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Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

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INTRODUCTION OF ADVANCED TECHNIQUES FOR THE PRODUCTION AND USE OF PREFABRICATED ELEMENTS AND COMPONENTS FOR INDUSTRIAL CONSTRUCTION 1/

by

J. Durai Raj*

* General Manager, Hindustan Steelworks Construction Limited, New Delhi, India.

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SUMMARY

The building industry which is a [illegible] sector of economic activity and represents a large share of [illegible] investment has remained more or less stagnant in spite of the rapid [illegible] in other industries, which have almost reached the stage of automation. [illegible] attempt has been made to [illegible] prefabrication in the building sector in the developing countries, [illegible] hardly any impact of this industrialization in the construction of industrial buildings. Structural steel continues to be indiscreetly used in industrial structures in spite of the fact that steel is in short supply in almost all the developing countries. The advantages in using precast concrete components in industrial buildings leading to overall saving in scarce raw materials, improvement in speed and quality of construction and economy in construction and maintenance costs have not yet been fully appreciated. This therefore calls for a radical change in the existing building techniques by the adoption of improved designs and building systems using the principles of standardization, modular coordination and typification and resorting to a change over from the out-moded labour intensive methods to industrialized processes of manufacture and construction.

This also requires economical norms and prerequisites to be laid down for the mass production of the various prefabricated elements and the factors to be taken into consideration for the location of on-site or off-site factories. The planning and organization of such manufacturing plants with special reference to the methods of manufacture, the pattern of control and time scheduling and the fields of close coordination between the manufacturer and the contractor also attain major importance in the successful implementation of the project.

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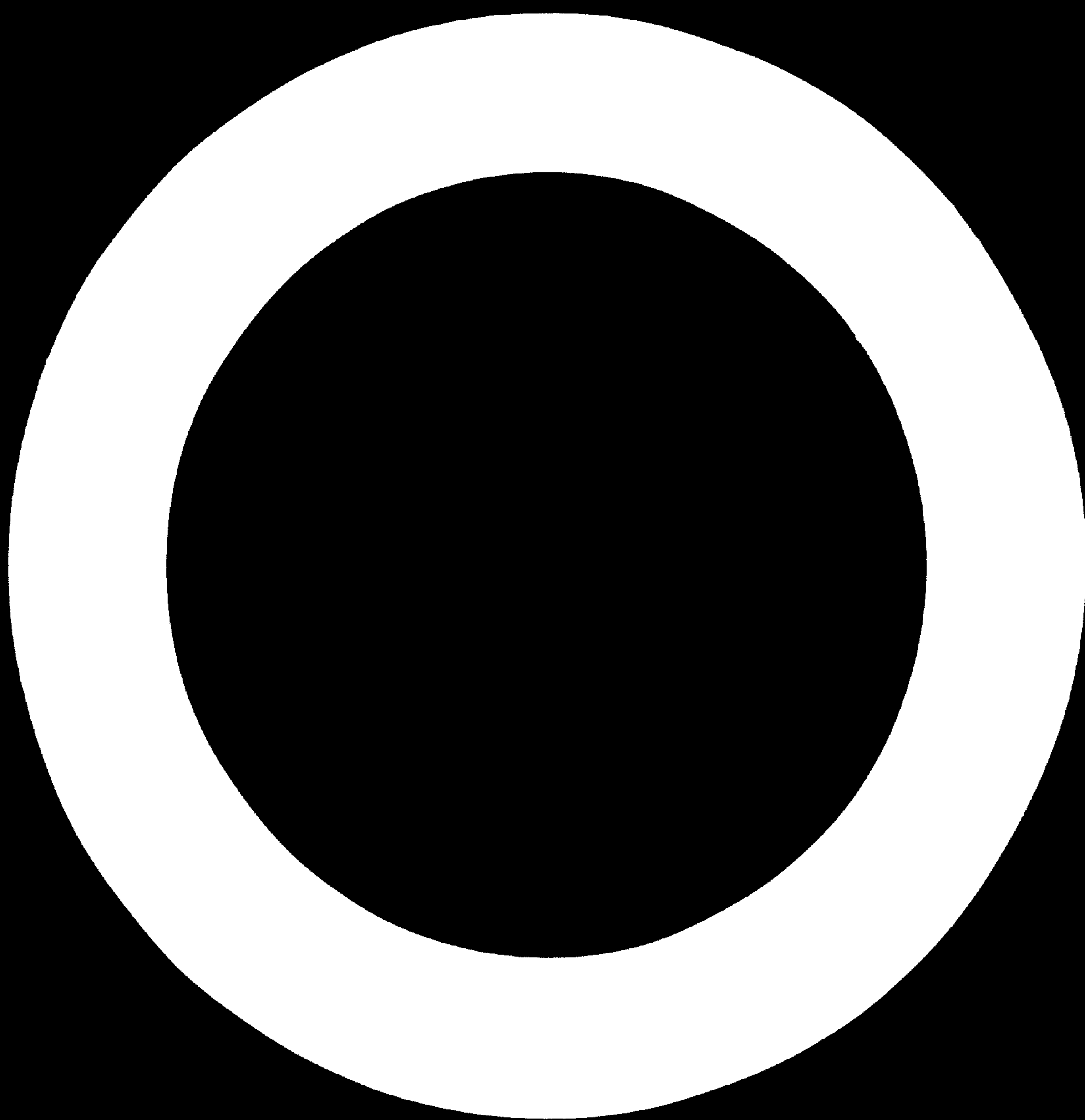

Introduction

An industrial building is one, the main function of which is to house an efficient manufacturing unit and provide a wholesome and congenial environment to all those who are associated with industrial production. Particularly, it should create an atmosphere for the workers to do their best in achieving the highest degree of efficiency. Every industrial building should therefore be consciously designed to make worthy of the new spirit of the industry and make it fit to take its place alongside the scientific and technological advance of our time. The new designs and techniques should also pin point the close connection between the social and functional aspect of each type of industry.

Industrial buildings can be broadly classified as buildings for heavy industry, medium industry, light industry, process industry and utility industry. Another general classification can also be on the basis as to whether cranes are used in the building or not. It need not necessarily mean that all industrial structures falling within a particular category say heavy industry should be heavy, as structures can be of various types. It may therefore, be reasonable to suggest that classification may be based on the number of cycles of specific loading cases [illegible] the position of the structure. On the basis of estimated life span and rate of load repetition, a further classification of the structures can also be made.

The term '[illegible]' or 'industrialization of construction' is used in this paper to describe the entire process of technical and organizational development of the construction industry from the simplest handicraft method to the most industrially advanced techniques. This term would also cover the whole gamut of construction involving continuity of production with a steady flow of demand, standardization, integration of the various stages of the production process, a high degree of organization, mechanization to replace manual labour wherever possible and research and experimentation integrated with production.

In the course of a change over from handicraft forms of production to industrialized forms, the construction industry should take advantage, where repetition of similar or analogous production processes exist, to introduce specialization and create the basis for the eventual introduction of mass production methods. A higher concentration of specialized operations makes it possible to introduce effective equipment and gradually replace manual labour by more efficient machine operations, with a view to bring about improvement in quality and speed. The mechanization of processes need not necessarily be restricted to centralized factories as some of these can with great advantage be carried out on site. As the process of industrialization, even the operations which are carried out at site get progressively mechanized.

While other industries have benefitted enormously from science and technology and in many cases have attained the stage of automation, this major sector of economic activity which represents a large share of investments has remained stagnant, more or less unaffected by the technological developments that have taken place during the last decade or two. There is therefore an urgent need to modernise the building industry with the ultimate aim of reducing costs, increasing productivity and rationalising and economising the use of materials. The structure of the industry has to be changed so that increasing demands could be met through better building techniques. Prefabrication and industrialized methods of building would not only supplement the existing capacity but also open up avenues for the use of new materials and processes and find new uses for old materials. The mechanics to be adopted for the introduction of prefabrication in a particular country would depend on the present status of the building industry and the infrastructure available. A beginning could however be made with the modernization of the building sector by introducing partial mechanization and by the use of small and medium sized prefabricated components which could be easily handled by small mechanical devices.

Inspite of the fact that steel production in most of the developing countries is not adequate to meet all the demands, one often sees the use of structural steel in most of the industrial structures. It is paradoxical to see more and more demand for use of structural steel, even for simple item like roof, inspite of inadequate availability of structural steel in time and also the right sections as per the design. The developments in Europe and U.S.A. show us the tremendous scope for prestressed and reinforced concrete structural members, mostly precast, in industrial construction. In these countries, precast concrete has become popular in spite of the fact that there is no scarcity of structural steel. By using precast concrete instead of structural steel, a substantial saving in the quantity of steel to the extent of nearly 60 to 70 per cent has been claimed. The problems associated with corrosion especially in coastal areas and consequent high cost of maintenance can also be overcome. As applicable to all concrete structures, precast concrete also has a higher fire rating compared to structural steel and is generally more durable under all types of climatic conditions and in all situations including those where materials of chemically aggressive nature are handled.

Prefabricated construction has its own advantages and shortcomings and should not therefore be applied indiscriminately to all situations. Economy versus the feasibility of adopting such a system should be considered before adopting prefabrication.

The main advantages of prefabricated construction could be avoidance of a variety of unnecessary sizes, facility for mass production, possibility for rigid quality control, elimination of the need for detailed design for individual cases, achievement of good finish and economy, adoption of most economical sections thus reducing material consumption and reduction in the planning and construction time. The heavy capital investment on equipment, transportation problems, handling, jointing and availability of suitable equipment and special skilled men for erection can be some of the factors which may discourage the introduction of prefabrication to some extent.

7. ECONOMIC PREREQUISITES FOR MASS PRODUCTION OF PREFABRICATED ELEMENTS AND COMPONENTS.

Analysis reveal that in countries which have amassed some experience with industrial methods of production and assembly of prefabricated components, the overall cost of prefabricated buildings is lower than that of conventional buildings by about 10 to 15 per cent. In countries where the production of components is undertaken only on a small scale and especially where conventional construction methods are well organised and rationalised, costs are generally higher than for traditional buildings. The use of industrial methods results in far greater savings in labour and material requirements and construction time than in construction costs, mainly for the reason that their use is necessarily limited to certain areas of the entire production process. Some economy is also possible in the services and special utilities systems which have been planned and woven into the fabric of construction. Cost studies however show that the present day level of industrial production in the building sector has a considerable potential for further savings. It is highly probable that further technical development, particularly in the mechanisation and automation as well as consistent application of modern organisation methods used in industrial production, will lead to additional substantial economies.

Economy in the mass production of prefabricated elements can also be achieved by adopting economical designs and building systems suited to the location, economical use of scarce building materials, by resorting to capital intensive methods, ensuring increased production with large repetitions suited to prefabrication and by making use of the principles of standardization, modular coordination and typification.

Rational design methods including adoption of new forms and shapes cou-ld result in saving of critical materials such as steel and cement as also the avoidance of wastage by adoption of proper standards consistent with safety for the designed loads and stresses. It is noticed that structures are still being designed using conventional elastic method instead of the use of ultimate load theory. It is very necessary that the latest design methods are made use of, which will permit a realistic assessment of the safety of the structure [illegible] use of different load factors for dead and live loads thus bringing about considerable economy in the design.

The building industry particularly in developing countries react sensitively to all economic changes by an increase or reduction in its activities. Unless long-term plans are formulated for the construction industry as a whole, such large fluctuations will continue to be a detriment to its rationalization, especially with regard to long term plans for investment in plant and machinery. The absence of adequate construction programmes and the discontinuity of demand are perhaps the most significant factors limiting the application of industrialized methods in developing countries. These factors exert an unfavourable influence on the development of labour productivity and of the capacity of building industries, as well as of construction costs and generally retard the industrialization of construction. It is therefore important to create a climate conducive to development of the construction industry by ensuring a constant increase in the requirements imposed on the industry, in accordance with the long term needs for development of the national economy. Placing long term orders with factories that have the potential for developing new teconiques and that are willing to make efforts to reduce the construction period and the costs, may lead to improvements in labour productivity and the use of more efficient methods.

[illegible], economical covered roof for conducting [illegible] operations, storage of raw materials and finished products. Except in rare cases, where the [illegible] are conducted in a vertical flow [illegible], most of the industry needs just large shed. [illegible] the example of the advanced industrial nations, it can be concluded that upto about 80 per cent of the sheds required by the various industries can be brought under standard spans with universal application. Precast concrete can become extremely competitive provided there is sufficient repetition of moulds and other processes involved. It is in this light, standardization assumes significance.

The standardization of parameters for industries by itself will be a very difficult task as it will not be possible to specify the requirements, lay out, heights etc. for each industry as these vary from industry to industry depending on the process of the end products. Though it may not be possible to specify any particular constraint on the parameters, a broad mesh can be fixed within which any industry could be accommodated.

A study of the industries already in existance will disclose that it is advantageous to follow a module of 3 metres for working out grids. For industrial buildings, the column spacing may be at 3 metres for light, utility and process industries, 6 to 12 metres for medium industries and 12 metres for heavy industries.

Likewise the span can also be standardised at 12 metres for light utility and process [illegible] metres for medium industries and 18 to 42 metres for heavy industries. Depending upon the type of roofing adopted, the inter-frames may also be [illegible] at [illegible] spacing.

[illegible] to [illegible] standard heights for columns [illegible] standardization of components. Keeping in view the height of crane rails, where cranes are provided, the height may be standardised as 4.5 metres for light industries, 6 to [illegible] metres for medium industries and 6 to 15 metres for heavy industries. The heights could be varied in preferred increments of 0.5 metre. In case where cranes are not required as in the case of light industries, the eaves height could be standardised at 3.5 metres.

It may not be possible always to standardize the capacity of crane to be used in an industry. However, from broad considerations, it may be suggested that crane capacities for light industries may be to a maximum of 5 tonnes medium industries 60 tonnes and heavy industries upto 150 tonnes in general and 200 to 300 tonnes for steel and iron making plants and such like industries.

Roofing is one item where much more effective standardization can be achieved, than in any other components of the industrial building. The basic factors that would have a bearing on the design will [illegible] seismic forces and the static live load, hence it should be easy to standardize the main and secondary roof members of the industrial buildings. Where North light roofing is preferred for better illumination and ventilation, the roof work will consist of truss girder, roof girder, main truss and inter-truss (figure 1). These members in turn can be standardized for the spans, for which the recommended parameters have been suggested earlier and for the loading conditions which will basically be in three or four types. With this standardization, it will be easy to plan each component as a prefabricated member either in concrete or in steel, depending upon economy and other constraints.

In USSR and in most of the East European countries, well established typification organizations play a pivotal role in the standardization of industrial building components. They work in close collaboration with other research institutes and advanced technical institutions. These organizations evolve optimum standard structural designs which can effectively save scarce materials such as cement and steel. Efficient structural system for each classification of industrial structures can be developed which will include experimental/theoretical study of different structural forms such as trusses with optimum configuration, economical purlin steel bents based on minimum weight design, columns, open web and castellated beams etc. Rational and safe design for frame girders with special emphasis on study of large and lateral forces, secondary effects such as fatigue and brittle fracture etc. can also be developed. This development would help in the standardization of structural systems and the lay out for each type of industrial building.

The success of the industrialized methods of construction will depend to a large extent on the possibility of developing and extending repetitive production and in bringing about an economy in the construction of buildings. Typification of building designs provides a means by which the greatest degree of repetition of all operations and products can be applied in design and production. Typification helps to reduce the number of types and sizes of components manufactured in the factory, permits streamlining of assembly operations on the building site and simplifies and reduces the variety of the equipment. It is an important prerequisite for the industrialization of building, as it helps to improve the functional quality of the building and brings about economy and improvement in the quality of construction. With this method, it is possible to use the components from the same production cycle to produce different types of buildings, provided the particular system follows the rules of modular coordination.

.. [illegible] production of prefabricated [illegible]

Walls and Partitions.

The method for manufacturing wall panels and partitions will primarily depend on the constructional features of the wall panels themselves, whether they are single or multilayered type and the required surface finish. In the case of multilayer panels, which are known as sandwich panels, horizontal casting is the best accepted practice.

Single layer panels such as internal wall panels are best cast in vertical battery moulds and this will also give smooth finish on both sides. Openings such as doors may not present any serious problem but window openings might result in some unfilled pockets.

For a production unit manufacturing walls and partitions, it will be necessary to ensure that the design of the member is economical on the basis of modern design theory, to make it competitive if not cheaper, than other conventional types of construction. It will also be essential to have an optimum number of standardized members of the repetitive type to be prefabricated to make the unit a viable proposition. For the unit to suffer no loss in real terms, there should be an optimum quantum of production depending on the size of the factory, continuity of demand, size and weight of the components to be handled and the production method adopted.

In some of the East European countries the annual capacity of a prefabrication plant manufacturing wall and partition element varies from 5,000 to 20,000 M^3 of concrete. In USSR the yard-stick for each prefabrication plant varies from 20,000 to 100,000 M^3 of concrete per year, mainly on account of the highly mechanised processes being followed in USSR and the large programme of construction they have. Some of the larger factories in USSR using flow line method of production have even reached an annual capacity of 270,000 M^3 of concrete per year.1/ It is felt for a viable unit in the developing countries, this capacity may be of the order of 25,000 to 30,000 M^3 of concrete per year.

Prefabricated walls and partitions are manufactured both in stationary and moving moulds. Though the manufacturing process may at the initial stage be in horizontal moulds, a gradual switch over to vertical casting and thereafter to flow line method with steam jacket arrangements can take place thereby increasing the efficiency and the production multifold. Wall and partition panels lend themselves very well to complete industrialization hence this process could be expedited with gradual mechanization. The ultimate economy for such a unit will however depend on the extent of mechanisation that has been introduced in the manufacture of these components.

<u>Structures.</u>

The components of industrial buildings that fall under this heading would be columns, gantry girders, different types of trusses,

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1/ Report of the team of Indian Specialists deputed to the USSR. National Buildings Organisation, Government of India Publication, March 1961 purlins, bracings etc.

In industrial buildings where cranes are provided, precast vierendeel type of columns will prove very economical as long as the crane capacity does not exceed 40 tonnes and the spacing of columns is within 12 metres. Solid precast columns either as parts of portal or of non-portal type will be an economical solution in buildings which do not have any provision for cranes.

Precast prestressed trusses, particularly lattice structures, have been successfully used for the construction of aircraft hangars, large span industrial sheds and crane girders. Skillfully and economically designed lattice trusses of spans upto 42 metres have been commonly used for industrial buildings in many of the East-European countries. The quantity of material used in such trusses is claimed to be very small as a truss of 32 metres span only consumes 0.023 M^3 of concrete and 4.42 Kg. of steel per M^2 of covered area, for trusses spaced at 6 metresapart.2/

In lattice structures, the bottom horizontal member and some of the web members are subject to tensile forces. Though these could be designed as reinforced concrete members with mild steel reinforcement, it will be economical to prestress or post-tension the tension members of lattice structures especially in spans greater than 12 metres, the choice of prestressing depending

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2/ Proceedings of the National Symposium on Planning, design and construction of Industrial complexes held at Tiruchirapalli, India. Paper by Mr.K.V. Swaminathan and Mr.C. Raj Kumar on 'Design Consideration and construction aspects of precast prestressed concrete roof trusses' upon the local conditions. Pretensioning can be conveniently carried out in factories but this would require transportation of the truss in one piece, making it difficult and expensive. It may prove advantageous to post-tension the bottom member and terminate some of the wires in the end tension diagonals. As post-tensioning of all the tension diagonals will require anchorages which are usually expensive, precast pretensioned members could be used instead.

In precast construction, weight of the member will be an important factor to consider. By adopting precast lattice trusses, the weight to be handled can be reduced by 25 to 50% For long spans, this aspect will become a very major consideration because of the limitations on the availability of suitable hoisting equipment. Further economy can be achieved if segments or panels of lattice system are manufactured in a factory and transported to site for fabrication and erection.

In addition to the above, there are a number of varieties of roofing systems that can be developed in prefabricated construction, and which may prove very economical when compared to the conventional roofing design. The hog -shaped girder is a very popular type of roofing unit used in prefabricated industrial construction. The girder may be cast as a single piece, pre-tensioned at the casting yard and transported and erected without any assembly work or any other type of site work. Being of flatter slope, a longer overlap length in the roofing sheets may be provided to prevent rain water leaking through the roof.

Pitched roof trusses similar to fink truss are also manufactured as precast units, but with a smaller number of diagonal members. These are cast in two or three separate pieces as reinforced concrete members and assembled at site to form the complete truss. The joining of the pieces may be done by interlocking of the protruding reinforcement, welding of steel embedded at the ends or preferably by post-tensioning of the top chord which will also help against buckling of the members during erection.

Other economical roofing systems relate to pitched portal frame-single hinged, two hinged or three hinged, North light roofing system and folded plate roof. Precast concrete folded plates have considerable scope in the span range of 10 to 30 metres.

Precast concrete purlins in the form of angles require considerably less materials than purlins with 'I', 'T' or vierendeel sections in view of the bi-axial nature of the bending moments. These are analysed as simple folded plate structural element. Such purlins have been used widely in a number of projects.

A novel application of precast lattice structure is also, as girders for carrying overhead travelling crane tracks. It is observed that the deflections of concrete gantry girders are also generally less than that in a corresponding structural steel gantry girder. Precast concrete rib slabs have also been used as walkway platform by the side of gantry girders which have proved very economical.

As in the case of the pre-fabrication unit manufacturing wall panels and partitions, this unit should also have a continuous demand for prefabricated products to make it an economically viable proposition. The standardization of the basic parameters of industrial structures like heights of columns, span, width of bay, crane loads etc. will lead to economical solutions. Standardization and modular coordination will also help in cost reduction and gradual switching over to open system of production.

Most of these components could be either cast in horizontal stationary moulds at the factory or in tilting horizontal moulds at the place of hoisting. In the latter case considerable economy could result due to saving in handling and transport.

Roofs and flooring elements.

Spiralling cost of staging and shuttering of in-situ construction is one of the factors for abnormal rise in the cost of roof and floor slabs. Because of this and from considerations of other advantages of a precast slab like efficient structural form, better quality of workmanship due to adopting systematic production techniques, and savings in building materials due to economical sections, conventional cast in-situ reinforced concrete slab construction is slowly giving way to slabs assembled with precast elements.

Roof and floor components may comprise either elements of smaller width such as hollow core slabs and channel units or in the form of room sized large panels which are often solid.

Composite construction with reinforced concrete or prestressed concrete battens and hollow block in-filling is also widely used in industrial buildings. The elements are of prestressed concrete for longer spans and are produced in a long line pretensioning bed using industrialized techniques. Prestressing enables earlier handling of the moulded element besides other advantages such as lesser deflection and little or no cracking. Electro-thermal method of prestressing in which the steel is elongated by thermal expansion due to application of a low voltage and high amperage electric current, is commonly used in East European countries.

Hollow core slabs can be cast in horizontal moulds with retractable steel cores or by extrusion process. These are extensively used in all the industrialized countries. Precast channel units or ribbed slabs with compression flange of widths varying from 50 cms to 150 cms and minimum thickness of 1.5 cms to 3 cms and longitudinal ribs of minimum 4 cms thickness are found to be very economical due to reduction in the consumption of steel and concrete and lower self- weight. In the system of concrete battens with hollow block infilling, staging and shuttering are completely eliminated, the construction time is also very much reduced and erection can be carried out with the minimum of equipment.

The initial labour intensive method of horizontal casting in stationary mould can be gradually switched over to capital intensive methods thereby increasing the productivity and bringing down the overall cost of production. Plants manufacturing these products should also have a minimum annual turnover of 25,000 to 30,000 M^3 of concrete with a continuous demand for a long period, to enable the unit to introduce modernization for economical and efficient working.

Other components:

Other components may include precast foundation units, staircases, ventilation shafts, refuse chutes, toilets, bathrooms and kitchen units and such like items. Single moulds are usually utilised for casting such volumetric elements. While staircases are vertically cast, the toilet, bath-room and kitchen units are pre-fabricated as box units, complete with sanitary, water supply and electrical fittings, leaving only the connection to the main services to be made at site.

Standardization of these items and design of such elements as box units have made the components very economical when compared to conventional method of construction. Further economy will accrue as and when open system of production is resorted to and the components sold as catalogue items.

B. Main requirements to the location of factories producing prefabricated elements.

The assembly of buildings from factory made components is the most effective method for industrialization of construction.

It divides the process of construction into two phases - the production of components in factories and their assembly on the site. Operations that are transferred from site to factory are more readily subjected to the application of industrialised methods which are characterized by high labour productivity. In addition, production is no longer influenced by weather conditions [illegible] working conditions similar to those [illegible] in other [illegible]. This also reduces turnover of labour and assists in the creation of permanent working groups. The level of skill and qualifications required of the workers is generally lower than what is required for the same operations on site. However, before this method of manufacture in permanent factories is decided upon, certain conditions need be fulfilled, the most important being capital investment in buildings and plant, ensuring continuing sale for the products and standarizing the requirements for the buildings. It will therefore be advisable to consider whether it may be more convenient and economical to use site prefabrication which may still improve productivity considerably.

Another problem in the development of industrialised building is the determination of the optimum capacity of a factory to produce building components. While an increase in production capacity will reduce both the initial and production unit costs, it usually gives rise to an increased area of operations thereby increasing the cost of transporting components to various sites.

while considering expansion of a plant, the net effect of the unit cost [illegible] proposed increase in factory capacity [illegible] must be taken into account. In areas where construction requirements are concentrated, larger precasting plants will be justified than in the case of areas where construction activity is dispersed over a wider area.

In developing countries, at the initial stage of industrialization, it may be advantageous to have temporary plants for prefabricated building components established at or near the construction site. These factories may at first manufacture a wide assortment of products which could later be pruned down to those items which are amenable to mechanization. New prefabrication plants, even of a temporary nature, should be located with due regard to both the present and future load centre of activities. If suitably located, even small temporary site plants can eventually develop into large centralized factories capable of supplying specialized products to building sites over a wide area.

For a regional planning involving production of precast elements on a large scale, a systematic attempt considering all aspects of costs would be desirable. The requirement of prefabricated components for industrial buildings is not as concentrated as in the case of housing industry and can be said to have a diffused demand pattern. The demand being diffused over a large area, the transport distance should be determined on a realistic basis. It will be necessary to consider various parameters like cost value, locations, zonal demand and alternate capacities while planning manufacturing plants for a minimum overall cost.

It is stated that in [illegible] the usual transportation distance is 200 to 300 Kms. and even transport upto 1000 Kms. has taken place. The maximum weight of transported members is also claimed to be 45 tons and the maximum length 32 metres. In Europe, however, the transport distances are not so great and the dimensions of the members are also much smaller.[3] In consideration of the local working conditions in developing countries and the magnitude of industrial building activity, an optimum lead of 60 to 80 Kms. for the supply of components from the factory to the construction site is considered to be a workable arrangement from the point of view of traffic costs, transport bottlenecks and other relevant factors.

A suitable production setup is the basic requirement for precasting which will primarily depend upon the desired output. For a given project, the factors influencing the choice of locating the production setup can be examined out of two possibilities either on-site or off-site production. On-site production cannot have the facilities of a well established permanent factory. The facilities in such a case have to depend on the size of the project and the number of years the production setup is required to cater to the project. It may be an open yard casting

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3/ MOKK, L 'Prefabricated Concrete for Industrial and Public Structures' 1964 Page-153.

with a com[illegible] possibility of [illegible] setup or a semi-permanent type of set-up with partially mechanised facilities for production. On the other hand, an off-site set-up is often a well [illegible] permanent factory with higher degree of mechanization [illegible] available within an economical distance from the given project site, the choice between the available permanent factory and the set-up to be newly established at site, is to be governed among other factors by the cost of the new set-up against the cost of transportation of the elements from the permanent factory. Other influencing factors can be desired rate of output and the transportation facilities available from the permanent factory to the project site.

A temporary set-up at site requires only limited capital investment but with reduced out-put and lesser sophistication in production. Open-yard precasting is the simplest of its form which is more often suitable in countries having warm and dry climate. The facilities and degree of mechanization in such production centres will have to largely depend upon the needs of the projects they are supposed to cater. This temporary site factory concept which could also be conceived as a mobile factory, shifting from one project site to another has, however, one advantage that it would enable the extension of such prefabricated construction to the many smaller centres and remote areas. This will also help in the dispersal of industries to the rural areas [illegible] to the cities. A temporary pre[illegible] set-up at site is likely to be economical if the demand is atleast [illegible] of concrete per year.

Against the above, [illegible] permanent factory will be highly [illegible] automated achieving increased output. [illegible] techniques of preparation, casting, compaction, curing and handling are employed and elements produced in this way can be erected within 2 or 3 days after casting. The capital investment on such a factory can only be economical if the factory has assured demand for a long time to come and is located within an economical distance from the areas of such construction activity. In normal cases, the above economical distance is taken to be not in excess of 50 Kms.

An ideal location for a prefabrication plant will be as close to the load centre as possible and will take into consideration the availability of road and rail facilities for receipt of raw material within a reasonable distance and adequate quantities of water and power. Local availability of skilled and unskilled labour for the factory will also be an added factor governing the location of the plant.

C. Calculation theory of energy, water and other requisites needed for the production of prefabricated elements.

In some of the developing countries, the man hour requirement in respect of buildings constructed by traditional method is stated to be about 25 man hours per M^2 of covered area. A ratio of 15 man hours per M^2 might be considered an achievement in these countries. However, in countries where mechanized equipment is generally used for introducing light prefabrication in traditional buildings, the figure may be 15 man hours per M^2 or even less. For completely industrialized methods, the ratio will be of the order of 10 man hours per M^2 which will even go down to 7 man hours per M^2 in some of the highly developed countries. 1/

Erection time for a large panel is about 15 to 20 minutes. The shortest time for construction is when box units are used. It is claimed that a block of apartment comprising 50 flats using large panel techniques has been completed in a period of 2 months while conventional methods would have taken over 9 to 12 months. 1/

A reinforced concrete factory in USSR, manufacturing precast beams, trusses, floor and ceiling slabs, staircases and landings of which 50 per cent are prestressed, produces 25,000 M^3 of concrete per month. In the process, the factory consumes 500 to 550 thousand units of electricity, 3,000 to 4,200 tons of steam and 2000 to 3000 tons of water per month. 1/

As against the above, the average consumption of power and water at one of the prefabrication plant in India is of the order of 37.5 K.W.H. and 63.6 K.L. per M^3 of concrete respectively.

1/ Report of the team of Indian Specialists deputed to the U.S.S.R. National Buildings Organisation, Government of India publication, March 1961.

This factory is comparatively a labour intensive one and uses power for general lighting and running of welding sets, concrete mixers, vibrators, [illegible] machines and the mechanised workshop. Water is utilised for concrete batching and for curing of concrete components, in boilers for steam generation, for drinking and in the concrete laboratory.

II THE PRODUCTION OF PREFABRICATED ELEMENTS AND COMPONENTS AT SPECIALIZED FACTORIES.

A. Organizational principles of mass production of prefabricated elements at specialized factories.

In planning a new production set-up, the requirement of space and facilities are the two essential features to be considered. The amount of space for the production, storage and for the installations depend upon the desired rate of out-put, besides the variety and the sizes of the components that are required to be produced. Space for production is determined on the type and number of moulds. While horizontal moulds take up larger areas, vertical battery moulds need only less amount of floor space. Providing adequate working space around the moulds is also essential. The area of casting shed is usually worked out based on the above requirements. The height of the casting shed is determined on the basis that it is possible to lift and move one precast component over another. Vertical moulds may be a deciding criteria in this regard. Arranging vertical battery moulds in pits saves need for large head room. Additional space for preparations such as making reinforcement cages, cleaning and touching up of the moulded units is also to be kept in view. The casting shed is also to be equipped with a travelling overhead crane of suitable capacity or any other alternative arrangement.

Space for storage yard should depend upon the size of the daily output and the demand. A storage space for components of atleast three weeks production is usually provided in the production centres of such countries where prefabrication is quite popular. In developing countries where the demand may not be as high, the storage space has to cater to a larger quantum of production. The additional storage space is to equalize possible fluctuations in demand and delays at erection sites. The storage yard may be aligned with the casting shed in such a manner as to form an open-air extension thereof enabling the overhead cranes to travel out on gantries into the yard. The storage yard can be otherwise provided with a travelling portal crane. The yard should be so laid that the transporting vehicles can be efficiently served by the overhead crane.

Space for facilities depend upon the type and size of the ancillary facilities required by the production set-up. These may constitute storage of raw materials such as cement, coarse and fine aggregates and reinforcing steel, concrete batching plant, mechanical workshop, boiler and compressor house, laboratory and office. The concrete batching plant should be located for a minimum distance of concrete transportation. Cement, fine aggregates and coarse aggregates will be stored close to the batching plant. The size of the batching plant will depend upon the turnover of concrete required per hour. The capacity of cement and aggregate storage should however depend upon the need for a longer stretch of period say for a month, depending on the lead time involved in such supplies. The capacities of boiler and compressors are determined based on the extent of their services planned in the production process. Other facilities such as mechanical workshop, office and laboratory space largely depend upon the size of the production set-up itself.

The development of industrial methods, the increasing capacity of the construction industry, the size of the projects, the full utilization of highly efficient machines and the coordination of multitude of sub-contractors and operations, all require better efficient methods for the preparation, programming and control of the whole construction process. Operations research and the application of computers, which have already found many fields for application in other sectors of the national economy, are now becoming important aids to the construction industry. With their use, it is possible to introduce progressive forms of organization and management as they enable a speedy analysis of complex situations such as the relative effectiveness of various production methods, comparison of various designs, the selection of most economical investment etc. In recent years, these aids have been applied more frequently in planning and controlling large projects, determining the demands being made on the construction industry, preparing long term programmes and the calculation of complex structures.

For bringing about increased efficiency, it will be necessary to rationalize site operations in order to remedy organizational and technical defects or traditional methods which are impeding the economical use of more advanced industrial methods. There is a wide range of construction activities in which a close examination will bring fruitful results such as improvements in construction technology, development of simpler machines and improvements in machines already in use and establishment of temporary site plants to produce simple building components. Even some minor technical and organizational changes can result in considerable overall improvement.

Many factors are required to be taken into account for choosing a method of manufacture of a precast element.

- size and total number of elements to be produced.
- desired rate of output.
- shape, type and constructional features of the element.
- facilities available in the production set-up.
- economic aspects.

The size of [illegible] may decide the requirement of space for production as well [illegible] for storage and may influence the method of [illegible] [illegible], if there can be [illegible] floor panel. The size of the element may also influence the method of curing. A mass-produced element, if small in size, can be steam cured under high pressure in autoclave while the same technique will not be possible for bigger elements without heavier investments. The weight of the elements will decide the capacity of the handling equipment. The desired rate of output and the total number of elements to be produced will have direct bearing on the number of moulds, required degree of mechanization and need for accelerated method of curing. Features such as special shapes, protruded or projected reinforcement, required finish on the surface and single layer or multi-layer largely influence the design of the mould and the technique of casting. Horizontal casting techniques are favoured for ribbed or curved elements, multilayered elements and elements which require some particular surface finish. Vertical casting is favoured for single layer solid panels which require no special treatment nor have any protruded reinforcements from their edges. The facilities available in the production set-up also greatly influence the choice of a suitable method of manufacture. An accelerated curing facility will result in a quick turnover of moulds which can be advantageously used for a production in series. Facilities such as concrete batching plant and overhead gantry crane will also aid speedy production and handling and will influence the manufacturing method. While choosing a method of manufacture for a given project, the influences of the above factors have to be considered simultaneously with a view to achieve least cost of production.

For manufacturing large panel elements, two types of horizontal moulds are usually employed. They are :

- fixed horizontal mould and
- tilting horizontal mould.

Some of the horizontally cast elements such as cored slabs and trough units are sometimes produced by methods like slip forming and extrusion.

In fixed horizontal moulds, both moulding and demoulding are done in horizontal position whereas in tilting horizontal moulds, although moulding is done in horizontal position demoulding is carried out when the moulds are tilted to an almost vertical position. Fixed horizontal moulds are less expensive than tilting horizontal moulds.

Tilting horizontal moulds, though more complex and costlier, are better suited as extra reinforcement in the wall panels will not have to be provided since the demoulding is carried out at an almost vertical position, more often not less than 70° to the horizontal. Such mou-lds are therefore mainly intended for casting wall panels. For some special surface finishing techniques, such as exposed aggregate finishes, the tiltability of the mould is an added advantage. External wall panels are more advantageously cast in such tilting moulds.

Slip-forming and extrusion method is achieved with a moving machine mould which forms the cross-sectional shape of the element. Components such as precast prestressed floor elements both solid and hollow are sometimes manufactured using this technique. A long cored slab is cast on a horizontal bed in which prestressing wires are kept tensioned by extruding the concrete from an extruding machine which pushes itself on rails against the effort of extrusion. The extruded slabs are subsequently cut to suitable lengths after hardening. Projecting reinforcements from the edges or providing castellations are, however, not possible with this method.

Vertical moulding is another possibility in the stationary production method. Individual moulds or a battery of moulds can be used for such a casting. Internal wall and floor panels are often cast vertically using battery moulds. Vertical moulding is best suited for panels that require a smooth surface on both sides. Staircase panels are also produced by vertical moulding. The special advantages of vertical moulding are :

- a large number of units can be produced in a small space.
- Concreting the units proceeds fast as there is no need to spread the concrete as in the case of horizontal moulding.
- surface finishing not necessary due to smooth mould faces.

- heat of hydration developed within the concrete is conserved which accelerates hardening.

Another sophisticated method of production which is commonly termed as 'Flow line production' is highly mechanized, approximating to the assembly-line production practised in the mechanical engineering industry. This is a travelling horizontal mould system in which the moulds are moved along with the element from one working position to the next through a series of stations such as demoulding, mould cleaning and oiling placing of reinforcement, concreting, vibration, surface finishing and curing. A steam chamber forms part of the continuous travelling chain. After the elements attain their required strength, they emerge out of the chamber in individual wheeled pallets. These are placed on a tilting table where they are tilted and brought on to a vertical position and are cleared by an overhead crane. In this method, the various processes are subordinated to the speed of the moving pallets and as such are to be completed in a fixed period of time.

Apart from the normal production planning and plant layout techniques which are an essential part of factory management, it will be necessary to resort to material management and proper inventory control of stores which has an ultimate bearing on the overall cost of manufacture. ABC analysis is suggested in this connection which will help in identifying the major items of control out of the large number of consumable stores, tools, spare parts etc. maintained in the factory. A continuous work and method study would also streamline the various operations and bring about improvement in the overall productivity in the factory.

Quality control is another field which can result in good dividends, and this can be achieved by organising a well equipped concrete quality control laboratory manned by qualified personnel. The laboratory should have, apart from other ordinary items like concrete moulds, vibrating, grading, sieving arrangements etc., a compression testing machine, facilities for conducting tests on the final products and materials used in the manufacture and instruments for checking the stability and setting of cement and the consistency and workability of concrete. The laboratory should be in a position to design and control the various mixes of concrete used in the manufacture.

b. Combination of different production units in one complex.

The basic components required for an industrial building are columns, gantry girders, different types of elements to make up the roofing system and components for side cladding. The type of components to be manufactured in a production unit will however be governed by the building systems adopted for the construction. The components will have to be prefabricated in such a manner that the complete structural system suits the individual requirement. If different production units are to be combined in one complex, manufacturing components for industrial buildings, it will be a necessary requisite that standardisation and modular coordination are rigidly adhered to. This will be essential if components manufactured from various units are to match and fulfil the desired function. It will be rather difficult to envisage which of the units will manufacture which of the components as this will be essentially a planning decision. Economic factors will also come in while taking this decision. A broad division on the basis of normal practice adopted in certain countries, will be to have columns and side coverings manufactured in one unit, trusses, purlins, bracings etc. in a second unit and other roofing elements like shells, folded plates etc. in a third unit.

For a combination of different production units to be a success, the units should be in a position to adopt open production system, requiring precision thereby ensuring that all components needed for a complete building are standardized and are obtainable from various sources and be able to fit and work together. The units should be able to offer their components in the market through catalogues, just like any other manufactured product. The manufacturers adopting such schemes should also be ready to guarantee specified tolerances for their factory produced materials and should ensure the most exacting standards of accuracy to facilitate interchangeability between components from different sources. The open system offers greater scope for the extensive development of industrialisation but it would need complete standardisation and high quality precision for adoption. It is

[illegible]

[illegible] industrial [illegible] developing countries, [illegible] may [illegible] improvements [illegible], prefabrication, [illegible] the industr[illegible].

[illegible] Prefabrication [illegible]

Most of the developing countries have indicated their keenness to resort to partial prefabrication on some of their building projects in the initial stages which may involve mechanization of the existing building operations, improvement of the building techniques and introduction of precast elements in the conventional construction, and later when they gain sufficient experience and mechanization and standardization in the industry improve, the countries could consider changing over to full prefabrication. The integration of prefabricated building components into conventional buildings will have the effect of speeding up the construction, improving the quality and reducing the overall cost. In buildings where the walls are masoned following conventional methods, it may be possible to introduce precast floors and roofs, lintels, beams, sunshades, staircases, balcony slabs, railings, doors, windows etc. as a first step towards prefabrication. Such prefabricated components in some construction [illegible] per cent of the total construction [illegible] claimed that in one of the systems of partially industrialized construction, there has been a saving of 2[illegible] per cent in cost, 46 per cent in construction time and [illegible] per cent in the number of site operations, compared with the traditional construction. Gradually the in-situ structural framework and walls of traditional materials could be substituted by precast members and the entire building process industrialized to the maximum extent possible. It is therefore suggested that a building system or systems suited to the needs of the country may be devised after studying the popular systems in vogue in the developed countries.

The simple precast elements which can be initially produced may be concrete hollow blocks for walls and roofing, precast reinforced and prestressed concrete battens, ribbed, hollow cored or solid slabs for floors and roofs, sun-shades, lintels and beams. Simple precast roofing systems for industrial buildings could also be introduced. These are easy to manufacture in stationary horizontal moulds at the initial stages and then gradually switched over to more sophistication by resorting to vertical moulds, extrusion processes and flow line technology.

Most of the reinforced concrete components can be cast in stationary horizontal moulds using timber, steel or concrete. Wooden moulds are usually used for smaller production programme and if properly done to the requisite standard of workmanship will serve about 20 to 30 [illegible] without needing any major repairs. Apart from [illegible] than steel moulds, wooden mould are not volumetrically stable and therefore often need rechecking and repairs [illegible] accuracy.

Steel moulds are [illegible] for the requirement but they work out relatively expensive. [illegible] reuses, the moulds can be made robust and vibrators can also be mounted on it. The useful life of steel moulds [illegible] 300 to 500 reuses if properly handled and maintained. As adhesion between steel mould and concrete is not significant, it gives smooth finishes and demoulding also does not present any difficulty.

Concrete or masonry moulds are usually used for the manufacture of precast roof and floor units such as channel units, funicular shells and folded plates. Such moulds are also used in battery moulding either horizontal or vertical. In the latter case, the mould leaves are of reinforced concrete as in the case of vertical battery casting of wall panels. The concrete mould surface must be finished absolutely smooth, otherwise excessive adhesion may cause difficulties in demoulding. Such moulds are reusable about 50 times without much major repairs.

The pretensioned prestressed members like battens, purlins, hog beams etc. are usually cast by the long line system using timber or steel moulds, or in gang moulds using pressed steel. Other components like columns, lintels, beams, stiffners, roof members, sun-shades etc. are usually cast in single moulds of either timber or steel depending on the number of components to be prefabricated. The sides of these moulds are made separable so that they could be removed after 24 hours, whereas the bottom mould could be removed after 48 to 72 hours.

Curing of these components can be by sprinkling of water or keeping the elements moist or immersing them in water tanks. As this tends to reduce the manufacturing capacity of the plant by as much as 25 to 30 percent, it may prove economical if faster curing methods or artificial methods are adopted as this will allow elements to be demoulded much earlier, permitting early reuse of forms.

Any of the following methods is suggested depending on the extent of sophistication that is considered necessary and the type of components to be cured.

(a) By heating of the aggregates as well as water to about 70° C to 80° C before mixing the concrete and placing the same in the moulds, sufficiently high earlier strengths are developed to allow the elements to be stripped and transported.

(b) Steam curing may be done under high pressure and high temperature in an autoclave. This technique is more suited to smaller elements. For light weight concrete products when steam cured under pressure, the drying shrinkage is reduced considerably. Due to this reason, high pressure steam curing in autoclave is specified for light weight low densities ranging from 300 Kg/per M^3 to 1000 Kg./M^3.

Alternatively, steam curing can be done using low pressure steam having temperature around 80° C. This can take place under tarpaulin, hoods, chambers and in tunnels. It should be ensured that the steam has a uniform quality through out the length of the member. The precast elements shall be so stacked with sufficient clearance between each other and the [illegible] enclosure, so as to allow proper circulation of steam.

For normal heavy concretes as well as light weight concretes of higher densities, low pressure steam curing may be desirable as it does not involve using high pressures and temperatures requiring high investment in an autoclave.

(c) Low pressure saturated steam is injected into the mixer while the aggregates are being mixed. This enables the heating up of concrete to approximately 60° C. Such a concrete after it is placed in the moulds, attains high early strength.

(d) The concrete elements are kept in contact with hot air with a relative humidity of not less than 80 per cent. This method is specially useful for light weight concrete products, using porous course aggregates.

(e) The concrete elements are kept in a bath of hot water around 50°C to 80°C. The general principles of this type of curing are not much different from steam curing.

(f) The passage of current through the concrete panels generates heat through its electro resistivity and accelerates curing. In this method, the concrete is heated up by an alternating current ranging from 50 Volts for a plastic concrete and gradually increasing to 230 Volts for the set concrete. This method is normally used for massive concrete products.

(g) Consolidation by spinning is generally used in the centrifugal moulding of pipes and such units. The spinning motion removes excess water, effects consolidation and permits earlier demoulding.

(h) Vacuum treatment removes the surplus air and water from the newly placed concrete as in slabs and similar elements. A suction upto about 70 per cent of an atmosphere is applied for 20 to 30 minutes per centimetre thickness of the units.

D. Inter-relationship between manufacturers of prefabricated elements and contractors:

It is an accepted fact that the breaking up of the production process of a building between too many independent units such as the manufacturers of different building materials and components for mass production, has been the main impediment to speedy industrialisation in the developing countries. This split pattern of production made each producer concentrate only in making his own part of production, without any concern whether it fell in line with the overall building policy of the industry.

It will therefore be necessary to recognise these peculiarities and take suitable steps to modify the methods and organisation of mass production to meet the needs of the building industry.

In view of the various types of work to be coordinated in a prefabricated industrial construction, a detailed and a systematic approach to the scheduling, on the basis of a project, work study is a must for efficient and quick completion of the project. The whole building system is made up of a number of inter-related activities which shall be very closely dove-tailed to ensure a smooth flow of materials and components according to a planned time schedule and the uninterrupted progress of transport, assembly and site operations. This is a field where PERT/CPM plays an important role in analysing and arriving at a proper sequence of operation and in completion of the work in the shortest possible time. Critical Path Method is very effective management tool for the control of heavy construction projects, unmatched by any other management control technique. Both CPM and PERT are capable of moulding vast cumbersome projects into totally integrated and manageable systems of operations. The conventional planning and scheduling techniques followed for many years have severe limitations in the fact that modification of planning best suited to a changed situation is not possible. Under such conditions if prefabrication is to be success, there has to be a rigid time scheduling of all the activities involved.

A close coordination is essential between the manufacturer and the contractor in that the manufacturer plans his production to suit the time schedule in the CPM/PERT charts as furnished by the contractor to his client and supplies the components in the sequence as required at the construction site. The manufacturer should also be in a position to load the components on to the contractors transport with the least possible delay to keep up the overall programme of work. The close coordination will also involve supply of feed back information by the contractor to the manufacturer so that problems if any that arise at the site are analysed forthwith and immediate solutions arrived at. It may be a desirable practice for the manufacturer to post one of his representatives at the construction site to attend the minor hindrances as and when they arise.

Apart from the inter-relationship between the manufacturer and the contractor, it will also be necessary to maintain close coordination at all stages of the building process - designing component production and work at the construction site, for the successful implementation of the project. The various participants in the project, the designer, the architect, the producer of building materials and the builder himself shall be involved at the stage of designing itself, so that no change in specifications or methods arises subsequently. There shall also be continued consultation among the participants throughout the duration of work to iron out all problems as and when they arise and thus maintain a close control over quality and speed.

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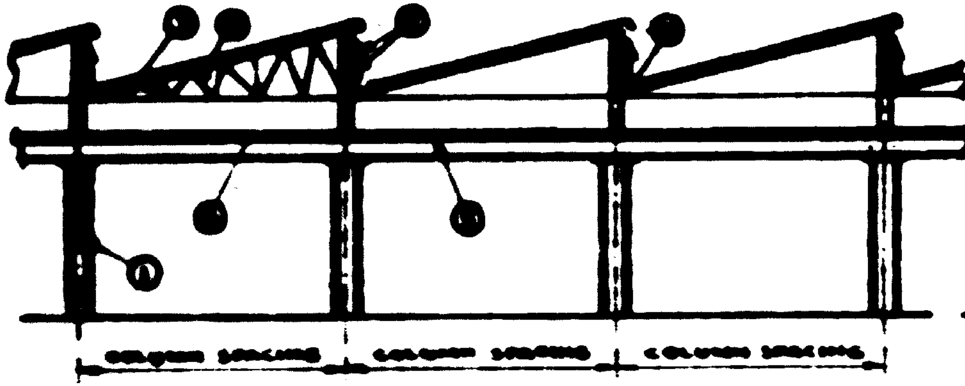

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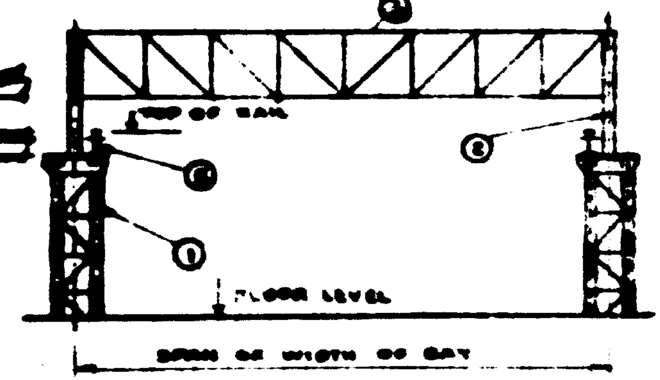

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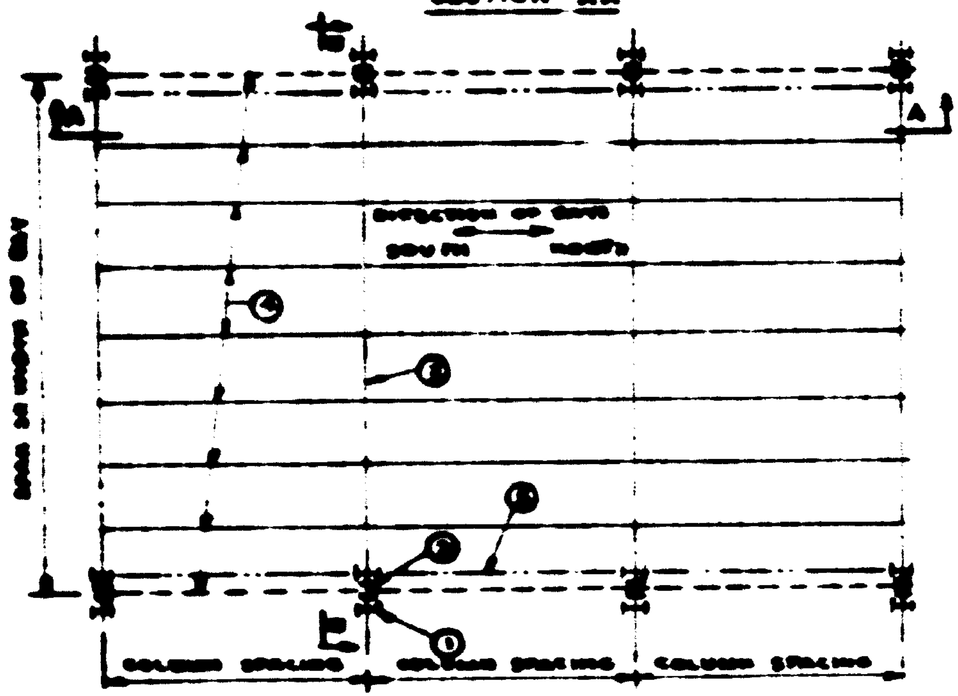

PLAN AT ROOF LEVEL

ITEM	DESCRIPTION OF PART
9	GUTTER
8	NORTH LIGHT GLAZING
7	PURLIN
6	CRANE RAIL
5	CRANE GIRDER
4	INTER TRUSSES
3	ROOF GIRDER
2	ROOF LEG
1	COLUMN/CRANE SHAFT

TYPICAL FACTORY BUILDING

DIRECTION OF BAY - NORTH - SOUTH

FIGURE - 1

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