average rates, the number of man hours per sq.ft. of shell is 0.34.

[4] Labor 11 percent; materials 5 percent.

Note: Comparison of conventional concrete frame construction using masonry and drywall partitions and industrialized construction using precast walls and partitions and site cast slabs. Labor Cost Average: Factory $3.75 per hour, site $7.15 per hour.

Source: Reference No:30 A , page 329

TABLE: 15

COST PER SQUARE FOOT OF BUILDING

	Labor cost, shell	Material cost, shell	Total cost, shell	Total direct cost building
Conventionally built	$ 2.55[1]	$ 2.35[2]	$ 4.90[3]	$ 14.00
Industrially built	2.29[2,4]	1.71	4.00	13.10
Difference	.26	.64	.90	.90
Savings (percent)	10	27	19	7[5]

[1]Man hours per square foot of shell are: 0.33

[2]Includes labor cost for mixing concrete.

[3]At the average labor rates, the number of man hours (factory and site) per square foot of shell are: 0.37.

[4]Cost breakdown per square foot is as follows:

	Square foot	Percent
Engineering	$0.05	2
Factory work	1.00	44
Site work	1.24	54
Total	$2.29	100

[5]Labor 2 percent; materials 5 percent.

Note: Comparison of conventional precast and prestressed concrete cosntrucion with drywall partition and industrialized construction with precast walls and partitions and site-case slabs. Labor cost average: Factory, $3.80 per hour, site $7.80 per hour.

"Low-Rise" Rochester Apartments -2 Stories, 840 Sq.Ft./D.U.

Source: Reference No:30 A , page 328

TABLE: 16

BREAKDOWN OF CONSTRUCTION COSTS

	Materials $		Direct Labor $		Overhead & Profit $		Total $
Single-family detached, conventional on-site construction	5.94	(53%)	2.99	(27%)	2.24	(20%)	11.17
Single-family detached, manufactured box units;							
On-site	1.21	(54%)	0.57	(26%)	0.45	(20%)	2.23
Off-site							7.44
							9.67
Multi-family 15-story apt., conventional on-site construction	9.00	(51%)	5.22	(30%)	3.42	(19%)	17.64
Mobile home, furnished	4.82	(68%)	0.82	(12%)	1.45	(20%)	7.09
Mobile home, furnished (Reston Report)	3.94	(67%)	0.35	(6%)	1.59	(27%)	5.88

Source: Reference No: 30A page 326

TABLE: 17

DIVERSIFICATION CLAIMS OF 207 MODULAR BOX FIRMS

Types of modular box units produced:	Percentage of Manufacturers
Single-family	85.9
Multi-family	42.7
Vacation house	43.2
Twonhouse	38.8
Non-residential	43.7
Other types of building manufacturing done:	
Mobile homes	30.1
Prefabricated (packaged) components	27.2
Basic structural material used:	
Wood	67.0
Metal	10.2
Wood-metal combination	24.3
Concrete	2.4
Other	2.4
How units are sold:	
Sell to any qualified builder-developer	71.4
Sell to franchise dealer-erectors	35.4
Produce for own company use	16.0
Manufacture and put in place for others	31.6
Other methods	10.2

Source: Professional Builder, "Who's Who in Modulars," November 1970.

TABLE: 18

USAGE PATTERNS OF BUILDING SYSTEMS

Among those who have used building systems:

	Arch	Eng	GC's	All
Widely used and widely accepted	23.1%	33.3%	42.5%	32.4%
Used but not as frequently as possible	75.0	63.9	47.5	63.4
Not ready for use, nor are they perfected	1.9	1.4	7.5	3.0
No answer	---	1.4	2.5	1.2
	100.0	100.0	100.0	100.0

Outlook for next 12-24 months among previous users:

	Arch	Eng	GC's	All
Extremely optimistic	26.9%	30.6%	35.0%	30.5%
Expect to use more often, due to cost savings/labor shortage	65.4	61.1	52.5	60.4
Don't expect to use, until they prove to be a better way of doing things	7.7	8.3	12.5	9.1
	100.0	100.0	100.0	100.0

Source: Building Design & Construction/September 1971, p: 28

TABLE: 19

AREAS OF PANELS IN VARIOUS DWELLING TYPES

	Low				High			
	Narrow frontage		Wide frontage		Maisonette		Corridor	
Area within dwellings	840		791		845		636 (i)	
Access	76		49		127		156	
	916		840		972		892	
Panel type	ft^2	r (ii)	ft^2	r	ft^2	r	ft^2	r
External panels	400	0.48	465	0.59	461	0.55	325	0.51
Internal load/bg	680	0.81	657	0.83	784	0.93	468	0.74
Floors and roofs	1,074	1.28	1,028	1.30	1,063	1.26	937	1.48
Total (iii)	2,165	2.56	2,150	2.72	2,308	2.74	1,730	2.73
Partitions	483	0.58	394	0.50	405	0.48	292	0.46
Total (iii)	2,647	3.5	2,544	3.21	2,713	3.22	2,022	3.19

(i) Mixture of two-and three-bedroom dwellings with smaller than average floor area

(ii) $r = \frac{\text{area of element}}{\text{useful floor area}}$

(iii) Plus specials, stairflights say, 50 ft^2/dwelling

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

TABLE: 20

PRECAST UNITS PRODUCT MIX

	Volume	%
Flooring :	21 000 m^2	56
Bearing Walls :	9 000 m^2	24
Façade Panels :	7 000 m^2	20
Other Elements:	6 000 m^3 (1)	

(1) Such as balconies, stairs, cornices etc...

Source: J. Barets: An example of heavy prefabrication at high altitude - Paper F1, Ref. No.:8

TABLE: 21

PRECAST UNITS PRODUCT MIX

	per cent
Floor slabs and panels	28.0
Wall and partition panels	20.5
Outside wall panels and block panels	16.5
Roof slabs and panels	6.0
Columns and beams	5.0
Roof trusses	2.0
Stair components	1.7
Bridge structures	1.3
Miscellaneous items and individual products	19.0

Source: United Nations, Ref. No.: 137 , page 98

TABLE: 22

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: Reference No. 141

TABLE: 23

REPRESENTATIVE RANGES IN THE OUTPUTS FOR CONSTRUCTION MIXERS

Size mixer	Time per cycle, min Min	Max	Batches per hr Min	Max	Output,* cu yd per hr Min	Max
3 1/2S	1.5	2.25	27	40	3.5	5.2
6S	1.5	2.25	27	40	6.0	8.9
11S	1.5	2.5	24	40	9.8	16.3
16S	1.5	2.5	24	40	14.2	20.1
28S	1.75	2.75	22	34	22.6	35.3
56S	2.00	2.75	22	30	45.6	62.3
84S	2.25	3.00	20	27	62.2	84.0
112S	2.50	3.25	18	24	74.5	99.5

* These values are based on a 60-min hour and should be adjusted to fit actual job conditions.

Source: reference 127

TABLE: 24

COMPARISON OF CONCRETE PLANT MIXER TYPES

Typical Characteristic	Single-compartment two-opening nontilting type	One-opening tilting type mixing angle of drum 15° with horizontal	Two-opening rear-charge and front-discharge horizontal drum tilting type	Vertical-shaft type	Horizontal shaft type
Slump range, in..	2-5	0-3[a]	1 1/2-3[a]	0-5	0-5
Max aggregate size, in.[b]	2 1/2	6-10	6-8	1 1/2-2 1/2	1 1/2
Mixing time, sec[c]	60-90	50-180[c]	50-180[c]	20-60	180-300
Peripheral drum or blade speed	270-300	280-310	260-370	550-750	270-290
Revolutions per minute	10-17	8-13 1/2	9-15 1/2	18-25	20
hp/cu yd...........	10-18	8.6-10	8.9-15	28-40	20-35
kwhr/cu yd.........	0.21-0.42	0.13-0.54	0.14-0.71	0.33-0.87	0.79-2.12
Charging time, sec[d]	15	10-15	15-30	15-30	15
Discharging time, sec	30-40	10[e]	15[e]	20-30	15-25
Cycle time, sec....	105-145	85-215	90-220	65-120	220-340
Liner and blade wear[f]	Moderate	Low	Low	Very high	High

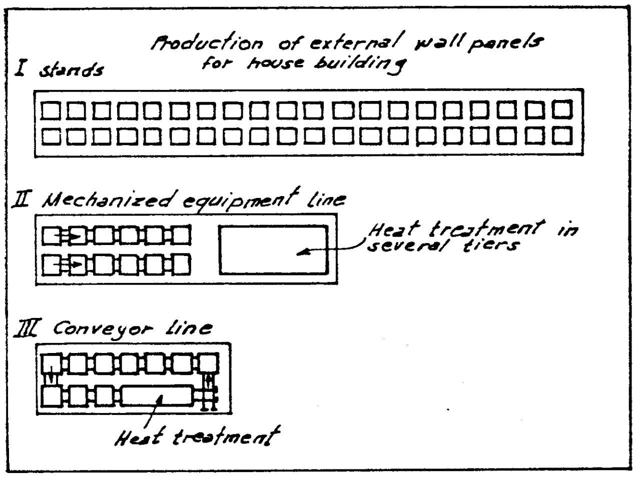
COMPARISON OF CONCRETE PLANT MIXER TYPES

Typical Characteristic	Single-compartment two-opening nontilting type	One-opening tilting type mixing angle of drum 15^{o} with horizontal	Two-opening-rear-charge and front-discharge horizontal drum tilting type	Vertical-shaft type	Horizontal shaft type
Hydraulic discharge, hp/cu yd...........	g	3-6	2-5		
Air discharge, cu ft free air/cu yd.....	1-2	4-7	3-10	9-14	1-2
Concrete temp rise, ^{o}F per min of mixing	0.4	0.3	0.3	1.0	0.9

Source: W.H. Taylor,
Concrete Technology and Practice Ref. No: 127

TABLE: 25

RELATIVE SCALE OF OUTPUT

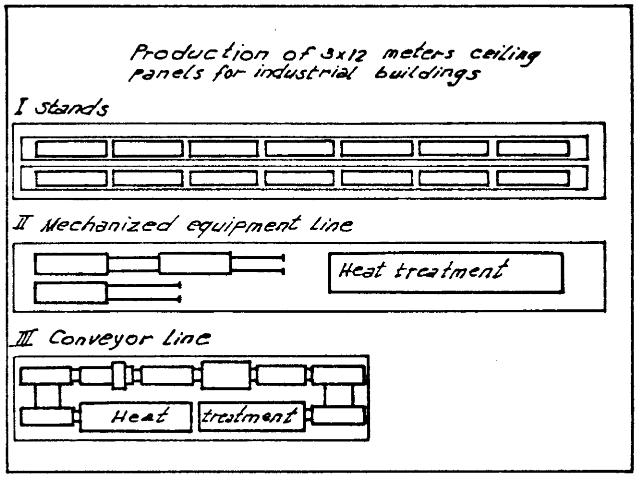


Ratings	I	II	III
1. Output per m^2 of production area in m^2 of articles per year	504	762	1500
2. Weight of equipment per m^2 of article in Kg.	0.7	0.9	1.0
3. Output per worker in m^2 of articles per year	1530	2720	7000

Source: Reference No.128 , page 308

TABLE: 26

RELATIVE SCALE OF OUTPUT



Ratings	I	II	III
1 Output per m^2 of production area in m^3 of precast reinforced concrete	22.4	12.0	16.0
2 Weight of equipment per m^3 of precast reinforced concrete in Kg	48.7	24.1	21.6
3 Output per worker in m^3 of precast reinforced concrete	281	812	2000

Source: Reference No.128, page 308

TABLE: 27

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

Source: Reference No.14 , page 34

TABLE: 28

LABOUR REQUIREMENTS FOR CASTING LARGE PANELS

Mould type	Panels produced	Area of average panel (ft^2)	Manhours (labour directly involved in casting)	
			Mh/pan	Mh/100ft^2 pan
(a) Horizontal, on concrete bed, normal curing (1- or 2-day cycle), timber edge moulds	Loadbearing walls, floors with light-weight infill: not self-finished	76	4.7	6.2
(b) Horizontal, wall panels in tilting moulds, air cured for 1 or 2 days, floor panels in timber framed moulds, and hot air cured for 12 h	External and internal walls, some complicated. Cored floor panels. Not self-finished	68	5.3	7.8
(c) Horizontal steel tilging moulds, accelerated curing on 4-hour cycle, steel edge moulds	External wall panels with in-fill surface finish and openings. Internal walls with openings	89	3.5	4.0
(d) Horizontal, steel pallet, accelerated curing on 1-day cycle, handled by crane from vibrating supports to curing bay	Cored floor panels, of uniform width, self-finished on soffit	56	0.8	1.3

LABOUR REQUIREMENTS FOR CASTING LARGE PANELS

Mould type	Panels produced	Area of average panel (ft^2)	Manhours (labour directly involved in casting	
			Mh/pan	Mh/100 ft^2 pan
(e) Horizontal steel pallet, accelerated curing in curing tunnel, handled on conveyor system	Cored floor panels, uniform width, self-finished on soffit	41	1.0	2.5
(f) Horizontal, continuous casting (Kozlov) process (as claimed)	Waffle wall and floor panels self-finished on the surface	Up to 12x40 ft	-	1.4
(g) Vertical in batteries operated on 1-day cycle	Wall and floor panels without openings, self-finished	135	2.6	1.9
(h) Vertical in batteries operated on a 1-day cycle, some operations mechanized	Standard wall panels, some with conduits and other fittings, self-finished	52	1.4	2.6

Note: All examples assumed to be operating at rate intended by promoter: this is seldom achieved in practice.

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

TABLE: 29

MAN-HOUR REQUIREMENTS

HORIZONTAL CASTING OF LARGE PANELS

Operation	Man-Hours per 100 ft^2 Range	
Casting	4.0	4.3
Steel Placing	1.7	1.4
Finishing	0.2	1.1
Dispatching	0.8	0.6
Total	6.7	7.4

Source: Overseas Building Notes, No. 97
Building Research Station, Garston, England

TABLE: 30

VERTICAL CASTING OF LARGE PANELS

Operation	Man-Hours per 100 ft^2
Casting	1.9
Steel Placing	1.7
Making Good	0.2
Dispatching	0.8
Total	4.6

Source: Overseas Building Notes, No. 97
Building Research Station, Garston, England
Reference: 19

TABLE: 31

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 ft² of panel	per panel	per 100 ft² of panel	per panel	per 100 ft² of panel	per panel	per 100 ft² of panel	per panel	per 100 ft² 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

TABLE: 32

MONTHLY CRANE RENTALS

Size	Bare Crane	Operators	Total
30 T truck mounted	$1980	$4224	$6204/month
35 T " "	2420	4224	6644
40 T " "	2640	4224	6864
45-50 T " "	3036	4224	7260
60-65 T " "	3696	4224	7920
70 T " "	4576	4224	8800
82 T " "	5588	4224	9812
90 T " "	5896	4224	10120
140 T crawler	9000 + set up	4500	13500 + set up
150 T "	6000 + 2000 set up	4600	10600 + 2000 set up
300 T crawler with an outrigger ring	9000 + 5000 set up	4600	13600 + 5000 set up

Source: Reference No: 30 A , page 355

TABLE: 33

LABOUR REQUIREMENTS FOR SUPERSTRUCTURES OF TWO BLOCKS OF FLATS (i)

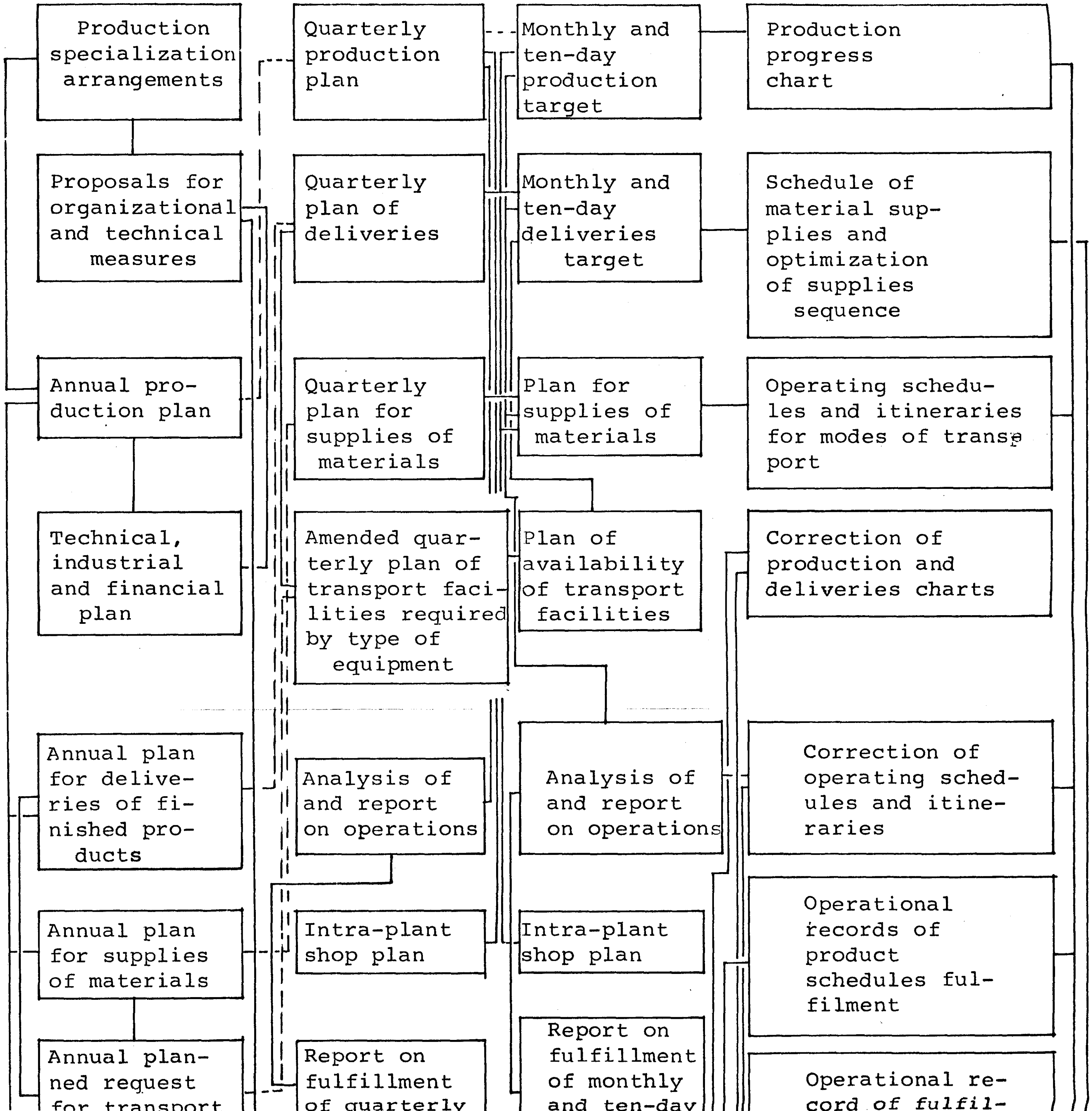
	Manhours per dwelling (ii)			
	A Building constructed with average-quality panels and finished in the ordinary way		B Building constructed with high-quality panels and designed to reduce work of finishing trades	
Panels delivered to site		256		235
Site				
Erect, joint and make good	149		126	
		405		361
Finishings				
Partitions and linings	51		25	
Plastering	89		58	
Joinery	166		43 (iii)	
Plumbing and heating	83		11 (iii)	
Painting and glazing	190		43	
Sub-total	579		180	
Specialists	88		78	
Finishings		667		258
Total		1,072		619

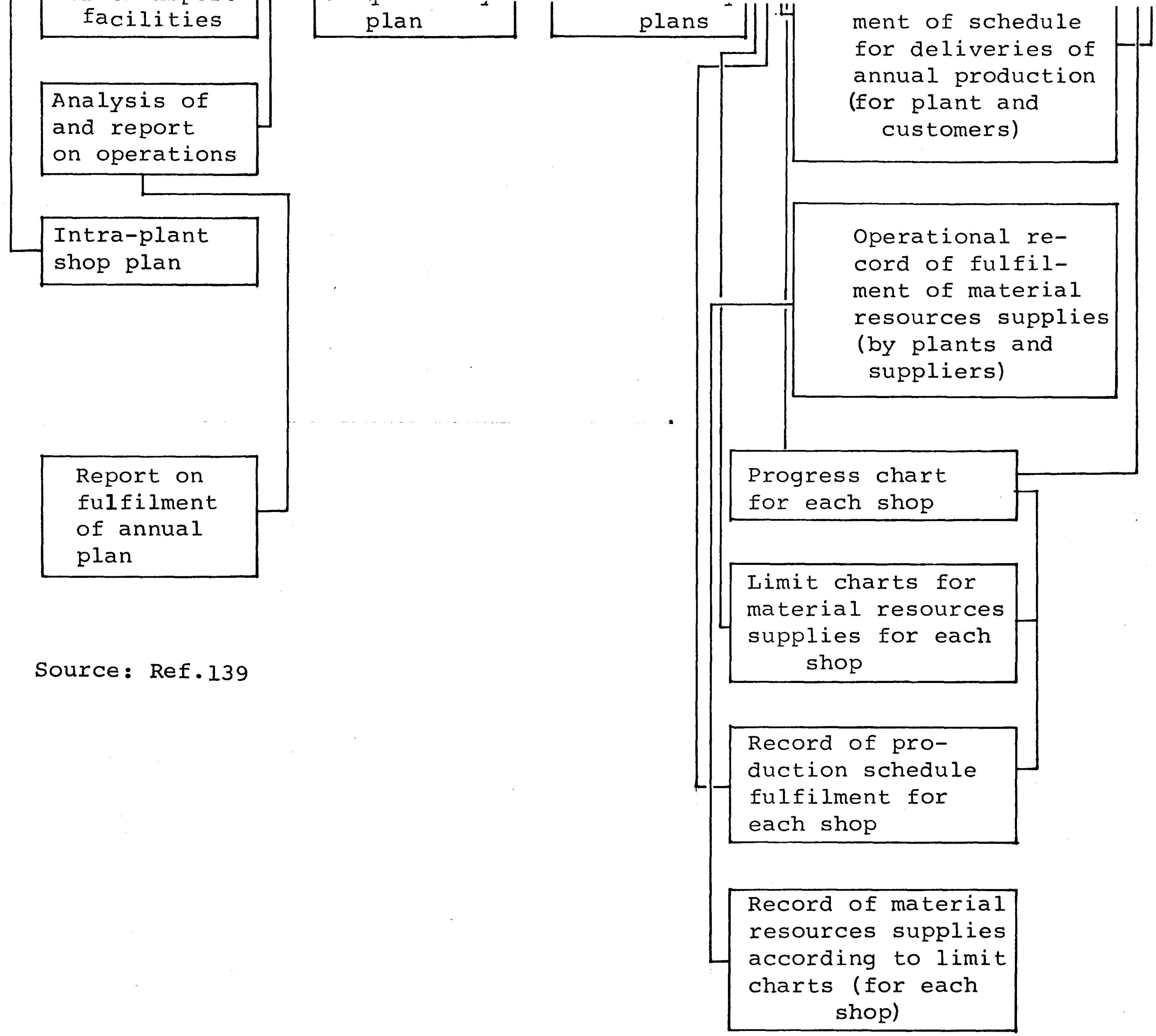
(i) Stairwell access: three-roomed dwellings

(ii) Roughly 2,200 ft^2 of panel

(iii) Mostly prefabricated

Source: Reference No.20

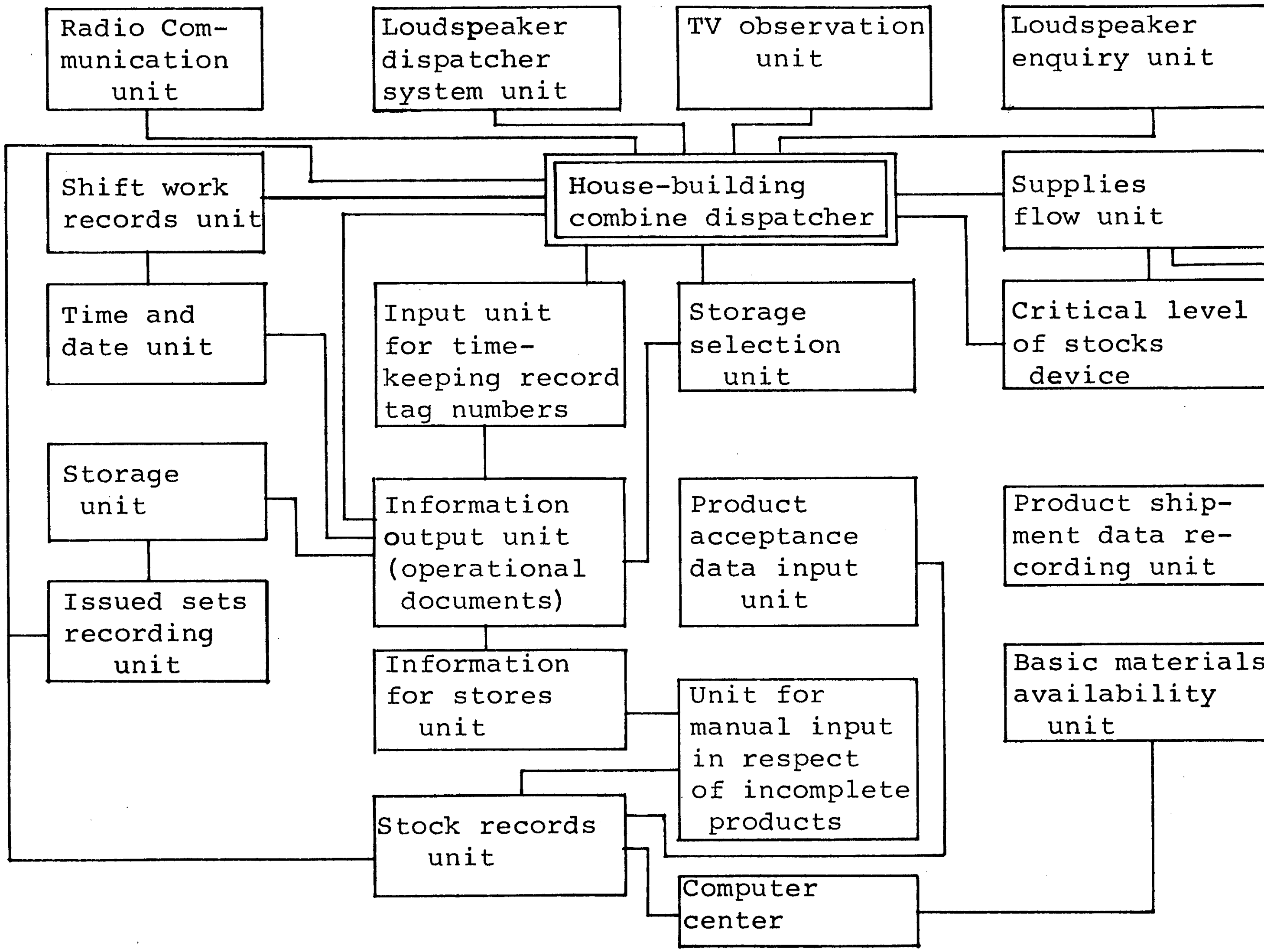

Production specialization arrangements
Proposals for organizational and technical measures
Annual production plan
Technical, industrial and financial plan
Annual plan for deliveries of finished products
Annual plan for supplies of materials
Annual planned request for transport
Quarterly production plan
Quarterly plan of deliveries
Quarterly plan for supplies of materials
Amended quarterly plan of transport facilities required by type of equipment
Analysis of and report on operations
Intra-plant shop plan
Report on fulfillment of quarterly
Monthly and ten-day production target
Monthly and ten-day deliveries target
Plan for supplies of materials
Plan of availability of transport facilities
Analysis of and report on operations
Intra-plant shop plan
Report on fulfillment of monthly and ten-day
Production progress chart
Schedule of material supplies and optimization of supplies sequence
Operating schedules and itineraries for modes of transport
Correction of production and deliveries charts
Correction of operating schedules and itineraries
Operational records of product schedules fulfilment
Operational record of fulfil-



Source: Ref.139

Schematic diagram of automated planning and production management system for a precast reinforced concrete plant.

TABLE : 35



Block digram of a house-building combine's automated dispatcher control system. Ref. 139

TABLE: 36

TYPICAL TIME-STUDY SHEET

Operation	Relative Performance Evaluation by A	B	C	D	Relative Scatter %	Average Perf. Eval.	Max. Dispersion %
Strand Tensioning	120	120	130	120	8	122.5	+7.5 -2.5
Insulation placing	100	105	110	105	9.5	105	+5 -5
Concreting	110	110	115	105	9	110	+5 -5
∅	110	111.7	115	110			

Source: Reference No. 99,

TABLE: 37

COST CENTERS

Account No.	Account Designation	Person in charge
	General and auxiliary services	
11	Plant and equipment maintenace	
12	Offices	
22	Supervision	
25	Utilities	
28	Energy	
	Production Center	
31	Formwork	
41	Batching plant	
45	Steel shop	
51	Concrete stations	
61	Stockyard	
	Administration - Overhead	
91	Direction and Operations	
95	Sales and advertising	

Source: Reference No:99

TABLE: 38

SAMPLE COST PLACE

COST CENTER ACCOUNT NO. 51 (CONCRETE STATIONS)

Account No.	Designation
511	Tilting Tables
514	Vertical Battery
516	Pallet Line
518	Prestressing Line

Source: Reference 99

TABLE: 39

1970 HOUSING STATISTICS
SPRINGFIELD SMSA

	SMSA	Chicopee	Holyoke	Springfield
Population	523029	66676	50112	163905
Housing Units	169957	20383	18458	56341
1 room	3462	207	542	1395
2 room	5136	632	741	1802
3 room	12871	1474	1875	4890
4 room	33748	4973	4796	11233
5 room	51958	7961	5570	17978
6 room	35523	3484	2969	12236
7 room	14781	1042	998	3787
8 rooms*	12230	602	953	3001
Median	5.1	4.9	4.7	5.0
Units/Structure				
1 unit	88458	9412	4859	23539
2 units or more	79902	10780	13572	32329

*excluding Connecticut, i.e. Tolland-Somerset

Source: reference 147

TABLE: 40

CONSTRUCTION MARKET ESTIMATES/1975 AND 1980

Value of Construction (billions of dollars)	1967 Annual	Current Dollars 1975 Projected	1980 Projected	Annual Rate of change 1967-1980	Projected Annual Increase In Costs
NONRESIDENTIAL BLDGS.					
Commercial	$ 7.0	10.8	14.9	6.0%	3.3%
Manufacturing	6.5	9.6	13.1	5.5	2.5
Educational	7.0	6.8	10.0	2.8	4.0
Hospital/Health	2.0	3.6	5.0	7.3	4.0
Public	2.2	4.0	5.5	7.3	3.1
Religious	1.1	1.8	2.3	5.8	3.3
Miscellaneous	2.8	4.4	6.2	6.3	3.0
	$ 28.6	$ 41.0	$ 57.0	5.5%	3.2%
RESIDENTIAL BLDGS.					
One-and-Two Family Homes	$ 14.6	$ 27.9	$ 41.1	8.3%	3.0%
Apartments	4.7	13.7	14.7	9.2	3.0
Additions & Alterations	4.4	8.6	13.2	8.8	3.0
Nonhousekeeping	1.3	2.4	3.3	7.4	3.5
	$ 25.0	$ 52.6	$ 72.3	8.5%	3.0%
TOTAL BLDGS.	$ 53.6	$ 93.6	$129.3	7.0%	3.1%

Source: Ref. 25

TABLE: 41

DISTRIBUTION OF CONTRACT AWARDS
HAMPDEN COUNTY

	1962	63	64	65	66	67	Average, %
Residential	47.6%	41.3%	43.7	44.8%	37.9	32.6%	41.3
Educational	12.9%	11.3%	10.7	4.8%	6.7	7.3%	9.5
Commercial	10.1%	17.9%	11.6	16.4%	18.3	15.1%	14.9
Manufacturing	4.9%	3.0%	3.4	8.1%	13.3	2.6%	6.4
All other non resid.	14.4%	8.2%	9.9	8.6%	9.5	17.0%	11.1
Public Works	10.1%	18.3%	21.2	17.3%	14.3	25.4%	17.7
Total $ Volume: 10^6	55.75	92.75	69.90	75.63	104.45	105.05	100.0

Source: Master Builders Inc.

TABLE: 42

SPRINGFIELD SMSA

DWELLING STOCK DISTRIBUTION of NEW RESIDENTIAL CONSTRUCTION

Year	No. of Units		%	No. of	Valuation	Average No. (1)
	Total:	5 + Family	Total	Structures	Million $	Units/Structure
1962	747	242	32%	--	n.a.	--
1963	1712	768	45%	--	n.a.	--
1964	2116	864	41%	--	n.a.	--
1965	3012	1277	41%	--	n.a.	--
1966	2838	1348	47%	76	9.584	18
1967	2579	804	31%	30	5.639	27
1968	3119	1328	43%	83	10.477	16
1969	3883	2039	52%	87	20.54	23
1970	2983	1409	47%	59	11.196	24
1971*	2573	1585	61%	113	15.404	--

* First 6 months only.
(1) Rounded to nearest unit.

Source: Derived from references 71,72,146

TABLE: 43

HOUSING CONSTRUCTION
SPRINGFIELD, MASSACHUSETTS AREA

Year	Single Family	Multi Family	Total	% Change From Previous Year
1960	1,374	178	1,552	-21.0%
1961	1,438	548	1,986	+30.0
1962	1,511	264	1,775	-10.6
1963	1,588	909	2,497	+40.7
1964	1,517	1,118	2,635	+ 5.5
1965	1,433	1,594	3,027	+14.9
1966	1,369	2,205	3,574	+18.1
1967	1,327	668	1,995	-44.2
1968	1,350	1,000	2,350	+17.8
1972	2,000	2,000	4,000	+70.2%

Source: Master Builders Inc.

TABLE : 44

POPULATION PROJECTIONS

PER CENT COMPOSITION AND CHANGE

1970 and 1980

PER CENT COMPOSITION

age groups	low 1970	low 1980	probable 1970	probable 1980	high 1970	high 1980
0-4	12.1	12.5	12.0	12.3	11.9	12.0
5-19	26.8	26.8	26.5	26.5	26.4	26.3
20-44	38.6	32.1	28.5	31.9	28.5	31.7
45-64	18.8	14.4	18.9	14.8	19.0	15.2
65+	13.8	14.3	14.1	14.6	14.3	14.9
	100.	100.	100.	100.	100.	100.

PER CENT CHANGE

	1960-70	1970-80	1960-70	1970-80	1960-70	1970-80
	12.0	7.6	13.5	7.7	14.2	7.8
5-19	13.3	3.9	15.5	4.7	16.3	6.2
20-44	-6.6	16.6	-4.5	17.1	-3.1	18.4
45-64	-9.5	-20.4	-6.7	-18.0	-4.7	-14.6
65+	21.3	7.0	26.7	8.5	30.1	11.2
TOTAL	3.1	3.8	5.5	4.9	7.2	6.7

Source: Reference No 92 page 67

TABLE: 45

HOUSING STARTS 1963-1977
(Thousands of Units)

	Total			Yearly Average			
	Single Family	Multiples	Total	Single Family	Multiples	Total	Percent Multiples
1963-67	4,544	2,616	7,160	910	521	1,432	37%
1968-72	4,900	3,950	8,850	980	790	1,770	45%
% Change	8%	47%	24%				
1973-77	7,450	2,500	9,950	1,490	500	1,990	25%
% Change	52%	-37%	12%				

Source: Components of future housing demand
Ref. No:126 , page 60

TABLE: 46

HOUSING AND ESTIMATED HOUSING PRODUCTION
BY TYPE OF CONSTRUCTION
1963 - 1985

		Number of Units Started or Manufactured (000's) Mobile and Factory-Built			
Year	Conventional	Mobile	Factory-Built	Total	Total Housing
1963	1,642	151	N[a]	151	1,793
1964	1,562	191	N	191	1,753
1965	1,510	216	N	216	1,726
1966	1,196	217	N	217	1,413
1967	1,322	240	N	240	1,562
1968	1,546	318	N	318	1,864
1969	1,500	413	17	430	1,930
1970	1,217	442	22	464	1,681
1971	1,510	450	40	490	2,000
1972	1,450	450	100	550	2,000
1973	1,300	450	250	700	2,000
1974	1,000	450	550	1,000	2,000
1975	1,000	---	---	1,000	2,000
Each Year, 1976-1985	1,000	---	---	1,000	2,000

Year	Conventional	Mobile	Factory-Built	Total	Total Housing
Total, 1971-1985	16,260			13,740	30,000

N = Nominal number of starts

Source: Figures through 1970 in Cols 1 and 2 are from Construction Review, June, 1970. Figures through 1970 in Col. 3, and figures for 1971-1985 are LCA estimates.
Reference 30 A

TABLE: 47

TRENDS IN HOUSING STARTS

(In thousands of dwelling units)

	1960	1965	1966	1967	1968	1969
Total Housing Starts[a]	1,274	1,510	1,196	1,322	1,546	1,500
Modular Box starts[b]						10
Prefabricated Starts[c]	127	233	230	225	240	316
Mobile Home Shipments[d]	104	216	217	240	317	413

Sources:

a. U.S. Bureau of Census, C-20, Construction Reports.

b. Equity Research Associates, 55 Broad St., New York, New York, an investment research report entitled "Industrialized Building Systems," September 14, 1970.

c. Prefabricated dwelling units are housing packages consisting of at least the structural shell. Estimates are based on Home Manufacturers Association surveys and other surveys by magazines such as Professional Builder and Automation in Housing and by Mr. Charles Field, Harvard-M.I.T. Joint Center for Urban Studies.

d. Mobile Homes Manufacturer's Association.

Quoted from Reference No: 30 A page, 441

TABLE: 48

INVENTORY OF INDUSTRIAL LAND, BUILDINGS AND EMPLOYMENT BY INDUSTRY

Industry	Land Acres	Floor Space, 1,000's sq.ft.	Employment	No. of Plants	Average Floor Space per plant, 1000 ft^2
Vacant (1)	3.9	158	0	7	
Construction	9.5	26	44	4	6.5
Ordnance	124.3	(2)	(2)	1	
Food	5.9	207	427	4	52
Textiles	8.3	(2)	(2)	1	
Apparel	1.1	(2)	(2)	2	
Lumber	1.4	(2)	(2)	1	
Paper	14.7	675	1,295	7	96
Printing and Publishing	6.2	286	1,000	5	57
Chemical	2.4	102	53	3	34
Stone, Clay, and Glass	4.6	(2)	(2)	2	
Primary Metals	59.2	603	1,990	10	60
Fabricated Metals	32.4	961	1,258	10	96
Machinery (exc.elec)	32.9	657	1,307	16	41
Electrical Machinery	64.2	1,507	2,174	4	377
Instruments	0.7	(2)	(2)	1	
Miscellaneous Mfg.	47.1	863	1,344	8	108
Warehousing	2.7	157	60	4	39
Electric Services	2.7	(2)	(2)	1	--
Wholesale and Retail Trade	67.4	1,785	1,593	61	29
Business Services	1.4	16	36	3	5
Mixed-Occupancy (3)	26.3	1,380	1,603	20	69
TOTAL	520.3	10,262	16,621	175	58

INDUSTRIAL LAND, BUILDINGS AND EMPLOYMENT BY INDUSTRY

(1) Plants totally vacant only. Does not include partial vacancies.

(2) Data withheld to prevent direct or indirect disclosure of data for individual plants.

(3) Plants in which under 90.0% of employment is in a single 2-digit SIC.

Source: Springfield CRP Industrial Survey, 1964 ,Ref. 92

TABLE: 49

POTENTIAL DEMAND FOR NEW PLANTS, 1965-1980

Source of Demand	Buidling Space Square Feet[1]	Land Acres	Employment[2]
Growth of 4 Industries (Manufacturing)	312,500	23.9	750
Replacement, Fair Manufacturing Buildings	1,200,000	91.8	2,880
Replacement, Fair Mixed-Occupancy Buildings	225,000	17.2	540
Replacement, Fair Wholesale and Retail Warehouses	436,000	33.4	500
Replacement, Fair Public Warehouses	61,000	4.7	30
TOTAL	2,234,500	171.0	4,700

1 Rounded to nearest 500 squares feet.

2 Rounded to nearest 10.

Source: Springfield CRP, Economic Base ,Ref. 92

TABLE: 50

PRIVATE PURCHASES OF NONRESIDENTIAL STRUCTURES
JUDGMENT PROJECTIONS, 1967-1980 (BASED ON 1958 PRICES)

Category	Annual Growth Rate	Distribution 1967	Distribution 1980
	(Percent)		
Industrial buildings	5.37	22.30	23.57
Commecrcial buildings	6.52	23.23	28.29
Religious buildings	6.94	3.58	4.59
Educational buildings	4.99	3.38	3.41
Hospital and institutional buildings	9.92	4.50	8.25
Other nonresidential building exc. farm	5.72	4.91	5.42
Railroads	-1.07	1.62	0.75
Telephone and telegraph	4.98	5.85	5.89
Electric light and power	2.21	11.92	8.48
Gas	1.49	5.81	3.77
Other public utilities	-4.78	0.54	0.15
Farm	-2.27	2.85	1.13
Petro natl gas well drilling and explor	-0.49	7.51	3.77
All other private construction	8.07	1.44	2.12
Brokers' commissions on sale of struc	2.41	0.48	0.35
Total	4.92	100.00	100.00

Source: National Planning Association
Economic Projection Series
Reference 79

TABLE: 51

DISTRIBUTION OF PANEL AREAS

Panel Type	r	Total Area, ft*
External Panels	0.51	183,000
Internal, L/B	0.74	268,000
Floors-Roofs	1.48	533,000
Sub-Total	2.73	984,000
Partitions	0.46	160,000
TOTAL (i)	3.19	1,150,000

* Rounded Numbers
(i) Excluding elevator shafts and stair flights
L/B: Load-Bearing

TABLE: 52

UTILIZATION OF MODULAR BUILDING UNITS

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

Source: Reference No.90

TABLE: 53

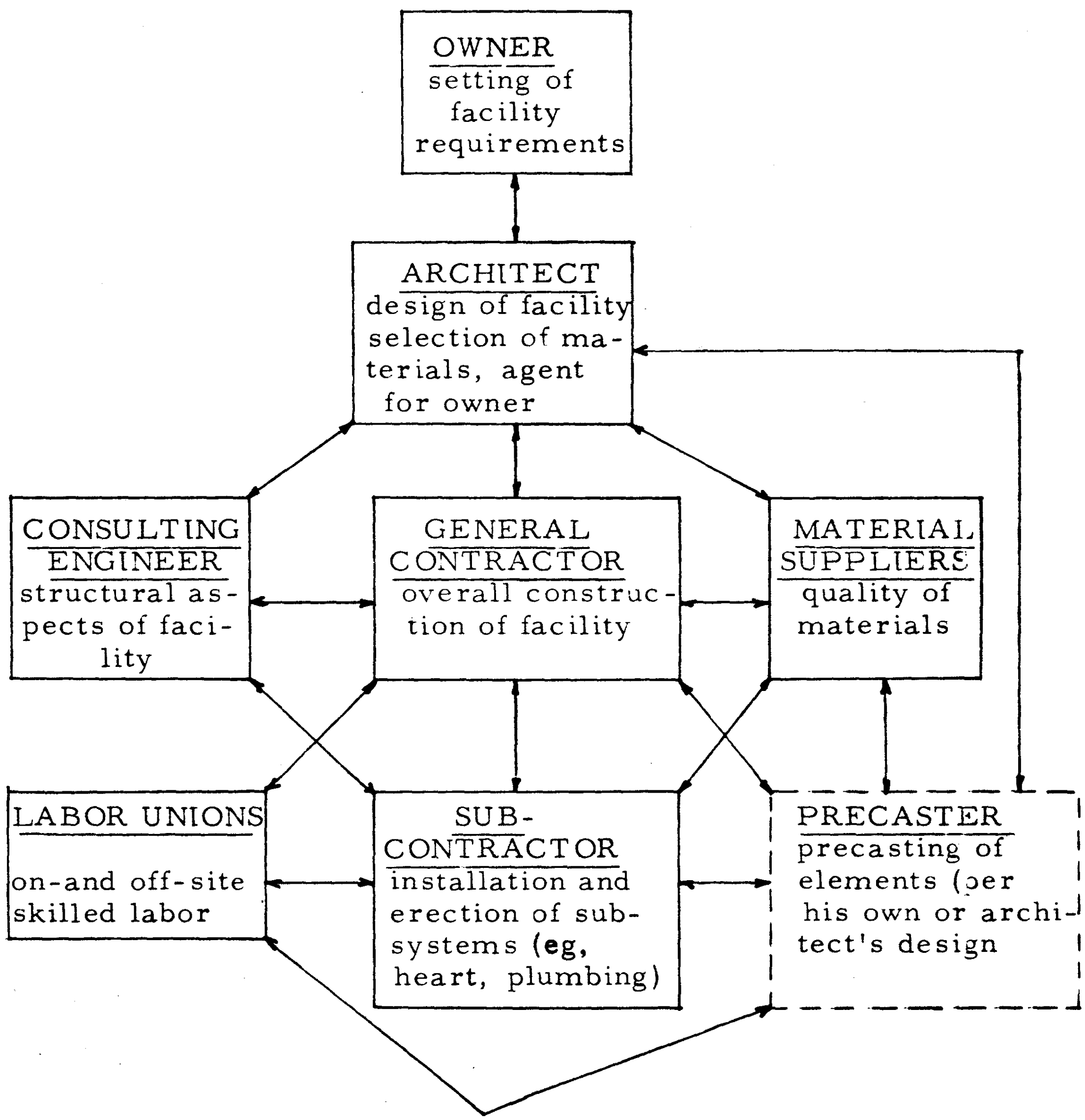
NUMBER OF ELEMENTS
AS A
FUNCTION OF BUILDING SYSTEM

Method of Construction	Number of Elements Required
Intermediate-sized block systems	40-60
Large-block systems	25-40
Large-panel systems	16-25
Box units with only one room	2-6
Box units with more than one room	1-2

Source: Rference No.115 , page 170

FIGURES

FIGURE: 1

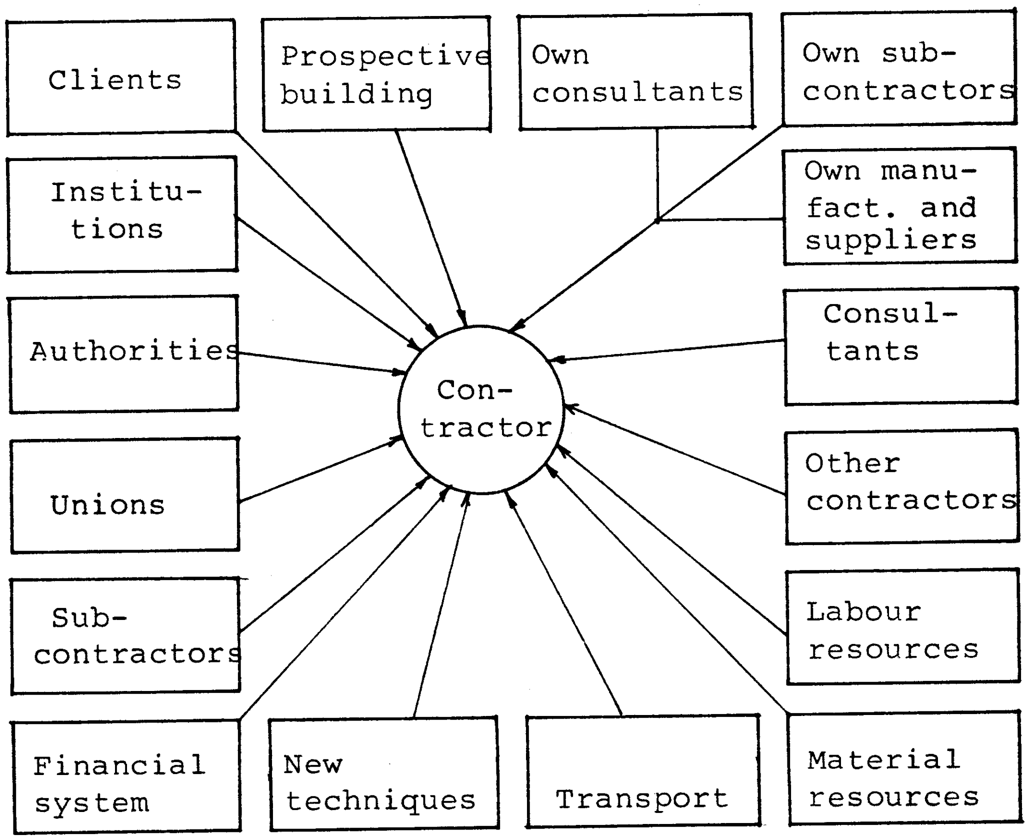


NOTE: The Actors and their interactions in the precast concrete industry . Arrows indicate the flow of information and control.

Source: Reference No. 105

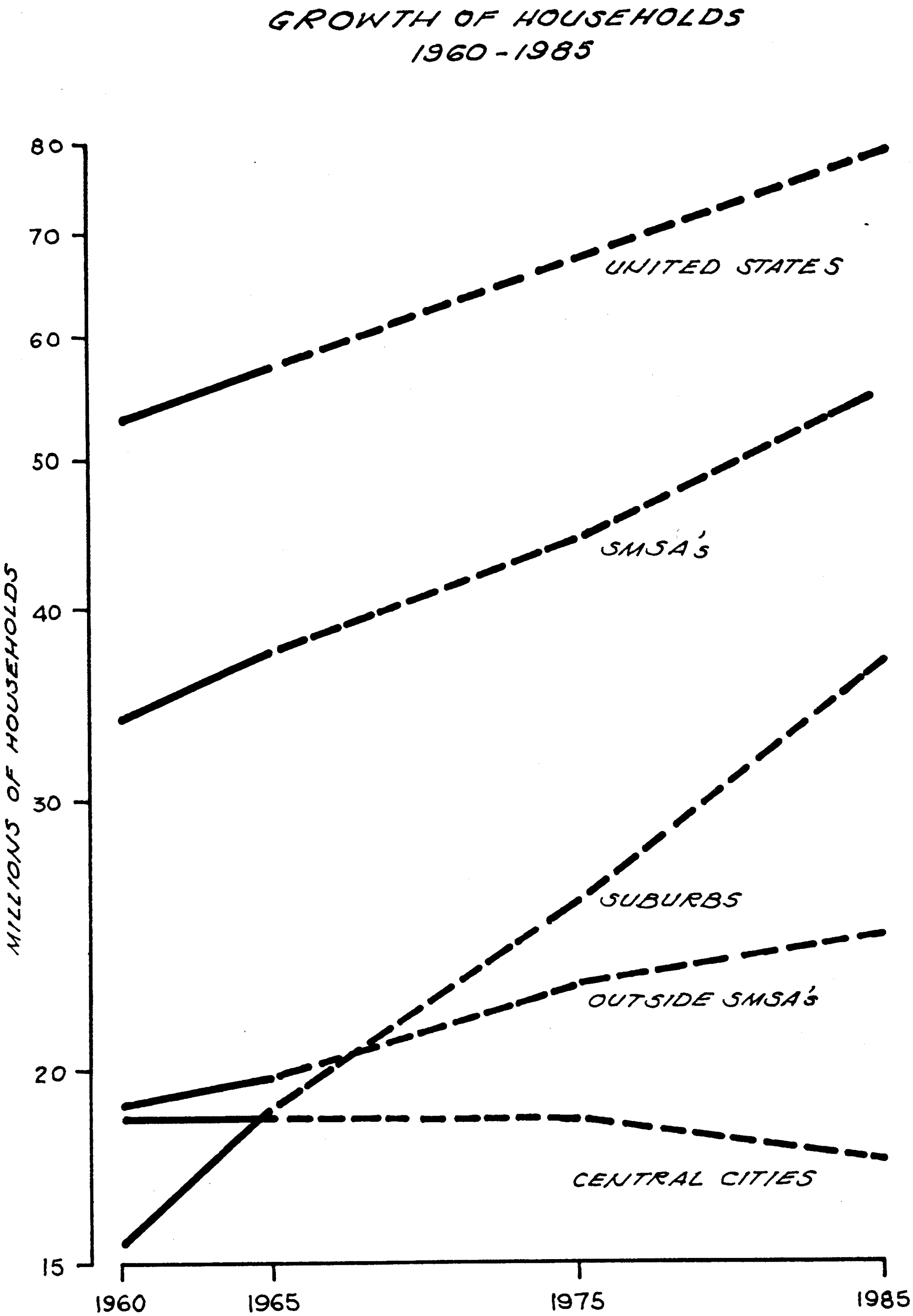
FIGURE: 2

SOME FACTORS IN THE CONTRACTOR'S ENVIRONMENT



Source: Reference Napir: A systems approach to the Ssedish Building industry

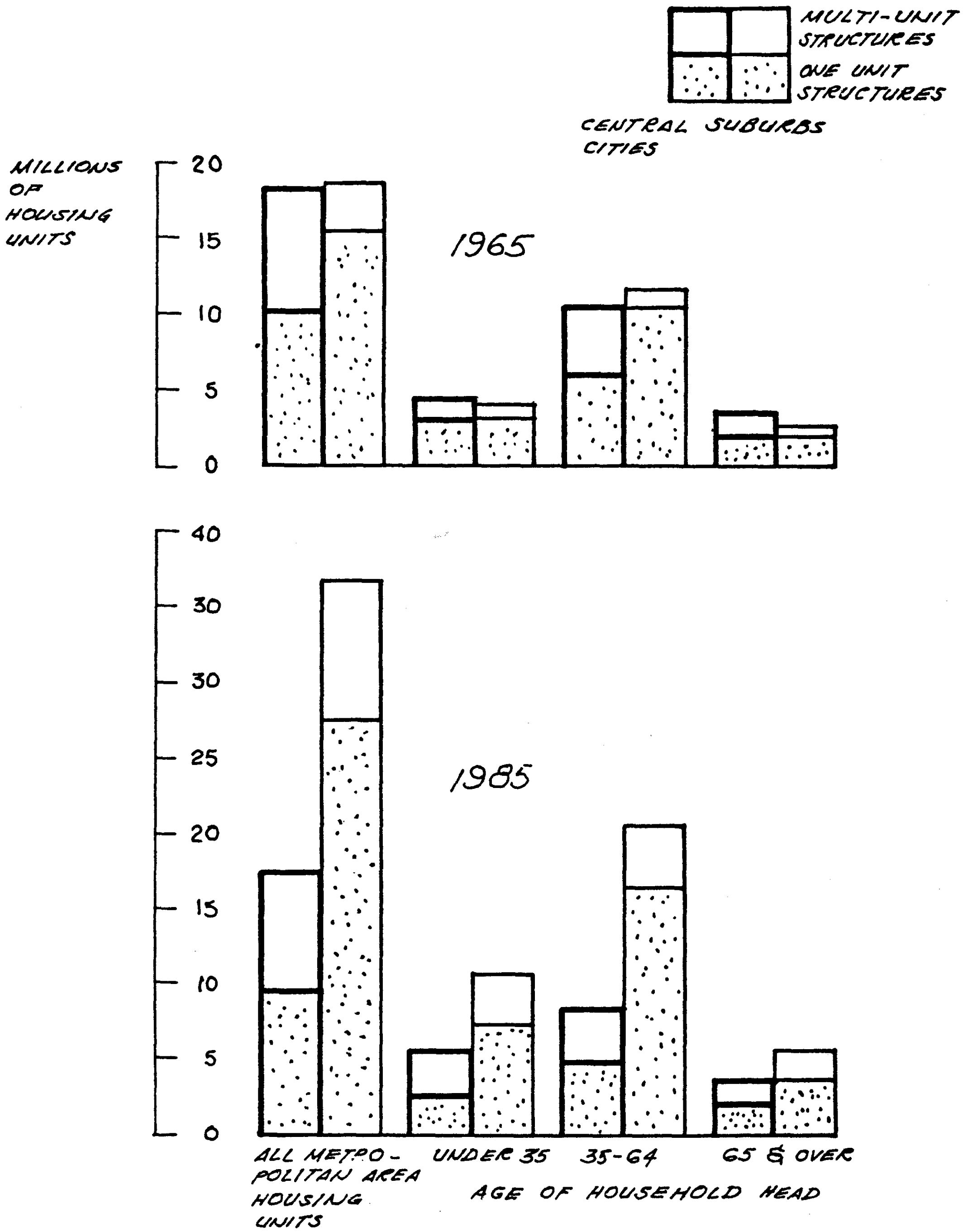
FIGURE: 3



SOURCE: TABLE, A-2 Page 8, Ref. No.
Reference 118

FIGURE: 4

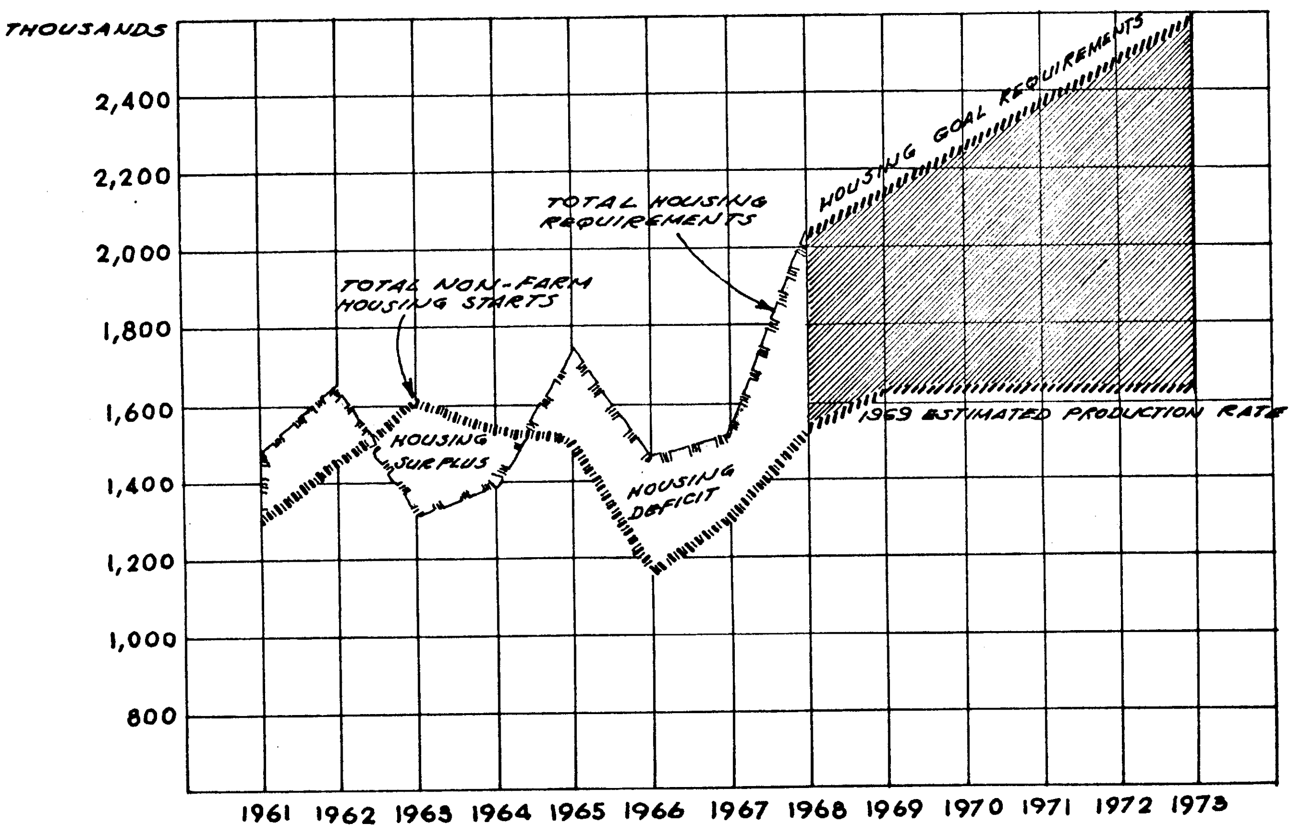
HOUSING UNITS BY TYPE OF STRUCTURE AND AGE OF HOUSEHOLD HEAD



SOURCE: TABLE A-5, page 19, Ref. No. 118

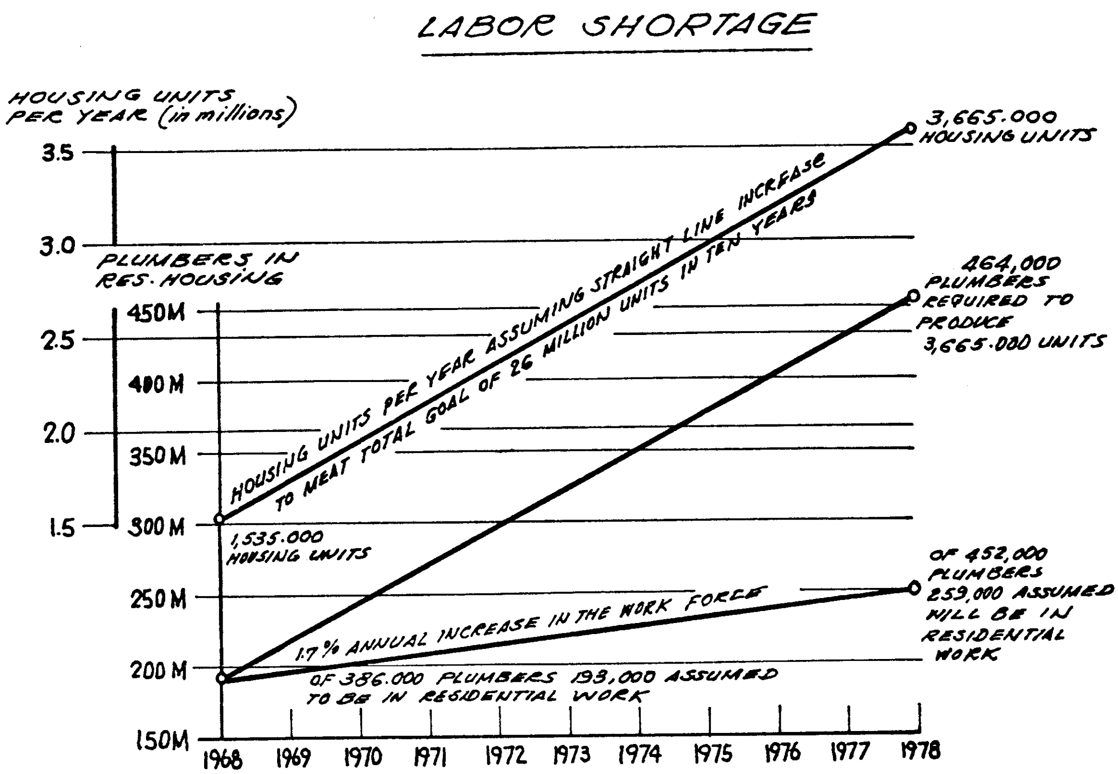
FIGURE: 5

HOUSING SUPPLY VS. HOUSING NEED
1961 - 1968



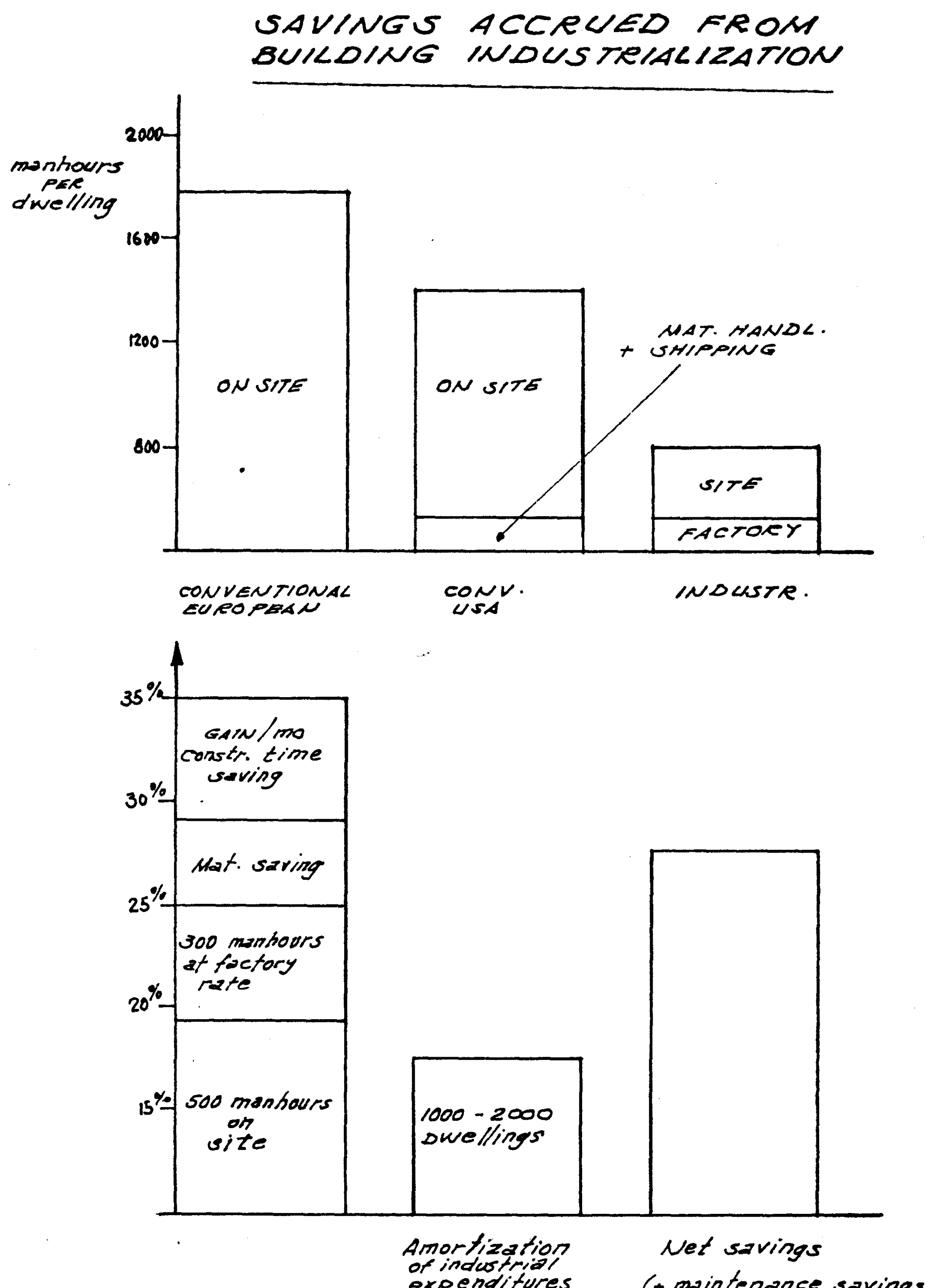
Source: Reference No. 51

FIGURE: 6



Source: Reference 49

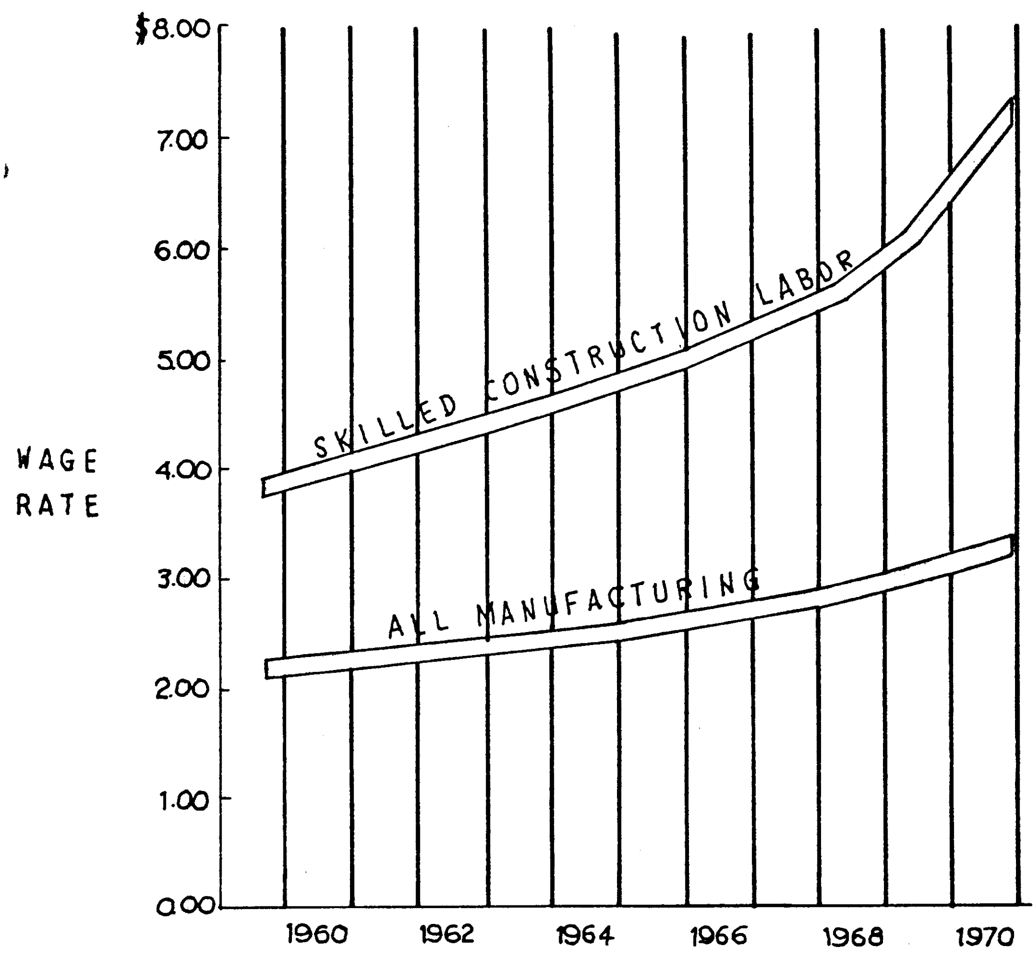
FIGURE: 7



Source: Reference No. 10

FIGURE: 8

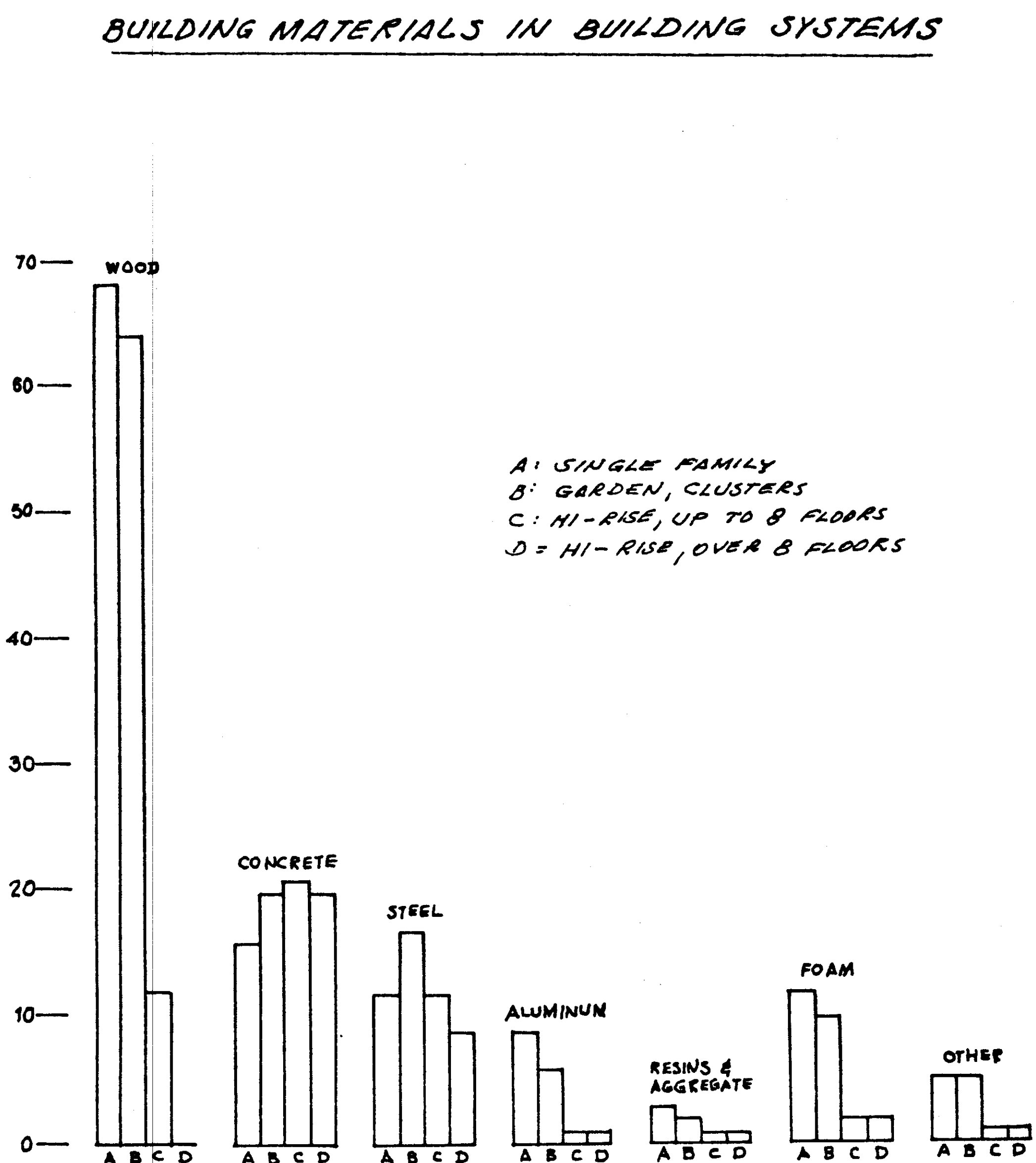
WAGE RATE TRENDS FOR SITE CONSTRUCTION BLDG. & FOR MANUFACTURING INDUSTRIES



SOURCES: BUREAU OF LABOR STATISTICS ENGINEERING NEWS RECORD

Reference 9

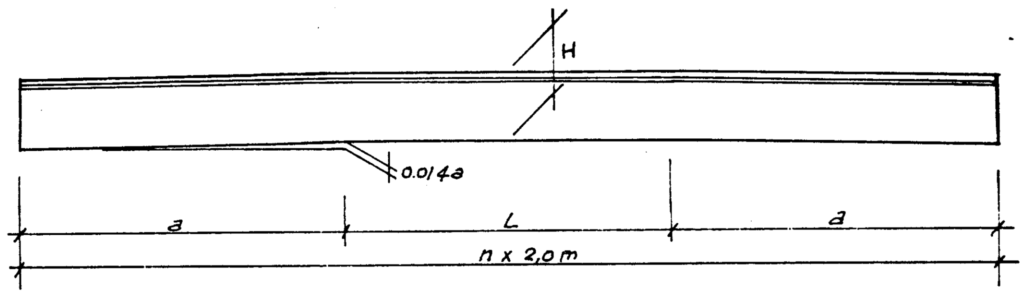
FIGURE: 9

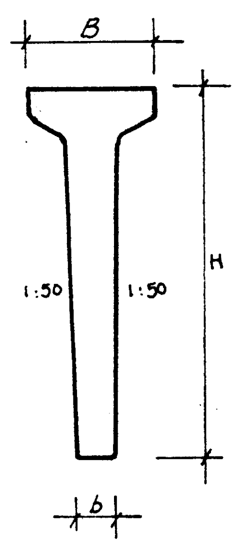


Source: Reference 65

FIGURE: 10

"ULTO" BEAM , SWEDEN

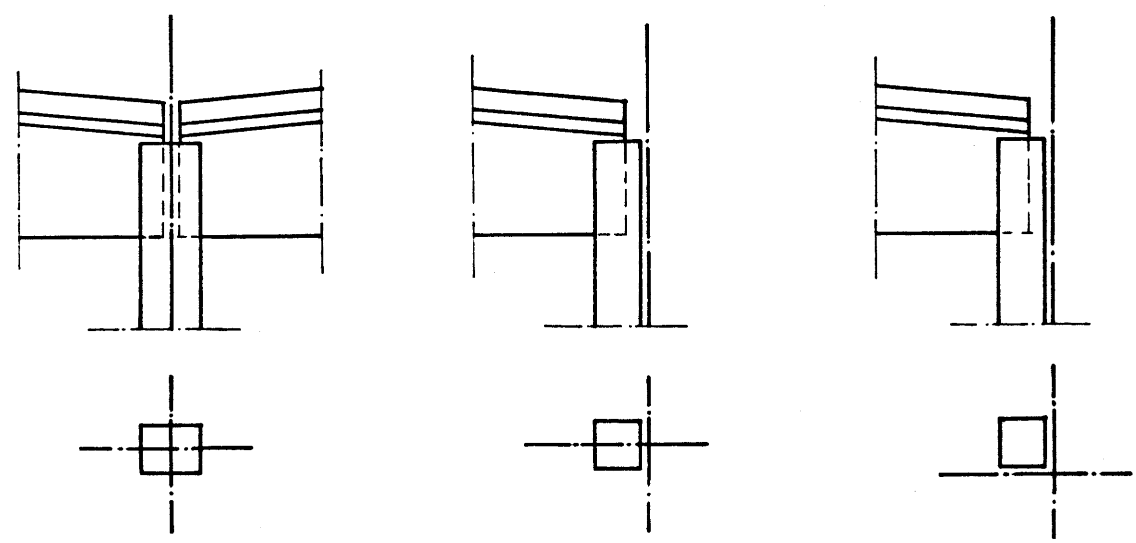




Source : Skanska Cementjuteriet,Malmö

FIGURE: 11

"ULTO" BEAM CONNECTIONS

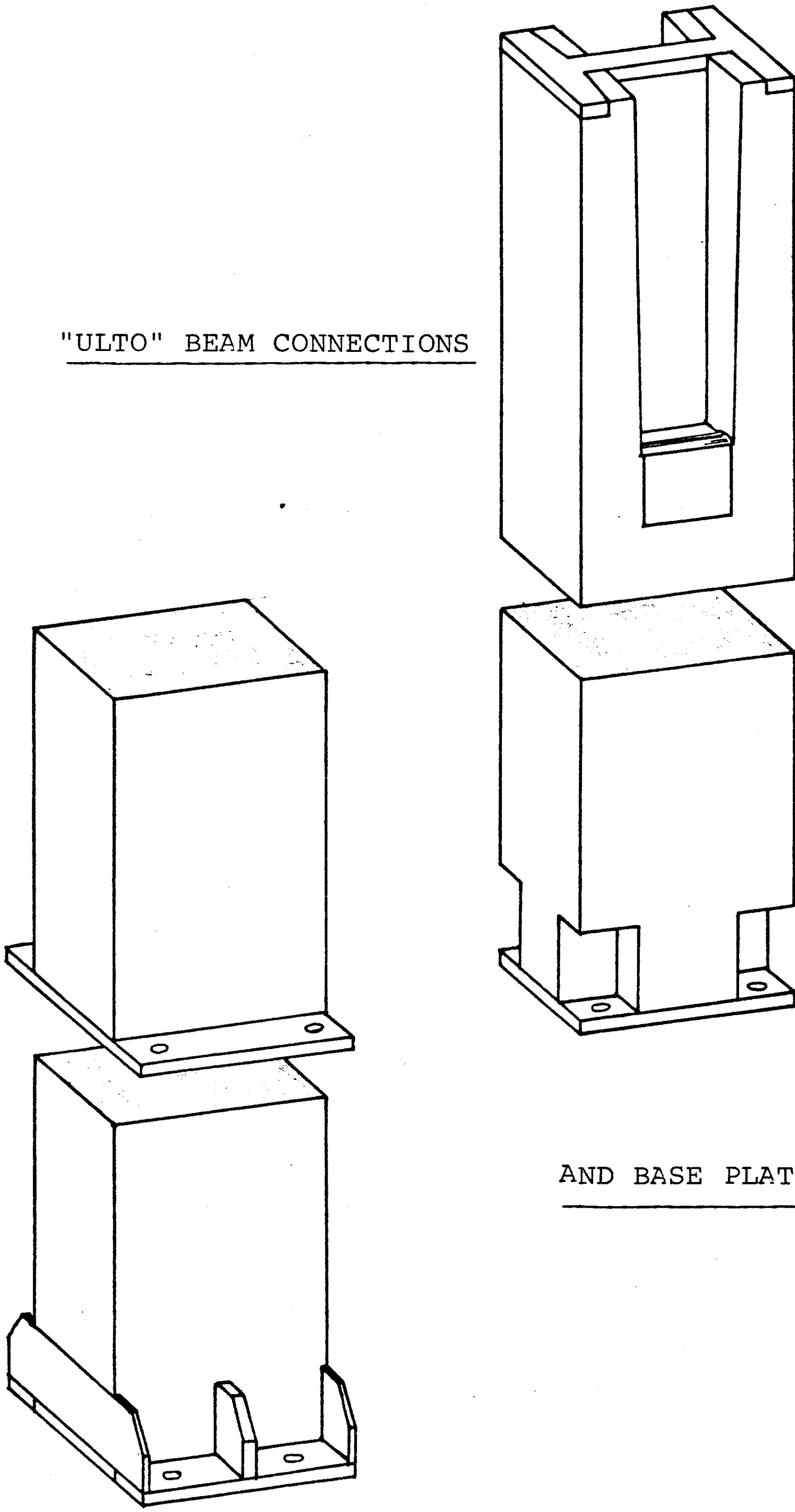


Source: Skanska Cementgjuteriet - Sweden

FIGURE: 12

"ULTO" BEAM CONNECTIONS

AND BASE PLATES



Source: Skanska Cementgjuteriet - Sweden

FIGURE : 13 TYPICAL PRECAST PANELS

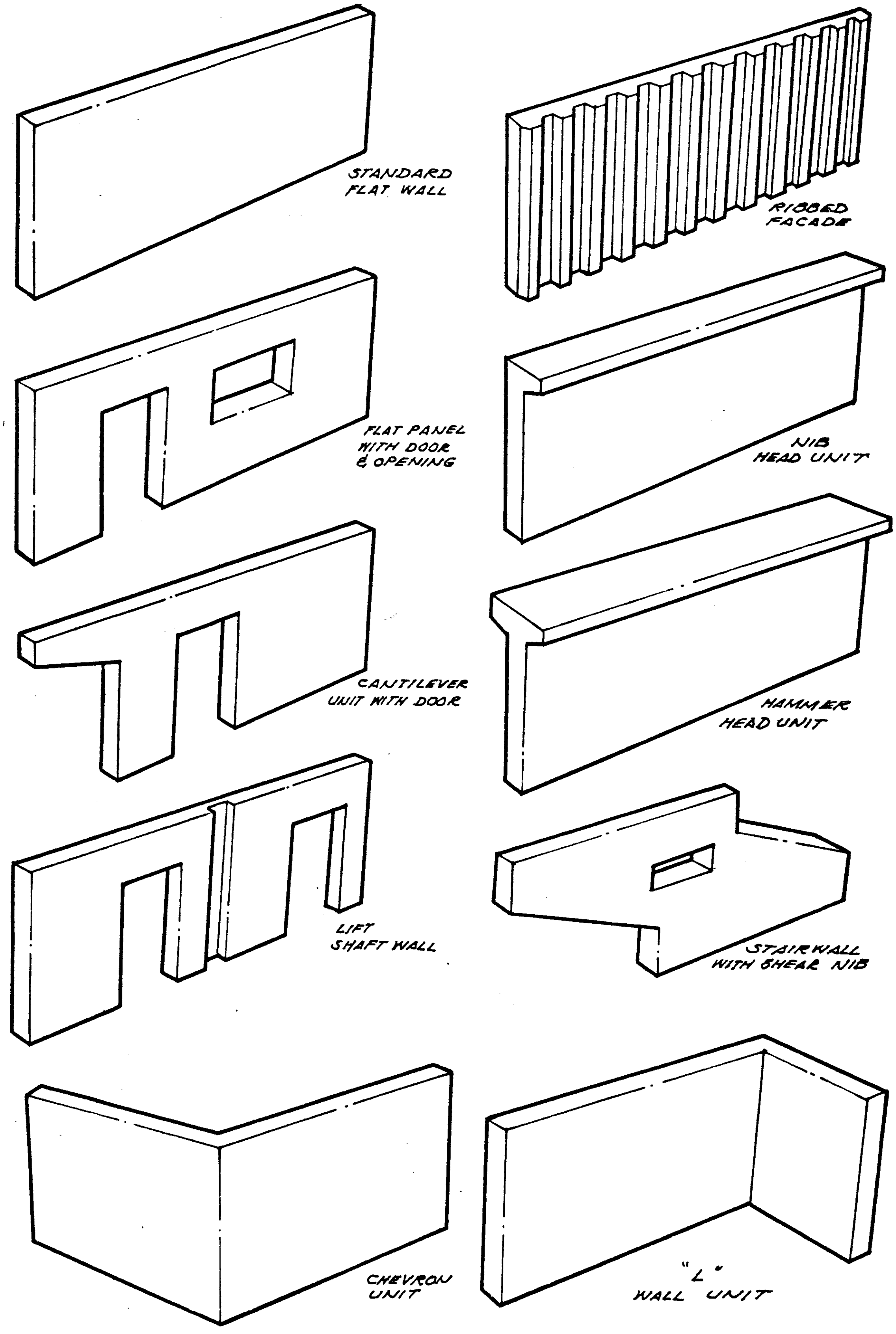
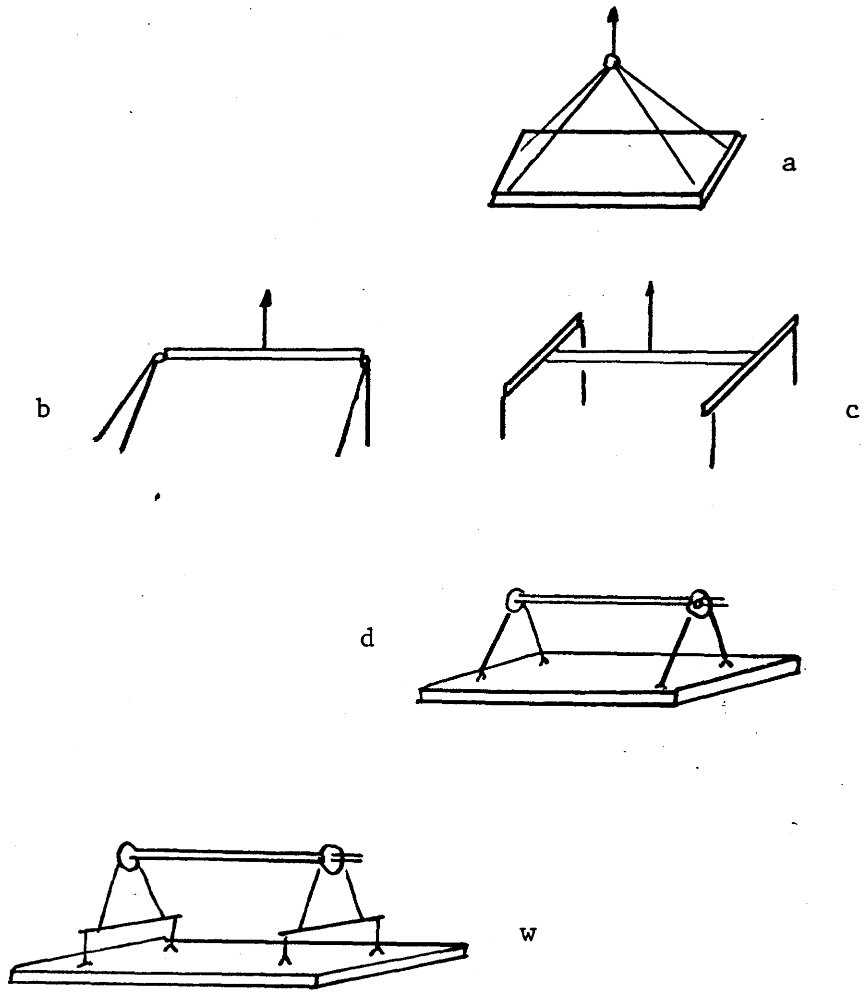


FIGURE: 14

LIFTING METHODS

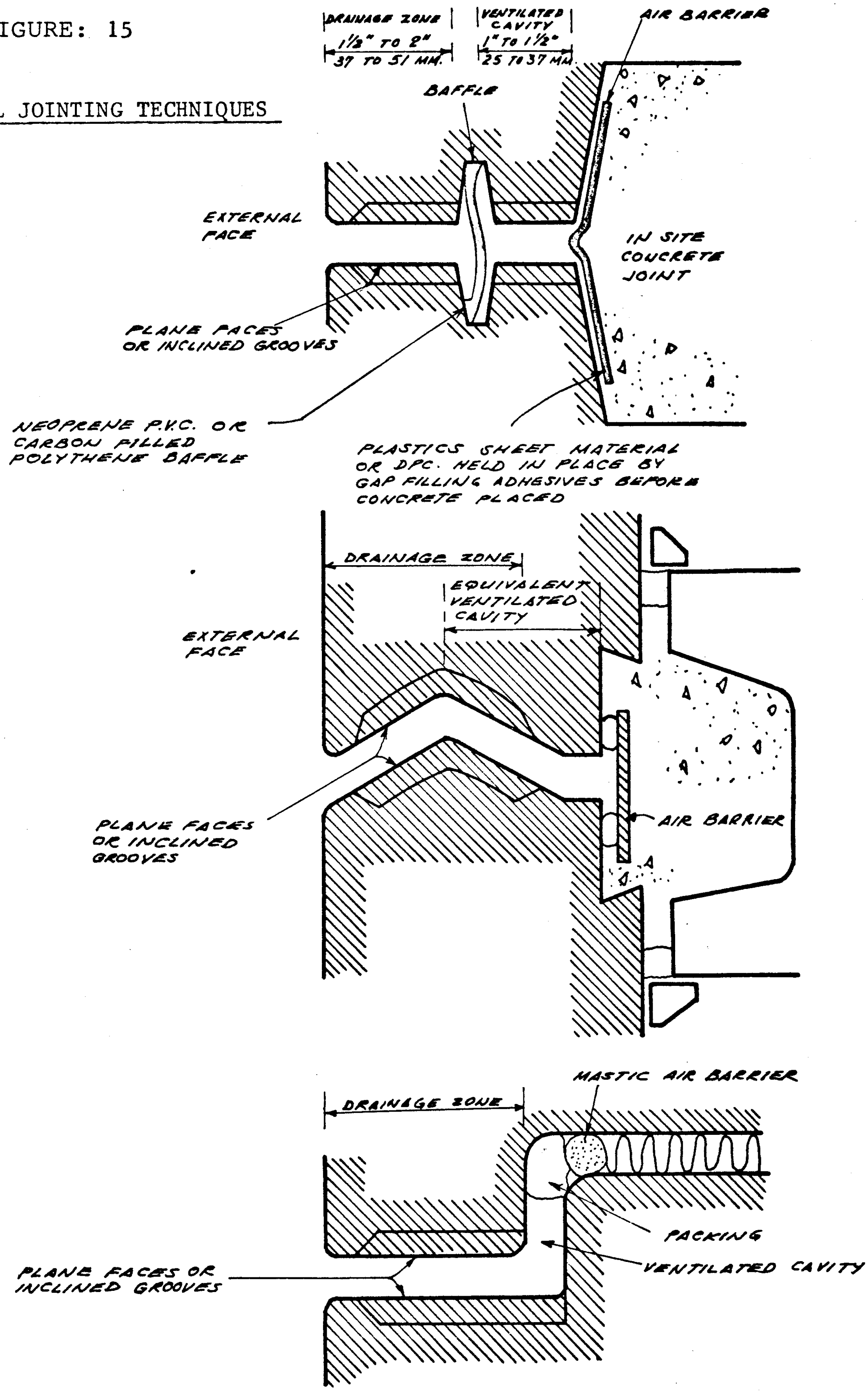


a : Cable rockers
b : Compounds of balance and cable rockers
c : Same as (b), hinged joints between spreader beams
d : Same as (b)
w : Variation of model (b)

Source: Reference 115 page 203

FIGURE: 15

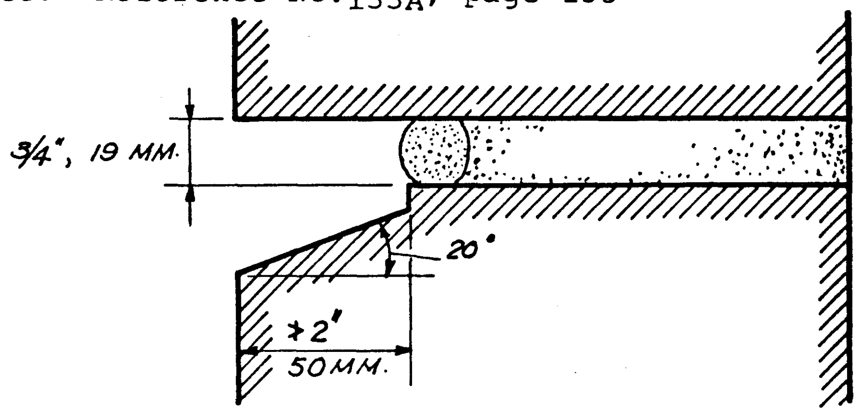
TYPICAL JOINTING TECHNIQUES



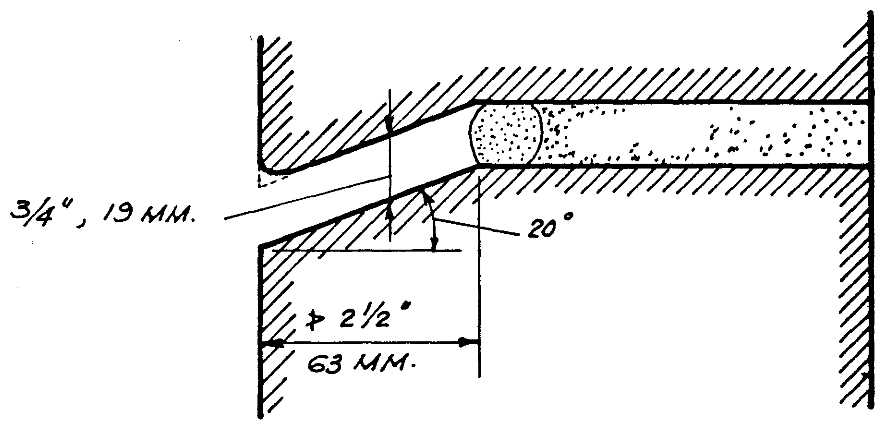
Source: Reference No. 133A, page 156

FIGURE: 16

Source: Reference No.133A, page 153



TYPICAL JOINTING TECHNIQUES



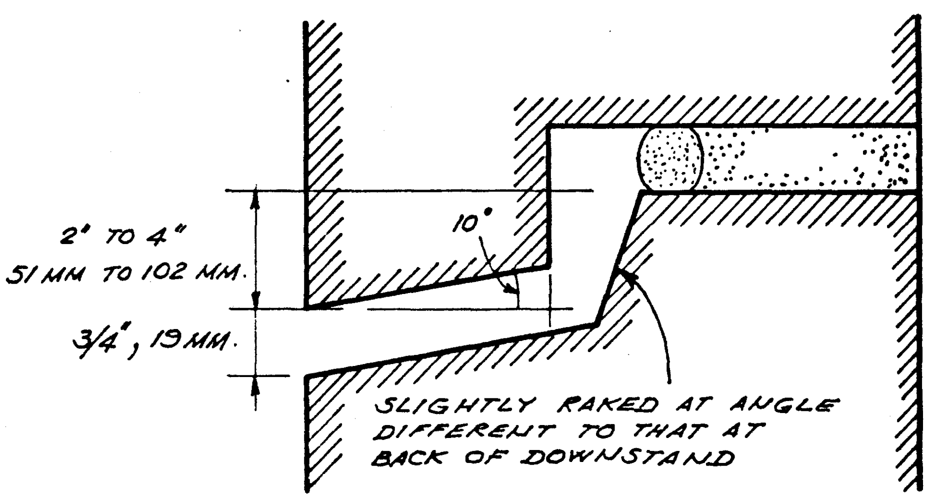


FIGURE: 17

EXAMPLES OF PRECAST PANEL JOINTS

Source: Reference No.133A, page 155

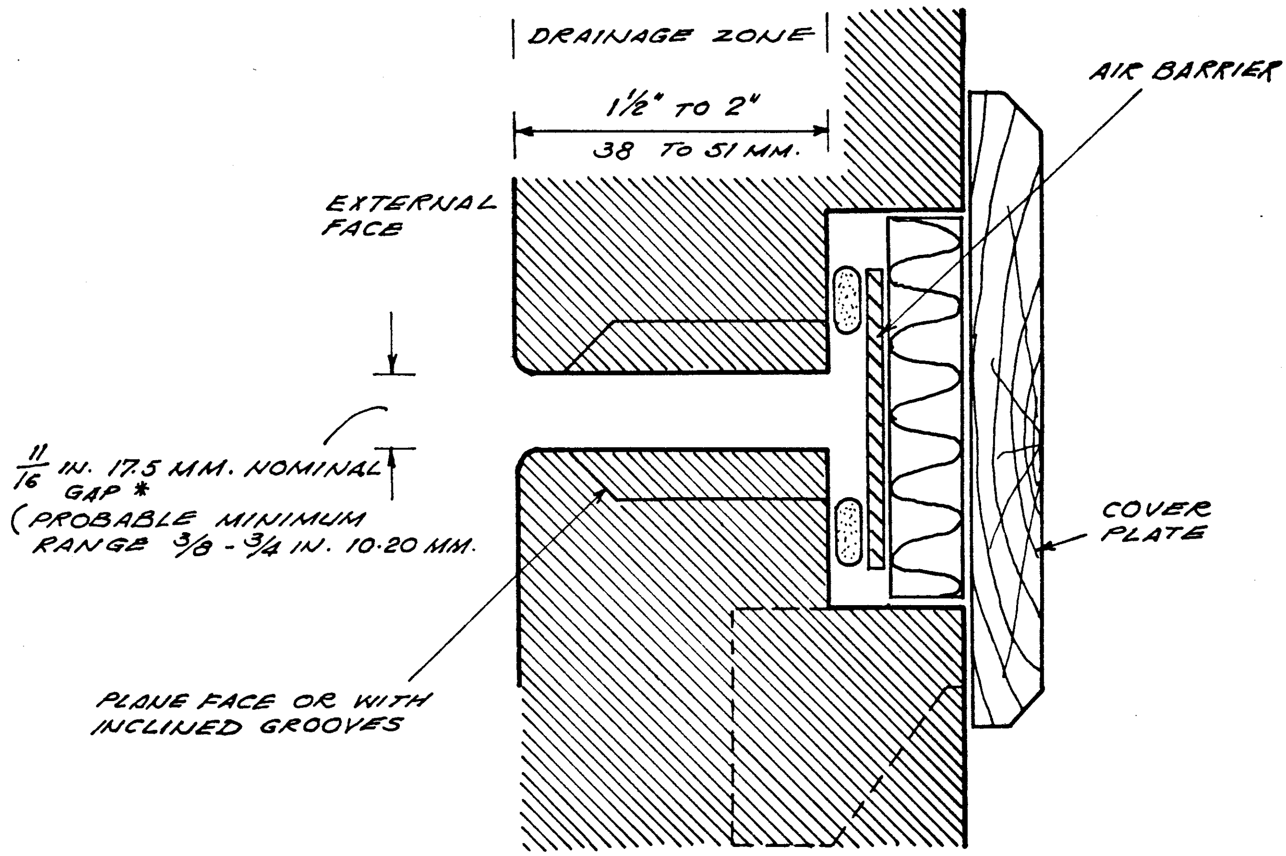


FIGURE:

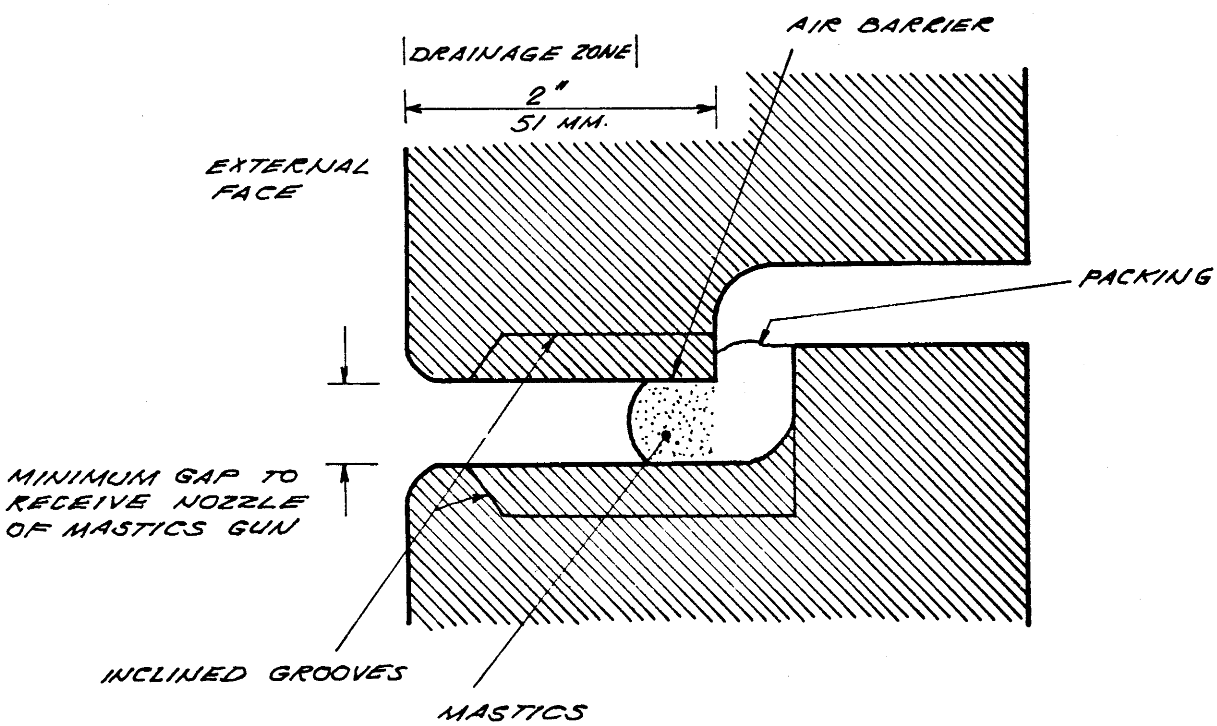
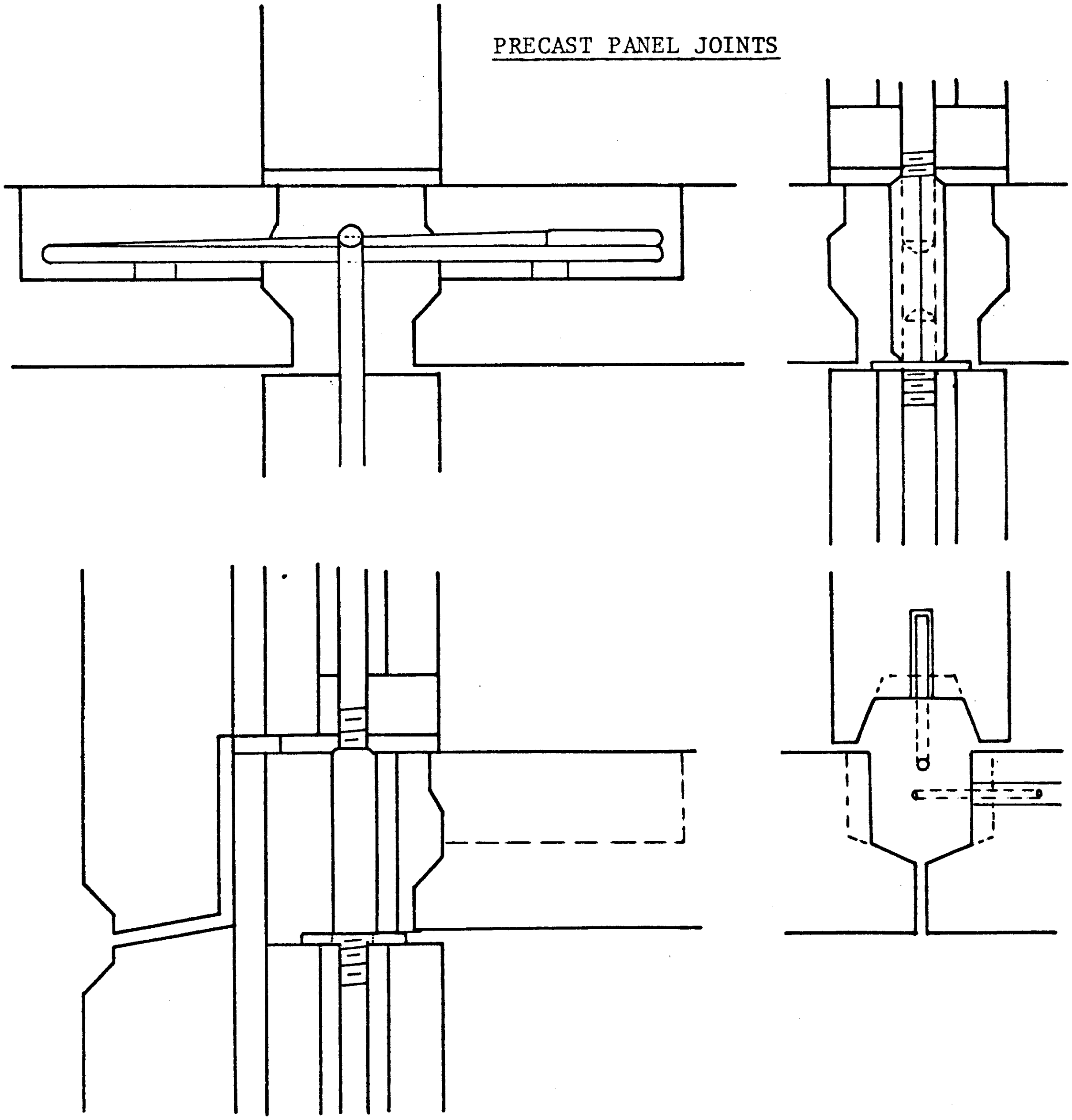


FIGURE: 18

PRECAST PANEL JOINTS



1 SECTION OF JOINT BETWEEN FLOOR SLABS

2 EXTERNAL WALL VERTICAL JOINT

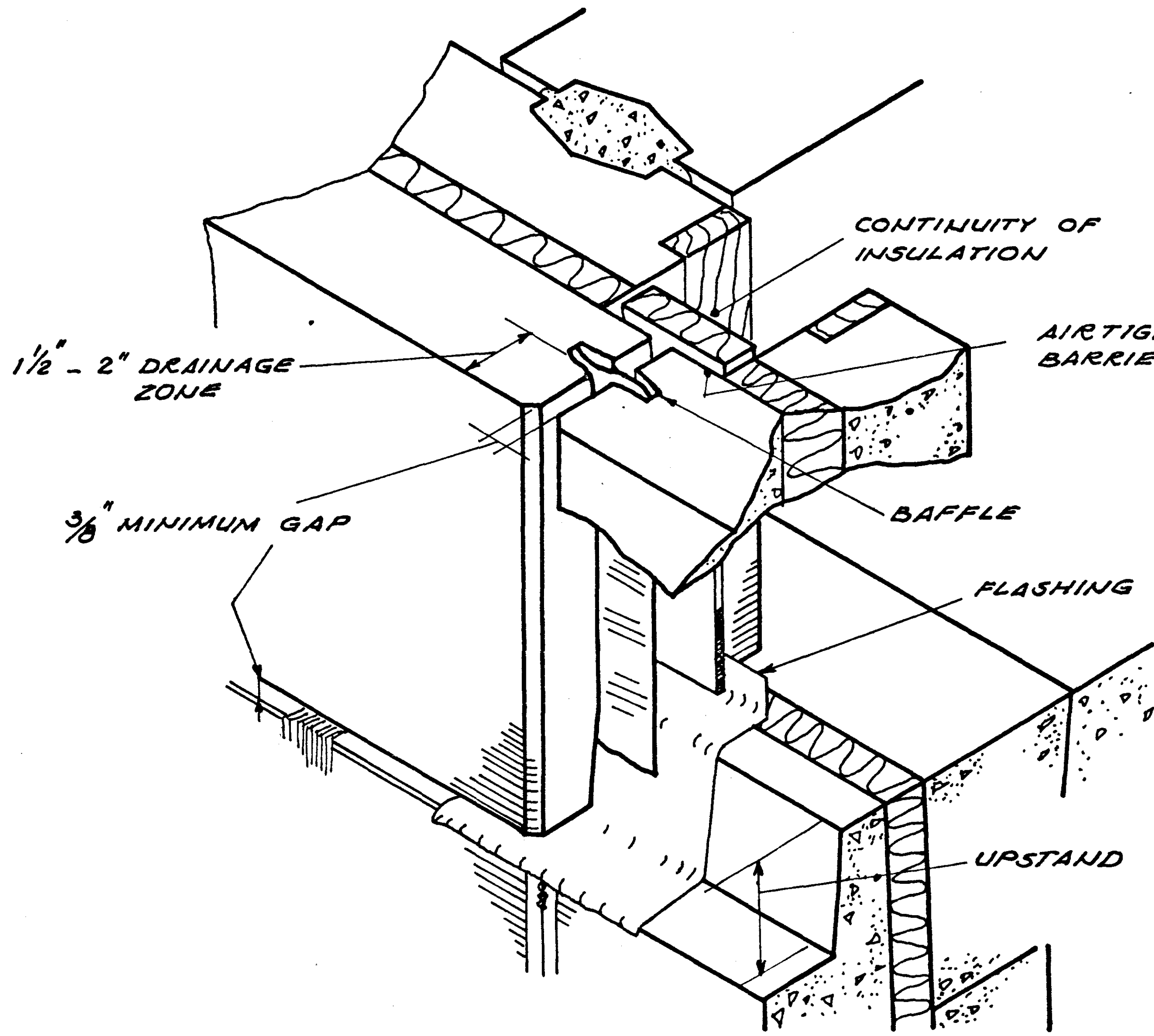
3 SECTION OF JOINT BETWEEN INTERNAL WALLS AT EACH FLOOR LEVEL

4 PLAN OF JOINT BETWEEN ADJACENT INTERNAL WALLS

Source: Reference No.155 , page 73

FIGURE: 19

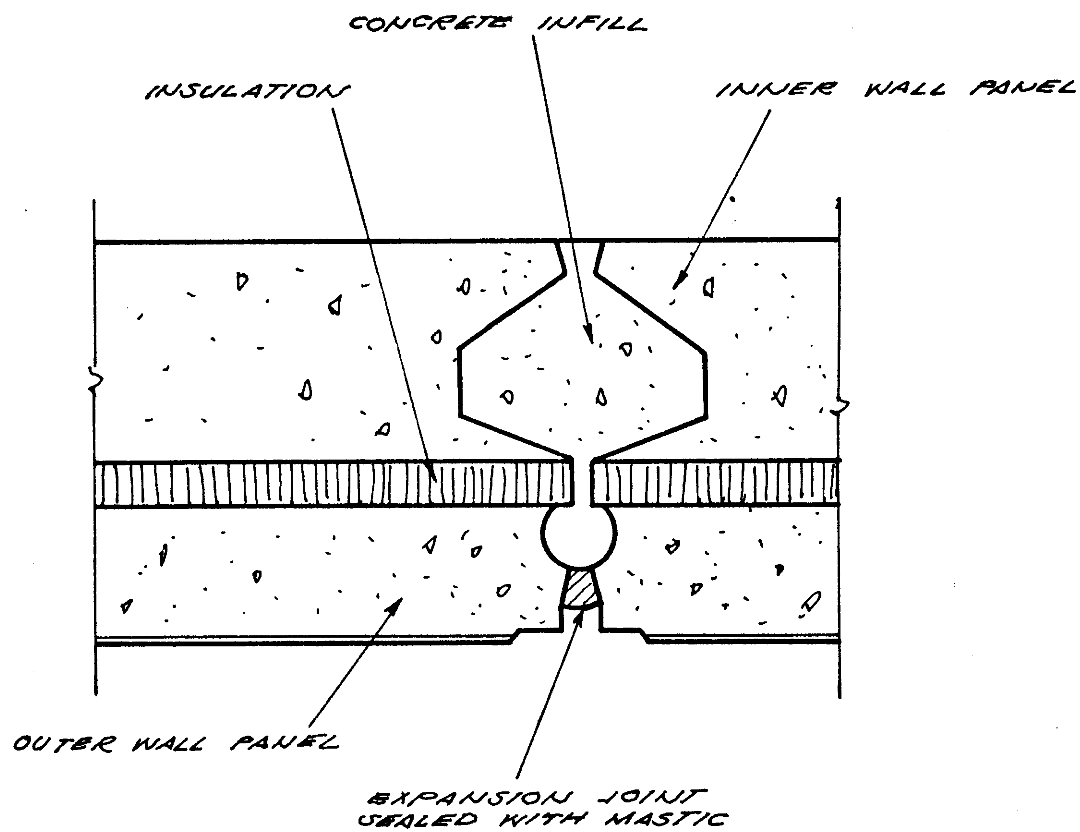
ISOMETRIC VIEW OF PRECASR PANEL JOINT



Source: Reference No.155 page 154

FIGURE: 20

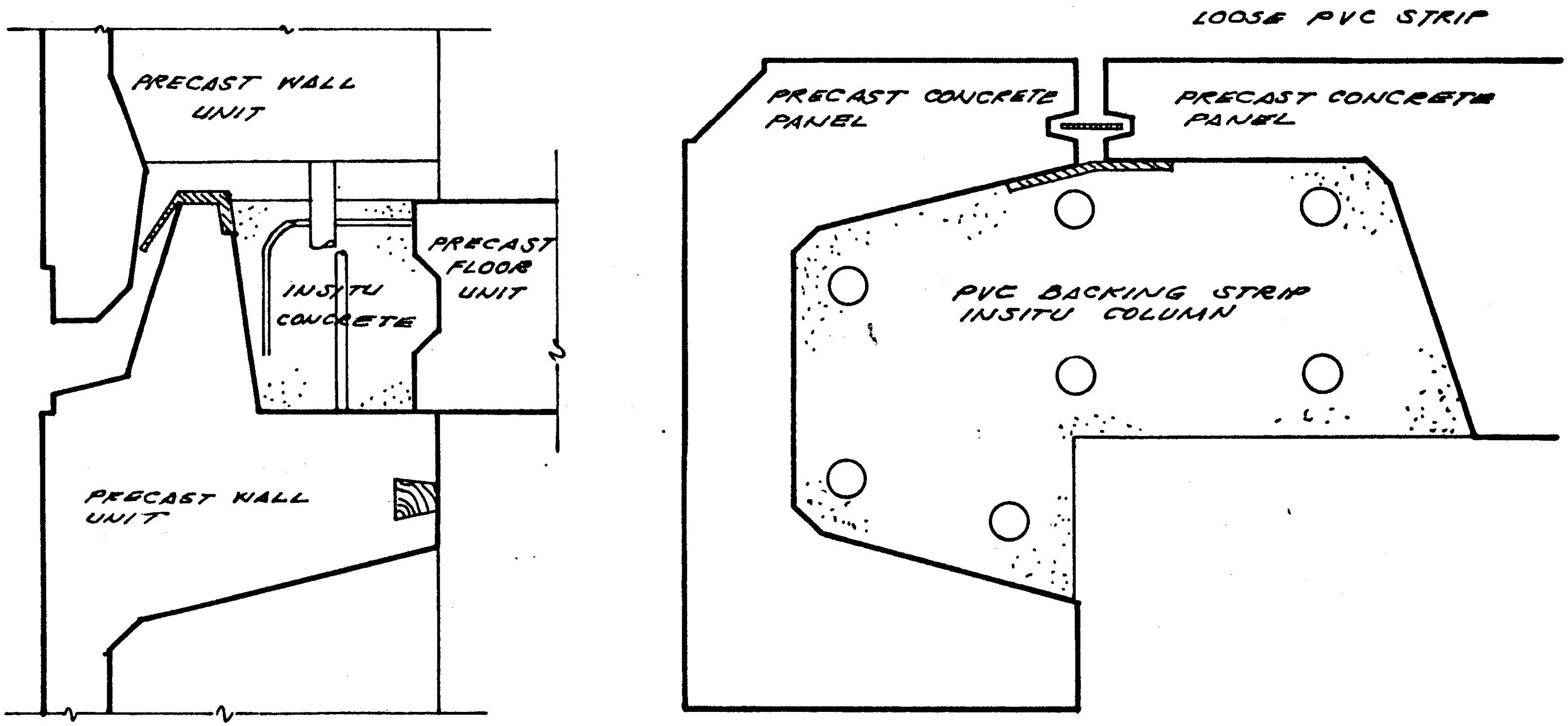
EXAMPLES OF PRECAST PANEL JOINTS



Source: Reference No. 155, page 72

FIGURE: 21

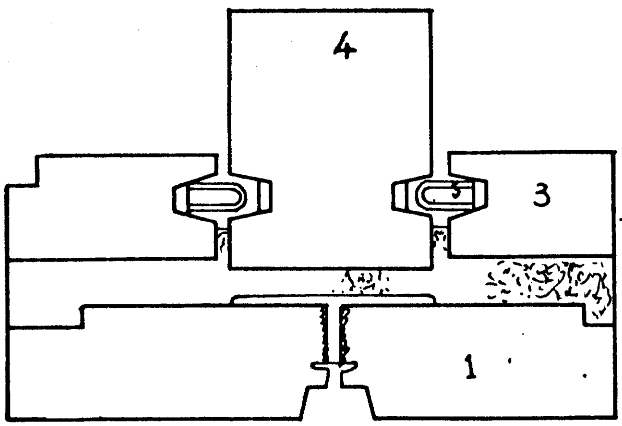
EXAMPLE OF PRECAST PANEL CONNECTION



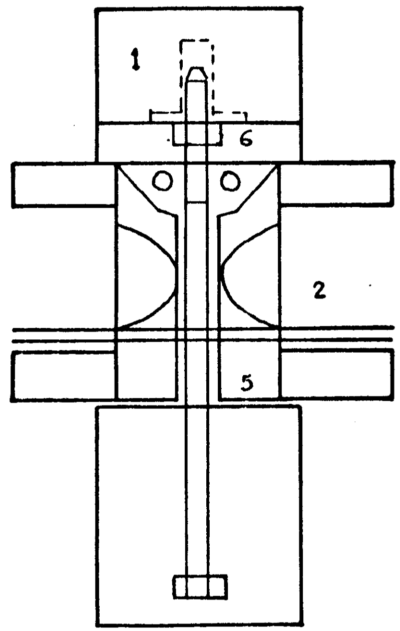
Source: Reference No. 155, page 75

FIGURE: 22

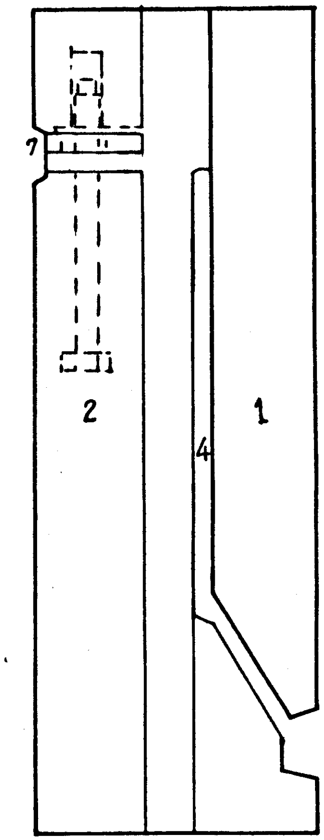
EXAMPLES OF PRECAST PANEL CONNECTIONS



a. HORIZONTAL SECTION BETWEEN FACADE AND WALL ELEMENTS. KEY: 1 EXTERNAL CONCRETE, 2. INSULATION, 3. INTERNAL CONCRETE, 4. WALL ELEMENT, 5. TIE-LUG, 6. FILLING, 7. RAIN PROTECTION



b. VERTICAL SECTION OF JOINT BETWEEN WALL ELEMENTS AND FLOOR SLAB. KEY: 1 WALL ELEMENTS 2. FLOOR SLAB, 3 GUIDING AND HOISTING BOLT, 4. ADJUSTABLE NUT, 5. ROOFING FELT UNDER TWO BEARING PROJECTIONS, 6. GROUTING WITH CEMENT MORTAR, 7. GUIDE HOLE IN WALL ELEMENT

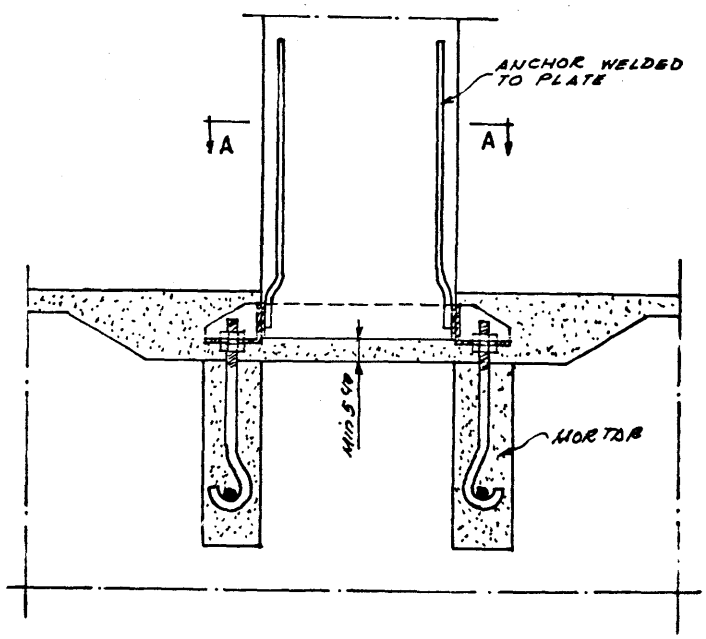


c. VERTICAL SECTION OF JOINT BETWEEN STAIRCASE FACADE ELEMENTS. KEY: 1 EXTERNAL CONCRETE, 2. INTERNAL CONCRETE, 3. INSULATIO 4. PLASTIC FOIL, 5. GUIDING AND HOISTING BOLT, 6. FILLING, 7. CEMENT MORTAR JOINT

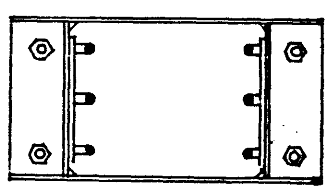
Source: Reference No. 155 , page 65

FIGURE : 23

COLUMN CONNECTION



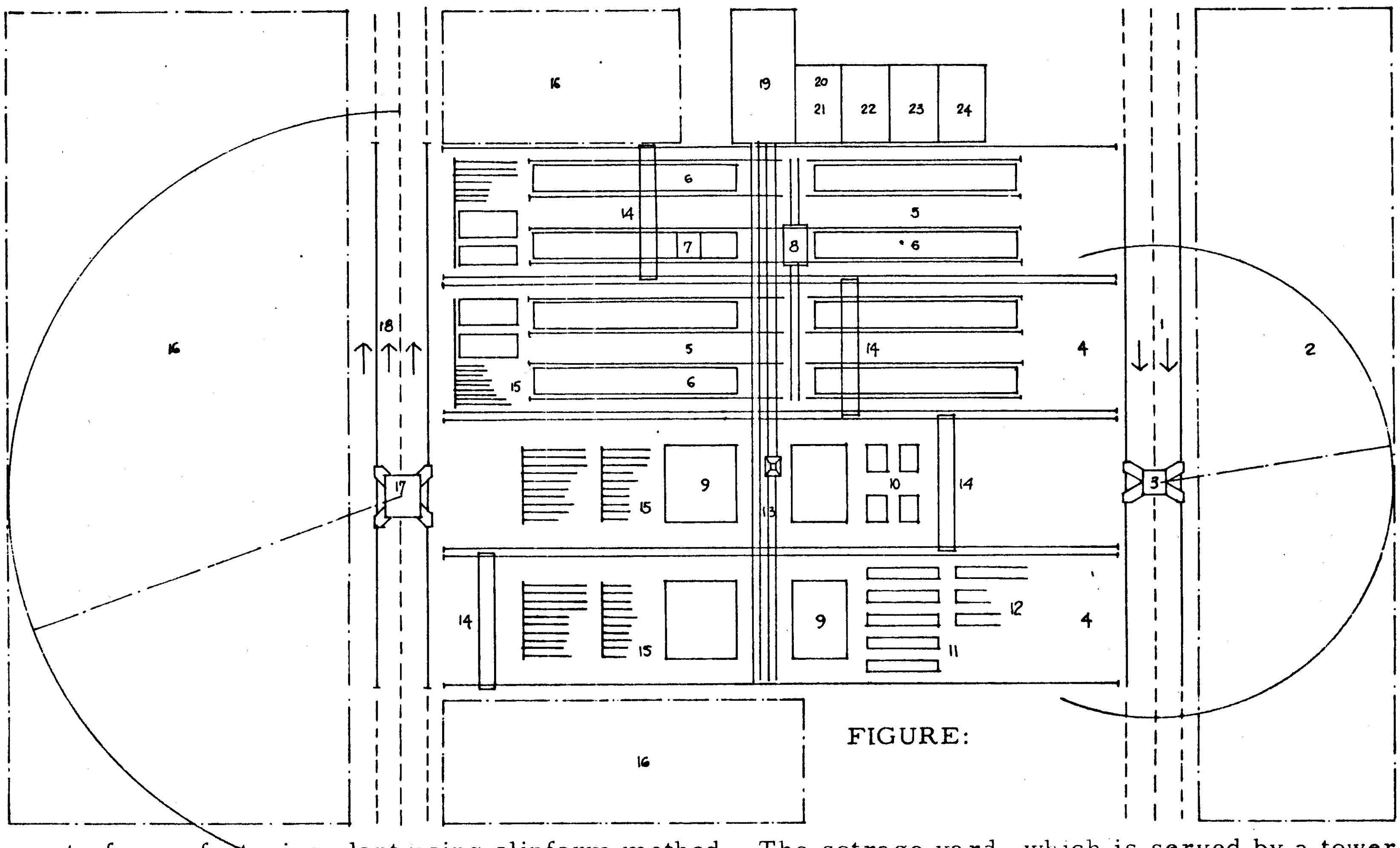
SECTION A-A



Source: Ref 53

FIGURE : 24

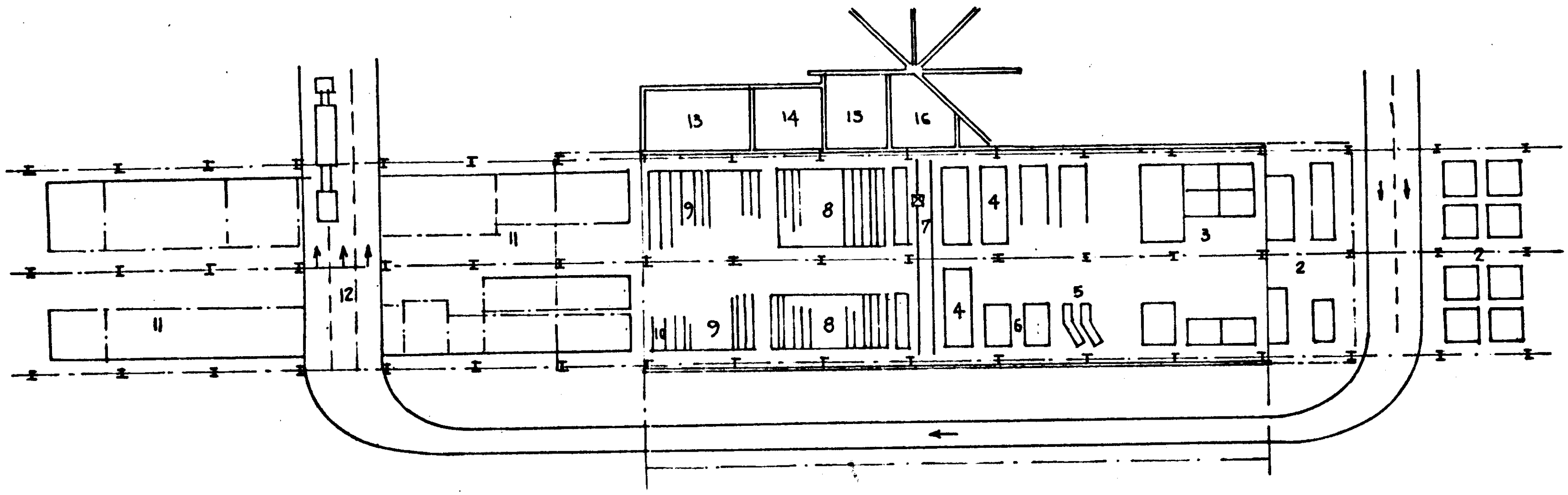
PLANT LAYOUT



Layout of manufacturing plant using slipform method. The sotrage yard, which is served by a tower crane, is located transversely to the centre-line of the cating shed: (1) tower crane track, (2) storage yard, (3) tower crane, (4) casting bays, (5) (6) slipforming 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 engineering workshop, (22) boiler house, (23) compressor plant, (24) transformer station.

Source: Reference No. 66 , page 310

FIGURE : 25



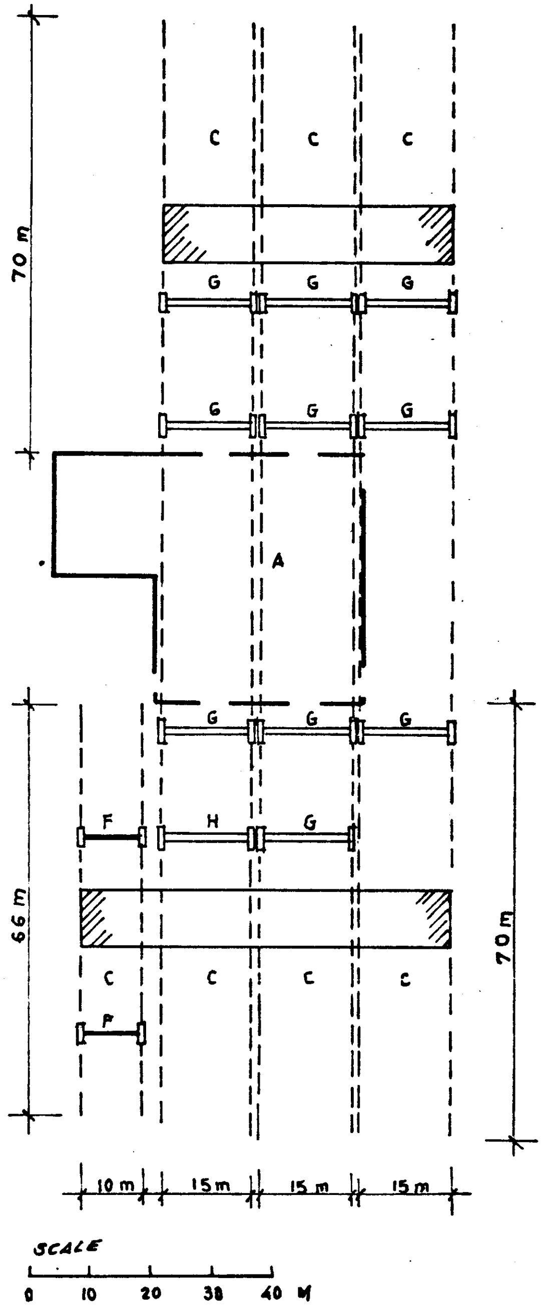
PLANT LAYOUT

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: Reference No. 60 , page 305

FIGURE: 26



A = PRODUCTION AREA
C = STOCKYARD

PLANT LAYOUT

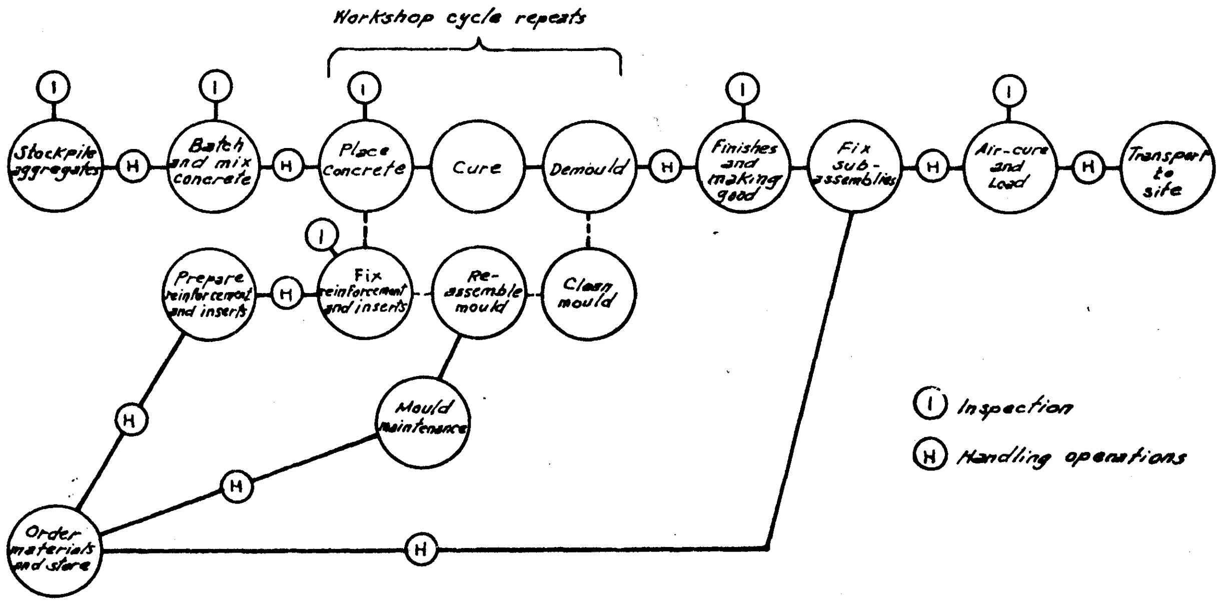
LIFTING EQUT.
F = PORTLAND CRANE
G = BRIDGE CRANE 10 TONS
H = —"— —"— 5 TONS
▨ = UNLOADING AREA

Source: Reference 60

FACTORY A6 - SITUATION PLAN

FIGURE: 27

SEQUENCE OF OPERATIONS; PRECAST PANEL PRODUCTION



Source: Reference 14 , page 27

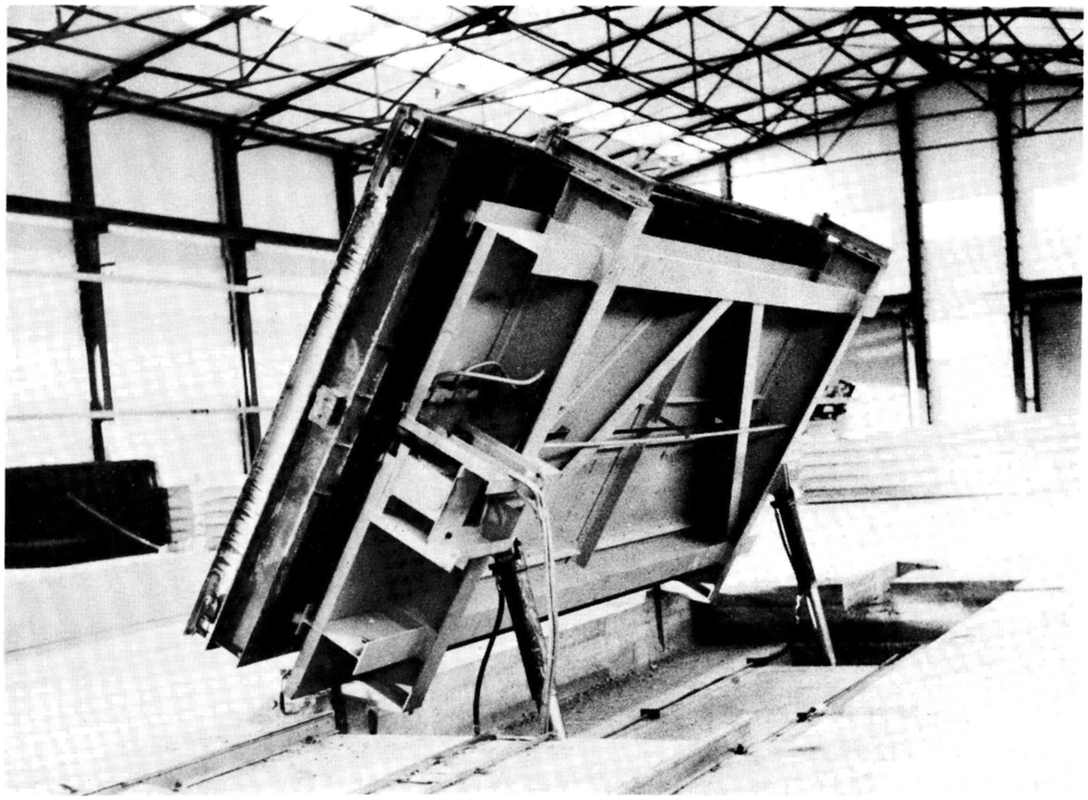
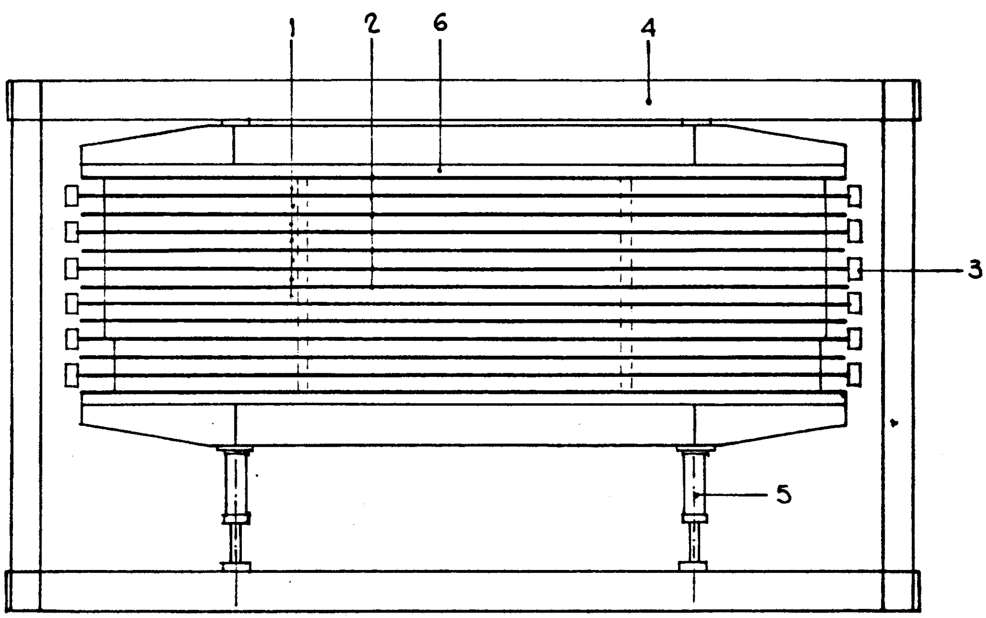


Figure: 28 ARBAU-Pallet on a tilting table in a pre-cast factory.

FIGURE: 29

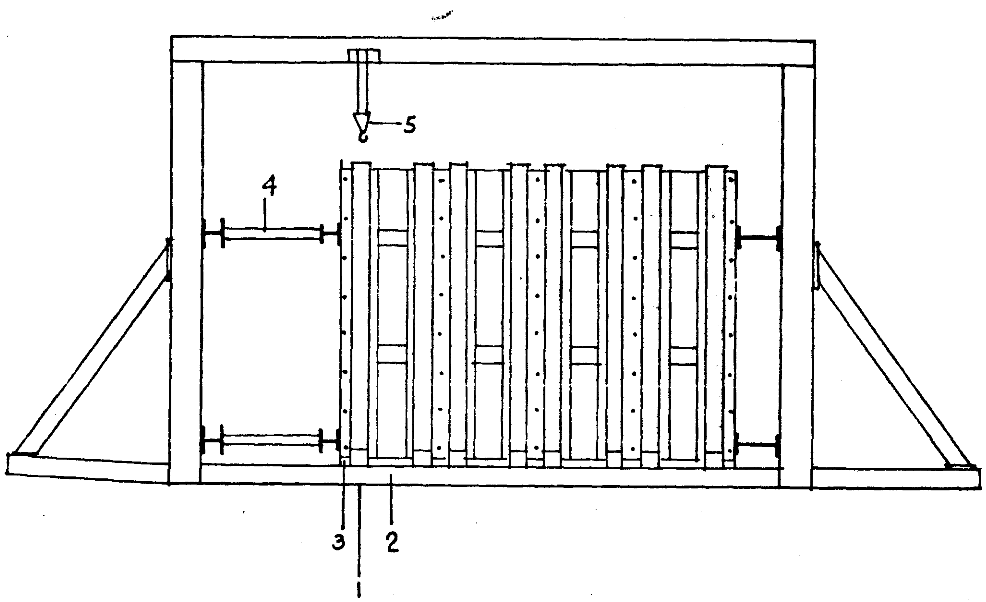
Plan of battery mould with
vibrators attached to the ends:
(1) precast concrete unit
(2) steel mould plate
(3) external vibrator
(4) battery mould frame
(5) hydraulic jacks
(6) end mould panel (mould type
Luchterhand and others)



Source: Reference No.60 , page 288

FIGURE: 30

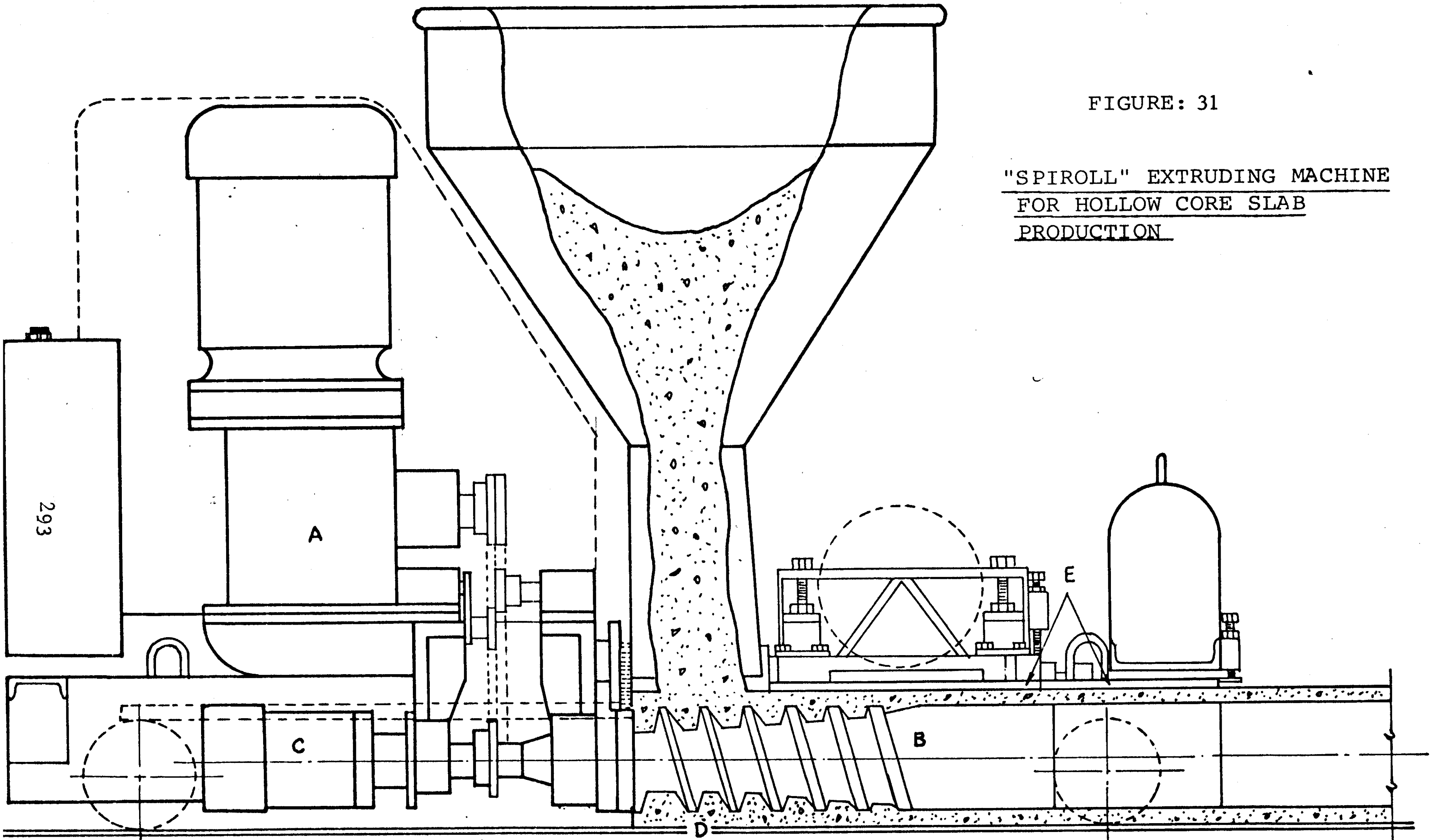
Cross-section through a battery mould with heating elements and vibrating elements; the latter are each equipped with five high-frequency vibrators:
(1) frame, (2) vibrating element, (3) heating element, (4) hydraulically powered thrust props for pushing the various parts of the mould together, (5) pulley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



Source: Reference No. 60 , page 287

FIGURE: 31

"SPIROLL" EXTRUDING MACHINE FOR HOLLOW CORE SLAB PRODUCTION



Source: Spiroll Ltd-Canada

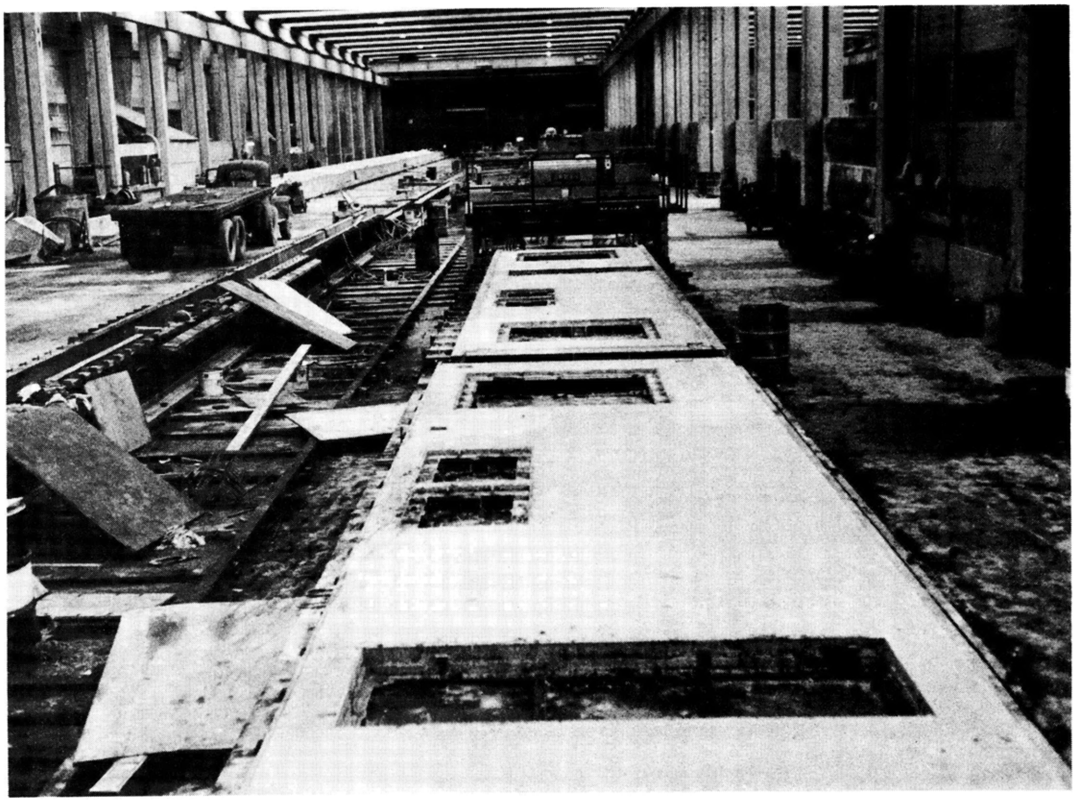


Figure: 32 ARBAU-Machinery train in a pre-cast factory near Boston/Mass.- USA

Figure: 33 ARBAU-Finishing Screed floating a two-piece element.

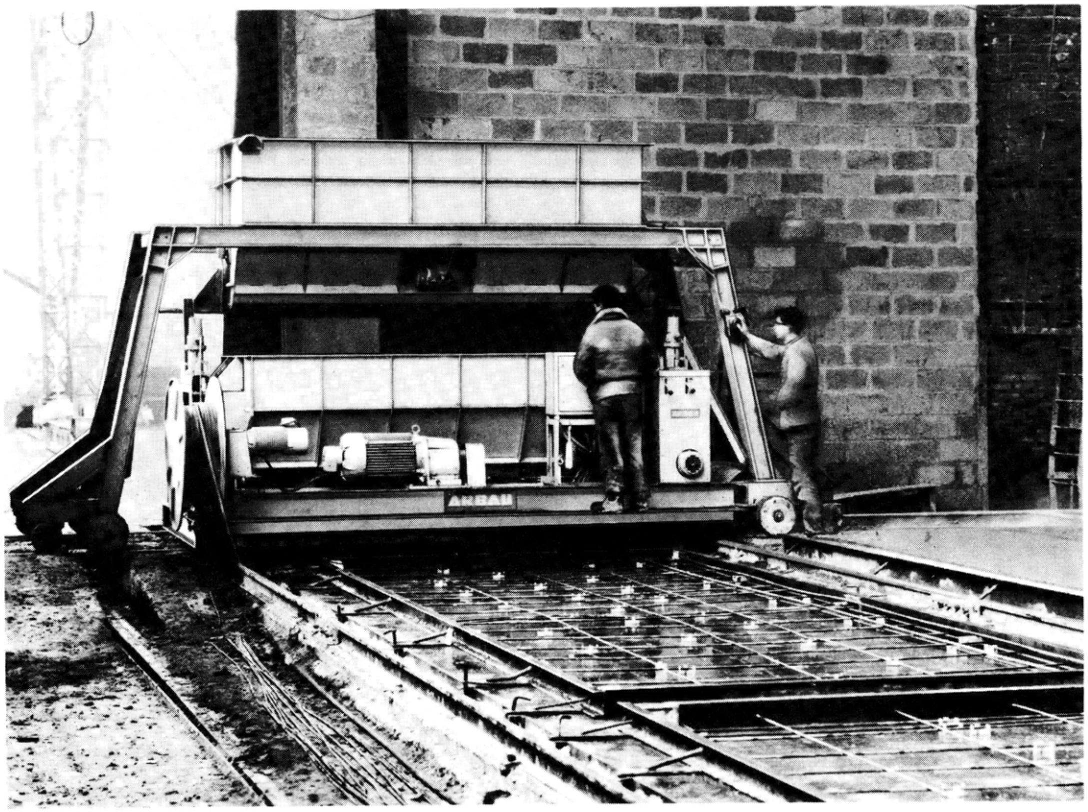


Figure: 34 Spreader receiving the concrete from a transversally traveling storage hopper.

Figure: 35 ARBAU-Compactor compacting a wall element.

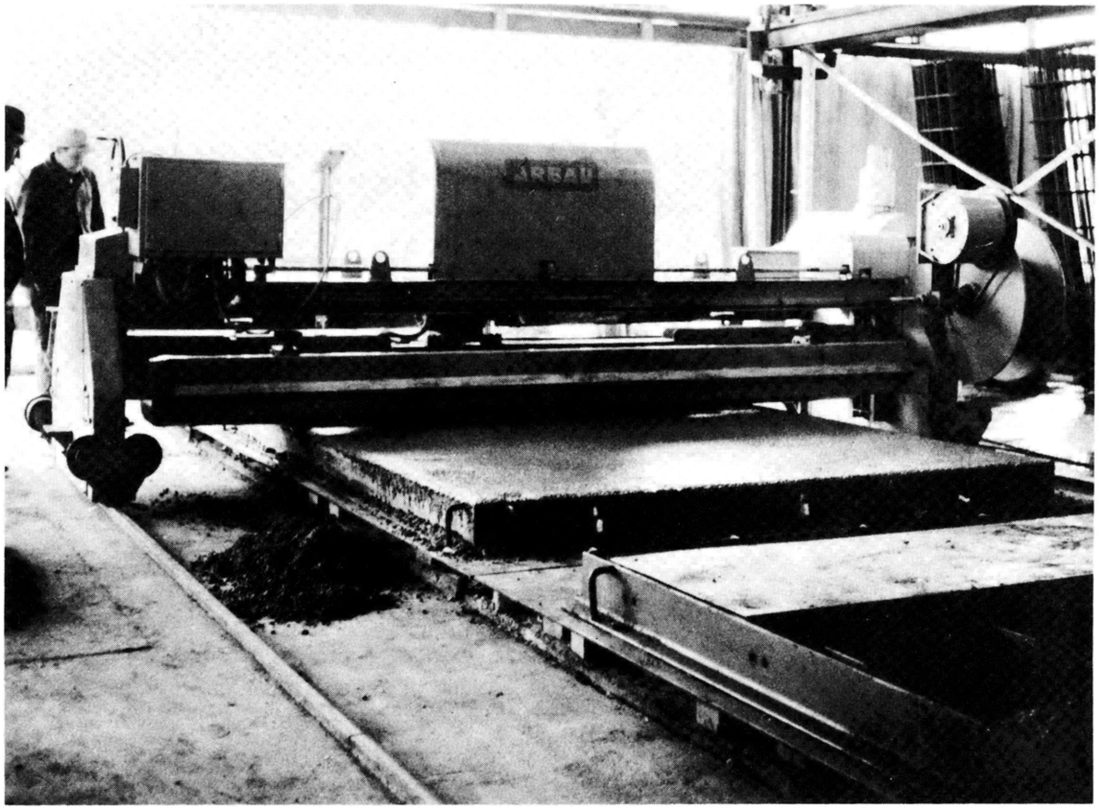
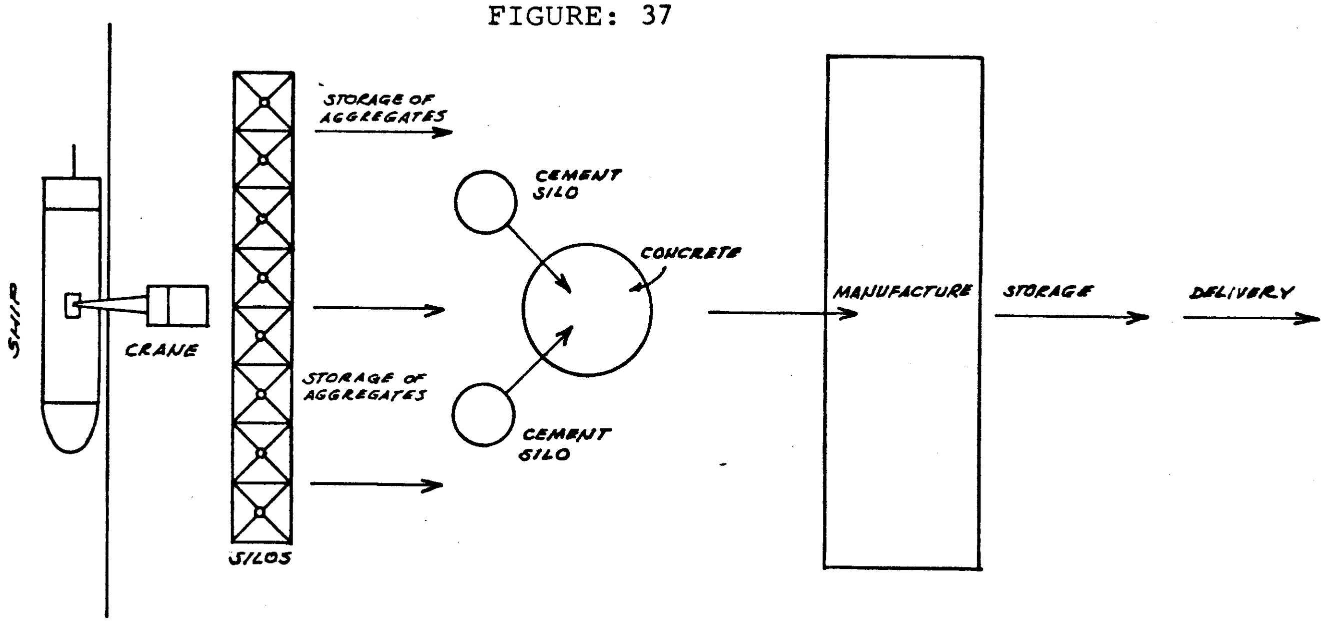


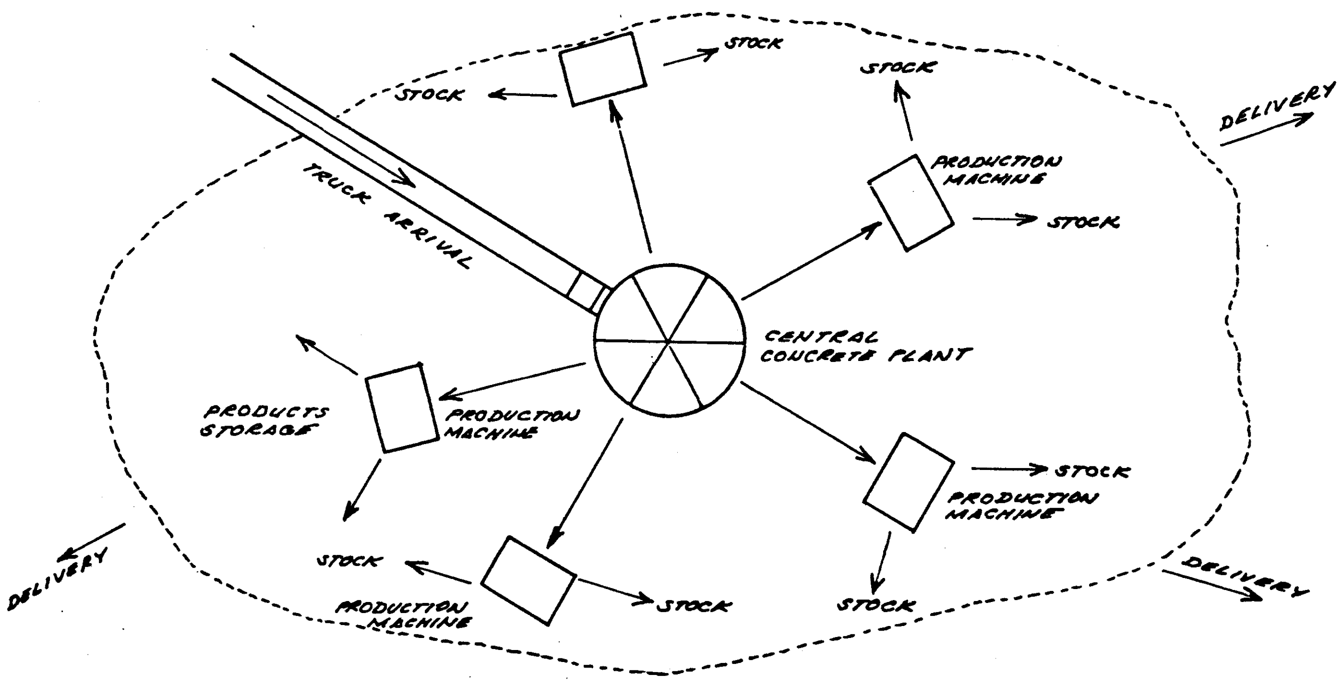
Figure: 36 Finishing Screed passing over a compacted wall element.

FIGURE: 37



LINEAR LAYOUT

CONCRETE PLANT LAYOUTS

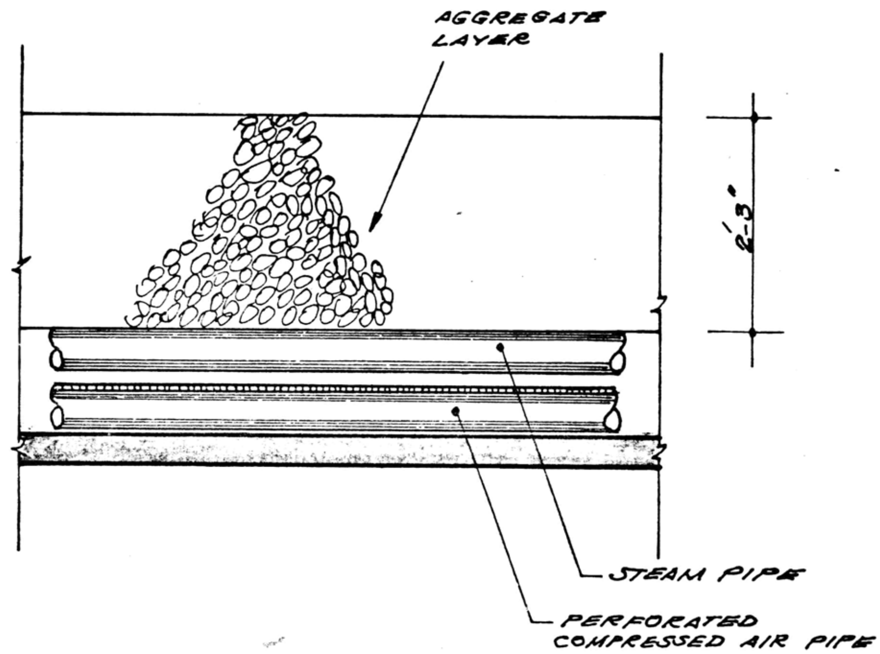


STAR LAYOUT

Source: Reference No. 53

FIGURE : 38

AGGREGATE HEATING SYSTEMS



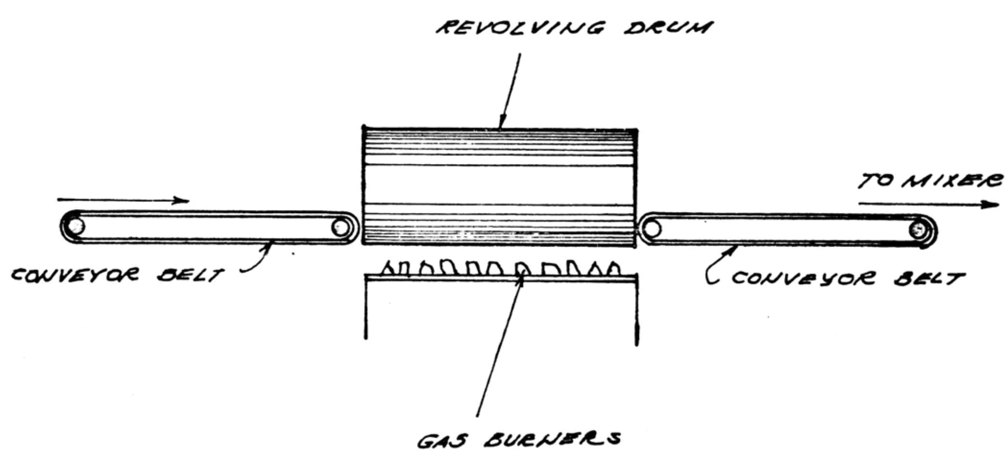
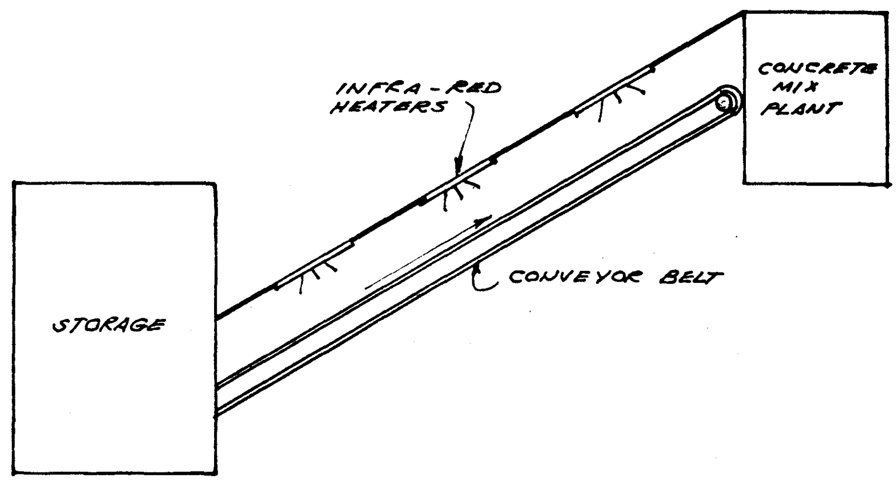


FIGURE: 39



AGGREGATE HEATING SYSTEMS

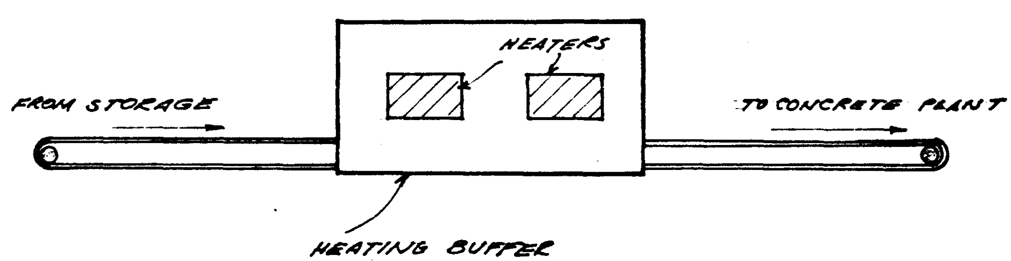
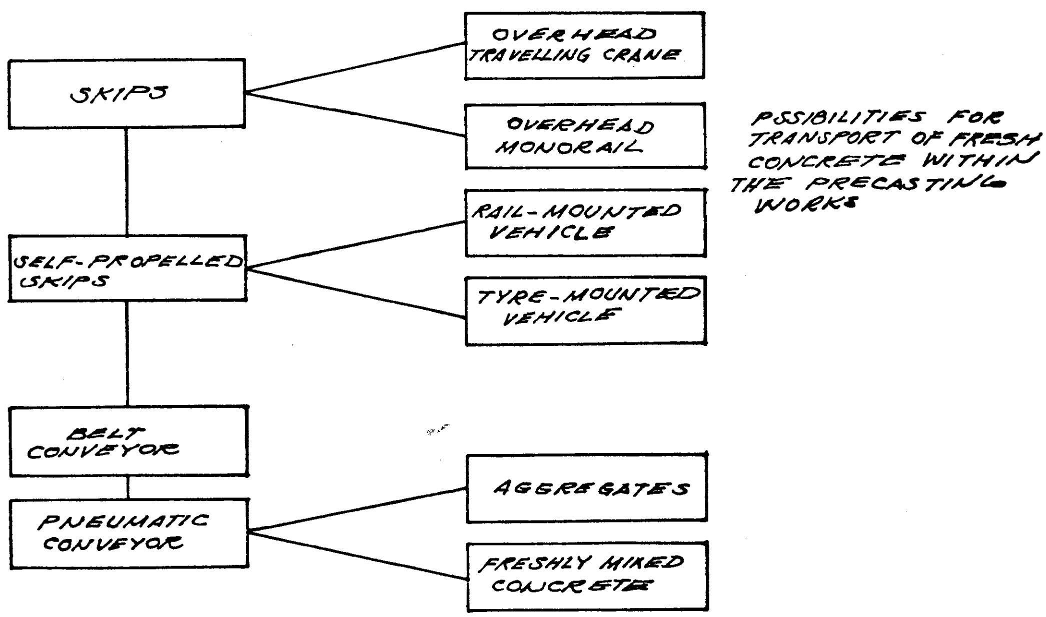


FIGURE: 40

METHODS FOR IN-PLANT DELIVERY

OF FRESH CONCRETE



Source: Reference No. 60

CODE	OPERATION	CREW
	SLAB TESTING	2
	STRAND RELEASE	3
	SLAB CUTTING	1
	STRIPPING	3
	CLEANING & WAXING	2
	LAYING STRAND & STRESSING	2
	EXTRUSION	3
	SLAB CLEARANCE	3
	EXTRUDER CLEANING	3
	EXTRUDER MAINTENANCE	1
	CURING	1

FIGURE: 41

Instruction Notes

1- The operation steps in the 24 hr. production cycle are coded for ease of reference.
2- Each code represents a distinct step in the production cycle. For example, the code represents strand release.
3- The ordinate length of each extrusion bed graph indicates time required for a given step in the production cylce.
4- The abscissa width on each extrusion bed graph indicates number of crew-men required for a given step in the production cycle.

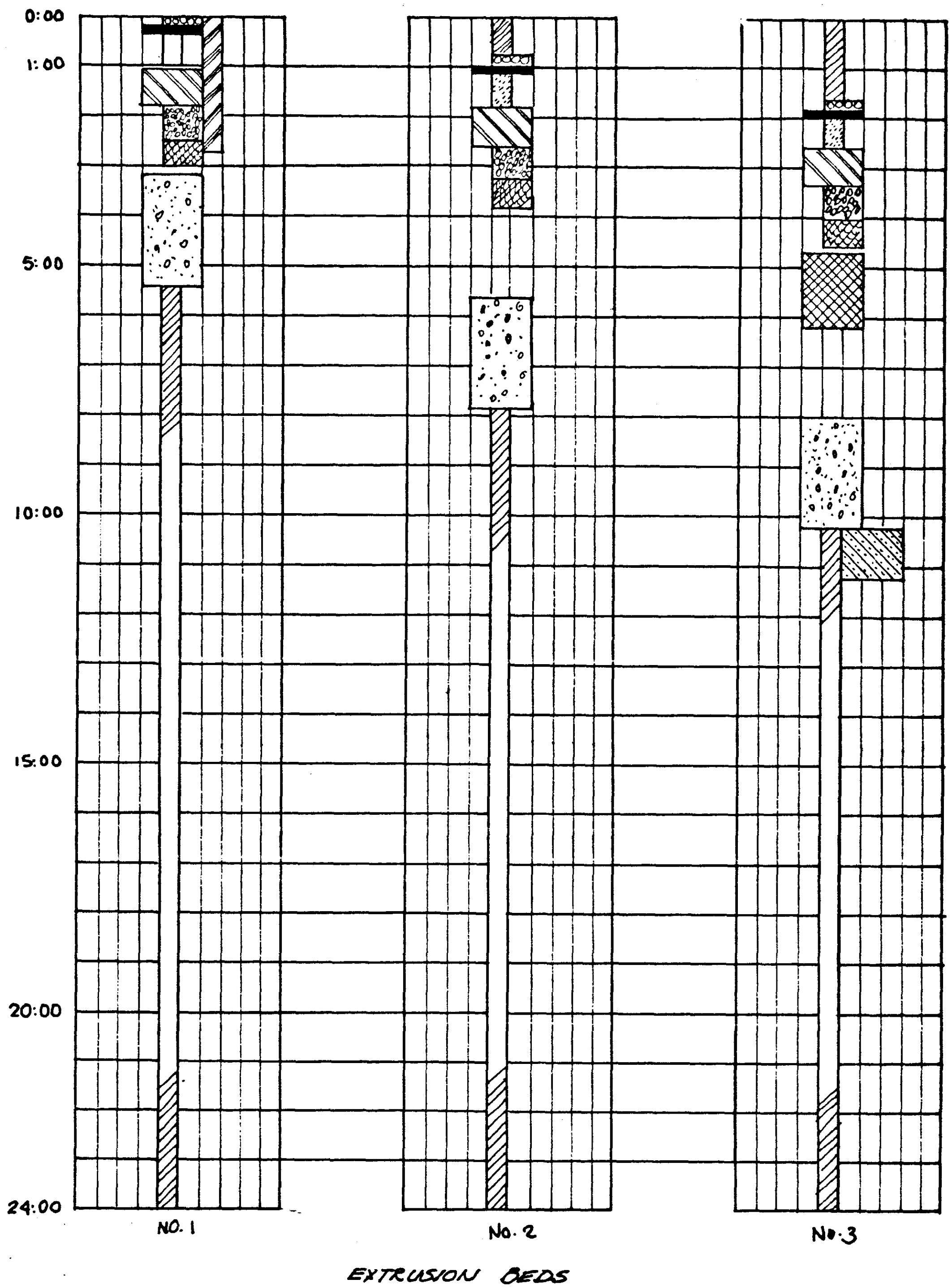
Source: Spiroll Ltd-Canada

General Notes

1- Time span indicated is non-datum 24 hr. cycle. Production cycle can commence at hour determined by producer.
2- Due to regional climatic disparity and work habits, lunch and rest breaks are not incorporated in the production cycle.
3- Total daily production of plant is 4,000 sq. ft.
4- Annual production of plant is 1,000,000 sq. ft.

LABOUR REQUIREMENTS FOR HOLLOW SLAB PRODUCTION

FIGURE : 42

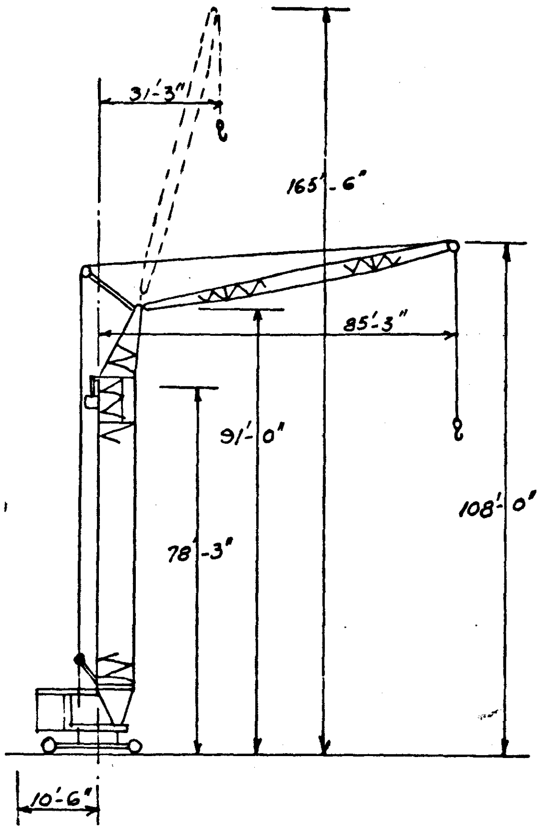


LABOUR PRODUCTION ANALYSIS

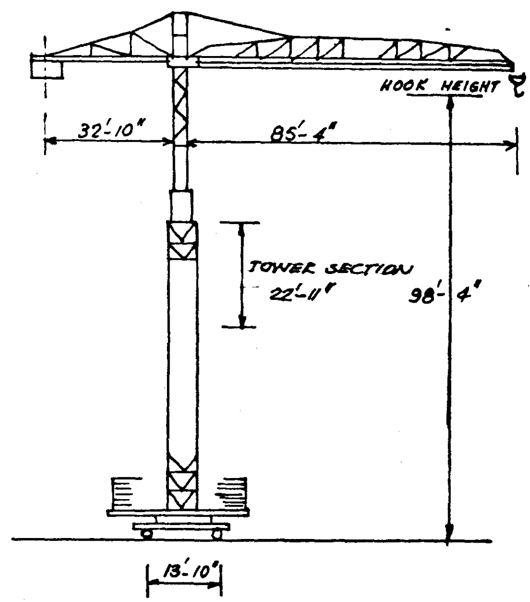
Source: Spiroll Ltd-Canada

FIGURE : 43

CRANE CHARACTERISTICS



NOTE:
MAX. HEIGHT 236'-0" WHEN MOORED TO BUILDING



RADIUS	85'-3"	65'-6"	31'-3"	MOTOR H.P.
SAFE WORKING LOAD	BELOW 1T-5 CWTS	1T. 15C	3T. 10C.	
HEIGHT OF LIFT	108'-0"	144'-4"	165'-6"	
HOIST SPEED FT. PER MIN.	262'-0"	114'-0"	65'-0"	18.0
TRAVELLING SPEED	115' PER MIN.			2/7.0
SLEWING SPEED	1 REVOLUTION PER MIN.			4.0
LUFFING SPEED	60 SECS. MAX. TO MIN. RAD.			18.0
RAIL GAUGE	12'-3"			
WHEEL BASE	13'-9"			
TAIL RADIUS	10'-6"			
BALLAST	22¼ T.	UNDER CARRIAGE 10¼ T. SUPERSTRUCTURE 12 T.		

TYPICAL TOWER CRANE WITH LUFFING JIB

RADIUS	85'-4"	59'-0"	39'-4" TO 4'-10"
SAFE WORKING LOAD	1T. 5C.	1T. 18C.	3T. MAX.
HEIGHT OF LIFT WITH TWO EXTENSIONS			98'-4"
HOIST SPEED FT. PER MIN.	149'-6"	118'-0"	60'-0"
TRAVELLING SPEED	65'-7" per MIN.		
SLEWING SPEED	0.75 REVOLUTIONS PER MIN.		
CRAB SPEED	115' PER MIN.		
RAIL GAUGE	12'-5⅝"		
WHEEL BASE	13'-10"		
CRAB MOTOR	2 H.P.		
BALLAST	19 TONS		

TYPICAL TOWER CRANE WITH LEVEL JIB

Source: Ref. 17

FIGURE: 44

CRANE CHARACTERISTICS

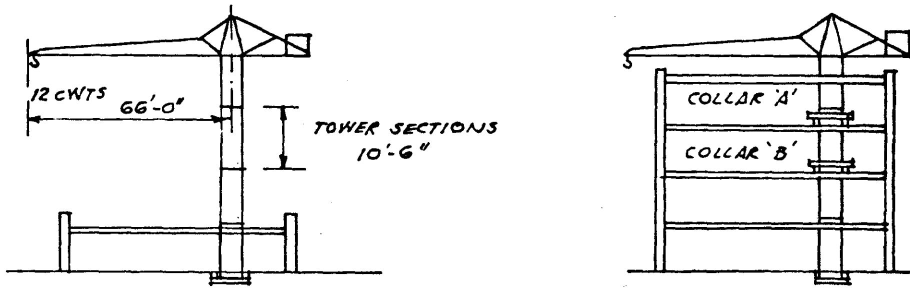


FIG. 1. (LEFT) CRANE ERECTED ON FOUNDATIONS. CONSTRUCTION STARTS, HOLES LEFT IN FLOORS FOR MAST. FIG. 2 (RIGHT) COLLARS FITTED AROUND MAST AND ATTACHED TO TWO FLOORS ON GIRDERS SPANNING STRONG POINTS.

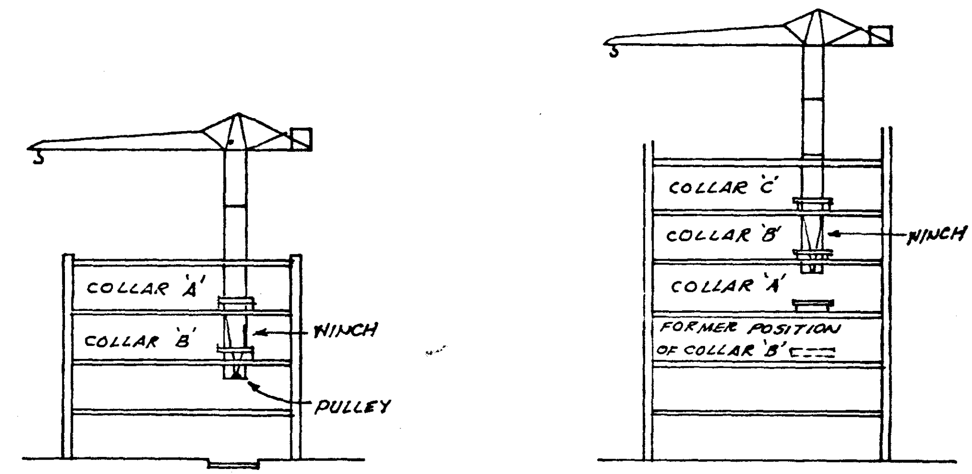


FIG. 3 (LEFT) CRANE DETACHED FROM FOUNDATIONS, LIFTED THROUGH COLLARS WITH HAND WINCH AND REFIXED

FIG. 4 (RIGHT) SUBSEQUENT LIFTS EMPLOY A THIRD COLLAR, FREEING THE FIRST FOR LATER USE

RADIUS	27'-0"	43'-0"	52'-0"	66'-0"
SAFE WORKING LOAD	2 TONS	1 TON	17 CWTS	12 CWTS
HEIGHT OF LIFT	DEPENDANT ON ANCHORAGE			
HOIST SPEED FT. PER MIN.	60 FEET PER MIN.			
TRAVELLING SPEED *	100 FEET PER MIN.			
SLEWING SPEED	1 REVOLUTION PER MIN.			

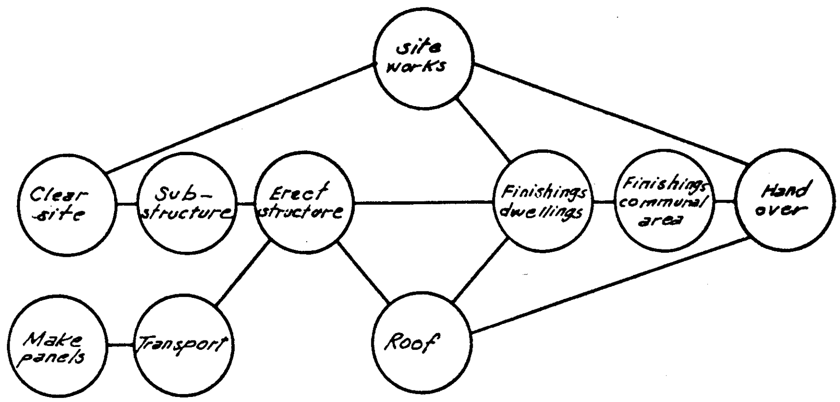
TRAVERSING SPEED	100 FEET PER MIN.
RAIL GAUGE *	9'-3"
WHEEL BASE *	9'-3"
HOISTING WINCH	11 H.P.
WT. OF CRANE	10 TONS (APPROX.)
BALLAST *	18½ TONS ON BASE

VERTICAL LOAD	HORIZONTAL LOAD ON EACH FLOOR WITH OUT OF SERVICE WIND AT APPROX. 100 M.P.H			
7½ TONS	COLLARS 10'-0" APART	COLLARS 12'-0" APART	COLLARS 15'-0" APART	COLLARS 20'-0" APART
	6.9 TONS	5.8 TONS	4.6 TONS	3.5 TONS

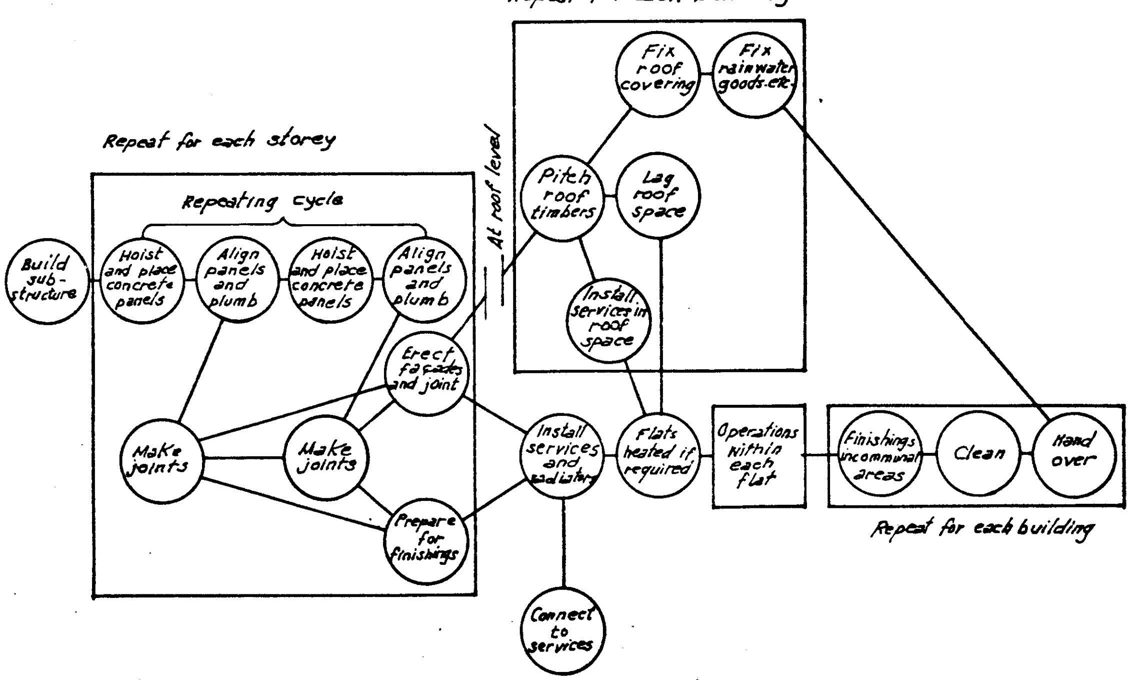
TYPICAL CLIMBING CRANE

Source: Ref. 17

FIGURE: 45



SEQUENCE OF OPERATIONS; LARGE PANEL CONSTRUCTION

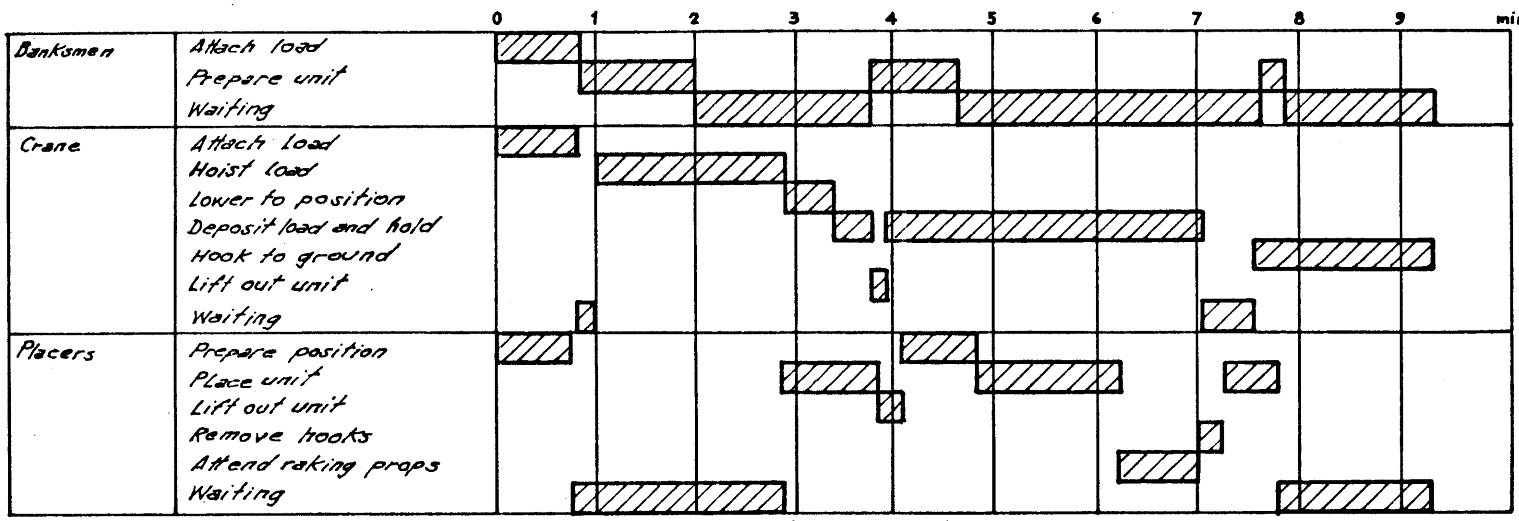


SEQUENCE OF OPERATIONS FOR A BLOCK OF FLATS WITH STAIRWELL ACCESS

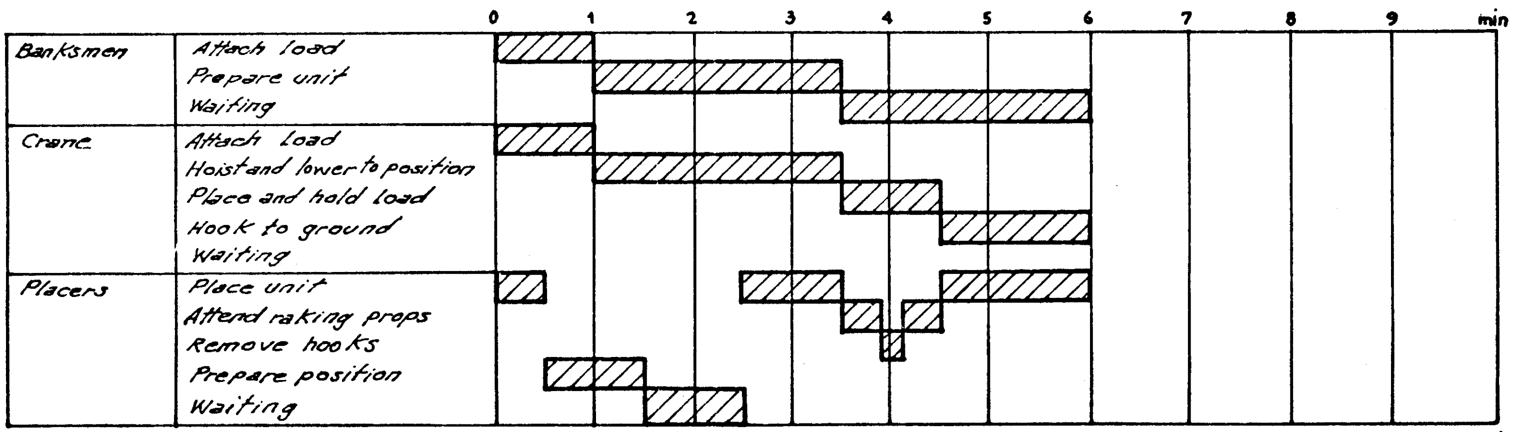
Source: Reference No. 14 , page 15

FIGURE: 46

PANEL ERECTION; EFFECT OF ORGANIZATION OF WORK ON CYCLE TIME



Average cycle time per panel obtained when crane is retained while panel is accurately positioned

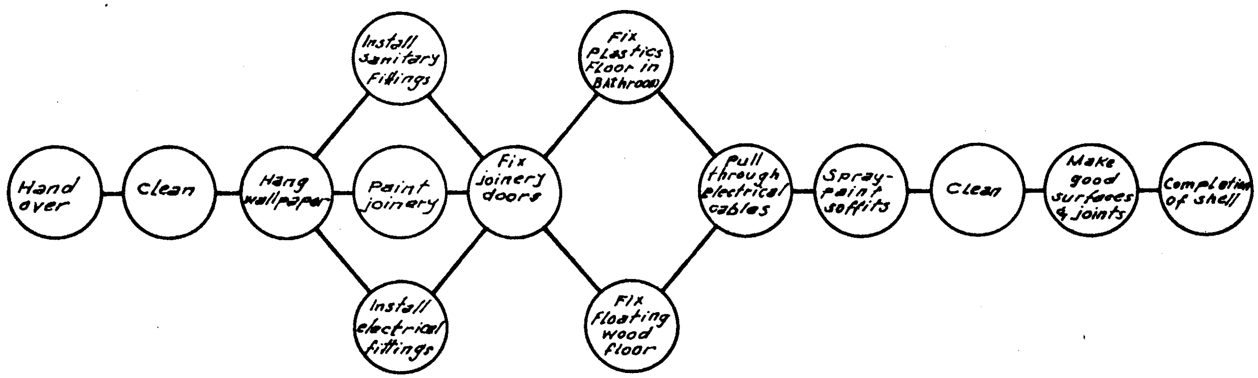


Potential cycle time per panel which could be obtained if crane were released immediately panel is secured

Source: Reference No.14 , page 16

FIGURE: 47

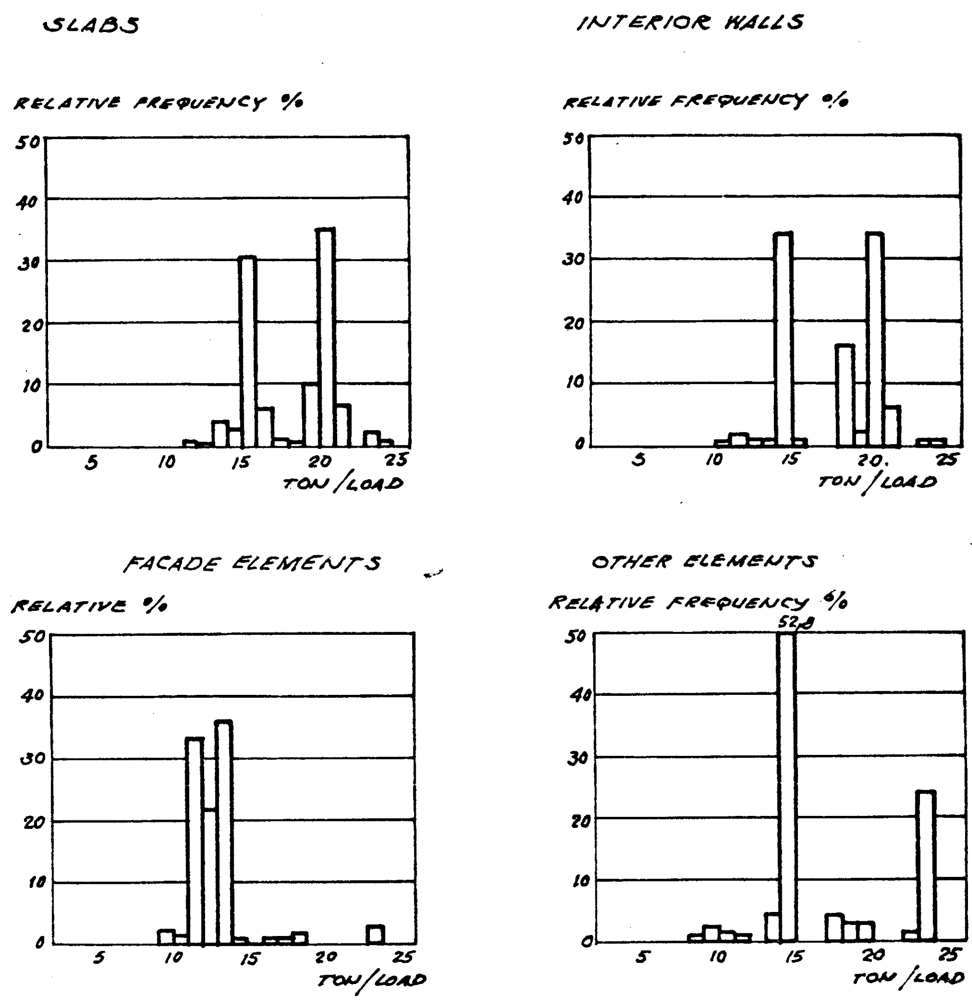
SEQUENCE OF OPERATIONS FOR FINISHINGS AND SERVICES WITHIN EACH FLAT



Source: Reference No: 14 , page 19

FIGURE : 48

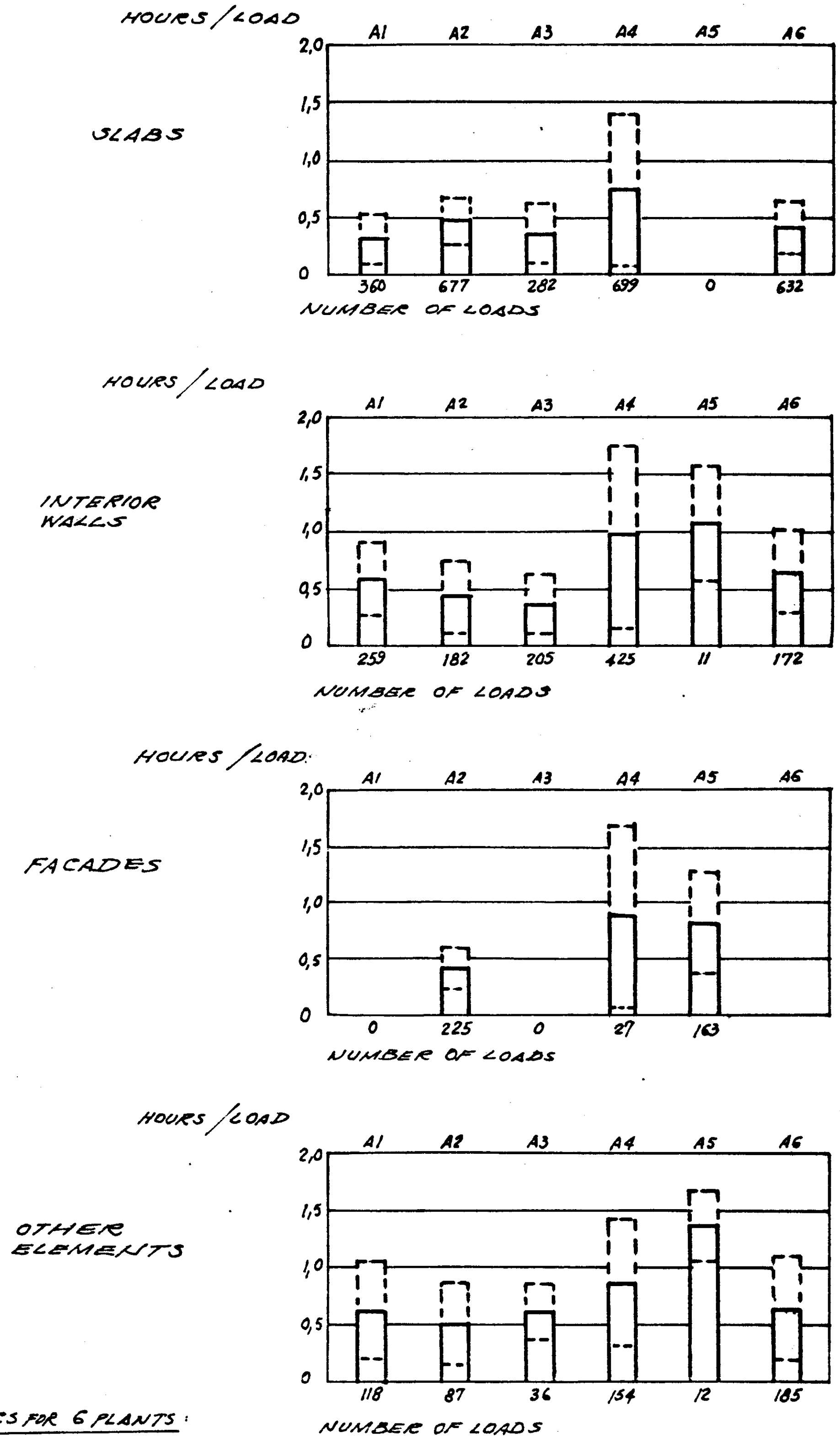
WEIGHT DISTRIBUTION OF TRUCK LOADS



Factory A2. Loaded weight. Dispersion, relative frequencies.

Source: Reference No. 36 , page 87

FIGURE :49 TRUCK LOADING TIMES



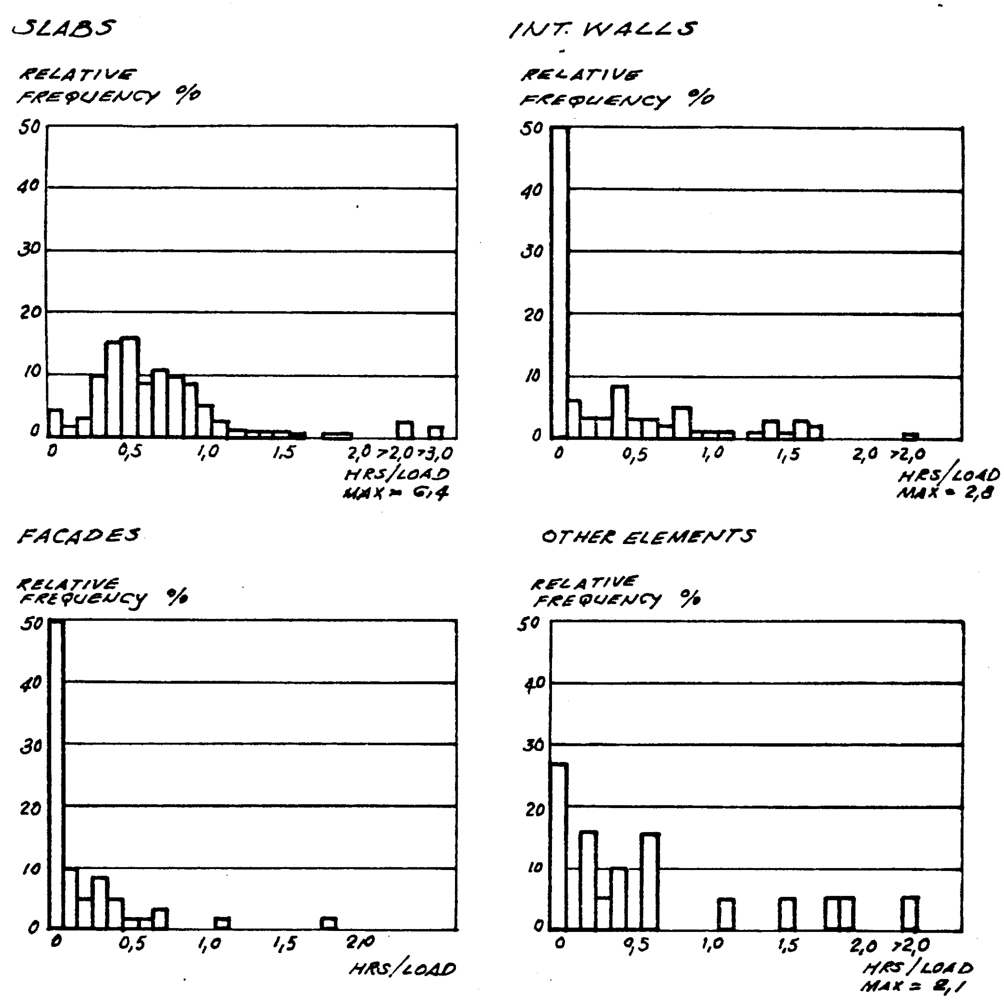
STATISTICS FOR 6 PLANTS:

TIME FOR LOADING, MEANS AND DISPERSION FOR FLOORS, INTERNAL AND EXTERNAL WALLS AND OTHER KINDS OF UNITS. THE CONTINUOUS LINE = THE MEAN, THE BROKEN LINE = A STANDARD DEVIATION. THE DISPERSION IS CALCULATED FOR THE MEAN OF THE TIME PER HAUL DURING ONE DAY FO EVERY VEHICLE USED.

Source: Ref.36

FIGURE: 50

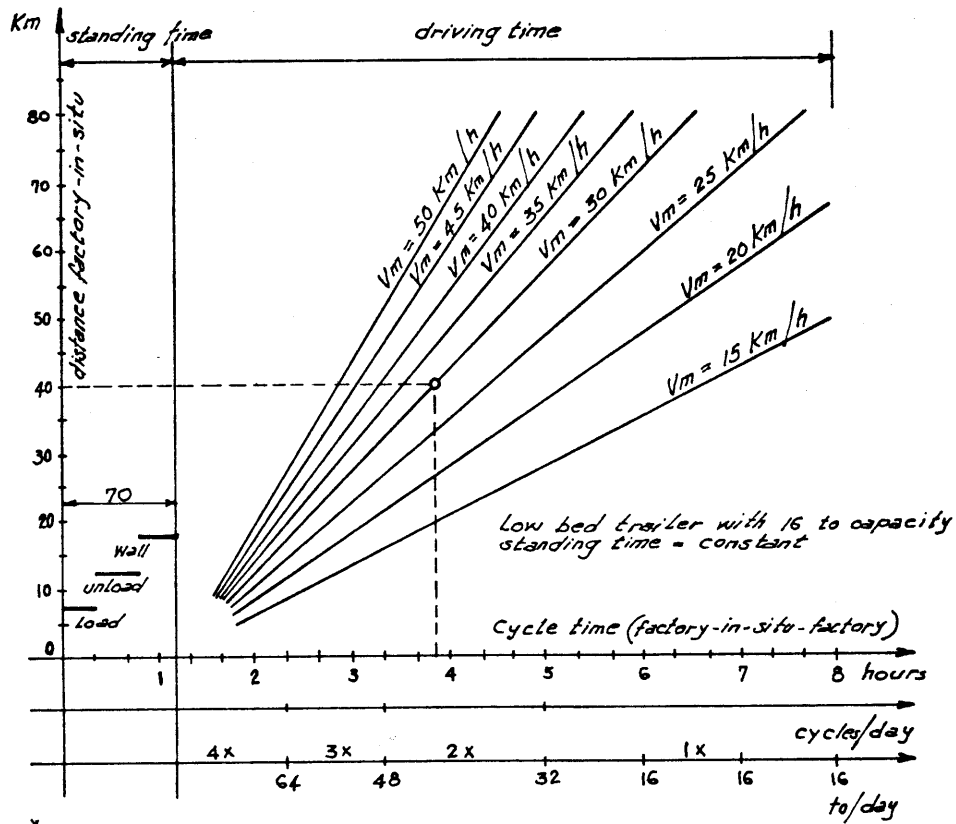
UNLOADING TIMES



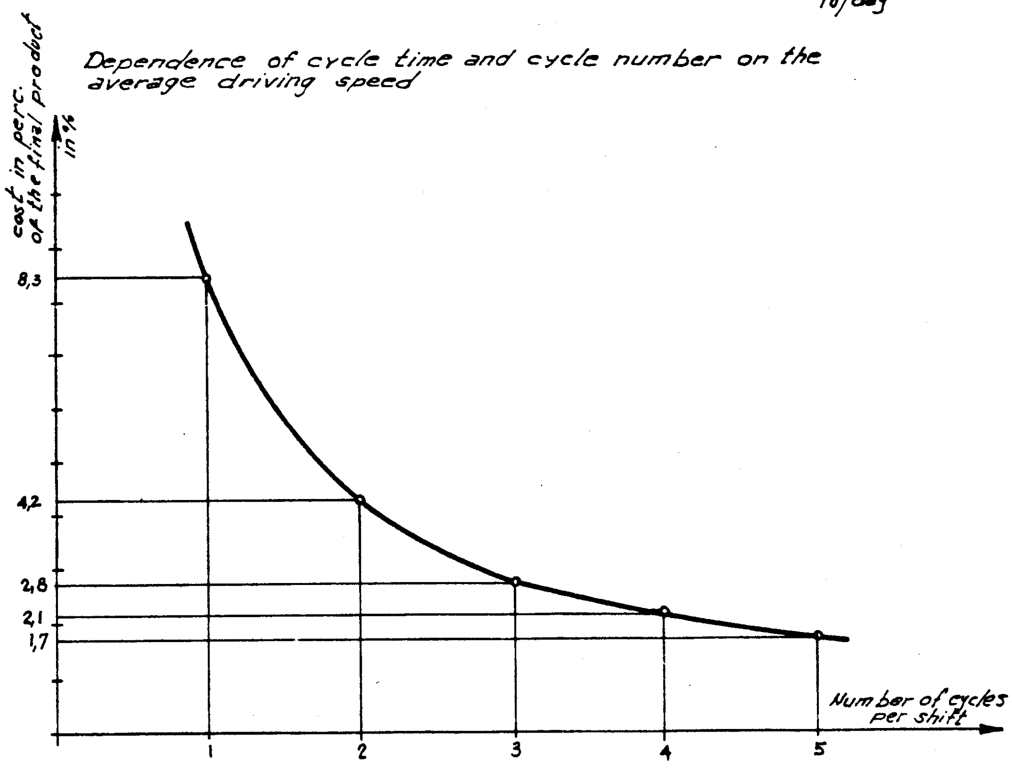
Building 02. Time for unloading. Dispersion, relative frequencies.

Source: Reference No 36 page 107

FIGURE: 51



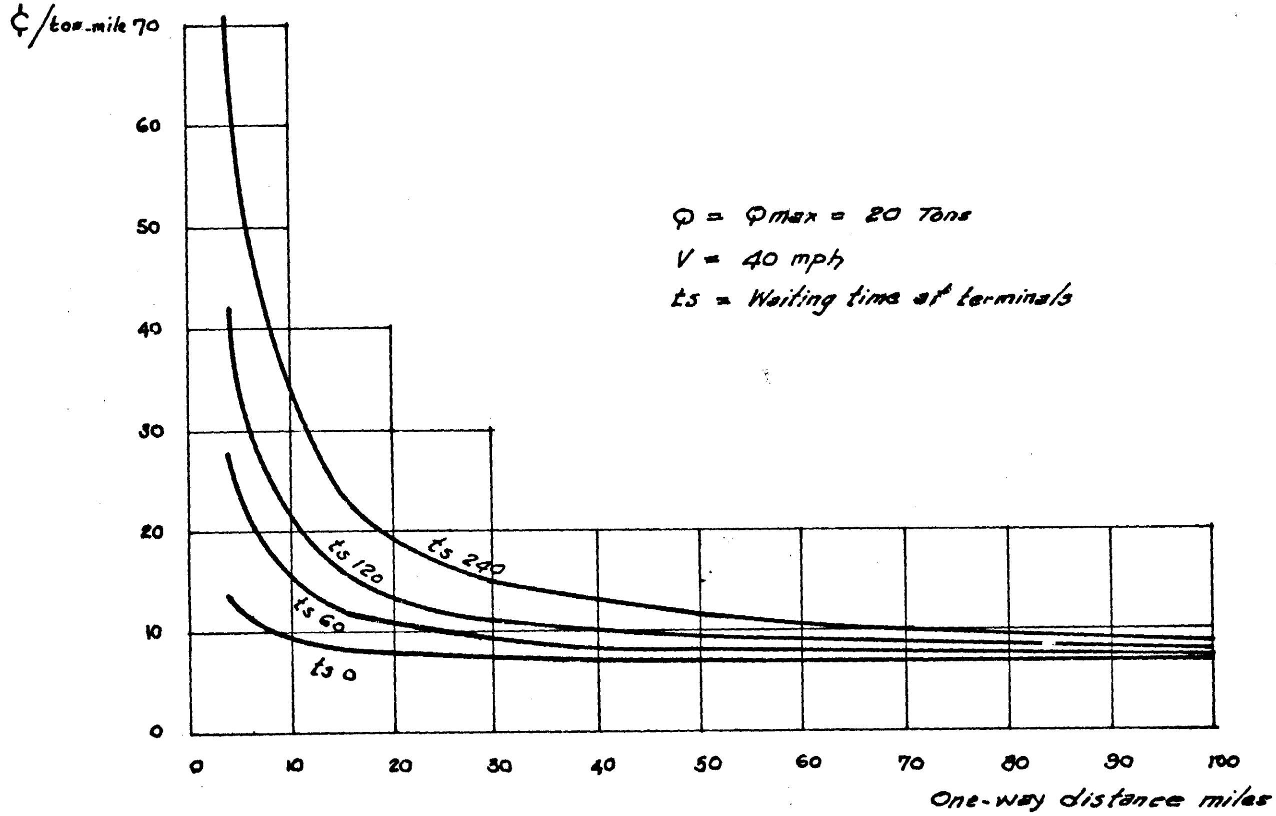
Dependence of cycle time and cycle number on the average driving speed



Dependence of transport-cost-charge of the final product on the number of cycles

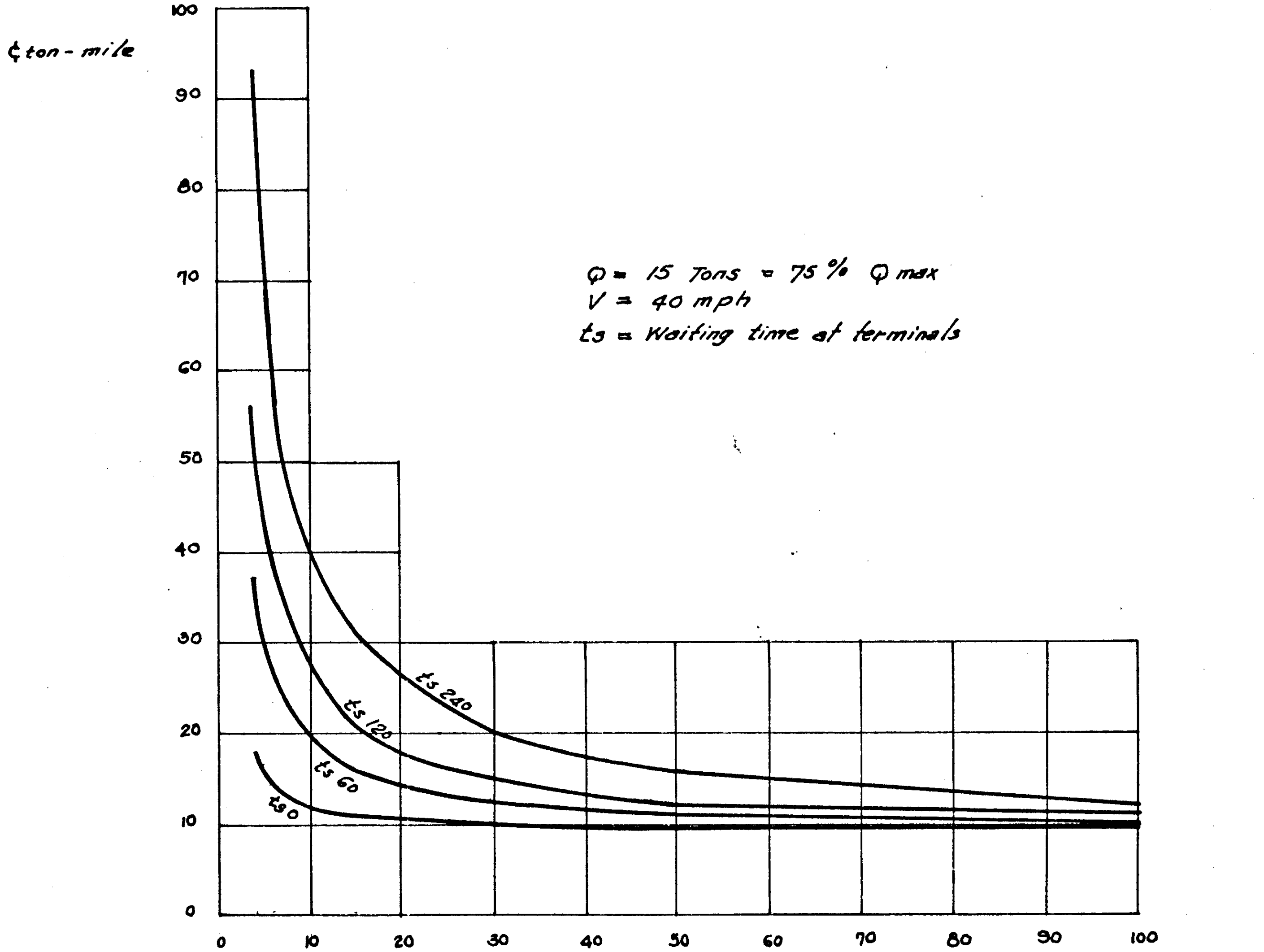
Source: Ref. 128

FIGURE: 52



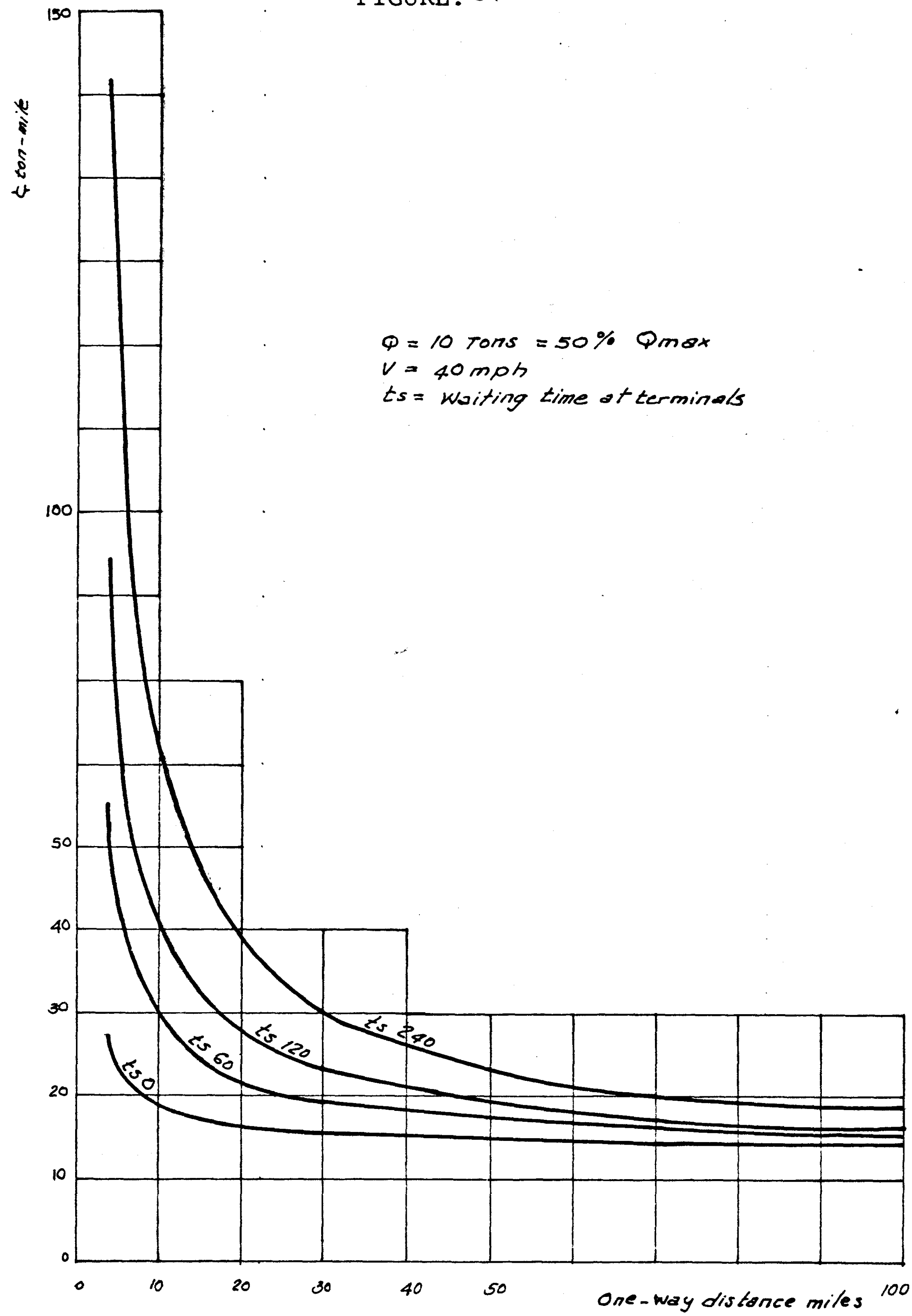
TRANSP. COST OF PRECAST ELEMENTS

FIGURE: 53



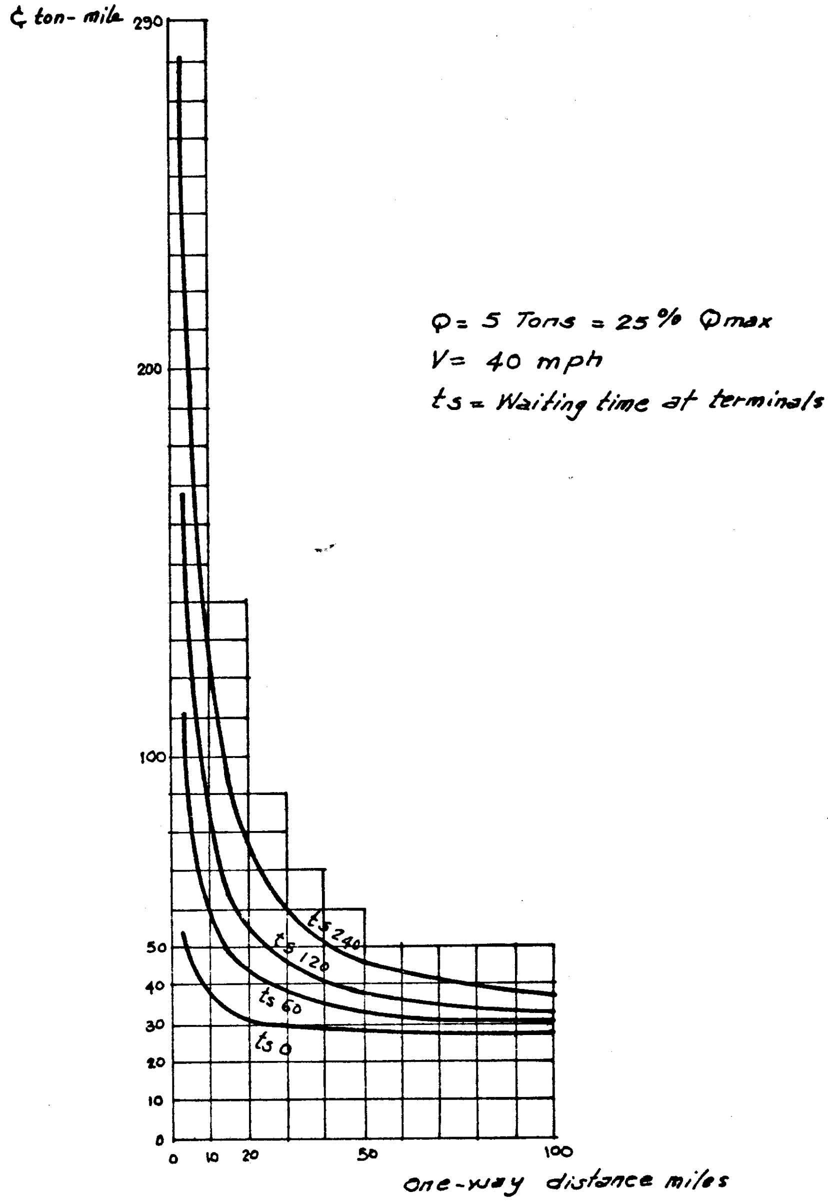
TRANSP. COST OF PRECAST ELEMENTS

FIGURE: 54



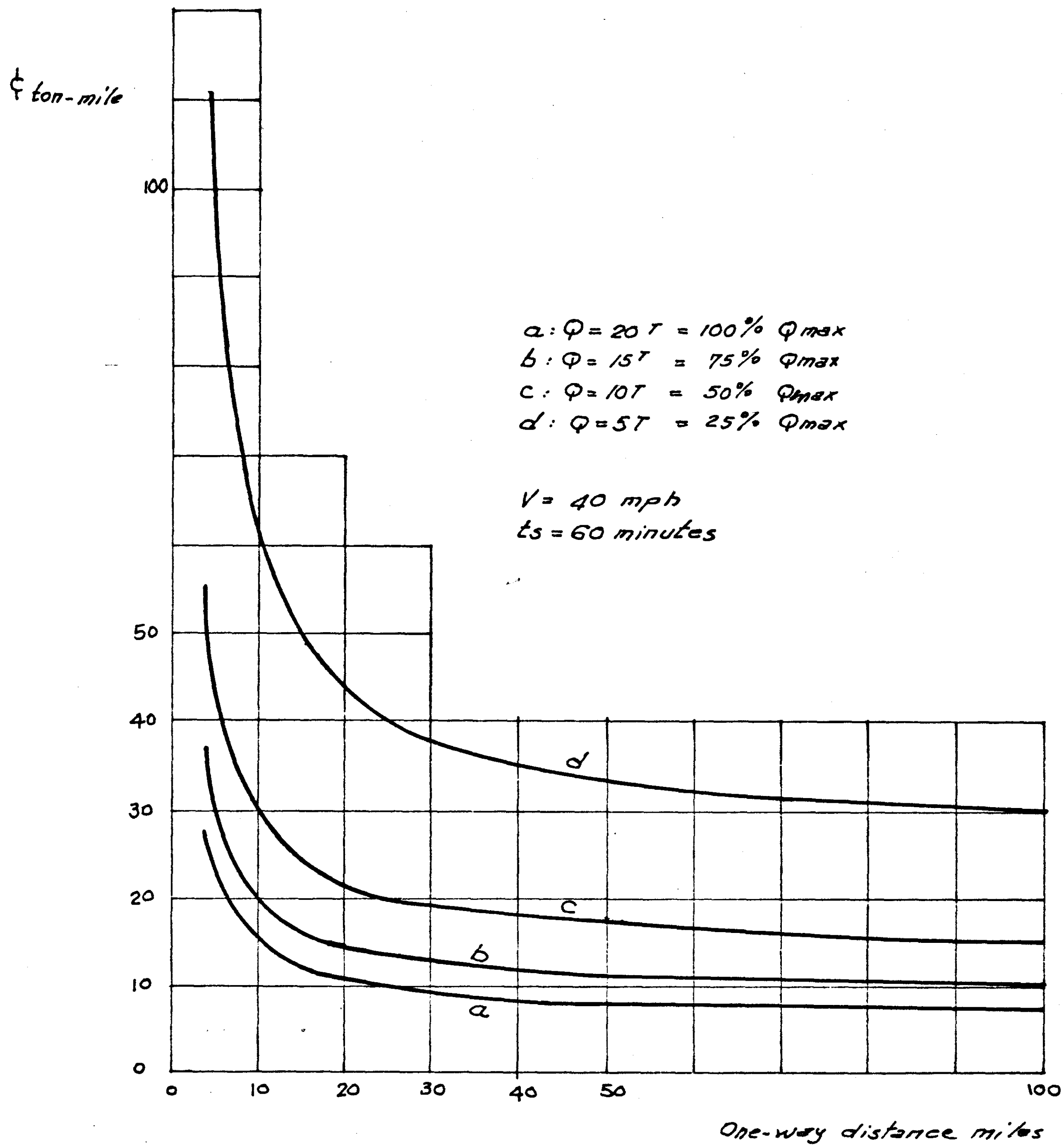
TRANSP. COST OF PRECAST ELEMENTS

FIGURE: 55



TRANSP. COST OF PRECAST ELEMENTS

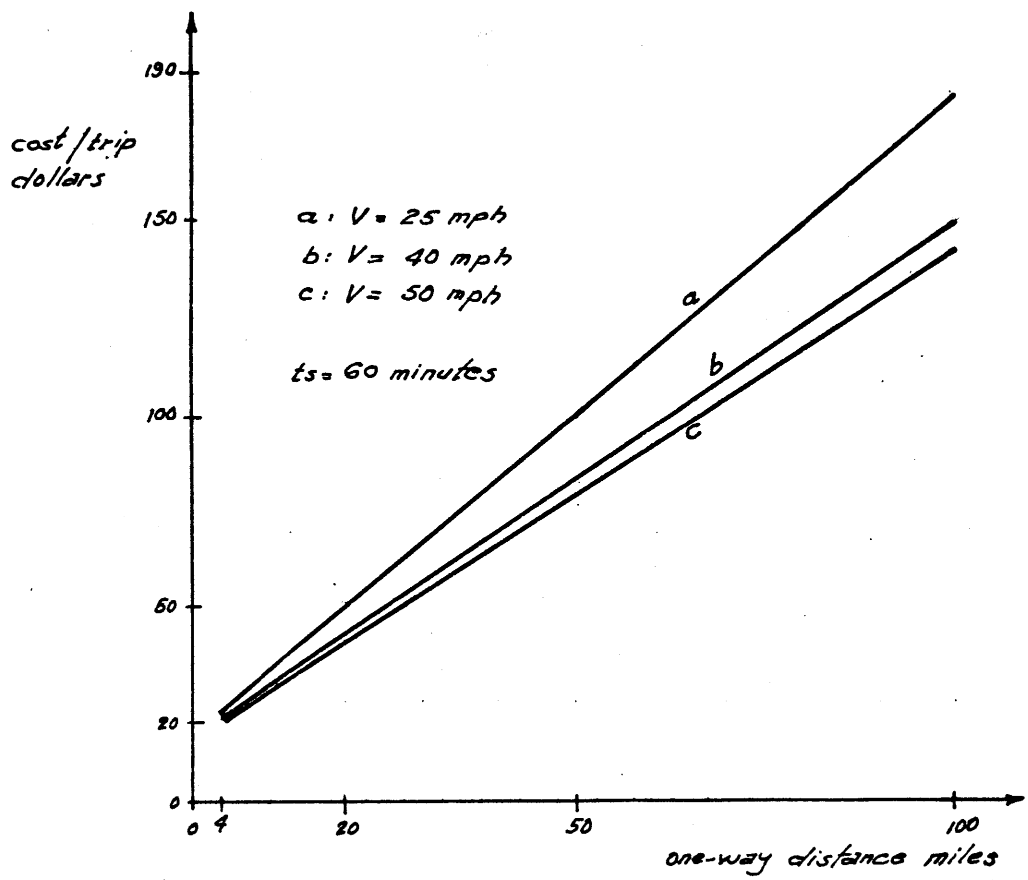
FIGURE: 56

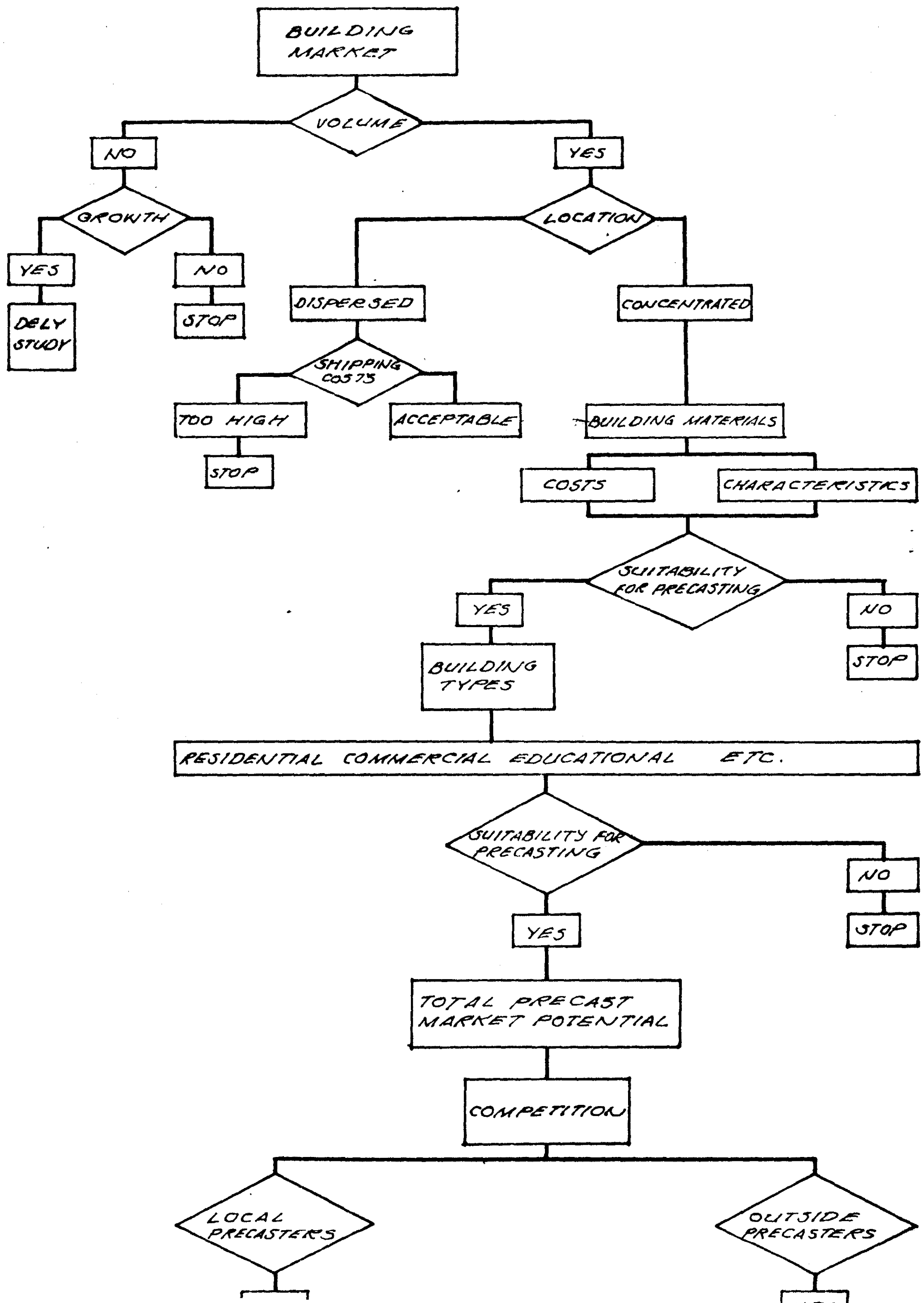


TRANSP. COST AS A FUNCTION OF LOAD FACTOR

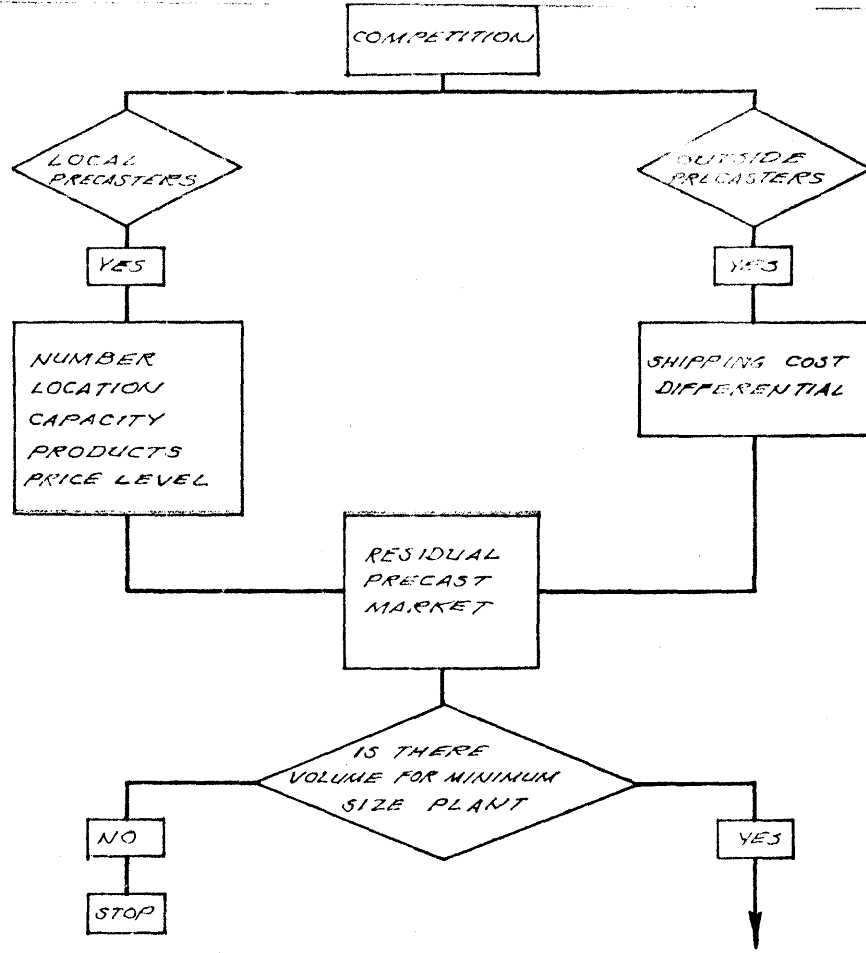
FIGURE: 57

INFLUENCE OF DRIVING SPEED
ON
TRANSPORTATION COSTS





BUILDING MARKET
VOLUME
NO
YES
GROWTH
YES
NO
DELY STUDY
STOP
LOCATION
DISPERSED
CONCENTRATED
SHIPPING COSTS
TOO HIGH
ACCEPTABLE
STOP
BUILDING MATERIALS
COSTS
CHARACTERISTICS
SUITABILITY FOR PRECASTING
YES
NO
STOP
BUILDING TYPES
RESIDENTIAL COMMERCIAL EDUCATIONAL ETC.
SUITABILITY FOR PRECASTING
NO
STOP
YES
TOTAL PRECAST MARKET POTENTIAL
COMPETITION
LOCAL PRECASTERS
OUTSIDE PRECASTERS

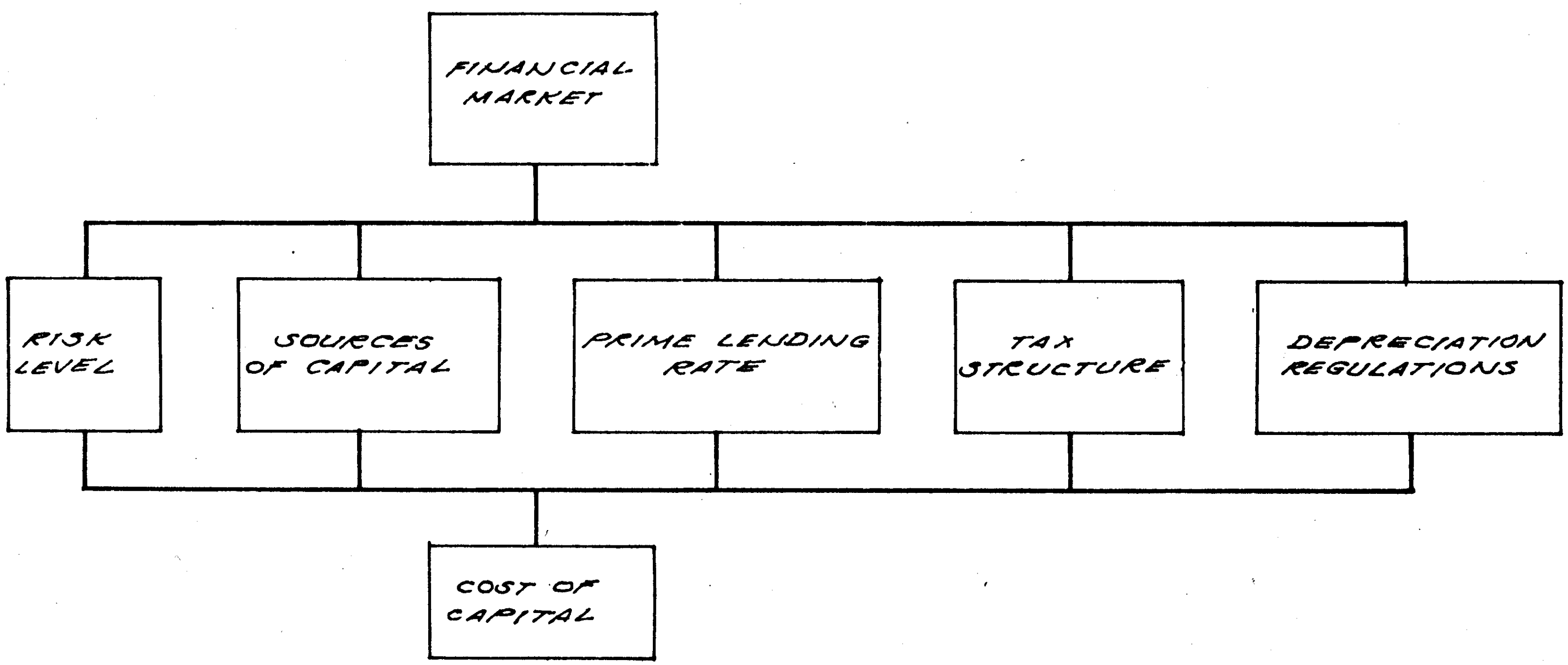


FLOW-CHART FOR BUILDING
MARKET ANALYSIS

FACTOR SPECIFIED:
PLANT LOCATION
PLANT CAPACITY
MIX OF PRODUCTS
SHIPPING COSTS
PRICE LEVEL

FIGURE: 58

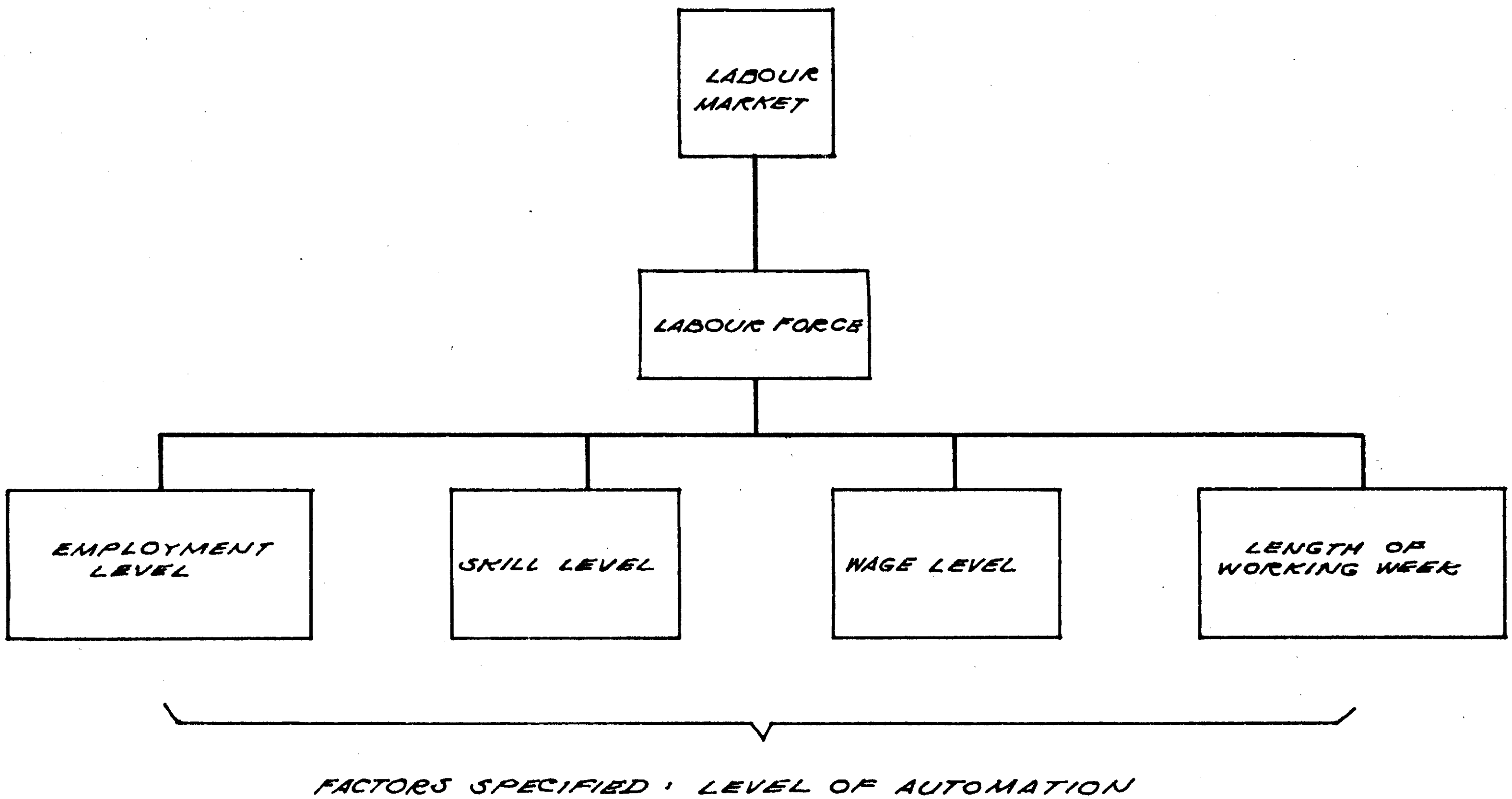
FIGURE: 59



FLOW-CHART FOR
FINANCIAL MARKET ANALYSIS

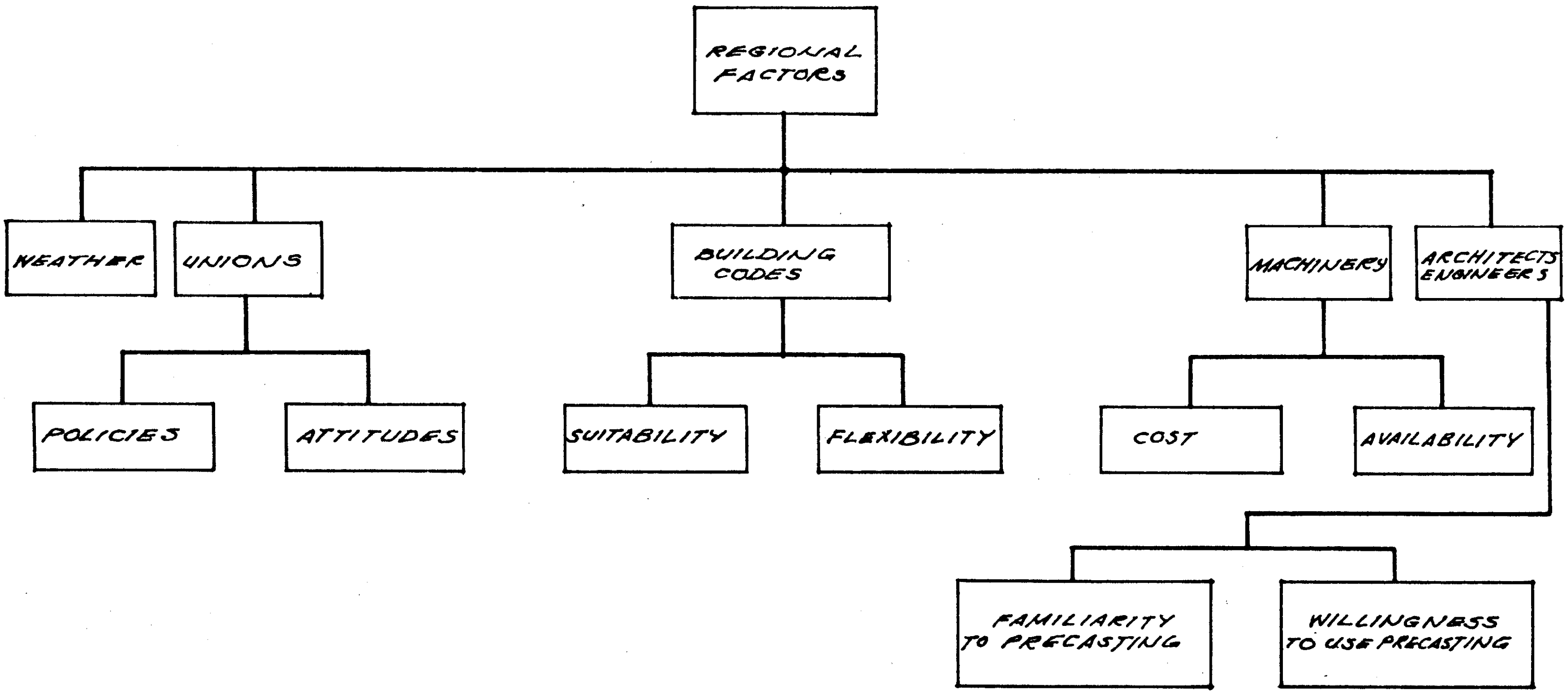
FACTORS SPECIFIED:
EQUITY
LEVERAGE
RATE OF RETURN
AMORTIZATION
DEBT SERVICING

FIGURE: 60



FLOW-CHART FOR LABOUR MARKET ANALYSIS

FIGURE: 61



FACTORS SPECIFIED:

DESIGN STANDARDS
LABOUR PRODUCTIVITY
LEVEL OF TECHNOLOGY
PEAK PRODUCTION LEVEL
SEASONALITY

FLOW-CHART FOR REGIONAL FACTORS ANALYSIS

FIGURE: 62 .FACTORS INFLUENCING PLANT CAPITAL INVESTMENT REQUIREMENTS

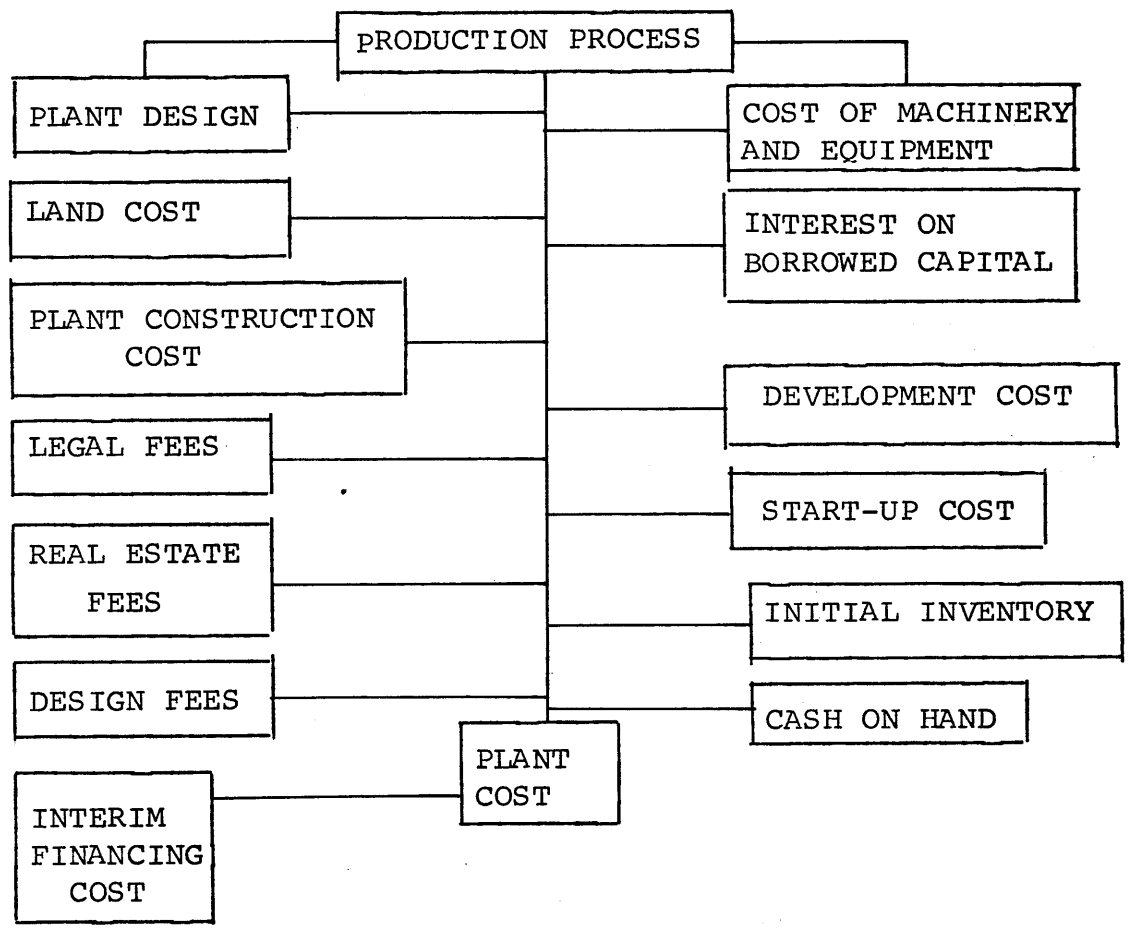


FIGURE: 63 . FACTORS AFFECTING PLANT OPERATING COSTS

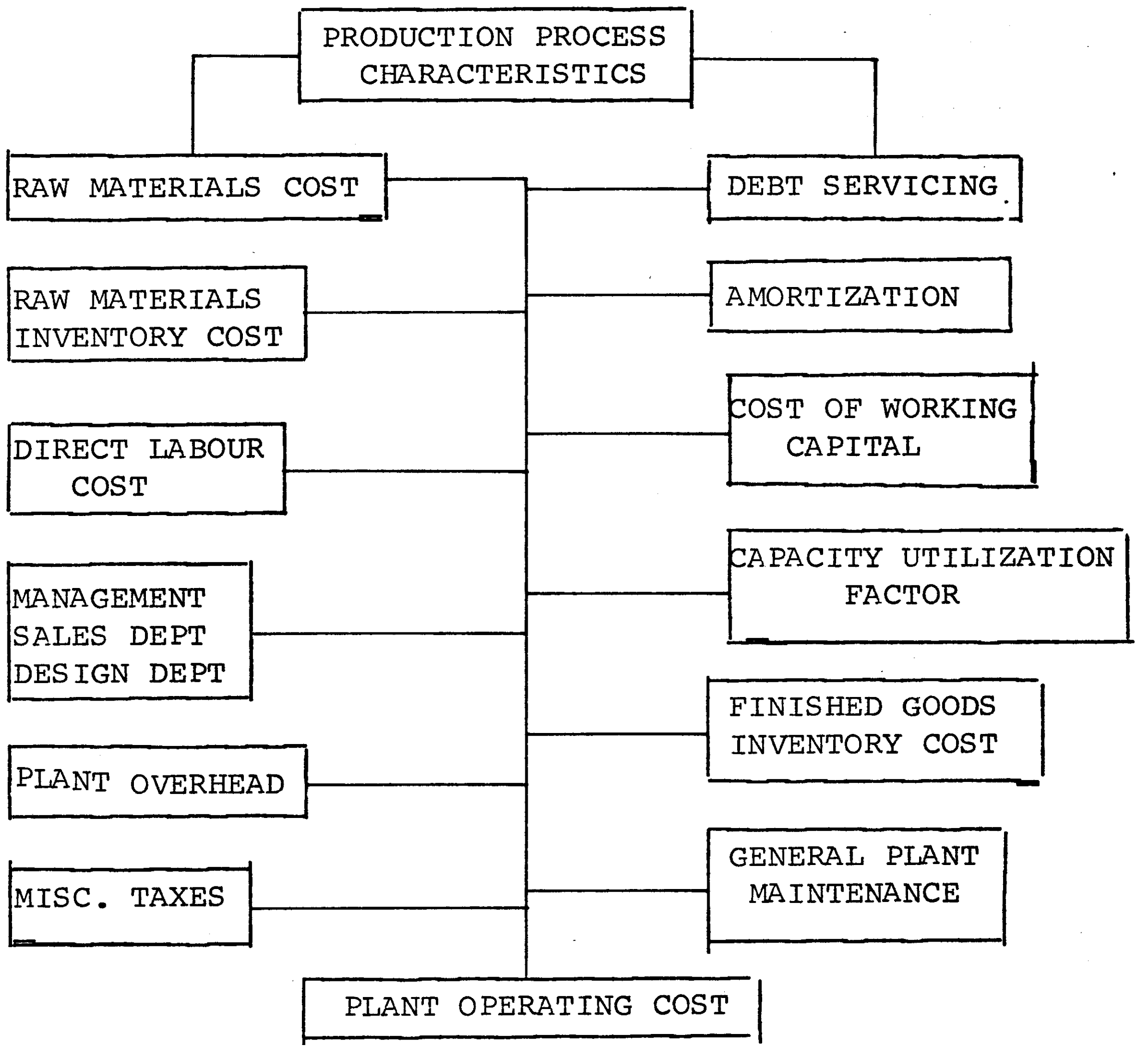


FIGURE : 64

PROCESS COST Per 1000 ft²

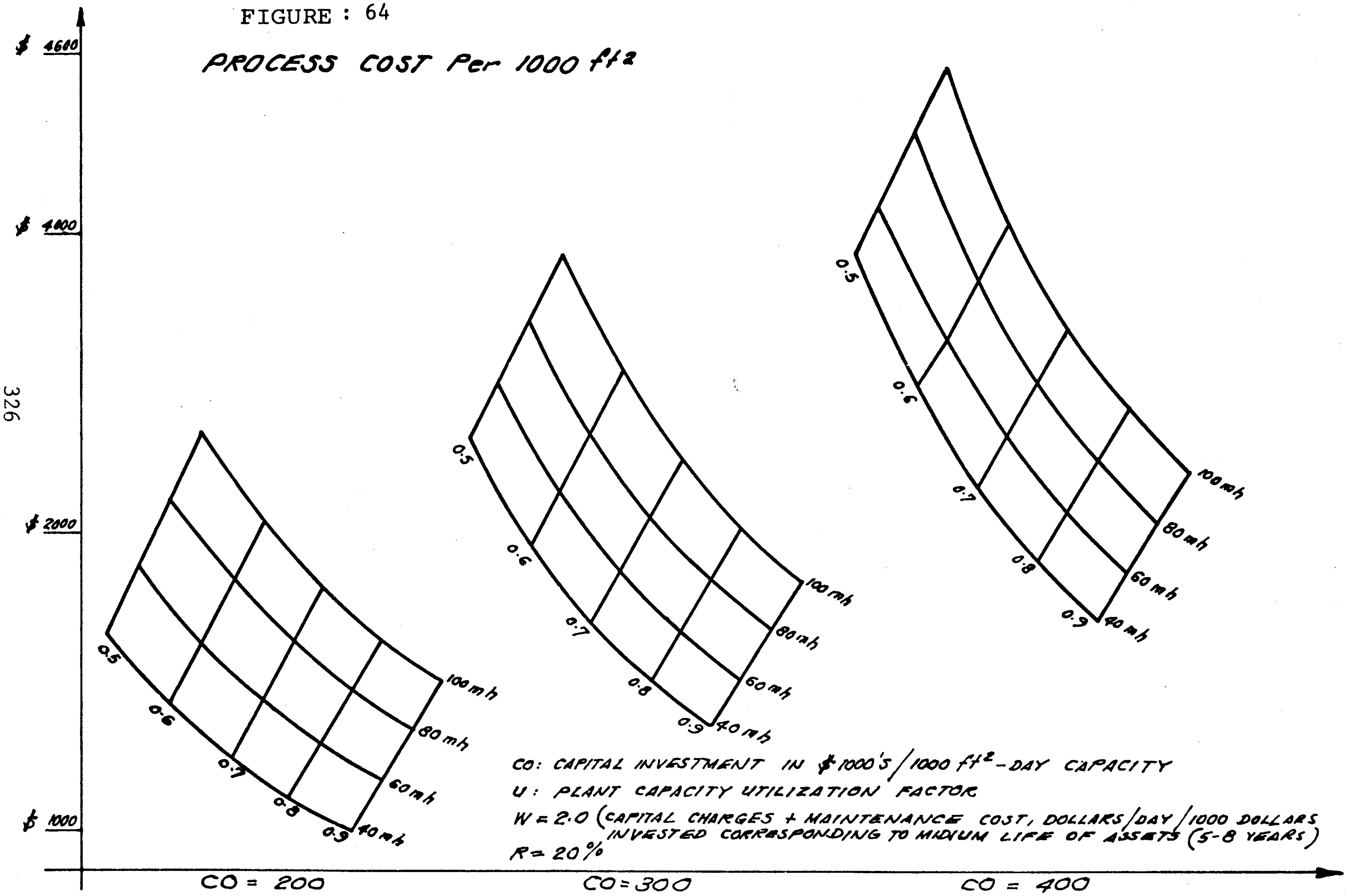


FIGURE: 65 PANEL PRODUCTION COST=

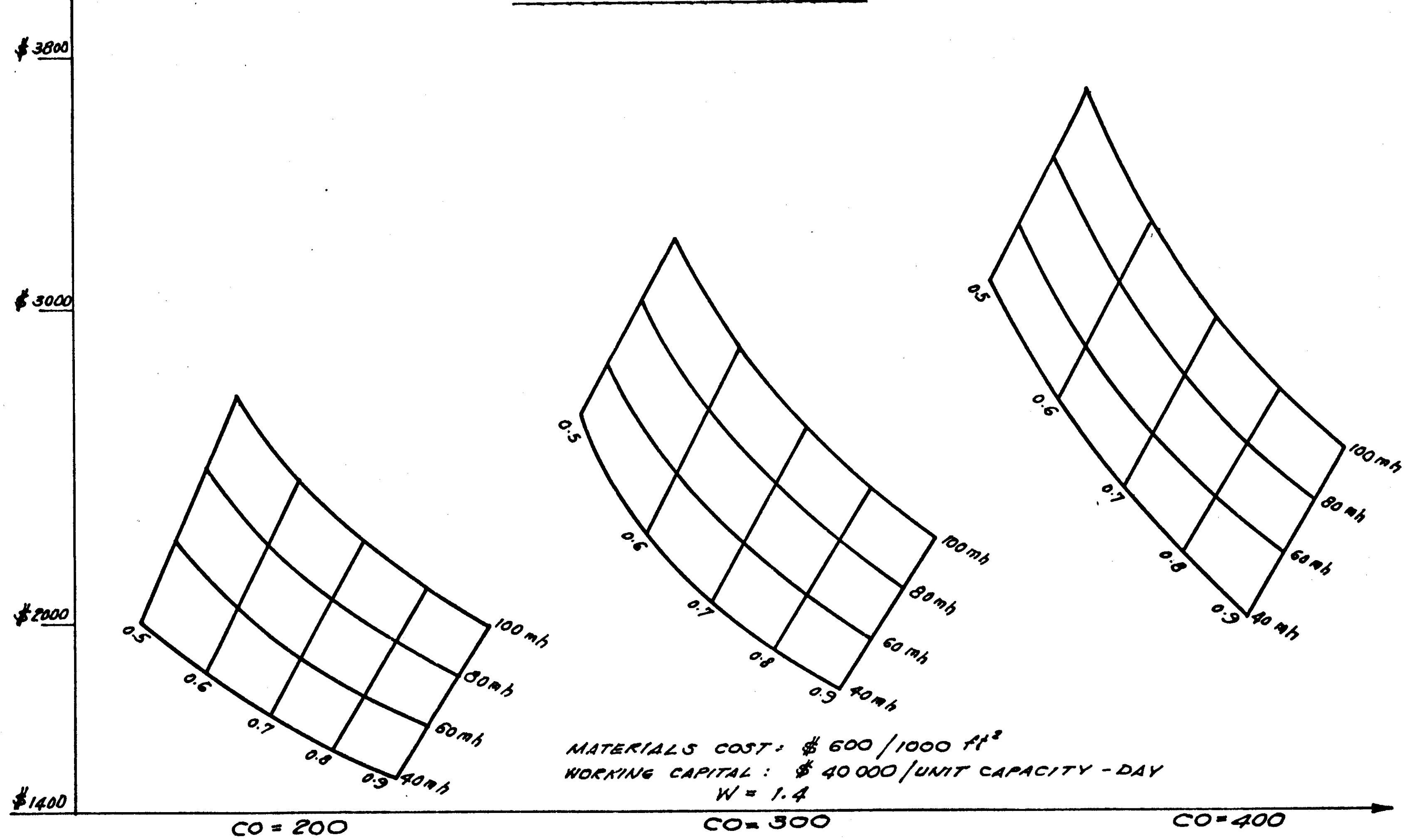
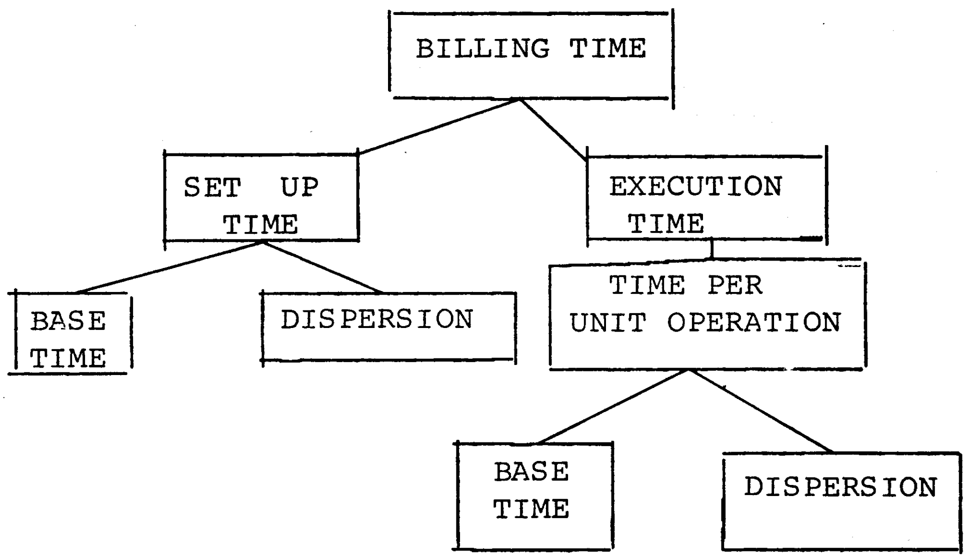


FIGURE: 66

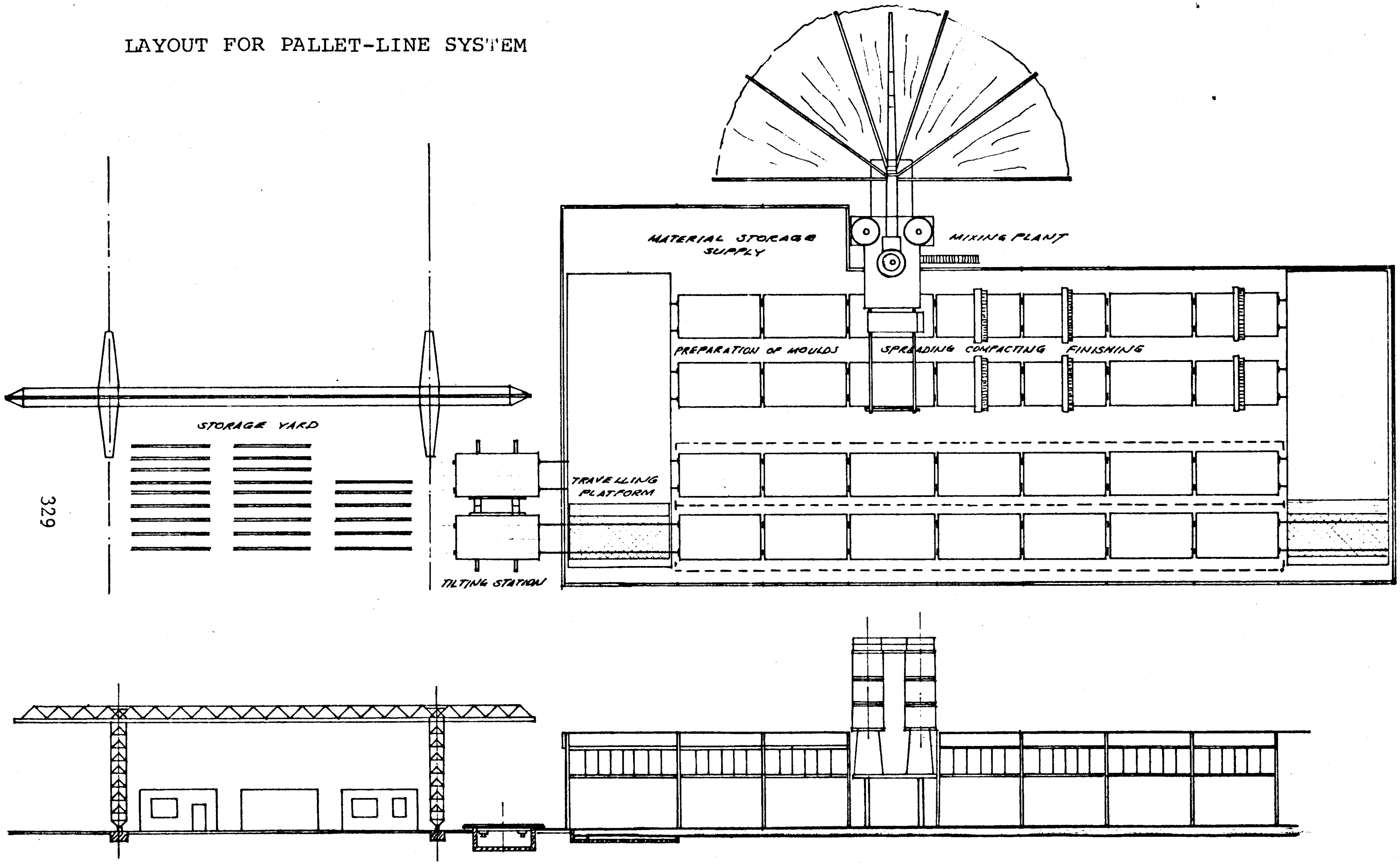
DERIVATION OF BILLING TIME



Source: Reference 99

FIGURE: 67

LAYOUT FOR PALLET-LINE SYSTEM



Source: Reference No.155

FIGURE: 68 FINAL PLANT DESIGN

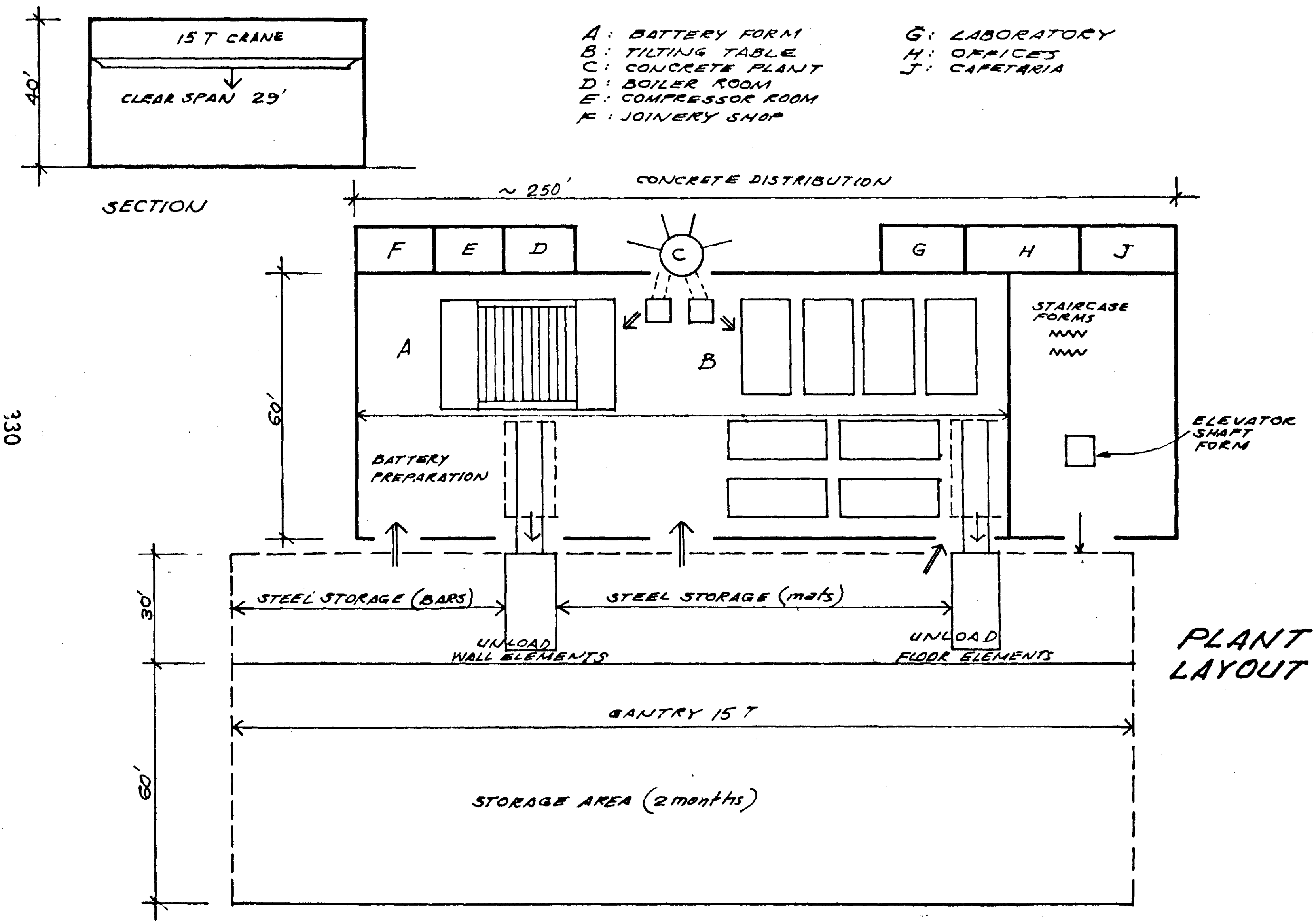
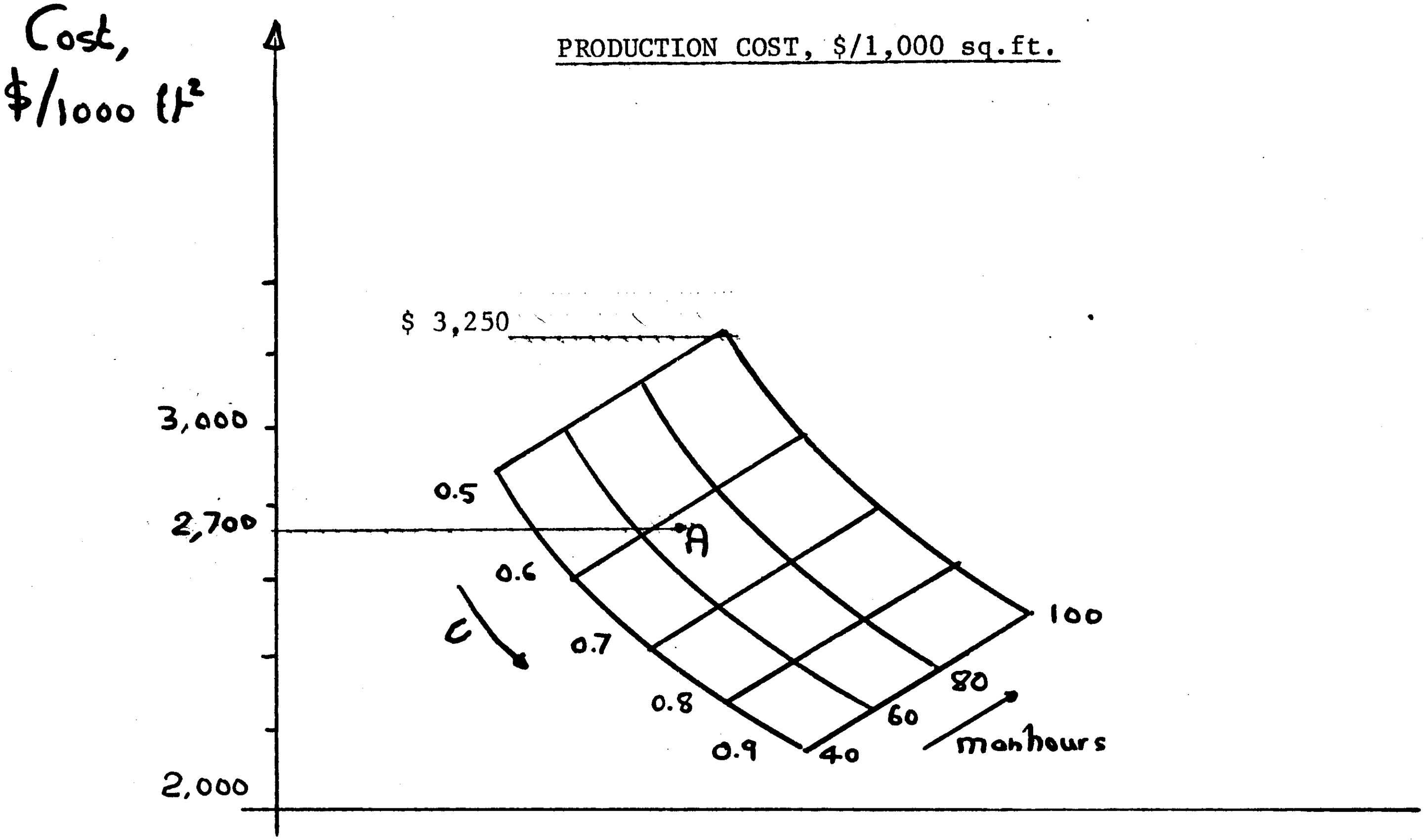


FIGURE : 69

PRODUCTION COST, \$/1,000 sq.ft.



C_o = 225   r = 8%

W = 1.50   r'= 13.67%

g = 0.50

Note: Point A on the graph corresponds to an annual output of 360 units

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155. U.S. Dept. of H.U.D. : Application of Component Construction to Multi-storey, Low-income Housing, I.T.T.R.I. Research Project No. M6171 - Final Reports, Vols. I, II, III.

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161. White, R.B. : Prefabrication : A History of its Development in Great Britain - London, Ministry of Technology, B.R.S., H.M.S.O., 1965.

162. Yannas, M.F. : "Concrete Prefabricated Systems as Applied to Building Industry", Unpublished Research Paper, Dept. of Civil Engineering, M.I.T. - 1971.

163. Zalewski : Design of Factories for Housing Modules Production, M.I.T. Report R71-9, Cambridge MITP - 1971.

164. Zimmerli, M. : "Herstellung von Wand und Deckenteilin in Kleinen und mittleren Serien durch den Wandfertiger", Betonstein Zeitung, Heft Sept. 1969

APPENDIX A

TIME STUDIES FOR PANEL PRODUCTION

Relevant information was obtained from the following companies:

ARBAU :	Heidelberg, Germany
Dresser Crane:	Muskegon, Michigan, U.S.A.
STELMO Ltd.:	Ashford, England
Lear Siegler:	Salem, Illinois, U.S.A.
Advance Construction Equipment Company:	New Braunels, Texas, U.S.A.
VIBCO:	Lodi, New Jersey, U.S.A.
Spancrete Machinery Corporation:	Milwaukee, Wisconsin, U.S.A.
Stow Manufacturing Company:	Binghamton, New York, U.S.A.
Spiroll Corporation Ltd:	Winnipeg, Manitoba, Canada
Hastings Dynamold Corporation:	Hastings, Nebraska, U.S.A.
Wacker Corporation:	Milwaukee, Wisconsin, U.S.A.
Eastern Engineering Sales Company:	Quincy, Massachusetts, U.S.A.
Noble-Aggregate Corporation:	Santa Clara, California, U.S.A.
Industrialized Concrete Associates, Inc.:	
Unistress Corporation:	Pittsfield, Massachusetts, U.S.A.
Blakeslee:	New Haven, Connecticut, U.S.A.
Universal Prestressed Concrete:	Plympton, Massachusetts, U.S.A.
San-Vel Concrete Corporation:	Littleton, Massachusetts, U.S.A.
Span-Deck, Inc.:	Franklin, Tennessee, U.S.A.
R. L. Spillman Company:	Columbus, Ohio, U.S.A.
Strong Betong:	Goethenborg, Sweden
Skanska Cementjuteriet:	Malmo, Sweden

Explanation of Tables

Tables A-1 to A-4 : Production of panels on tilting tables

Tables A-5 , A-6 : Production of panels in battery form

Note: -Add 3 minutes per lifting hook installed
-Assume 7 % of production time required for maintenance

TABLE A-1

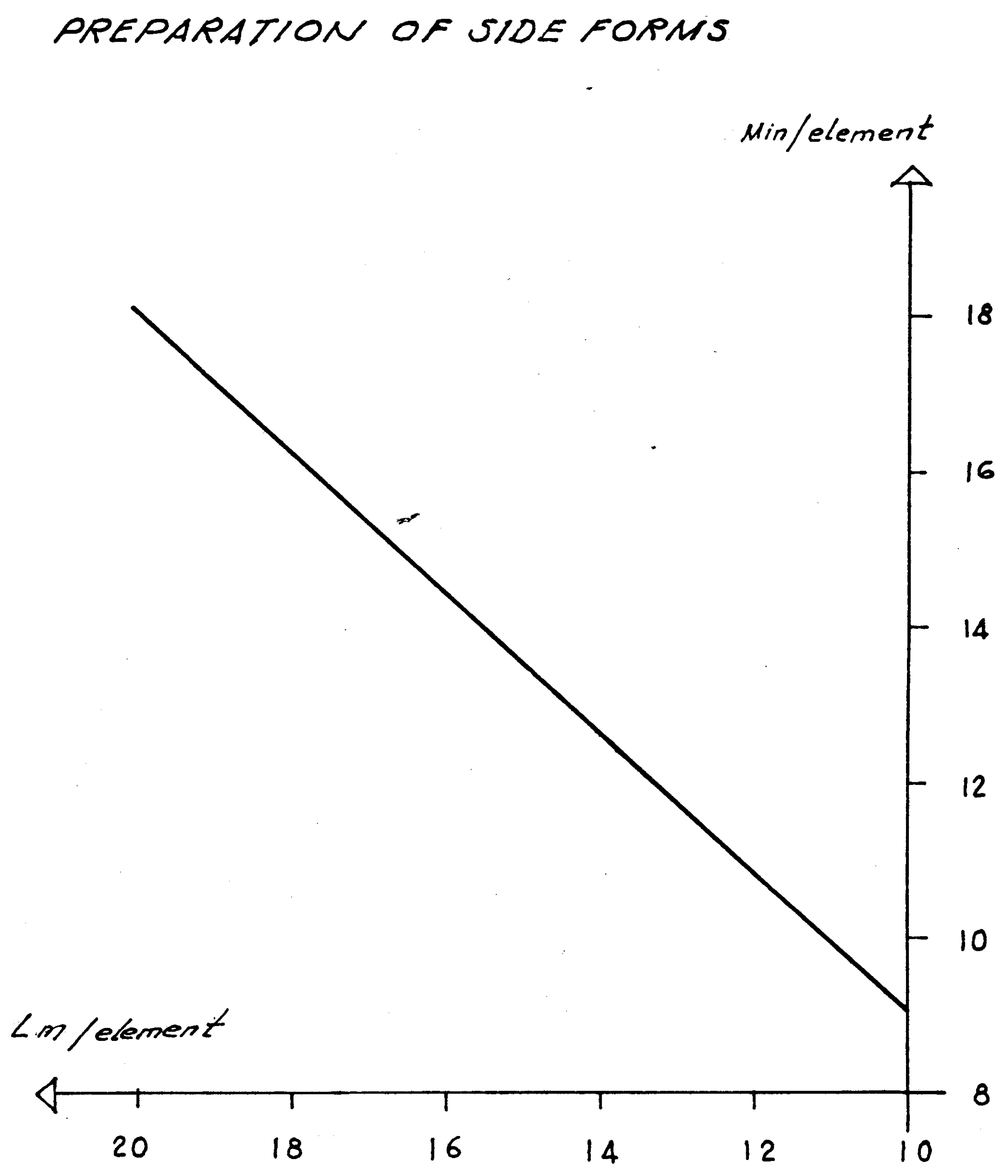
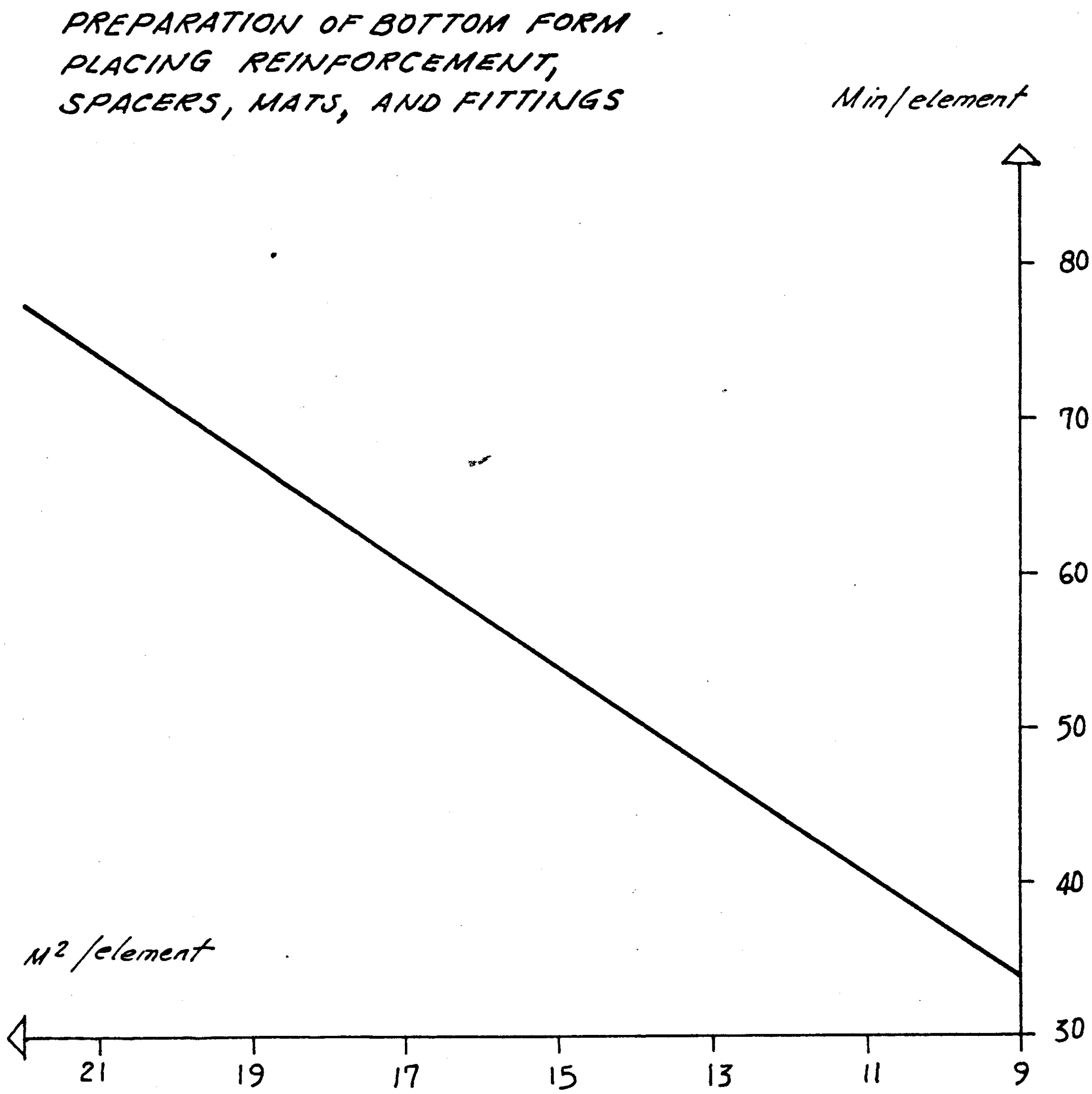

PREPARATION OF SIDE FORMS
Min/element
18
16
14
12
10
8
Lm/element
20
18
16
14
12
10

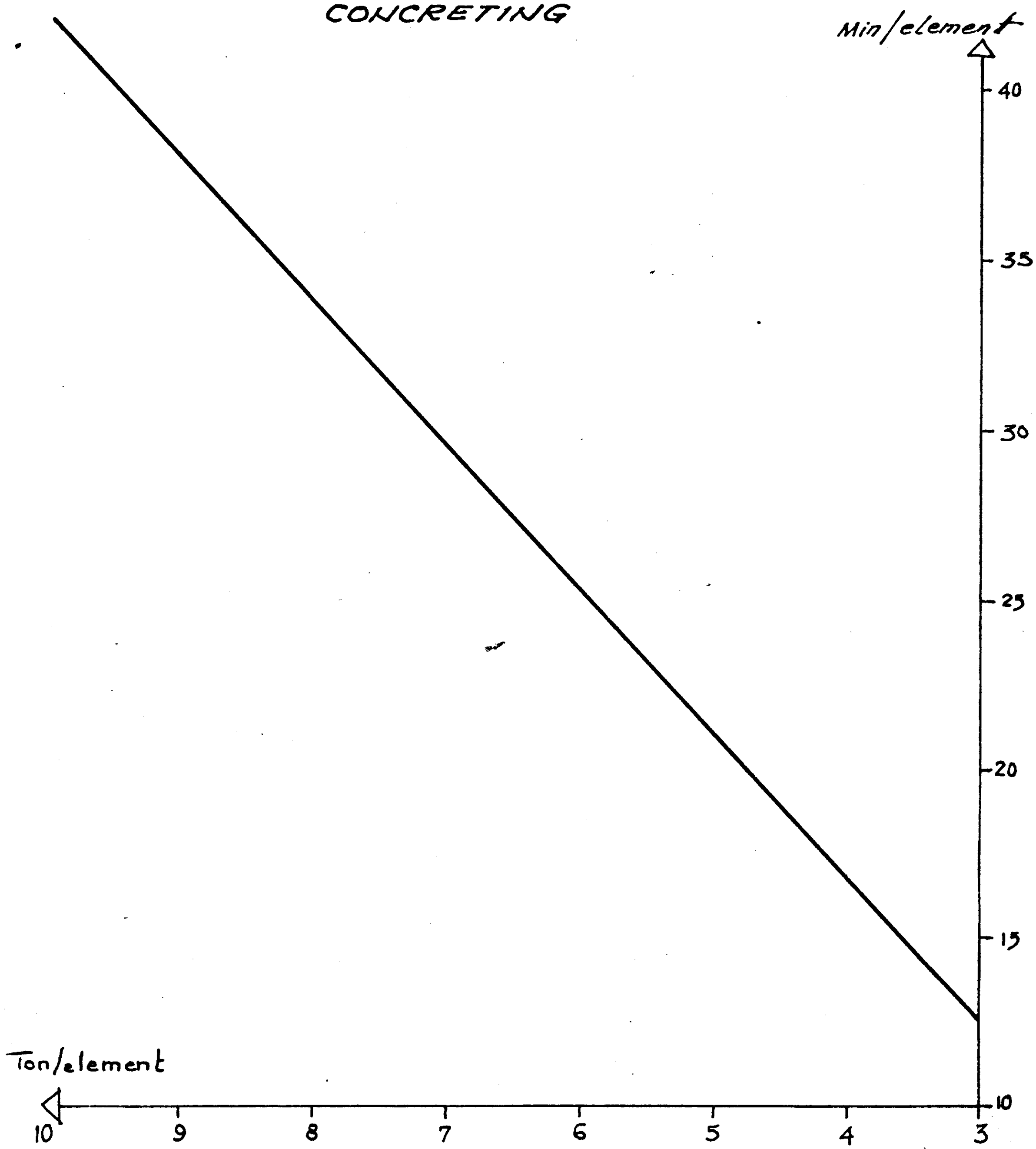
TABLE A-2



PREPARATION OF BOTTOM FORM
PLACING REINFORCEMENT,
SPACERS, MATS, AND FITTINGS
Min/element
80
70
60
50
40
30
M² /element
21
19
17
15
13
11
9

TABLE A-3

CONCRETING



DESPATCH ELEMENT TO STOCKYARD : 13.4 min/element

TABLE A-4

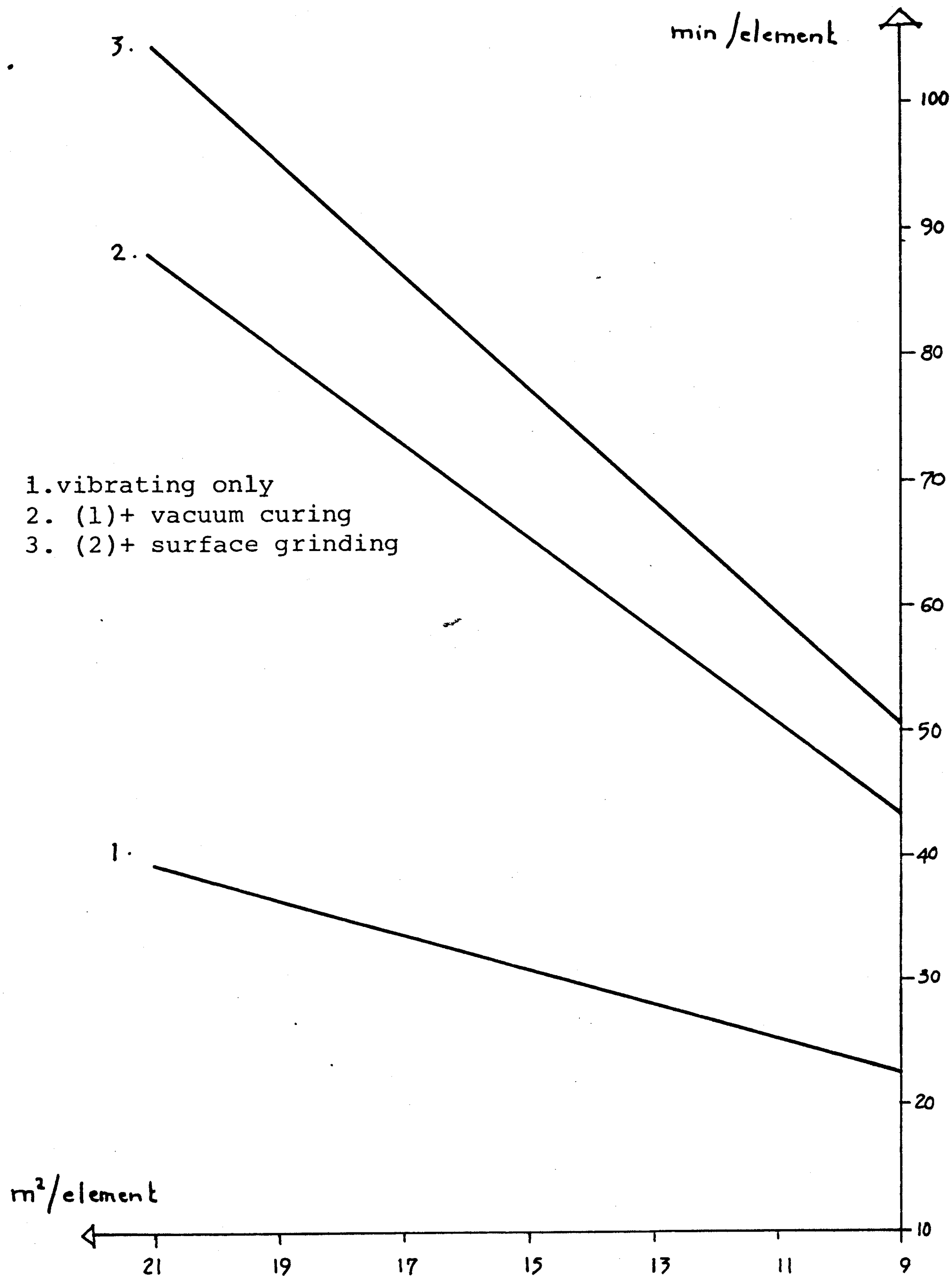

min /element
m²/element
1.vibrating only
2. (1)+ vacuum curing
3. (2)+ surface grinding
1.
2.
3.
100
90
80
70
60
50
40
30
20
10
21
19
17
15
13
11
9

TABLE A-5

PREPARATION OF BATTERY= STEEL PLACING

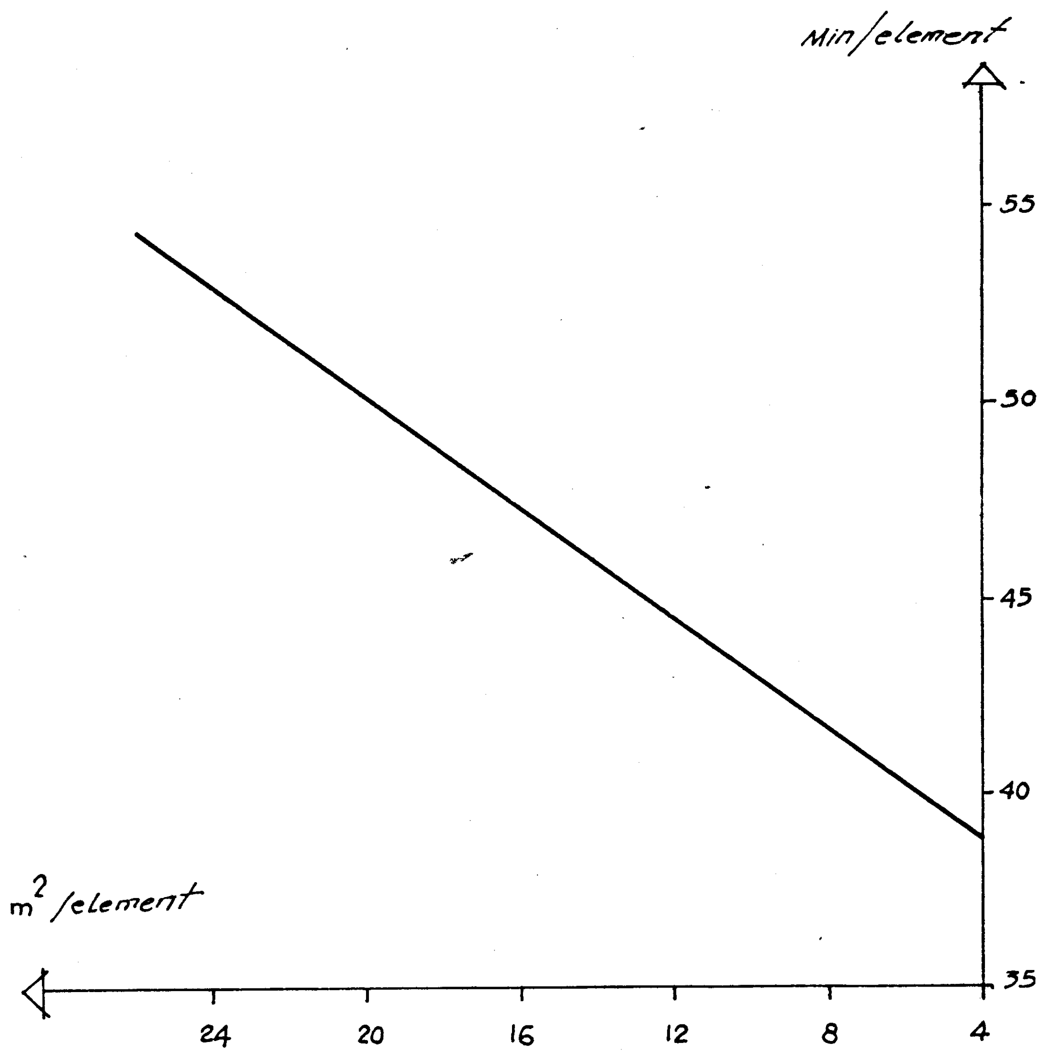
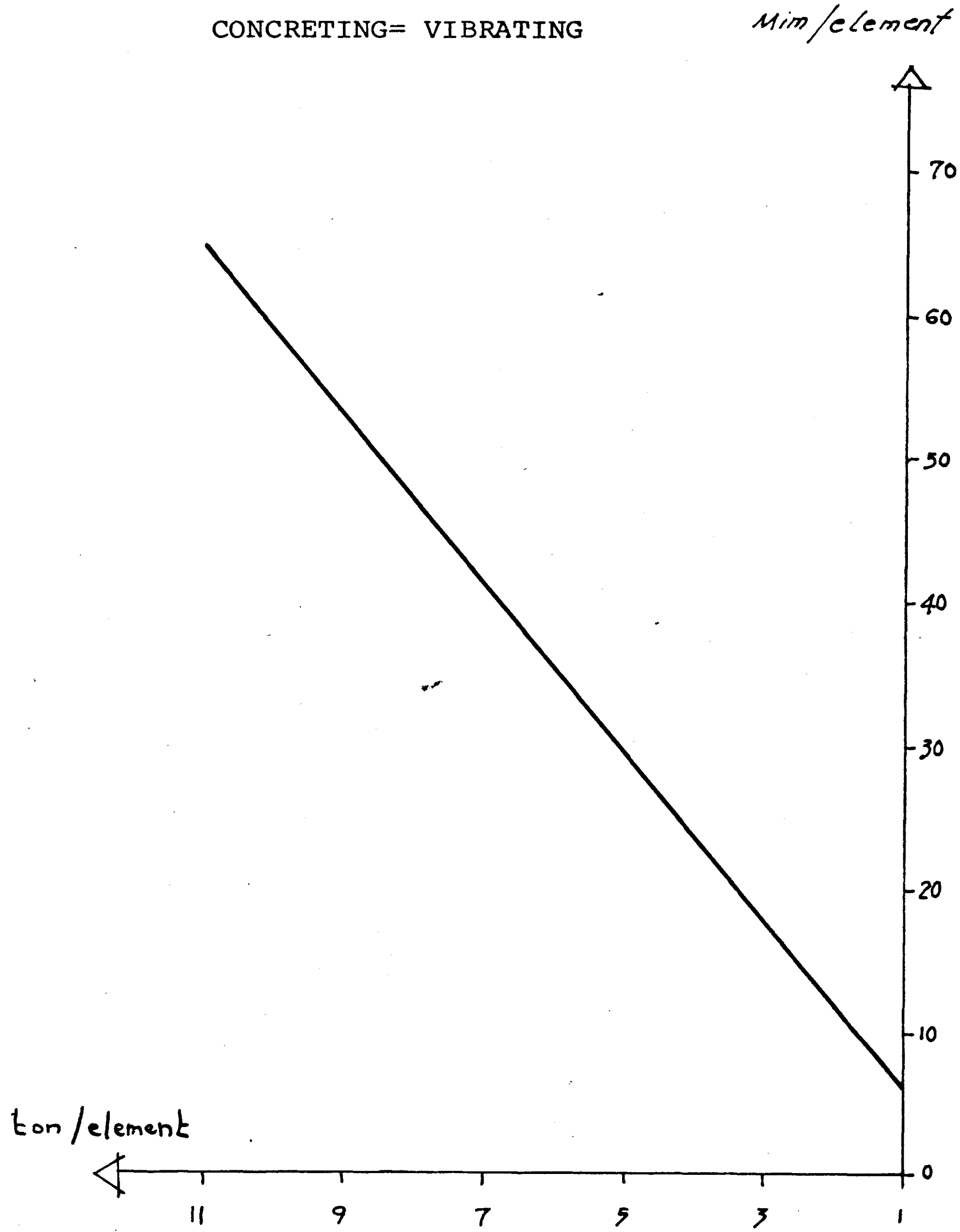


TABLE A-6

CONCRETING= VIBRATING



APPENDIX B

DATA FOR THE TRANSPORTATION COST MODEL

FUEL CONSUMPTION

This cost item is extremely variable. Without going into a lengthy technical discussion about the effects of each factor, let us simply mention that speed, speed changes, pavement grade, attitude, load, engine characteristics, and a host of secondary elements affect the gasoline consumption.

The results of extensive studies made by R. Winfrey (1) are tabulated in the following pages.

To take into account the variability of fuel consumption, (see Tables B-1,2) without producing an infinite variety of solutions, we shall proceed as follows:

--Pick a fuel consumption from Table B-3 which reflects in our best judgment the actual driving conditions of the fleet.

--Adjust fuel cost to chosen level, by including taxes, federal and state.

--Further take into account the probable increase in average speed with increasing delivery distance. This is based on Swedish experience (2), and is believed to be in accord with American practice. If anything, the use of the Swedish figures would result in higher figures, as on the road speed averages in the U.S. are higher than in Europe--in the range where increasing speed still reduces consumption (10 to 40 mph).

(1) Reference: I59 (2) Reference: 36

Operating Data

Representative Speed(1)	25 mph (from Swedish graph)
Corresponding Fuel Consumption	0.24 gallons/mile (1--2% gradient)
Fuel Cost, no taxes included	$17.62 \times \frac{0.24}{0.11}$ = \$38.0/1000 miles
Corrected Fuel Cost	38.0 x 1.69 = \$65/1000 miles = 6.5 cents/mile

(1) Corresponding to delivery distance of 6 miles--See Fig: B-1

The figure of 6.5 cents/mile is to be compared with average intercity fuel cost of 4.6 cents/mile for Motor Carriers of Class I, in 1968 (2).

The Swedish Report uses a varying fuel consumption which is function of the cycle distance of delivery. The higher the delivery distance, the higher the average speed, when starting off from 4 mile distances. The corresponding U. S. figures are adjusted for each haul according to the same ratio. The "Representative Speed" of 25 mph is used only as a basis for establishing the ratio. Higher speeds would produce lower fuel consumptions, hence the conservative approach of minimum average speed selection.

The results are tabulated in Table B-7, which shows operating data used in the Cost Model.

Tables B-4,5,6 are the data used to apply the cost model equatios developed in Section J of Chapter III

(2) American Trucking Trends, 1970--71, p: 24. American Trucking Association, Inc.

TABLE: B-1

FUEL CONSUMPTION TABLE

Diesel, 35-2, 50 Kip Truck

High type pavement
Unit: Gallons/mile
Engine: 200 HP

Speed mph	Level	GRADE, %				
		+1	+2	+3	+4	+5
5	0.4	0.43	0.46	0.49	0.51	0.54
10	0.21	0.27	0.33	0.39	0.44	0.49
15	0.15	0.22	0.29	0.36	0.43	0.49
20	0.12	0.20	0.27	0.35	0.43	0.50
25	0.11	0.19	0.27	0.35	0.43	0.52
30	0.10	0.18	0.27	0.36	0.46	0.56
35	0.10	0.18	0.27	0.37	0.49	
40	0.10	0.19	0.29	0.40		

Source: Adapted from: R. Winfrey, Economic Highway Analysis.
Reference No. I60

TABLE: B-2

DOLLARS RUNNING COST AT UNIFORM SPEED ON LEVEL TANGENTS BY COST ITEM

Vehicle: 50-kip, 3-S2, diesel
Unit : Dollars per 1,000 vehicle-miles

Roadway surface: High type pavement in good condition

Speed mph	Running Cost By Item					Total Cost
	Fuel	Tires	Engine Oil	Maintenace	Depreciation	
5	64.70	1.30	5.15	28.51	67.06	166.72
10	34.05	2.68	3.34	28.22	51.91	120.20
15	24.30	4.17	2.67	28.82	43.45	103.41
20	19.86	5.77	2.37	30.05	37.76	95.81
25	17.62	7.56	2.18	31.88	33.68	92.92
30	16.64	9.50	2.03	34.18	30.67	93.02
35	16.46	11.75	1.90	36.96	28.44	95.10
40	17.06	14.33	1.71	40.04	26.71	99.85
45	18.38	17.32	1.49	43.31	25.30	105.80
50	20.53	20.83	1.32	46.80	24.15	113.63
55	23.66	25.04	1.37	50.41	23.18	123.66

Source: Adapted from: R. Winfrey,
Economic Highway Analysis
Reference No. 160

TABLE: B-3

DOLLAR RUNNING COSTS AT UNIFORM SPEED ON LEVEL TANGENTS

Vehicle: 50 Kip - 3.52 Diesel
Unit : Dollar per 1,000 vehicle mile

Roadway surface:
High type pavement

Speed mph	Running Cost By Item					
	Fuel	Tubes	Engine Oil	Maintenance	Converted Fuel Cost	$/mile
5	64.70	1.30	5.15	28.51	109	0.109
10	34.05	2.68	3.34	28.22	57	0.057
15	24.30	4.17	2.67	28.82	40.7	0.040
20	19.86	5.77	2.37	30.05	33.4	0.033
25	17.62	7.56	2.18	31.88	29.6	0.0296
30	16.64	9.50	2.03	34.18	28.0	0.028
35	16.46	11.75	1.90	36.96	27.8	0.0278
40	17.06	14.33	1.71	40.04	28.7	0.0287
45	18.38	17.32	1.49	43.31	30.9	0.0309
50	20.53	20.83	1.32	46.80	34.5	0.0345

Note: Tax not included in Fuel Cost.
Assumed Unit Cost: 16 cents/gallon.

Conversion: Federal Tax: 4 cents
State Tax : 7 cents
Total: 11 cents

Change in Cost: $\frac{27}{16} = 168.75\%$

Converted Fuel Cost: Fuel Cost x 1.69

Source: Adapted from:
R. Winfrey
Economic Highway Analysis
Reference No. 160

TABLE: B-4

SUPPORTING DATA - TECHNICAL

Truck

Curb Weight,	lb	30 000
Maximum Payload,	lb	42 000
Height,	ft	12.0
Width	ft	8.0
Number of Wheels		10
Number of Axles		3
Size of tires,	in	11 x 22
Maximum Horsepower		335, at 2 000 r.p.m.
Maximum Torque	lb-ft	930, at 1 600 r.p.m.
Maximum Speed, m.p.h.		78

Trailer

Length	ft	40.0
Width	ft	8.0
Number of Wheels		8
Number of Axles		2
Size of tires	in	11 x 22

Cost Data

Truck :	$ 22 000, 25 000, 28 000
Trailer :	$ 6-7 000, 8 000, 10 000
Tires :	each $ 200
Residual Value:	10% of purchase price

TABLE: B-5

DATA FOR MILEAGE INDEPENDENT TRANSPORTATION COSTS (*)
TRUCKS

	Symbol	1	2	3	Unit	
Purchase Price	K_v	22 000	25 000	28 000	$	
Residual Value	K_r	2 200	2 500	2 800	$	
Tire Cost	K_t	2 000	2 000	2 000	$	
Lubricant Cost	R_l	0.003	0.004	0.005	$/mile	(1)
Repair-Maint.	R_r	130	130	130	%	(2)
Unforseen Costs	R_u	6	6	6	%	
Taxes	A_t	3 000	3 000	3 000	$/yr	(3)
Insurance	A_i	1 000	1 250	1 400	$/yr	(5)
Other Misc.	A_o	1 000	1 000	1 000	$	(4)
% for Ind.	A_o	1 000	1 000	1 000	$	(4)
Driver Wage	A_o	10 000	12 000	15 000	$	
Int. Rate, w	I_w	10	10	10	%	
Int. Rate, c	I_c	10	10	10	%	
Overhead	S_a, B_a	5	5	5	%	(2)
Marginal	S_m, B_m	10	10	10	%	(2)
Utilization	T_u	1 900	1 900	1 900	hours/yr	

(*) Mileage independent means that the unit costs are not a function of the houling distance, that is: Cumulative Cost/Cumulative mileage = Constant

(1) Derived from R. Winfrey, Table A-5, p: 684, op.cit.

(2) Derived from Swedish data, op. cit.

(3) Average Taxes, 5 axle Diesel trailer combination, GVW = 72 000 lb, = $ 3 400. $ 400 arbitrarily imputed to semi-trailer charges.

Source: American Trucking Trends, 1970-71, p: 21

(4) Judgment Value Figure, corresponding to 1.5 times Swedish figure.

(5) Assumed to be 5% of Initial Investment Cost.

TABLE: B-6

DATA FOR MILEAGE INDEPENDENT TRANSPORTATION COSTS
SEMI-TRAILERS

Item Symbol	1	2	3	Unit	
K_r	4 000	6 000	08 000	$	(1)
K_t	1 600	1 600	1 600	$	(1)
K_r	400	600	800	$	
R_1	0.08	0.08	0.1	cent/mile	(2)
R_r	45	45	60	%	
R_u	6	6	6	%	
A_t	400	400	400	400	(3)
A_i	120	180	240	$/year	(4)
I_w	10	10	10	%	
I_c	10	10	10	%	
S_a, B_a	5	5	5	%	
S_m, B_m	10	10	10	%	
T_u	2 000	2 000	2 000	hr/year	

(1) Private Communication: Average Trailer Cost: $ 4-6000,
Dimensions: 40' x 96"
(2) See footnote 4 of Table: B-5
(3) See footnote 3 of Table: B-5
(4) Assumed to be 3% of Investment Cost.

TABLE: B-7

DATA FOR MILEAGE DEPENDENT TRANSPORTATION COSTS
TRUCKS

Length of Houl--miles	Vehicle Life (mv) - miles	Tire Life (mt) -miles	Fuel Cost, RF gallons/veh.mile		
			1	2	3
4	105 000	27 500	6.5	6.8	7.1
6	146 000	29 000	6.5	6.8	7.1
10	185 000	31 500	6.1	6.4	6.7
15	232 000	34 500	6.0	6.3	6.6
20	244 000	35 500	5.8	6.05	6.35
30	285 000	38 000	5.65	5.90	6.20
50	300 000	42 500	5.70	6.0	6.30
60	310 000	42 500	5.70	6.0	6.30
70	320 000	42 500	5.70	6.0	6.30
80	325 000	42 500	5.70	6.0	6.30
100	330 000	42 500	5.70	6.0	6.30
125	330 000	42 500	5.70	6.0	6.30

(1) Based on 6.5 cents/vehicle mile at 25 mph, corresponding to a fuel consumption of 0.24 gallons/mile - Diesel fuel.

Source: National Swedish Building Research:
External Transport of Concrete Units For Residential Buildings.
Doc. No. 1. -1969- Adapted figures (km to mile)
Ref. No.: 36

TABLE: B-8

MILEAGE DEPENDANT COSTS

Distance, one-way	Cost per mile, cents		
Miles	Truck	Trailer	Combination
4	92.086	13.601	105.687
6	70.604	9.825	80.430
10	58.095	7.783	65.879
15	48.689	6.234	54.923
20	46.578	5.933	52.512
30	41.307	5.098	46.405
40	39.307	4.845	44.152
50	38.462	4.693	43.155
60	37.669	4.551	42.221
70	37.291	4.483	41.775
80	36.925	4.417	41.343
100	36.925	4.417	41.343

Note: These values have been obtained by applying the equation giving mileage dependant costs (M) , in Section J of chapter III. The parameters used in the equation are taken from Table B-7.

TABLE : B-9

TRANSPORTATION COST PER TRIP

(cents per ton-mile)

distance	waiting time at terminals								
	0 min			60 min			120 min		
miles	20 t	10 t	5 t	20 t	10 t	5 t	20 t	10 t	5 t
10	9.43	18.87	37.75	15.13	30.27	60.55	20.83	41.67	83.3
20	8.10	16.20	32.40	10.95	21.90	43.80	13.80	27.60	55.2
30	7.49	14.98	29.96	9.39	18.78	37.56	11.29	22.58	45.1
40	7.26	14.53	29.06	8.69	17.38	34.76	10.11	20.23	40.4
60	7.07	14.14	28.28	8.02	16.04	32.06	8.97	17.94	35.9
80	7.02	13.96	27.93	7.97	15.39	30.78	8.40	16.81	33.6
100	6.98	13.96	27.93	7.83	15.10	30.21	8.12	16.24	32.5

Note : Average driving speed = 40 mph

These costs are represented graphically in figures 52 to 56

TABLE: B- 10

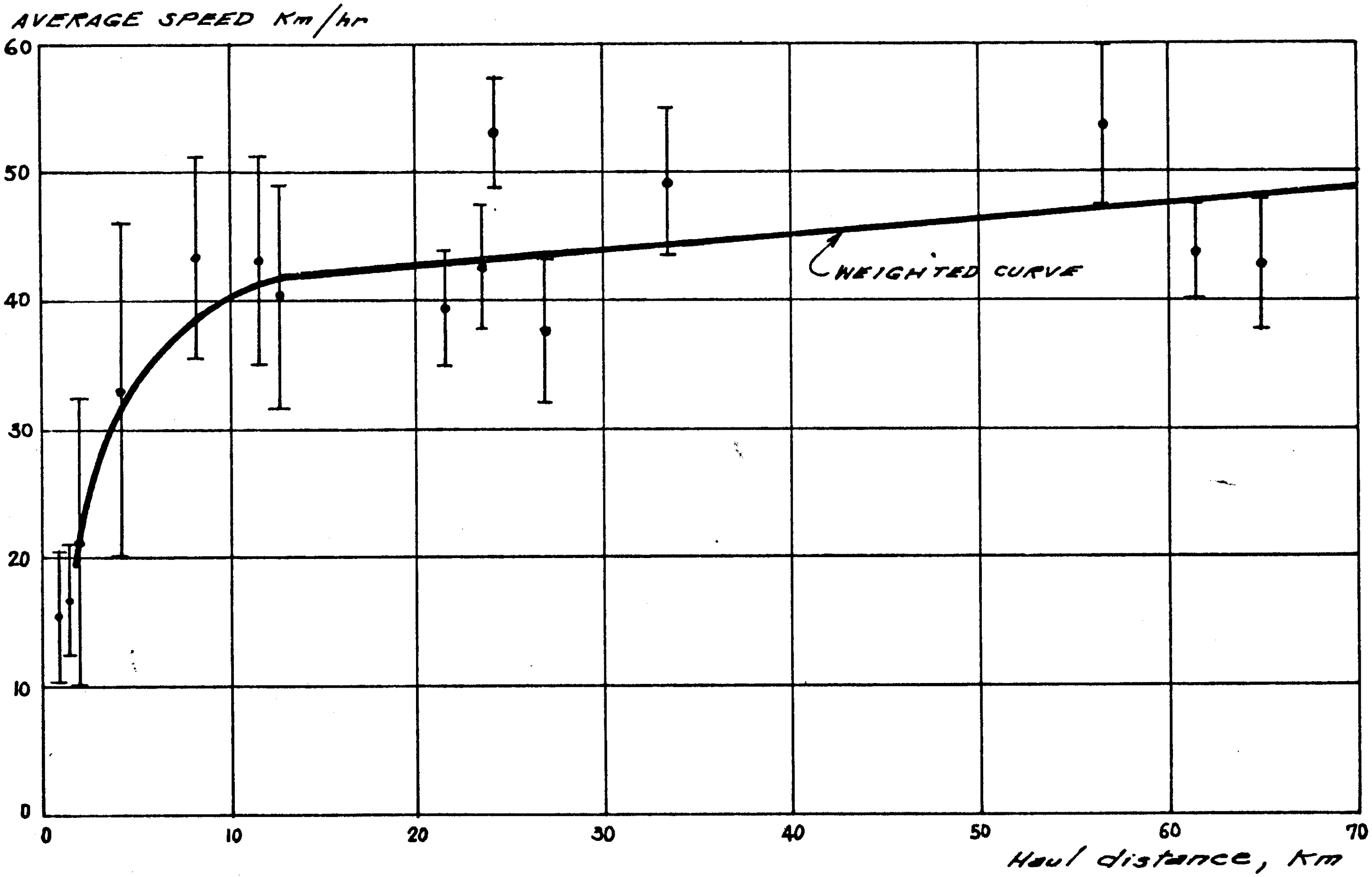
INFLUENCE OF DRIVING SPEED
ON
TRANSPORTATION COSTS

One-Way Distance miles	COST PER HAUL, DOLLARS		
	Speed, mph		
	25	40	50
4	23.50	22.13	21.67
10	33.70	30.27	29.13
20	50.64	43.80	41.52
30	66.60	56.34	52.92
50	100.15	83.05	77.35
70	133.71	107.77	101.80
100	185.28	151.08	145.28

Note: These results are shown graphically on figure 57

FIGURE: B-1

AVERAGE DRIVING SPEED IN FUNCTION OF HAUL LENGTH



Source: Reference No. 36

APPENDIX C

DESCRIPTION OF PRODUCTION EQUIPMENT

TABLE C-1

VERTICAL BATTERY FORM

Plate Dimensions

Height	3,200 millimeters
Length	9,000 millimeters

Maximum Element Dimensions

Height	3,100 mm
Length	8,850 mm
Thickness	200 mm
Area	27.43 square meters

Space Requirements for Battery Shuttering

Length	10 meters
Width	14 meters
Area	140 square meters

Admissible Tolerances

Plate surface: ± 1.5 mm (3 meter ruler)
Width of mould edge: - 1 mm
Height difference,overall : 2 mm

Curing System

Spray tube heating, end plates and all intermediate plates.
Working pressure: 3-5 atmospheres
Heat requirements,net : 39,000 kcal/ cubic meter

TABLE C-2

TILTING TABLES

Plate Dimensions

Height	180 millimeters
Width	3,5 meters
Length	12 meters
Area	42 square meters
Plate thickness	8 millimeters
Weight,empty	7.2 tons
Weight,full load	28.2 tons (500 kg/m^2

Admissible Tolerances

Plate surface	± 1.5 millimeters (3 meter ruler)
Max. deflection	1 millimeter

Curing System

Steam pipe network attached to bottom plate.
Working pressure: 3-5 atmospheres
Heat requirements,net: 450,000 kcal,at full load

Tilting Mechanism

Hydraulic operated tilting mechanism
Oil pump capacity : 9 liters/minute
Oil sump capacity : 100 liters
Tilting angle : 80^{o}
Time for full tilt: 3 minutes.

TABLE C-3

CONCRETE PLANT- DESCRIPTION

Capacity :	35 cubic yards per hour
Mixer	2 cubic yards
Cycle time	35-65 seconds
Aggregate bins	4
Capacity,each	15 cubic yards
Feed	Radial scraper
Cement silos	2
Capacity	350 bbl, 50 bbl
Feed	Screw conveyor
Water tank	2,500 gallons
Boiler	20 BHP
Pump	50 gpm, 30 psi

Operations

Gates	Pneumatically operated
Mix	Semi-automatic,punch cards

APPENDIX (D)

ECONOMICS OF HOLLOW-CORE SLAB PRODUCTION

1. Plant Facilities

The hollow core slab plant is considered here as the extension of existing precasting facilities. Therefore the installations do not include new offices, and new administrative staff. Nor do they include a new batching plant -- Instead, concrete is billed at cost to the hollow-core plant. Handling facilities for stockyard handling are included, but truck loading facilities are not.

2. Capital Investment

		Cost $
- Land: 0.5 acres, at $10000/acre	:	5.000
- Building: 430' x 30', 21' high: including electrical, plumbing installation	:	150.000
- Curing system, including boiler, pipe installation, pumps, motors, expansion tank, controls	:	50.000
- Extrusion Bed: 3'x342'x4' wide		
Abutments	:	15.000
Pallets: $35/ft x 1026'	:	35.000
Installation thereof	:	5.000
- 10 Ton Crane, 30' span	:	18.000
Electrified track: $15/ft x 1000'	:	15.000
Beam and base plate installation	:	15.000
- Extruder equipment, including saw, clamps installation	:	65.000
- 5 Ton Gantry Crane 18' span	:	15.000
748' of track, $2/ft.	:	1.500
Installation thereof	:	1.000
- Yard crane, 25 ton capacity, 41' span	:	65.000

1. <u>Plant Facilities</u>

The hollow core slab plant is considered here as the extension of existing precasting facilities. Therefore the installations do not include new offices, and new administrative staff. Nor do they include a new batching plant -- Instead, concrete is billed at cost to the hollow-core plant. Handling facilities for stockyard handling are included, but truck loading facilities are not.

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		Cost $
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Pallets: $35/ft x 1026'	:	35.000
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- 10 Ton Crane, 30' span	:	18.000
Electrified track: $15/ft x 1000'	:	15.000
Beam and base plate installation	:	15.000
- Extruder equipment, including saw, clamps installation	:	65.000
- 5 Ton Gantry Crane 18' span	:	15.000
748' of track, $2/ft.	:	1.500
Installation thereof	:	1.000
- Yard crane, 25 ton capacity, 41' span	:	65.000

1. Plant Facilities

The hollow core slab plant is considered here as the extension of existing precasting facilities. Therefore the installations do not include new offices, and new administrative staff. Nor do they include a new batching plant -- Instead, concrete is billed at cost to the hollow-core plant. Handling facilities for stockyard handling are included, but truck loading facilities are not.

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		Cost $
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- Extruder equipment, including saw, clamps installation	:	65.000
- 5 Ton Gantry Crane 18' span	:	15.000
748' of track, $2/ft.	:	1.500
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2. Capital Investment

		Cost $
- Land: 0.5 acres, at $10000/acre	:	5.000
- Building: 430' x 30', 21' high: including electrical, plumbing installation	:	150.000
- Curing system, including boiler, pipe installation, pumps, motors, expansion tank, controls	:	50.000
- Extrusion Bed: 3'x342'x4' wide		
Abutments	:	15.000
Pallets: $35/ft x 1026'	:	35.000
Installation thereof	:	5.000
- 10 Ton Crane, 30' span	:	18.000
Electrified track: $15/ft x 1000'	:	15.000
Beam and base plate installation	:	15.000
- Extruder equipment, including saw, clamps installation	:	65.000
- 5 Ton Gantry Crane 18' span	:	15.000
748' of track, $2/ft.	:	1.500
Installation thereof	:	1.000
- Yard crane, 25 ton capacity, 41' span	:	65.000

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Installation thereof	:	1.000
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- Concrete Delivery Cart	:	5.000
400' of railway track, installed	:	1.000
- Welding Equipment	:	1.500
- Prestressing Jacks: 15 tons, hydraulic pum, controls, installation	:	4.000
- Testing Lab Equipment	:	5.000
- Prestressing chucks	:	2.000
- Spare parts, tools and supplies	:	2.000
- Cable Cutter	:	1.000
- Start-up Costs, 1 month operations	:	80.000
TOTAL	:	$ 557.000

3. Labour Cost

		Cost, $	
9 plant labourers,	at $5/hr	90.000	
1 foreman	at $8/hr	16.000	
	Sub-Total		106.000
Fringe benefits, paid holidays, taxes, insurance etc. 30% thereof:			32.000
	TOTAL		$ 138.000

Cost per square foot (1): $ 0.138

(1) Assuming an annual production of 1.000.000 square feet

4. Production Costs.- per Square Foot

Material:

Concrete, at $18/cubic yard	0.310	
Pretensioning cable	0.150	
Aggregate heating	0.050	
Waste material	0.010	
Sub-total		0.520

Labour

Sub-Total		0.138

Cutting-Curing

Blades	0.008	
Electric power, slab curing	0.050	
Sub-Total		0.058

Maintenance

Maintenance, repairs:	0.030	
Sub-total		0.030
Total Direct Cost:		0.746

Indirect Cost (*)

Amortization, Building, over 10 years, at 1 Million sq.ft./year. including curing system and casting beds	0.0255
Machinery and Equipment, over 5 years	0.0592

(*) Excluding property taxes and equivalent charges.

Interest: On the basis of 3 equal annual repayments, 10% rate on declining balance	0.0358	
Sub-Total		0.1205
Total Production Cost:		0.8665

Note: Data is drawn and adapted from suggested figures of different manufacturers, and is believed to represent fairly accurately actual conditions.

5. **Break-Even Point**

Fixed Costs : $ 120.500

Variable Costs : $ 0.746/sq.ft.

Selling Price, F.O.B. Plant: $ 1.25/sq.ft.

$$1.25 \times Q = 120500 + 0.746 \times Q.$$

Q even = 239070 square feet. (Refer to chart)

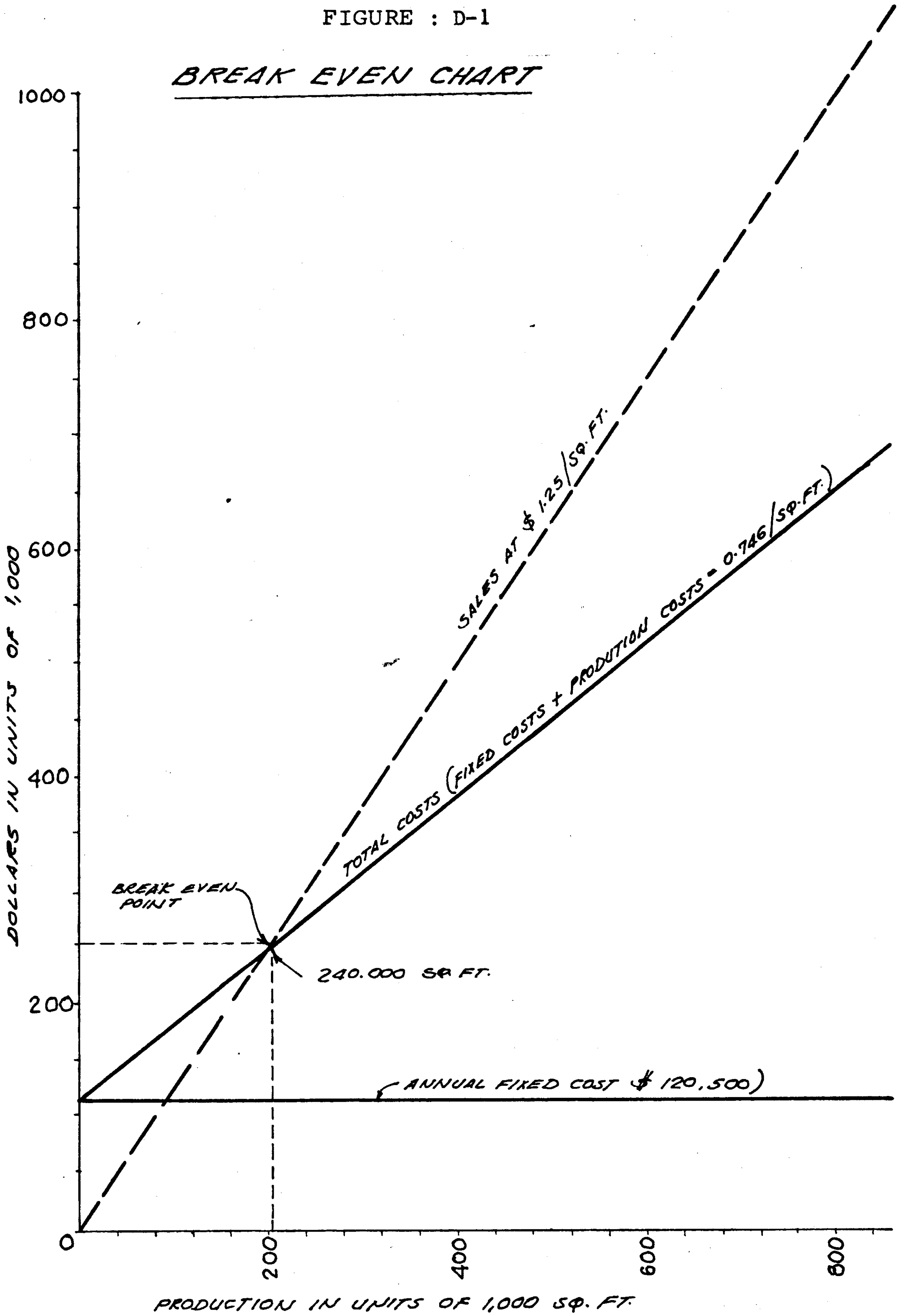
Comments

- The break-even point shows that a potential producer should sell a minimum of 240.000 square feet annually to cover his costs.
- The actual break-even is probably substantially higher, as all calculations are based on a maximum annual output of 1.000.000 square feet
- At 70% capacity utilization, with the same set of figures,

break-even point jumps to 363.000 units, i.e., 120.000 more square feet to be sold annually, just to cover costs.

- If complete facilities are added to obtain full independance of operations, that is, batching plant plus management and clerical staff, the break-even point is even higher.

FIGURE : D-1


BREAK EVEN CHART
1000
800
600
400
200
0
DOLLARS IN UNITS OF 1,000
SALES AT $ 1.25/SQ. FT.
TOTAL COSTS (FIXED COSTS + PRODUTION COSTS = 0.746/SQ.FT.)
BREAK EVEN POINT
240.000 SQ FT.
ANNUAL FIXED COST $ 120,500)
200
400
600
800
PRODUCTION IN UNITS OF 1,000 SQ. FT.