THE ECONOMIC PRINCIPLES
OF INDUSTRIALISED SYSTEM BUILDING

A thesis submitted by
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ABSTRACT

The large volume required of all types of building, and the shortage of available skilled labour for their construction has led to the development of mechanised methods of factory production and site erection for the manufacture, assembly, and rapid construction of standardised buildings and component parts in order to achieve greater productivity, minimise site labour requirements, and reduce total construction costs.

The pre-fabrication of building components can reduce (a) material costs by standardising high outputs, and (b) site labour costs by finishing and assembling in the factory components which incorporate services and fittings, replace manual labour by machinery, and substitute semi-skilled or unskilled factory workers for skilled craftsmen on site.

Industrialised system building subordinates the costs of enclosing large spaces to a minimum of standardised components manipulated to achieve a variety of buildings with diversity of shape, height and appearance. Economic construction depends upon (a) efficient design, programming and control of all operations, (b) co-ordination of design, manufacturing and erection processes, and (c) adequate volume of demand.

Selected ranges of standardised components available on the open market and suited to the requirements of each particular building type could provide a flexible architecture of interchangeable parts of buildings with adaptability to improved space and living standards, ultimate economy pertaining when the design factor determined all the processes involved. But until (a) present diverse and unco-ordinated industrialised building techniques advance to the mere assembly of 'open' components selected from Catalogues of British Standard Component parts for all types of buildings, and (b) Government policy provides for a planned long-term sustained demand for a vast programme of new buildings geared to the building and allied manufacturing industries' capacities to undertake it, system building will tend to achieve faster construction and increased output rather than economy of cost.
when compared with techniques based on traditional methods of construction which employ more site labour and less pre-fabrication.
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The Cement and Concrete Association
The British Iron and Steel Federation
The Association of Industrialised Component Manufacturers Ltd.
The Aluminium Federation
The Hampshire County Council
The Royal Institution of British Architects
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The Institution of Civil Engineers
The British Museum

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CHAPTER 1.

REVIEW OF EXISTING SYSTEMS

1.1 General

Industrialised system building comprises methods of planning and organising the increased production and rapid assembly of standardised buildings and their component parts integrated into a complete building by co-ordinating design requirements with industrialised techniques and machinery in order to speed erection and save manpower by

(a) the factory production of standardised complete buildings

(b) the integration into a building system of (i) standardised structural steel sections, or pre-fabricated pre-cast concrete structural elements and (ii) mass produced non-structural components of various materials incorporating services or parts of services;

(c) rationalised methods of poured in-situ concrete construction for structures, and pre-fabricated components for finishings;

(d) rationalised methods of brick load-bearing structural elements, with pre-fabricated secondary elements such as front and rear timber clad infill panels, floors, and roofs handled to position and fixed by crane in one operation.

The sequences of traditional building constitute well defined boundaries as between structural work, cladding, carcassing, finishing trades, and decorations, but such divisions are less clearly defined in system building, where a structural element may contain service pipes and electrical conduits, and also be faced externally, and finished sufficiently smooth and true internally so as to require only decoration on exposed room surfaces.

Industrialised building systems are designed (a) to minimise site labour and the adverse effects of bad weather on erection operations, (b) avoid chance happenings, (c) eliminate cutting, fitting and wastage of
materials, and (d) determine the economic mass production of a minimum number of standardised components, and the methods and sequence of their rapid and simple assembly.

One example of the substantial cost reductions that can be achieved by efficient standardisation is evidenced by the savings obtained through standardising 35 ft. to 55 ft. bridge sections in 1957, which at current prices cost approximately 30 per cent less than similar non-standard sections, despite the great increase in costs that have taken place since that date.

Building systems are suited to the standardisation of (a) complete single unit buildings on individual sites, such as small factories, substations, rural schools and (b) the component parts of most types of buildings which can be standardised (e.g. dwellings, offices, factories, schools, hospitals), but they are not appropriate for industrially designed special purpose buildings, such as museums and churches.

The economic standardisation of industrially manufactured components needs to be based on a more developed application to selected building types than at present in order to provide a wider variety of design within limited component ranges. In theory, the economics of enclosing large spaces with standardised frames and cladding units is mainly influenced by the number of components designed to achieve aesthetic effect, as there is no fundamental difference between the requirements of a 4-person dwelling type or a 100-person maternity ward type hospital, whether to be built in London or Reading, except for variations in the sub-structure due to differing site conditions - the same basic standards apply within the buildings. But at present, components are being designed and manufactured in relation to an excessively large number of different types of systems for too limited a variety of building types on the basis of non-integrated and unco-ordinated conceptions. This prevents the full advantages of system building being obtained:
(a) optimum replacement of manpower by machinery;
(b) rapid speed of construction;
(c) improved standards of finish due to more controlled and accurate factory processes;
(d) reduction of temporary ancillary works such as scaffolding and shuttering;
(e) reduction of non-productive time due to bad weather, drying out wet trades, and one trade waiting on another;
(f) economic factory production costs derived from large serial runs;
(g) obviating by accuracy of manufacture time required for cleaning down, cutting and fitting, and making good;
(h) reduction of design costs;
(i) good psychological effects in the operatives due to their witnessing the rapid results of their work;
(j) centralised management of the whole building process from design stage to completion of construction works, including the co-ordination and design of modular planning, tolerances and jointing techniques; weathering details, thermal and acoustical insulation, cladding finishes, standardised structural elements based on strength and cost economy; dry finishings; mechanical, plumbing, and electrical services design and installation, crane layouts, erection sequences, the economical balance of site labour and mechanical plant, and the co-ordination of factory production and delivery sequences.

Climatic conditions and available local sources of materials strongly influences the types of building systems most economically suited to a particular country. For example:

(a) in the U.S.S.R., which has long and extended cold winter months when site work is difficult, housing systems are based on the indoor factory production of large dense pre-cast concrete panels or boxes for the rapid construction of high rise blocks of dwellings during the comparatively short summer months;

(b) in the U.S.A., domestic building is mostly based on low-rise timber construction, because machinery is cheap compared with labour, and timber is in plentiful supply and is suited to factory mass production methods for components;

(c) in Great Britain, timber construction is expensive compared with concrete and brickwork, and is mainly used for fittings and secondary elements such as in-fill cladding units, floors and roofs.

The main disadvantages of industrialised system building relate
to (a) design disciplines required for standardisation, which impose
certain restrictions on freedom of design, and (b) dependence upon adequa­
te volume of demand for economic factory component production.

1.2 'Closed' and 'Open' Systems

At present, two different categories of systems are used in Great
Britain for industrialised building; (a) 'closed' systems, and (b) 'open'
systems, a distinction which does not exist in countries with a planned
and controlled economy.

'Closed' systems are operated by sponsoring contractors on the
basis of proprietary, and often Continental designs subject to the pay­
ment of royalties for production under licence in relation to a limited
range of building types based on the sponsors' assessment of market con­
ditions, e.g. the "Ballency" and "Jesperson" systems. A severely restricted
number of structural elements, which are not interchangeable with other
systems, are individually designed and manufactured by each separate sponsor
of a "closed" system, and supplemented with standardised non-proprietary
components obtainable in the open market from outside manufacturers.

Sponsors have fairly complete control over these firms, as they
are usually specially selected to accord with their own particular expert­
ise, and are consequently fairly well placed to ensure that deliveries of
these components are geared to suit site assembly requirements in order to
avoid any delays to the cycle of erection operations.

"Open" systems are not subject to the payment of royalties, and
are based on components designed by Government Departments, Local Authorit­
ies, and other clients for buildings with similar basic requirements and
performance standards such as schools, hospitals and government office
buildings, with sufficient flexibility to comprehend other types of build­
ing. A system of standardised structural elements is dimensionally
co-ordinated with a sub-system of standard non-proprietary components which are designed and selected for assembly in different ways. Examples of such systems are:

(a) the 'Public Building Frame', designed by the Ministry of Public Building and Works in conjunction with the Cement and Concrete Association. This is an "open" system not tied to any commercial interests, which incorporates standardised profiles of pre-cast concrete framing suited to most types of multi-storey buildings. The basic elements comprise storey height columns, edge beams with end cantilevers, and a minimum of other components which can be readily assembled and jointed with simple grouted dowel connections;

(b) the Compendium of Hospital Building Assemblies, published by the Ministry of Health for the Industrialised Hospital Building Programme in order to (i) ensure that components and assemblies presented in the Compendium have the widest possible use in the Hospital, Health and Welfare programmes, (ii) save designers' time in producing a system, and (iii) eliminate separate tendering for individual projects by selecting three or four component manufacturers in national competition.

This procedure enables designers to select standardised components from the Compendium which are suited to the hospital programme, and incorporate them in schedules for pricing at the most competitive rates offered by the selected manufacturers.

(c) the "S.C.O.L.A." and "C.L.A.S.P." systems suited to schools, and developed and controlled by Consortia composed of various Educational Authorities who have pooled their potential resources and building programmes in order to obtain a sufficient volume of demand for economic industrialised production. These types of systems are complicated and provide contractors with less control over site deliveries of manufactured components.

Some component manufacturers have developed their projects to form essential features of certain 'open' systems, e.g. for the National Building Frame system. And the liaison between main contractor and component manufacturer can be differently arranged in both 'open' and 'closed' systems. For the 'A.75' system for dwellings is based on a central co-ordinating group which arranges for the delivery of materials and components for site erection by a main contractor who is not made responsible for their specification and ordering.
1.3 Methods of System Production

1.3.1 Standardised complete buildings.

The manufacture of complete buildings by flow-line production methods is best suited to small unit buildings with similar requirements on individual sites. Such buildings can be economic in cost, but generally lack flexibility of design, and aesthetic value, and are unadaptable to social changes. One current attempt to mass produce low cost standardised 'semi-permanent' dwellings with light new materials is based on glass reinforced polyester units lined with thermoplastic, with a life of about 30 years. The units are of standardised exterior shape for connection on all sides, top and bottom, and comprise self-contained living cells which can be grouped together to form any type of house from a single storey terrace design to a two-storey family dwelling with spiral staircase and courtyard. The minimum plan layout consists of three separate units, which contain (a) an entrance hall with bathroom, (b) a kitchen/dining unit, and (c) a living/sleeping unit, which cost approximately £300, and appear most unsightly.

In the U.S.A., ranges of standardised complete dwellings of timber frame construction are listed in catalogues and mass produced in vast quantities each year for delivery in packages and rapid erection on prepared foundations. Some factories producing these dwellings are based on automated methods, and provide a variety of 12 designs for low cost dwellings with areas ranging from 1100 to 3800 sq. ft.

In addition to this type of housing, in the U.S.A. (a) approximately 220,000 new "mobile" homes are pre-fabricated each year, and delivered to sites complete with all fixtures and fittings, which include refrigerators, washing machines, and furniture.

Site installation consists of manoeuvring the unit onto prepared foundations, and connecting up services in a matter of hours.
(b) Complete rooms are pre-fabricated for insertion into existing blocks of dwellings to improve living standards in New York slum areas. Factory produced kitchen and bathroom units are hoisted by crane and inserted one on top of the other through prepared openings formed in existing roofs and floors by a special demolition system. Each unit comprises a self-contained heating plant, kitchen and bathroom; with a refrigerator, sink, gas stove, fitted cupboard, bath, shower, toilet and medicine chest. The time required to install one unit is 48 hours, i.e. six days of 8 working hours each. Such construction would normally take five or six months with traditional methods.

In Great Britain, standardised complete bungalows and other building types are mass produced at low cost, e.g. standard factory made single storey steel frame buildings of various types are designed on the basis of plastic theory, and programmed on a computer which can produce the optimum economic design to suit user requirements within one day. Portal frames ranging from 30 ft. to 150 ft. span and 16 ft. in height are mass produced in 15 ft. and 20 ft. lengths for delivery to site and completion of the structure within two weeks.

1.3.2. Standardised structural elements combined with non-structural components.

(a) Steel structural elements obtained from outside manufacturers

Most systems for multi-storey buildings are based on reinforced concrete structural elements or rationalised composite steel and concrete construction rather than on steel frame skeletons, for reasons of fire protection and economy, but numerous steel based systems have been designed for schools, factories, low-rise dwellings, and other simpler building types. These systems incorporate light steel structural elements, and cladding units of timber, sheet metal, or various other materials:

(i) the "MAES" system for dwellings, based on light steel foam-filled panels forming load-bearing curtain cavity walls, and shuttered steel frames with poured in-situ concrete casings.
(ii) the "PREFRAME" system for hospital construction, based on standard steel sections for columns, and standardised joist, castellated, and open-web lattice beams.

(iii) numerous systems suited to two-storey dwelling types, based on light steel joist or tubular sections, with sheet metal or other type of cladding.

(iv) the "S.C.O.L.A." system for schools up to four storeys in height, based on a light steel frame with lattice type beams, 3 ft. 4 in. planning Grid, and a range of components (e.g. infill panels, fixed and open glazing, partitions) for which bulk purchase tenders can be obtained for Consortia requirements.

(v) the "N.E.N.K." system developed by the Ministry of Public Building and Works for all types of services buildings, based on a 4 ft. x 4 ft. grid, with 2\(\frac{3}{4}\)" and 4" square steel columns, 2 ft. deep double large flat grid space decks formed from 4 ft. x 4 ft. (on plan) pyramids constructed with mild steel angles, and steel rod or tube diagonals. This excessively complicated system is now being superseded by the Ministry's pre-cast concrete frame or panel systems.

(b) Pre-cast concrete structural elements

Pre-cast concrete structural elements for "closed" panel, frame, or composite pre-cast and poured in-situ concrete systems are manufactured to suit individual sponsors' required production in their own factories, which are either (a) installed away from the site in permanent factories for vast continuous outputs of units to serve many different projects, or else (b) set up on individual sites as temporary factories for the limited requirements of a particular project, and subsequently dismantled for use on other sites.

The elements required for "open" systems may be similarly produced, or else obtained by contractors from outside specialist manufacturers of pre-cast concrete work.
(c) **Panel Systems**

Pre-cast concrete panel systems are used extensively in Great Britain, Europe, the U.S.S.R., Japan and elsewhere abroad for dwellings, and comprise wall and floor panel units of one or two dimensions with jointed connections for box-shell construction. A minimum number of structural elements are standardised for economic production and simple, rapid site erection. Factory production of the elements achieves (a) close control of the concrete to obtain improvement in quality, (b) savings in materials costs, (c) satisfactory finishes to exposed concrete surfaces and (d) incorporation of service pipes and electrical conduits in the moulds. Maturing of the concrete units takes place before they are built into the structure, thus eliminating shrinkage of fresh concrete.

Panel systems require an adequate volume of sustained demand for economic factory production, but are capable of achieving outputs of units for 1800 dwellings per annum, with a speed of site erection averaging nine hours crane time and 120 man hours per dwelling.

(d) **Frame Systems**

Frame systems permit extensive unification of the structural frame on the basis of a modular system suited to building types with relatively large areas and spans. Their main disadvantage is that too many other structural elements cannot be so readily standardised for economic factory production and co-ordinated into a complete system. As a consequence, floors, staircases and stability walls are often constructed with poured in-situ concrete.

Some systems suited to high-rise structures incorporate an increased standardisation and co-ordination of structural elements, for example: by standardising "T" shape spine frames and "L" shape traverse frames stabilised by pre-cast concrete floor slabs and perimeter beams, with panel units for party walls and gable ends to complete the basic structure.
In the U.S.A., pre-stressed pre-cast concrete structural elements have been developed to provide very large open spans. Units of 110 lbs. per cu. ft. density with strength of 5000 lbs. per sq. in. at 28 days are cast with large ducts for service pipes and pre-finished smooth on top surfaces and soffits to form wall, floor and roof elements up to 100 ft. long x 8 ft. wide and 20, 21 and 22 ins. deep. Permissible loading on floor units varies from 62 lbs. to 108 lbs. per sq. ft. for spans up to 70 ft., and 283 to 400 lbs. per sq. ft. for spans up to 40 ft.

The pre-cast concrete structure of a two-storey school in California with 59,000 sq. ft. of classroom area incorporating such units was recently constructed on prepared foundations in 15 days at a cost of £4.10.0 per sq. ft.

(e) Composite pre-cast and poured in-situ Concrete Systems

Systems based on the factory production of load-bearing pre-cast concrete wall units and poured in situ concrete floor construction for dwellings compensate tolerances in the erection of the concrete units, and obviate the complex jointing of fully pre-cast concrete systems.

Site factory production of annual outputs of units for 1500 dwellings can be achieved for rapid erection by comparatively few operatives, e.g. a tower block with 48 dwellings can be erected in 40 working days of 9 3/4 hours each with one erection crane and associated teams of 22 men.

1.3.3. Rationalised methods of poured in-situ concrete construction

Systems utilising these methods are based on the sponsoring contractors' designs of pre-fabricated shuttering (or proprietary steel shutters), steel reinforcement, methods of accelerated concrete curing, and available sources of aggregates.

For limited volumes of production insufficient to justify the economic installation of a site factory for manufacturing pre-cast concrete units, carefully designed systems based on poured in-situ concrete construction can approach the productivity, speed, and accuracy of pre-cast concrete panel construction. But they are unsuited to vast-scale production due to the
larger number of site man hours required, and the limitations of batching plant and equipment.

Speed of construction is obtained by (a) pre-fabricating standardised shutter elements of steel or timber for handling by cranes in large accurate units to form both wall and floor shutters, and achieve concrete surfaces capable of spray painting or wall papering with a minimum of making good;

(b) Accelerating concrete curing, and reducing the striking time of shutters to enable floors slabs poured during an afternoon to be self-supporting the following morning. Cracking in the slabs can be reduced by introducing limestone or light-weight aggregates, such as pulverised fuel ash;

(c) Designing reinforcing units of maximum size for transportation and handling by cranes; the units can be wired together with electrical and other services at ground level and hoisted to position in one operation.

Site labour can be reduced by pre-fabricating partitions and cladding panels which incorporate plumbing and electrical services, and help to achieve accuracy of the structure.

1.3.4. Rationalised methods of brick construction

These methods are used mainly for dwellings and include:

(a) Construction based on pre-fabricated storey height brick panels and mechanised methods of handling bricks for low-rise housing.

(b) Traditional brick load bearing structural elements dimensionally co-ordinated to brick sizes so that bricklayers can complete their work independently of other operations, secondary elements (e.g. infill panels, floors and roofs) being handled to position and fixed complete in one operation by crane.

When combined with a suitable mechanical handling system for off-loading palletised brick deliveries, conveyors for transporting the pallets
to required positions, and platform hoists to speed the handling of bricks to higher levels, systems based on these methods can achieve high productivity with comparatively low site manhours.

(c) Patented methods of pre-casting standard bricks into 12 ft. x 5 ft. (maximum) units with a similar potential as pre-cast concrete panel construction, and suited to any building type up to 13 storeys in height.

External wall panels are pre-fabricated in the factory with a brick outer skin, and light-weight inner concrete skin which varies in thickness according to building heights. The brick panels can also be used for cladding steel or concrete frames.

The inner skins and internal load-bearing walls are based on similar size panels of gravel, no-fines, or light-weight aggregate concrete, with provision made at the time of casting for ducts, switch points, fixings, and holes.

Floors and roofs are of standard concrete, steel or timber construction. One crane and associated team, including the crane driver, can erect the panel units to form the equivalent of a two-storey dwelling in one day.

1.4. Component Production

1.4.1. General

Traditional building is an assembly industry which is already industrialised to the extent that many conventional materials (e.g. glass, bricks, cement, steel, sanitary ware) and building components (e.g. doors, windows) are produced in factories to satisfy a vast and continuous volume of demand, which tends to increase productivity and reduce costs due to specialisation of production and long series runs. But for greater economy, the separate item production related to traditional building methods for a variety of uniquely designed parts should be replaced gradually by the efficient use of suitable mass production methods in factories to achieve vast outputs of selected, standardised, dimensionally co-ordinated and interchangeable
components suited to each particular building type.

Optimum standardisation is essential so that component manufacturers may obtain larger series runs to balance turnover against capital, minimise time taken in changing over machines, reduce production costs by the bulk purchase of materials, and attain better quality production of fewer varieties of component types with fast operating cycles related to a large and sustained volume of demand. Merely by standardising storey heights, ranges of standardised units for staircases, refuse chutes, wall units and similar type components could be greatly extended.

Modern industrial production methods normally operate with short cycle times and/or continuously in shift operations to achieve high serial runs, the production line moving from one station to the next with varying frequency in time. Such methods involve high capital and operating costs, and are only suited to a limited variety of components with a large and maintained volume of demand. The completely automated production of simple components such as baths, or doors, standardised to comparatively few types and sizes would achieve an enormous increase of productivity. Limited to five sizes and types, annual outputs of approximately half a million severely standardised units could be obtained, so great is the increase within a given production method with the same kind of machine.

But such a limited variety and vast output is not suited to many types of components. Even a comparatively simple type such as a flush door would require standardising runs at, say, 3 ft. widths, and eliminating w.c. doors 2 ft. 6 ins. wide for completely automated productions, as any complexity of size and type obviates the economic use of the method. Most types of components are better suited to less sophisticated assembly-line and semi-automated methods for effective production and economy.

1.4.2. Factory production of pre-cast concrete structural elements

(a) Permanent off-site factory production

This type of factory production is based on mechanised handling
methods and semi-automated production line principles under controlled conditions capable of a high output ratio of accurately pre-finished units. Economy largely depends on the maintenance of an adequate and sustained volume of demand, often unknown, in order to justify the highly intensive capitalisation required for production. Some sponsors have become bankrupt recently through their failure to secure a sufficient continuity of orders for economic production.

Off-site production replaces labour costs by capital costs, minimises all forms of wastage by regular production and control, and avoids the "learning curve" and falling off in efficiency that may arise each time a temporary site factory is installed and dismantled. High volume production of standardised modular co-ordinated components can be achieved with minimum variation and maximum interchangeability to satisfy a high, constant and long-term volume of demand, e.g. 2500 dwellings per annum with two shift working.

The main disadvantages are:

(a) necessity for long production series geared to a vast predetermined programme, as insufficient volume of continuous demand results in decreased utilisation of expensive machinery and plant, with consequent increase of production costs,

(b) high costs of factory overheads,

(c) high costs of transporting large and cumbersome units to distant sites, with the difficulty of accurately predicting delivery times in congested traffic areas,

(d) double handling in transport, with consequent increased risk of damaging units and delaying the erection operations.

(b) Temporary site factory production

Transportation problems around city areas, combined with uncertainty of adequately sustained volume of demand in relation to capital expenditure
and high running costs, have led some sponsors to produce their pre-cast concrete structural elements in temporary factories installed on sites to satisfy the demands of individual projects where adequate space is available. The main advantages are:

(a) Ease of setting up, dismantling, and transferring the factory to other sites without additional overheads,

(b) Capital costs are within contractors' normal financial resources, and relate to a known volume of demand. Moulds can be acquired to suit individual projects, timber moulds for small outputs, and steel moulds if there is continuity of production for other sites. Capital investments can be amortised within three years on the basis of outputs of 10,000 cu. ft. of concrete units per week,

(c) Any number of production lines can be set up as suited to a particular project, whereas with off-site production, outputs are limited to the same standardised units,

(d) Factory production and site assembly can be integrated under one control to co-ordinate output with assembly requirements, reduce double handling and transportation costs, and minimise delays to the erection cycle due to late deliveries, or damage to units in transit.

Successful construction is based on uncomplicated component design to reduce site jointing, highly pre-finished units geared to site cranage, tolerances which facilitate erection, and the maintenance of production targets, to balance stock piling with demand.

1.5 Site Assembly and Erection

In addition to economic design and factory production, the success of an industrialised building system also depends upon effective programming, timing, and the control of all activities in order to integrate labour, mechanical plant facilities, and phased supplies of materials and components with transportation and erection requirements to ensure a smooth flow in the movement and cycle of all site operations.
Detailed day-to-day planning and site supervision is essential to achieve co-ordination of the overall programming and continuity of the erection cycle. Individual items of mechanical plant should be positioned for inter-activity (e.g. concrete mixer-cranage), and movement of materials controlled to maintain continuous operation at maximum capacity, with regular servicing of all plant and equipment to minimise repairs and breakdowns. Plant should be served by site power circuits and pick-up points which increase mobility, and extend the use of portable power tools. All site activities should be timed and planned to assist one another, and the overall programme should relate the timed construction sequences to relevant unloading areas, labour, materials, components, plant and transportation facilities.

The advantages of industrialised system building can only be realised when good management obtains in all its aspects. Such management, which depends upon economic environment and organisational structure, is decisive for rapid and economic construction, as mechanised methods of the pre-fabrication and handling of components are highly sensitive to delays and interference of productivity.

1.6 Classification of existing Systems

1.6.1. General

Building systems may be classified according to:

(a) type of sponsorship,

(b) method of production,

(c) degree of pre-fabrication and site mechanisation utilised,

(d) structural type, and the effects of building height on design (i.e. systems suited to low- medium- and high-rise buildings),

(e) materials, and weight and methods of assembling structural elements,

(f) application to different building types,

(g) flexibility of design,

and according to their varying permutations.

In general, (i) load-bearing wall construction is more
economically suited to building types with small spans, such as dwellings, and frame construction to other types,

(ii) systems for buildings up to five storeys in height are more economically designed as column and beam structures, with cladding panels and non-structural components selected from the wide variety of components available on the open market to provide flexibility of design and appearance,

(iii) structures over five storeys in height, where vertical loading increases, and supporting columns become larger, are suited to panel construction, which takes these heavier loads over a larger area, although requiring additional structural stability against wind forces by bracing with cross walls,

(iv) length variations with prismatic components such as beams and columns are less costly than with panel units,

(v) wing panel units cast integrally with columns at one or both ends help to stabilise loading,

(vi) the use of different materials for walls, floors and facades increases costs; the fewer different kinds of materials utilised for structural elements, the greater the saving in costs.

The most significant differences between different building systems relate to their structural types, which include:
1.6.2. Conventional load-bearing cross wall construction of concrete, brickwork, concrete blocks, or timber framing; with concrete, timber or steel framed floors and roofs; and cladding of pre-cast concrete, brickwork, pre-fabricated timber infill panels with glazed windows and boarded finish, or curtain walling of aluminium, steel, or other materials.

Timber infill panels with insulation and a variety of finishes are lighter and quicker to erect than faced and insulated pre-cast concrete facade units, but are not so durable, and require more maintenance. The timber frames can involve (a) difficulties in erection due to fitting the more accurately manufactured frame units into an in-situ constructed frame with coarse tolerances, and (b) high maintenance costs due to the timber shrinking and twisting under climatic conditions.

Curtain walling tends to be used less frequently than formerly due to problems of water penetration, heat insulation, jointing, aesthetics, and the difficulty of obtaining site tolerances which enable factory precision made units to be fixed easily.

1.6.3. Storey height plank construction in 16 ins. to 24 ins. widths of aerated pre-cast concrete units which form load bearing walls, floors and roofs for a variety of low-rise dwelling types.

1.6.4. Framed Structures of steel, concrete, or timber beams and columns able to support all live and dead loads; with pre-fabricated floors and roofs; and cladding of conventional materials manufactured on site, or pre-fabricated by outside forms. This type of system is suited to isolated low and medium-rise building types with large room sizes and comparatively few partition walls such as schools, fire stations and factories.

1.6.5. Load-bearing panels for the box-shell construction of low, medium and high-rise dwellings formed with medium weight (2½ tons) or heavy weight (6 tons and over) precast concrete panels for parts of, or full room size walls and floor units based on pin jointed box-shell construction, and designed so that all walls under wind loading remain in compression throughout their length, and have no continuity of bending moment through the joints. Panel systems
can be modified to form composite pre-cast and poured in-situ concrete structures, with (a) in-situ concrete staircase walls or lift shafts which provide rigidity to the structure, and (b) cladding formed with timber, brick, pre-stressed skins, or other materials.

1.6.6. **Composite systems** with steel or concrete frames; load bearing pre-cast or in-situ concrete external walls, floors and cross walls; and cladding units pre-fabricated of pre-cast concrete, brickwork, sheet metal, aluminium, or other materials.

1.6.7. **In-Situ Concrete Systems** based on (a) precision made steel shuttering for pouring concrete in rectilinear tunnel sections of room height and width, the shuttering being heated to accelerate concrete curing and enable striking operations to proceed within approximately 13 hours,

(b) pre-fabricated timber moulds which climb up the building from floor to floor, and are struck after the top floor has been poured, and

(c) other types of pre-fabricated and standardised shuttering.

1.6.8. **Box construction of monolithic or composite three-dimensional units** pre-fabricated with various degrees of finish and equipment to form completed dwellings:

(a) Monolithic room-size boxes forming bathroom or kitchen units of concrete or plastics integrated with plumbing and electrical services, doors, windows and all fittings, and decorated and completed in the factory. A small number of room elements (three or four maximum) restricts design flexibility, as the cost of more rooms greatly increases production costs.

The concrete elements are heavy (12\(\frac{1}{2}\) tons and over), but provide good insulation and finish, and satisfactory rigidity to stabilise the building; reduce site labour requirements, and speed erection. Manufacture involves a comparatively small production series, so that a very high volume of demand is required to justify the high capital investment needed for economic factory production.

(b) Similar boxes, but assembled from panels of concrete, timber or plastics.
Properly selected building box systems enable a relatively large choice of bigger and more pre-finished components to be assembled in smaller series from an assortment of relatively fewer unified simple products mass produced in large series, but require heavy and costly mechanised equipment for rapid site erection.
CHAPTER 2

PRINCIPLES OF ECONOMIC ARCHITECTURAL DESIGN

2.1 General

The design of an industrialised building system should aim to combine aesthetic value and satisfaction of user requirements with economy of materials, production methods, and erection techniques. The fundamental similarities of each building type can be comprehended by standardising plan forms and structural components to provide an economic basis for a variety of appearance by utilising different materials for cladding and finishings of facades. Economy of construction depends upon the standardisation of components suited to the simple assembly of standardised building types.

Economic design should avoid over-specification, and take into account methods of factory production in order to:

(a) limit the number of components and their essential variations per building type in order to minimise alterations to moulds, shuttering, and standardised methods of factory production;

(b) reduce industrial operations by sizing units as large as possible in order to minimise handling, cutting and fitting, jointing, and control accuracy of component dimensions within required tolerances;

(c) incorporate units in a more pre-finished state, combined with services and other components in order to eliminate wet trades, reduce the installation of services on site, and speed erection operations by carefully planned and controlled production processes geared to site assembly requirements;

(d) enable all site plant and equipment to be operated for continuous periods at full capacity, and simplify erection operations by (1) minimising variations in foundation depths and widths in order to
reduce changes in mechanical excavating equipment, (2) maintaining finished floor levels at a constant and uniform level, any necessary variations being taken up where possible in thickness of screeds for pavings, (3) modular dimensioning and maximum standardisation of units related to crane capacity, (4) minimising breaks and returns in walls by keeping straight runs to simplify shuttering, brickwork, etc., and excavations for foundations.

In order to avoid non-productive time caused by one trade waiting for another to finish, or by more than one team working on one operation at the same time, "flow-line" site production can be aimed at during design by (a) designing brick walls as storey height panels without openings, (b) doors and windows as storey height units, in order to confine the work of finishing trades to plain surfaces, (c) detailing to avoid division of trades and differences of materials, thereby minimising jointing, and obtaining optimum utilisation of mechanical plant.

Other general factors which influence the economics of design relate to:

(a) the percentage of public circulation space to total floor area;
(b) the ratio of external wall in ft. run to total area enclosed in square feet;
(c) the ratio of load-bearing walls to non-load bearing cladding;
(d) the ratios of wall perimeter to height,
   floor slabs to cross walls,
   cross walls to cladding,
   cladding to floor slabs;
(e) the percentage of internal circulation area to total area within the building;
(f) the total ft. run of non-load bearing partitions;
(g) the number of different plan types required;
(h) the location and nature of the site, and its environment;
(i) performance, specifications, materials and required finishes;
(j) required indoor climate;
(k) the effects on appearance of colour, shape, height, vertical or horizontal stream lining, curtain walling or open frame;
(l) the effects on design of design codes, building regulations, local byelaws, and any requirements of the Fine Arts Commission;
(m) density ratios in relation to building heights;
(n) the requisite structural type;
(o) dimensional disciplines determining the joints and tolerances of components;
(p) the use and life of the building;
(q) maintenance requirements;
(r) any future planning requirements.

2.2 Effects of Site Conditions on Design

The location and nature of the site influences design and affects costs in several ways. For example:

(a) Buildings in remote areas -
   (1) May not be within reach of adequate power for working tower cranes, and involve additional costs of temporary cables and sub-stations.
   (2) May necessitate substantial increased costs for the travelling time and transport of operatives to and from the site, or the provision of a hutted camp for their accommodation.
   (3) May require long haulage distances of materials, such as ballast and hardcore, etc., thereby substantially increasing costs of these materials delivered to site.

(b) Buildings in crowded city areas -
   (1) May have deliveries of materials and components held up in traffic jams, thereby seriously delaying erection operations.
   (2) Be subject to police regulations restricting the off-loading
of materials to within certain hours, thereby necessitating the extra cost of overtime work.

(3) The size of the site may restrict manoeuvrability of mechanical plant, or the installation of a site factory and stacking yard.

(4) May be subjected to the costs of under-pinning adjoining buildings, or necessitate special requirements for protecting the public.

(c) Few sites are level, and at best usually require the increased costs of stepped foundations, or variations in finished floor levels.

(d) The nature of the strata and amount of hard material to be excavated greatly affects the costs of excavations. The softness of the ground determines the type of planking and strutting required, as well as methods of stacking bricks and storing bulk materials.

(e) When ground water level is near the surface of the site, pumping operations may be continually involved during excavations. A wet site may necessitate raising temporary sheds and offices on brick bases, and involve more costly temporary roads for lorries making deliveries to the site.

(f) If the site has no load bearing strata near the surface, costly piling or deep foundations may be required.

(g) A site near the sea may require additional tarpaulins to protect men working on scaffolding from strong winds, which will slow up operations by restricting crane working.

(h) If the site is located near schools or large housing estates, additional costs may be required for a more expensive type of hoarding, or the provision of warning patrols for additional site protection against wilful damage.
The layout of buildings should be considered in relation to the environmental area of the site as a whole, and be determined by (a) ground contours in relation to earthworks, and (b) crane layouts, as well as aesthetics. It is more economical to plan so that one crane moving on rails can serve several buildings, instead of using two tower cranes, or one crane that has to be dismantled and set up again in other positions.

All spaces around and between buildings should be designed to fit into the environment planned so that more costly elements capable of resisting intensive use are designed to reduce wear on less durable areas.

Extensive site developments can cause problems of water conservation by altering the surface porosity of the soil. One successful concept for a pedestrian town has been planned on a vast site in the form of a huge mound, with an office and shopping centre located at the crest, and low- and medium-rise dwellings grouped around on the sloping sides in order to minimise cut and fill, and walking distances from the town's periphery to its centre. All traffic proceeds at natural ground level to central car parks, from which pedestrian access to the higher ground floor level of the shopping centre is provided by means of escalators.
2.3 Plan Shape and Function of Building

The use of a building influences its plan shape, floor areas, and arrangement of space and services. Building types tend to produce their own especial characteristics, and one plan form will tend to utilise ground area more effectively than another.

In general, a simple open design which harmonises architectural and structural requirements (a) provides uninterrupted internal spaces, (b) minimises planning restrictions, (c) eliminates unessential internal columns, and (d) reduces complicated connections. Where site conditions permit, the most economical plan form for any building type will be based normally on a rectangular shape and modular planning grid, with maximum planning at each floor level to minimise double handling, reduce crane traverses, provide the maximum use of shuttering, and afford direct access to the various parts of the building.

Some building types (e.g. offices) achieve planning economy by limiting floor spans to reduce beam sizes according to a column grid which achieves the maximum flexible planning within the building.

Where budget limits permit, the provision of central heating in low cost dwellings conserves space by enabling (a) the front door and staircase to lead straight into the living room, and (b) bedrooms to be used during the daytime as "bed-sitting" rooms. But as comparatively small changes of floor areas have little effect on areas of walls and roofs and quantities of materials and labour for structural frames, floor areas should not be too restricted, because future conversions to improved living standards tend to be more difficult when space is tight.

The cost of dwellings are directly related to areas planned as bathrooms, kitchens and toilets, as these rooms have the highest costs per sq. ft. of floor space. Consequently, dwellings of similar finish and construction cost more per sq. ft. of total dwelling space the smaller the floor plan.

The shape of factories is influenced by the amount of co-ordination
of manufacturing processes, size and weight of machinery for production, and type of product to be manufactured.

The plan shape of schools depends on (a) educational methods and type of instruction to be provided, and (b) on lighting, as increase of building depth may necessitate taller windows and higher rooms which reduce the enclosing wall perimeters or uncomplicated roofing in order to obtain adequate natural daylight.

The exteriors of building types such as offices, which (a) require an easily maintained facade without excessive deterioration, and (b) incorporate large areas of glass to lighten deep rooms, can be economically designed with "mullion construction" by means of which window mullions are load-bearing and coincide with the locations of partitions. Greater flexibility of their use can be obtained with open planning when the weight of partitions is treated as part of the superimposed loading. Areas with office equipment and stores require few partitions, and can be designed of light construction in order to increase the allocation of loading for stores and equipment. Areas planned as small private offices can have the floor loading reduced to 50 lbs. per sq. ft. to leave available 50 lbs. per sq. ft. for partitions of heavy sound-resisting construction.

2.4 Dimensional Disciplines Determining Joints and Tolerances

Industrial techniques and building construction are related by co-ordinating component sizes with a basic module, specifying a system of tolerances, and establishing a grid to enable a complex variety of units for different building types to be assembled dry with maximum flexibility of design.

There is no national module, but work on modular co-ordination is proceeding in the British Standards Institute, the International Modular Group, and in meetings organised by E.E.C. in the attempt to apply the standardisation of components to building types other than housing, for construction with acceptable standard ranges and conventions for jointing and a realistic understanding of tolerances.
At present, the various systems are based on different grids and modules. Some pre-cast concrete panel systems for high rise dwellings are based on modules which determine the size of moulds in relation to craneage; and other types of systems use other grids.

All modular techniques are limited by joints and tolerances due to the degree of accuracy achieved in:

(a) setting out the building;
(b) manufacturing processes;
(c) varying thicknesses of components as determined by physical and chemical properties.

A typical example of a commonly used grid, the "tartan grid", is based on a constant wall thickness, 1 ft. planning grid lines, and a 4 ins. internal grid:

<table>
<thead>
<tr>
<th>1'0&quot;</th>
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<th>1'0&quot;</th>
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<tr>
<td>-7 wall</td>
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TARTAN GRID with 1'0" Planning Grid
4" component grid, and 7" wall thickness
So long as the tolerances specified relate to the design of the building, and are compatible with production processes and methods of erection and completion, unavoidable inaccuracies can be accommodated by design, and will not obstruct the success of the system. Thus irregularities up to 1 in. on the shells of rationalised in situ concrete systems are masked by external rendering and internal wall board linings, and in systems based on the "tartan" grid, by make-up pieces. The following diagram indicates how tolerances in the assembly of partition components are taken up:
Diagram indicating method of determining tolerances in partition components.
The amount of information required to be shown on standardised drawings for building systems can be substantially reduced by providing:

(a) Site key plan.
(b) Location drawings.
(c) Assembly drawings which detail the methods and sequence of assembly, and all necessary holes and fixings required to ensure safety, ease of rapid erection, and adjustment of joints between units.
(d) Schedules of components.
(e) Separate detail drawings for each component type or unit.

These types of drawings can effect savings in design costs, because once a system has been detailed, all further buildings can be produced from the existing design sources.

2.5 Pre-cast Concrete Panel Systems for Housing

Because of the current urgent demand for more dwellings capable of rapid construction, the majority of large housing development projects have been based on systems utilising factory produced pre-cast concrete panel units for box-shell construction. Such systems require early co-operation between the architect and structural engineer in order to determine:

(a) the size, number and maximum weight of units, which influence
    (i) the number and type of vehicles required for transport from off-site factories to the site, or the number and type of cranes required for handling and stacking units produced in factories on site, (ii) the size, number and type of cranes required for the hoisting and erection of units, and (iii) the size and composition of teams for site erection cycle;
(b) the detailing of joints and pre-fabricated cages of reinforcement for pre-cast units;
(c) the maximum permissible stresses on components during erection, as those involved in stacking and lifting pre-cast units may be
greater than the stresses exercised by the normal building loads. Provision must be made in the components for extra reinforcement where necessary (e.g. columns, which are lifted on end need extra stirrups at lifting sockets; wall units with door openings require struts or ties to prevent the beam over from breaking);

(d) the closeness of tolerances, which affect manufacturing costs, as well as the costs of steel moulds for pre-cast units. Extreme care is required for the determination of tolerances, e.g. \( \frac{3}{8} \) in. oversize on a unit 10 ft. wide may reduce a joint width from \( \frac{3}{8} \) in. to \( \frac{1}{4} \) in.;

(e) a programme of site erection, which should minimise double handling of units delivered to site wherever possible by their being lifted direct from lorries to required positions.

The design of such buildings should take into account safety aspects of the erection processes, especially where no external scaffolding will be required. By utilising a minimum number of pre-cast structural units, an open plan can provide an economic basis for the mass production of units for single developments of limited size (e.g. 300 dwellings) without the need for very costly factory plant and equipment to achieve simple site erection. Where the design permits floors to be supported at only external bearings, site erection is further simplified.

2.6 Density ratio and height of building

Density ratios influence the construction costs of dwellings:

(a) the higher the density ratio per acre, the greater the cost per dwelling,

(b) the fewer persons per dwelling, the greater the cost per person in a dwelling, and

(c) the more persons per dwelling, the lower the cost per person, but the greater the cost per dwelling.
Subject to land values and site conditions, it is generally more economical to build at the maximum density ratio with low-rise blocks:

(a) 2-storey buildings for density ratios up to 80/90 persons per acre,
(b) 3 to 5-storey buildings designed without passenger lifts (where sloping site conditions permit), for density ratios up to 120 persons per acre.

With higher density ratios, it is usually more economical to build 15-storey or taller buildings.

The effects on total construction costs of tall blocks as compared with low- and medium-rise buildings is complex, and relate to:

(a) effective design
(b) type of structure and foundations, and
(c) volume of demand.

High-rise construction tends to increase work to structural frames, suspended floors, ratios of wall/floor areas, circulation areas with staircase and passenger lifts, and foundations. But in some conditions, the costs of foundations for high-rise point blocks can be substantially reduced by utilising large diameter bored piles without pile caps, which compare favourably with the foundation costs of low-rise dwellings, as these require a relatively large area of pile caps and ground beams for a small load (e.g. approximate cost of load carried by tower block 17/6d per ton compared with 25s. to 30s. per ton of load for low-rise dwellings).

Tall dwellings have greatly reduced roof areas, and can achieve economies for gas, water, and electricity services in point blocks over 30 storeys high, as they serve the same number of dwellings when planned in low-rise blocks, but with less runs of pipework and conduit. However, these savings may be substantially reduced by the need for costly pumping installations.

In general, blocks of multi-storey dwellings up to about 10 storeys
high cost more per dwelling than those from 10 to 20 storeys high because:

(a) the expensive tower cranes used for handling materials and components to position cannot operate so economically (e.g. the time taken for hoisting units to the higher floors of taller buildings can be reduced by quickening the speed of the crane's lift),

(b) increased labour output attainable by the effects of repetitive operations is less, as there are fewer floors in relation to the learning time required for the various tasks,

(c) the cost of lift installations, required in buildings over four storeys high, cannot be so economically apportioned to each dwelling. The cost of lift installations for blocks over 20 storeys high are substantially increased due to the need for operating high speed lifts;

(d) one roof does not cover so many dwellings;

(e) less uses can be obtained from the shuttering of in-situ concrete standardised concrete beams and slabs.

2.7 Special problems of tall buildings

Tall buildings present several problems which do not affect low- and medium-rise buildings:

(a) Structural movement. High buildings which sway in the wind can cause joints to open and shut and enable water to percolate into the building. All such joints, sealing materials and methods of application should be detailed to form an integrated and watertight system early in design stage.

(b) Climatic Conditions. Wind velocities increase with height and can (i) delay cranes working, (ii) cause problems of oscillation, rain penetration, heat loss, air filtration, and natural air ventilation, and (iii) impair chimney efficiency.

The rain catch on roofs of tall buildings is much greater than on
lower facades, and requires adequately sized outlets and rainwater pipes.

(c) **Noise and vibration.** The control and virtual elimination of noise from occupants inside buildings, and noise and vibration from traffic and aircraft outside is becoming a matter of increasing importance.

One effective method of insulating tall buildings from underground railway and road traffic is based on synthetic and natural rubber steel reinforced pads pre-fabricated with alternate layers of rubber and fibrous material placed underneath the foundations, at a cost of approximately one per cent of total construction costs.

### 2.8 Indoor Climate

Condensation caused by the sudden cooling of atmospheric water vapour inside a building, or by interstitial condensation within its structural elements can be avoided by:

(a) carefully designing walls, roofs and ground floors to provide a high resistance to thermal transmittance with a low 'U'-value,

(b) maintaining a background of warmth throughout the building, with some form of mechanical ventilation to assist airflow, and

(c) selecting materials for wall and ceiling finishings which provide an adequate degree of permeability to avoid cold bridges.

Considerable problems of virulent condensation have arisen in many recently constructed dwellings based on pre-cast concrete panel construction incorporating vast expanses of concrete surfaces finished with wall paper, lino tiles, spray painting and other materials which contribute very little to minimising heat loss in rooms supported by inadequate heat distribution and spasmodic periods of occupation.

The design of such buildings, when not continuously heated, could
avoid these problems by including:

(a) sandwich facade panels designed with insulation near outside surfaces, when no vapour barrier has been included on the inside surfaces of external walls. Where this has been provided, the arrangement of the panels is immaterial if the overall level of insulation installed is adequate to prevent surface condensation.

(b) Additional insulation behind inside wall surfaces in corners, and wherever the insulation is bridged by structural members.

Buildings constructed with pre-cast concrete panel units and provided with a high temperature background and a costly heating system require good insulation to reduce the capital and running costs of the heating installations. Buildings provided with only intermittent heating require:

(a) wall insulation located near inside surfaces to ensure rapid warming when the heating is turned on, and

(b) provision of a vapour barrier to prevent condensation within wall panel units.

The economic value of a building’s thermal insulation requires assessment on its individual merits by comparing the costs of the heating system and insulation provided on the basis of:

(a) insulation costs,

(b) heating installation costs,

(c) areas of windows and exposed surfaces,

(d) standard of heating to be maintained.

Although more open planning can assist air circulation to dispel dampness, where cost limits permit, the design of a system should provide for:

(a) the removal of all sources of hot humid air and sufficient moisture liberated inside the building to prevent humidity
rising to a level when it will condense on wall surfaces,
(b) the replacement of exhausted air with fresh air from outside the building, and
(c) the selection of materials for room finishings which minimise heat losses, and avoid critical water pressure by ensuring that sufficient water vapour is dissipated to the outside air by effective ventilation.

The problems of (a) controlling heat supply according to outdoor temperature, and (b) adequately ventilating air inside a building in order to maintain a constant temperature for warming incoming air are complicated by designs which provide:

(a) large areas of glass which permit a degree of solar radiation which affects room temperatures to an extent requiring counter-action,
(b) light insulated cladding units which do not even out adequately daily temperature variations,
(c) increased use of materials such as plastics and pre-finished concrete panels,
(d) rooms with low ceiling heights and restricted floor space; these include a comparatively small volume of air per person, with more claims on fresh air supply.

User requirements and habits may also tend to induce condensation; e.g. tenants decreasing day temperatures at night for reasons of comfort or economy.

Effective ventilation, air conditioning, and controlled heating are essential for the improvement of indoor climates, noise reduction, and increased comfort and health. The advent of high-rise dwellings in urban areas necessitates more effective procedures of replacing traditional individual heating systems by the provision of heat from a central source, with
mechanical ventilation to assist natural air flow in order to obtain substantial economies from:

(a) low grade fuels, which can be burnt at uniformly high efficiency,
(b) reduced maintenance costs, which would be low compared with the maintenance of large numbers of the smaller heating installations required to provide heating to the same standards,
(c) less air pollution,
(d) economy of labour. Large heating stations can be operated with a minimum of labour, and controlled and supervised by a conventional electronic computer system,
(e) the use of alternative fuels, and modifications at low capital cost to utilise the most economic fuel at a particular period, e.g. gas from under the North Sea, atomic energy for electricity generation,
(f) the incorporation of refuse incineration, and the recovery of waste heat.

2.9 Sound Insulation

Design considerations should comprehend all possible paths by which noise might enter a building (e.g. windows, open chimney flues, tiled roofs) in order to provide effective methods of sound insulation, which are influenced by weight of walls, airtightness of construction, pitch of sound, indirect transmission (e.g. along party walls), and structural discontinuity (e.g. cavity walls).

Pre-cast concrete panel systems for high-use dwellings can achieve a measure of sound insulation with dense concrete wall units and compressed polystyrene insulation on floor units. Other types of construction for systems applicable to low-rise dwellings reduce the weight of party walls to 12 lbs. per sq. ft. (instead of 35 lbs. per sq. ft. as required by the Building Regulations when a solid wall is used) by incorporating light weight insulated units
to form cavity walls which achieve the same acoustic performance.

2.10 Water Penetration

Modern materials such as concrete, steel, glass, aluminium and plastics have widely different coefficients of expansion. Their surface temperatures in Great Britain on relatively large components vary from above boiling point of water to many degrees of frost. As a result, the thermal expansion and contraction of joints between large panel units prefabricated of these materials is much greater than those of traditional materials. Moreover, their impervious weathering skins increase the risk of water penetration due to water collecting to form an unbroken sheet which may (a) be sucked in at any gap in the cladding of tall buildings due to differences of pressure, or (b) be blown upwards through weepholes, or other openings left in facades.

Metallic facades incur the possibility of corrosion at joints caused by (a) discontinuity of the surface, which encourages the retention of water or dirt, (b) the use of potentially aggressive sealants, (c) contact between the metal and surrounding material, and (d) bimetallic action at the junction of two different materials, which can cause premature failure at the joints of metals which have good corrosion resistance on freely exposed surfaces.

2.11 Design and Obsolescence

Pre-cast concrete panel systems for dwellings are not readily adaptable to future changes in user requirements and improved standards of living. They may well become the slums of the future, when every householder may be able to enjoy the increased comforts provided by more living space, artificial ventilation, improved sound insulation, and many other advantages provided by the use of new materials and techniques being rapidly developed all over the world.

Similarly, many new office buildings of recent construction may become
obsolete in the comparatively near future due to lack of requisite floor space, and improved standards of living.

We build at present for a 40-60 years unchanged environment, but should base our thinking on designs that will (a) provide structural stability to take increased loading from future user requirements, (b) provide bigger spans to enable removable non-structural units forming rooms to be utilised for increasing living and working space within the building, and (c) enable curtain walling and other forms of cladding to be readily altered to suit changed user requirements.

The increase of population that is expected to take place within the century, and may continue into the next, will inevitably affect design requirements so that:

(1) the present scarcity of land will tend to increase, necessitating higher buildings; and

(2) sewage problems may arise.

Advances in building technology will also affect design solutions in view of improved living standards such as artificial ventilation, improved sound insulation, larger living and working areas, the utilisation of gas from under the North Sea, which may make uneconomic the use of electricity for domestic purposes, and the more general use of new materials such as structural plastics for non-load bearing walls in place of brickwork and concrete.

Current tendencies to seek quantity and speed of erection while passing over the quality that must inevitably come from the advances of technology resulting in improved living standards and the need for higher buildings due to increased population density, if unchecked, will eventually lead to the creation of more slums, and the unnecessary and costly demolition of dense reinforced concrete structures capable of lasting hundreds of years, yet too confined in area and lacking current living standards to justify
their continued existence on valuable land.

Design requirements should attempt the provision of solutions to such problems by:

(1) providing "multi-purpose" buildings with sufficient foundation to take future increases of loading from increased storey heights and additional floor loading due to change in user requirements;

(2) utilising some form of frame construction which will achieve more open planning to provide for (a) change of building type, e.g. from offices to dwellings, (b) the future incorporation of new and lighter materials to facilitate re-planning of internal rooms and alterations to facades to accord with changed user requirements;

(3) provision of pipework in service ducts for future installations utilising cheap gas, and some form of ducting in sub-structures to accommodate future sewers.

But good design alone is not sufficient to solve these problems and attain the undoubted advantages that could be gained from industrialised building and more sophisticated techniques of construction. Good management is decisive for economic building, because mechanised methods of production and handling of components are much more sensitive to delays and interference of productivity. And present unnecessary and artificial factors inflating building costs need to be swept away, such as unnecessarily stringent fire grading regulations, uneconomical design codes, the separation of the various professions with water-tight compartments, and obsolete methods of measurement and tendering procedures suited to another age.
CHAPTER 3

PRINCIPLES OF ECONOMIC STRUCTURAL DESIGN

3.1 Choice of Materials for Structures

3.1.1. General

Systems are limited by the range of materials available for standardised structural units and their jointing techniques, but principally by volume of demand.

The two most readily available materials at present suited to meet the structural requirements of multi-storey buildings are steel and reinforced concrete.

The unreliability of concrete in tension, and its dependence upon good workmanship can be overcome by (a) adding steel reinforcement, (b) strict quality control, and (c) mechanisation of production. Steel is liable to rust, and weaken under fire, and these defects can be overcome by encasing it in concrete, the composite material having great strength, which can be varied and concentrated exactly where needed.

Pre-stressed concrete (a) enables the full strength of the constituent materials to be utilised (b) is comparatively costly; (c) provides economic advantages for (i) composite designs when its weight is an appreciable part of the load to be carried, and (ii) structures subject to impact forces or fatigue. The processes of pre-stressing and pre-casting complement one another, and fit into the trend of industrialised building construction by replacing quantity by quality, labour by machinery, and craftsmanship by automatic control. By pre-stressing together a number of pre-cast units to form a continuous structure, a greater control over the stresses induced in the structure can be introduced in its design.

The use of the particular material selected imposes strict disciplines on design owing to its strength, and may affect stocks available, as well as costs of transportation and handling of units, and the amount of protection
or treatment of the material needed to ensure minimum maintenance.

The economic advantages of steel and concrete relate to the effective use of their properties with high quality materials. High yield steel, which has the same elastic modulus as mild steel, is more flexible for sections of equal carrying capacity, can be used to a greater limit of permissible stresses than mild steel, and permits an increase in working stress of 40 per cent with a smaller section, thus achieving a net saving in costs.

In elastic design, the ratio of the elastic modulus for steel and concrete is usually limited to 15, the complementary compressive stress in the concrete being from 1/15th to 1/30th of the working tensile stress in the steel, according to the grade of steel used. Lower concrete stresses tend to increase floor thicknesses, and increase their dead weights. No advantage is gained from the use of high quality materials unless full utilisation can be made of their working stresses.

Costs of materials must be balanced against labour costs, and the availability of skilled labour. If concrete has been selected as the more suitable material for a system, available labour is of poor quality, and batch control not readily available under sufficiently stringent conditions, design stresses need to be related to an agreed mix by volume, rather than to a designed mix.

Other general factors which influence the choice of materials relate to current price levels in the steel and cement industries, user requirements for the building, nature and size of site, standardisation of structural sections, and fire resistance requirements.

Fire protection is one of the main factors which at present prevents steel from being economically competitive with concrete. Unprotected steel beams which would compare in cost with reinforced concrete beams, when bearing on load bearing brickwork can cause wall collapse in fires due to expansion in the length of the beam pushing out the walls, and therefore necessitate the additional cost of fire protection.
In general, economies can be achieved by the use of (a) high tensile steel framing to lower storeys and ordinary mild steel for the framing above of multi-rise steel framed structures, (b) higher strength concrete structural units to lower storeys, and lower strength concrete for the units above of reinforced concrete structures, (c) light weight materials for cladding and non-structural partitions and (d) locating structural partitions in positions to minimise loading.

Design codes have tended to become increasingly irrational and successively modified by arbitrary decisions which prevent full advantage being obtained from potential structural economies. The development of new materials and techniques of construction increase the importance of imposed loads as compared with dead loads. Improved knowledge of loading for different types of purposes could increase economies obtainable from controlling materials strengths.

More rational design rules would relate to the consideration of a set of limit states with suitable margins of safety, so that design could be on a semi-probable basis due to the difficulty of assessing many of the factors which influence the likelihood of failure or defects in the structure. Digital computers make the use of "limit state design" a practical proposition by allowing more accurate analysis of structures and statistical analysis of concrete strength which lead to economies in cement.

Present research into the possible use of fibrous and nylon reinforcement in concrete, better cements and light weight aggregates, improved mix designs, higher crushing strengths, the increased use of more reliable light weight aggregates for reinforced and pre-stressed concrete, the development of special steels, epoxy resins and other jointing and weather proofing materials, and the methodical study of the behaviour of concrete during maturing should lead to greater economies in the costs of reinforced concrete as a structural material.
3.1.2 Steel

The manufacture of steel involves standardised processes which make mass production easily possible on a huge scale, far beyond the capacity of other current mediums. By these means a high annual output is achieved of extensive ranges of standardised structural sections for various purposes manufactured with fine tolerances, and strength controlled and established during manufacture.

The universal steel sections and joists produced in accordance with B.S. 4. Part 1: 1962 have entirely changed the design and functions of steel structures due to their extensive ranges and sections, which are proportioned to minimise the need for compounding with plates. Developments in cutting and automatic welding now enable welded box and other sections to be used for structural units. The circular, square and rectangular hollow sections produced to comply with the requirements of B.S. 4. Part 2: 1965 provide great potential advantages for use as structures. These sections are available on the open market, and enable structures of all types to be rapidly erected and sealed in so that other trades can follow on continuously. In congested city areas, transport delays in delivery of steelwork and precast concrete units from off-site factories may occur to hold up site operations. Such delays can be avoided by manufacturing the pre-cast concrete units on site when space is available for setting up a site factory and stacking yard.

High tensile steel to B.S. 968, with a yield stress of 23 tons per sq. in. provides a higher strength/weight ratio and higher working stresses than mild steel, but requires the accommodation of deflections. It can achieve savings in structural and foundation costs by reducing the cross-sectional area of columns required to carry principal vertical loads.

The strength to weight ratio of steel, its ready availability, and the variety of shapes and forms in which it is manufactured provide many ways for use as rapidly erected load-bearing structural units. But as the
basic cost of steel is approximately £45 per ton before going through a steelworks, it is essential to reduce the weight of a steel structure for economy.

The careful spacing of columns may reduce weight of steel by as much as 35% through reducing a span in order to substitute a lighter girder section and thereby achieve savings in smaller section stanchions and reduced foundation bases.

In general, the structural frame of a building represents approximately between one-quarter and one-third of the overall cost of a project with normal site conditions.

The economic advantages of structural steel frames for multi-storey buildings include (1) overall reduction in size of structure, as the columns are smaller in section and obstruct less floor space, (2) precision of erection, (3) lower foundation costs due to reduction in dead weight of the structure, (4) flexibility in planning, (5) adaptability to the requirements of future user changes and improved standards of living, e.g. complete change of cladding to facades and alterations to the layout of internal planning can be readily made.

Design techniques for structural steel frames should not confine to the framework the stiffness required to stabilise the building, but take into account the potential for composite action between the various components of the structure, and the ability of floors, lift shafts and staircase walls to resist lateral loads in order to minimise permanent bracing systems and specially designed fixed end joints. Economy of design can be achieved by transferring the disturbing forces through walls to the ground, planning floors to act as horizontal girders between strong points, and designing stair well enclosures, service areas and permanent partition walls to act as vertical cantilever girders anchored to the foundations.

Structural steelwork can be closely and rapidly integrated with other materials and forms of construction such as in-situ and pre-cast concrete,
light preformed steel floor decking, dry-jointed plastic and steel facades fabricated in three-storey lifts complete with factory inserted window components, and with fabricated false ceiling and partitions. For large spans and light loading, open web beams are suited to economic mass production techniques.

Steel framing in composite construction of simply supported light steel beams, either with or without shear connectors (according to the design approach) acting as integral units with in-situ concrete floors enables both materials to be used economically so that the concrete takes the compression, and the steelwork is fairly uniformly stressed in tension.

Where user requirements and site conditions permit, multi-storey buildings may be rapidly erected by means of (a) hull-core construction achieved with steel perimeter stanchions and an efficiently planned reinforced concrete core structure with the lift shafts, staircases, service ducts and lavatory blocks built with sliding shuttering, and continuously poured in situ concrete and composite floors, (b) hull construction, in which the whole perimeter of the building is stiffened by the steelwork, which becomes a huge tubular section. Where wind resistance is provided by a concrete core, economies can be achieved by designing perimeter stanchions to support vertical loading only, with conventional steel beams linked to the stanchions, and tied to the core.

3.1.3 Fire Protection

Present local authority regulations concerning the protection of steel structures against fire are based on unrealistic assessments of fire hazards, and do not satisfactorily take into account (a) the efficiency of modern fire brigades and fire-fighting techniques and (b) the properties of steel. They are one of the factors which at present unnecessarily add to the cost of building.

There are considerable discrepancies between actual fire loads and assumed fire grading. Some structural elements which have been shown by actual fire tests at the Fire Research Station to comply with all the
requirements of B.S. 476: Part 1: 1953, are disallowed for use in actual
buildings. Fire grading is arbitrarily based upon classification of usage,
instead of on the actual fire load present, although a higher degree of
fire protection may well be necessary for different classes of occupancy of
a building.

Numerous fire tests have shown that for columns carrying their design
load, the critical temperature at which failure occurs is when the mean steel
temperature reaches approximately 450-550°C. The temperature reached by an
unprotected steel section at the end of a given time depends upon (1) the
weight of the section, or its thermal capacity, and (2) the shape of the
section and the area over which the heat is applied. Thus lighter sections
reach critical temperature more rapidly than heavier sections. In multi-storey
structures, sections used at lower levels would normally provide more than one
hour fire resistance without any fire protection.

The Post-war Building Study No.20 (Fire grading of Buildings) estab­
lishes the relationship between the fire-load and furnace test period
(e.g. 12.5 lb./ft.² = 1 hour), but research undertaken by the Joint Fire
Research Organisation indicates that the better method of assessing potential
fire severity is to take into account the ventilation of the building, and
to express the fire load per unit window area. A more balanced assessment
of the appropriate fire resistance to a building has been established by the
Fire Research Committee at Rotterdam in 1966.

The essentials of fire resistance require the structure to be ade­
quate to allow occupants to leave a building safely in the event of fire, and
permit firemen to deal with the fire without undue risk. The degree of pro­
tection to be afforded should be related to the fire load, i.e. the average
amount of fuel in the contents and construction of the building expressed in
terms of equivalent weight of timber per unit floor area. And considera­
tion should be given to (a) the isolation of areas of high risk and fire load,
sprinkler installations, and roof ventilation, and (b) the position and
exposure of the various protected elements.

Reinforced concrete provides much greater heat resistance than steelwork, the steel bar reinforcement being protected to some extent against temperature rise by the concrete cover. Where suspended ceilings form a part of the construction, the design of steelwork can ensure economical fire protection by concealing steel beams in the overall thickness of floors. Alternatively, in order to reduce the weight of the structure to a minimum, the steelwork may be protected by asbestos spraying or light pre-fabricated dry casings.

The economics of fire protection depend upon more realistic regulations, and (a) designing the steel frame to act compositely with structural concrete casing to support the final loading, (b) utilising lightweight casings to beams and columns to reduce foundation loading, and achieve savings of concrete and excavation in each stanchion base.

3.1.4 Concrete

Concrete is a flexible material which can take the forms of plain mass, reinforced or pre-stressed concrete as suited to structural requirements due to its relatively low cost, high compressive strength, good resistance to fire and corrosion, and constructional simplicity suited to unskilled labour. It can be pre-cast to special requirements, or used to bring production line methods to the site for the mass production of standardised structural units where a sufficiently large and continuous volume of demand justifies requisite capital investment.

The disadvantages of concrete relate to hidden deficiencies and specific characteristics which make its structural behaviour impossible to accurately forecast on account of variability of strength where good site control is not maintained, high thermal sensitivity, shrinkage, and plasticity. The elastic modulus of concrete varies according to the problems inherent in mixing, placing and curing, and changes due to plastic stresses and viscosity.
These can cause defects when the mixing leads to differences in the elastic modulus of the concrete in two collaborating members of the same structure, or when structural importance is related to decrease of the modulus with stress, or increase under repeated loading, or plastic flow under load.

Reinforced concrete (a) provides the possibility of designing structures in conformity with aesthetic and structural needs, (b) is the optimum solution where conditions necessitate either raft or pile foundations, (c) lends itself to standardisation and easy formation of shapes, and (d) permits the design of a reduced number of structural sections to standardise components with a minimum of variations and increased use of shuttering on account of the high compressive strength.

The cost of any extra concrete thickness due to over design is comparatively negligible, as it is the labour (manhour) content of any ordinary portland cement concrete item which is critical and needs to be minimised.

Pre-cast reinforced concrete panels for internal walls and floor slabs with domestic loading can be economically cast as standardised units in steel or concrete battery moulds. With box shell construction for multi-storey dwellings, walls can be standardised at 7 in. thickness to provide good sound insulation at any height, as no savings in costs are achieved by reducing their thickness. Floor panels can be at standardised thicknesses, even in corridors and narrow bedrooms where their thickness could be reduced, because it is cheaper to use the same steel moulds, with the insertion of a stop to reduce the width of the slab.

Concrete can be produced economically on site by the use of controlled batching plant, and aesthetically developed by the use of colouring or white aggregates and cement, facing with exposed aggregates to imitate varieties of natural stone, or embellishment by profile treatment. Unlike steelwork, concrete utilises a high proportion of unskilled labour for rapid site construction.

On jobs where only intermittent supplies are required, or the nature
of the site would otherwise preclude in-situ construction, or towards the end of the job when space becomes strictly limited, economies can be achieved by the use of ready-mixed concrete.

No-fines concrete in which all sand and fine stones are omitted from the aggregate, and the coarse aggregate is cement coated together, provides a better heat and water resisting concrete than dense concrete. As the hydrostatic pressure is greatly reduced, comparatively light shuttering enables large two-storey high box shutters to be used many times for no-fines infill built integrally with dense reinforced concrete frames. However, the potentialities of no-fines techniques are affected by the increasing shortage of natural aggregates for concrete, and research into the development of artificial aggregates is being undertaken on a vast scale in civilised countries.

Aerated concrete is virtually a weak strength grout, and contains no coarse aggregate, being composed of cement and lime putty with finely divided silica. Satisfactory results to obtain compressive strengths of 300 lb. to 600 lb. per sq. in. require high pressure steam curing, so that the material is only suited to pre-casting.

The use of light weight aggregate concrete can expand design possibilities, and is economical where the least density and greatest porosity are required for a given strength, and industrial waste products such as pulverised fuel ash and expanded clay or shale are readily available. By reducing the weight and thickness of walls, substantial savings can be made in foundations with large pre-cast concrete components of light weight aggregate.

The insulation of concrete by an expanded plastic either internally as a sandwich, or externally as an applied layer is expensive. The use of light weight concrete can reduce haulage and handling costs, but requires a space wasting thickness of 14" to obtain a U value of 0.2. By massive air-entrainment, light weight aggregate concrete can be reduced to 30 lb. per sq. ft. with reduced K and U values.

Reinforced light weight concrete, which comprises "aggregate"
and "aerated" concrete, has the disadvantage of being subject to damage in site erection and the advantages of reduced weight, easier transportation and handling, and improved thermal insulation.

On one site in the U.S.A., lightweight aggregate was used for pre-casting concrete units to save pre-stressing and reinforcing steel, and achieve greater use of the erection crane's working capacity. Beams and floor slabs were pre-tensioned in timber moulds, and wall panels cast in steel moulds to permit the design of extremely thin rib sections.

3.2 Comparative economies of poured in-situ and pre-cast concrete.

Factors influencing decisions as to whether or not it will be more economical to pre-cast or pour concrete in situ for structural members relate to:

(a) type of units required, amount of standardisation possible, and volume of production,

(b) type of building. Dwellings, which have small rooms and spans suited to panel construction, and building types with regular plan shapes suited to modular grids and standardisation (e.g. schools, offices, factories) are suited to pre-cast construction, as opposed to one-off buildings of individual intricate design, which are more economically constructed with in-situ concrete,

(c) the finalisation of all details and services, and the availability of completed working drawings, and specifications prior to commencing work on site. If full details are not available until work has commenced on site, resulting variations can be more readily incorporated into in-situ construction without the excessive costs and delays entailed with pre-cast construction. A lack of detailed information regarding holes and chases for service installations makes it difficult to co-ordinate pipe runs, etc., and substantially increases costs.

Comparative advantages and disadvantages of the two methods of
Producing concrete are:

**Pre-cast concrete units:**

(1) can incorporate finishings and services in the moulds to reduce site finishing time by approximately two-thirds, and save time by obviating the shuttering and fixing of steel reinforcement necessitated by pouring in situ.

(2) Where several buildings are to be erected on a site, the quicker erection achieved by pre-casting can be maintained, whereas by pouring in situ, speed of erection is considerably slowed down by the additional time required for finishings trades and service installations.

(3) Pre-cast systems require cranes to handle and position structural units weighing from 2 to 10 tons, according to design, yet may also be required to hoist skips of concrete weighing only 1 1/2 tons for stitching the in-situ joints between units. Such uneconomic cranage can be avoided on structures up to four storeys high by utilising a second and smaller mobile crane for hoisting the skips. The cost of cranes to handle units weighing 10 tons is more than double the cost of cranes with a hoisting capacity of 5 tons. Differences in the cost of cranes with hoisting capacities of between 5 tons and 2 tons is not so excessive.

(4) Poured in-situ concrete structures up to 10 storeys high generally require a crane with a hoisting capacity for 1/2 cu. yd. skips (weighing 1 1/2 tons filled with concrete), which is usually the heavier element, unless the design of shuttering for stability walls is greatly in excess of this weight; and therefore enables lighter and much less costly cranes to be utilised.

(5) Rates for Portland cement concrete contain a high labour element. For ordinary in-situ work, approximately 40 per cent materials, 40 per cent labour, and 20 per cent plant. These ratios differ for pre-cast concrete work, which are approximately 20 per cent labour, 40 per cent materials and 40 per cent plant, the higher plant costs replacing labour.

(6) Molds for pre-cast concrete units are more costly than the formwork
required for similar poured in-situ concrete members because

(a) the materials for the moulds required in pre-cast concrete factory production are of very costly precision made steel, instead of timber or other much less expensive materials,

(b) a mould for a pre-cast concrete unit such as a beam has to stand in isolation to produce the unit. If constructed of timber, substantial side supports and ties across the top are required.

Formwork for similar poured in-situ concrete members do not require so many stiffeners and side supports, as the beam and slab are complementary, and support one another.

(7) Work in foundations and the floor to floor erection cycle for either pre-cast or poured in-situ concrete operations for multi-storey dwellings, takes approximately the same time. But the finishing trades of pre-cast concrete structures 20 storeys high can commence during the fourth week at fourth floor level, enabling the whole building to be handed over 8 weeks after the twentieth storey has been roofed over. This is achieved by the finishing trades having progressed to the sixteenth floor by the time the roof is on.

(8) With poured in-situ concrete construction, when the twentieth storey has been roofed over, the finishing trades will only be proceeding at about the tenth floor, and it will consequently take approximately 16 weeks to hand over the building on account of the considerable extra time required for finishing trades and service installations.

(9) A stronger mix can be obtained with pre-cast concrete able to work economically with any steel reinforcement. Systems based on pre-cast concrete construction avoid the need for external scaffolding to facades, and employ a minimum of site labour for the rapid erection of large and continuous outputs of mass-produced units. An initial stock pile of pre-cast units should be assembled before erection operations commence, as 21 days must elapse before 80 per cent of the shrinkage in beams and wall panels will
have taken place. Columns can be erected after 7 to 10 days of casting, as any further shrinkage tends to be counteracted when taking up their loading.

(10) Concrete production on site, irrespective of whether for pre-cast or poured in-situ concrete, normally averages out at approximately 40 to 50 cu. yd. per day, based on a ½ cu. yd. skip and a mixing cycle of 2 to 3 minutes. Under these conditions, one tower crane would be utilised and suited to a ½ cu. yd. mixer producing 10 batches of concrete per hour for a daily output of approximately 40 cu. yd. It would therefore not be economical to use a mixer of 1 cu. yd. capacity, as it would produce all the concrete required for one day's operations in 5 hours, leaving the mixer standing idle for the remainder of the day, and the crane under-utilised.

The economic gang strength for producing either pre-cast or poured in-situ concrete averages eight men for mixing and placing approximately 40 to 50 cu. yd. of concrete per day. The gang normally comprises two men on the mixer, one crane operator, one banksman, and four men placing, vibrating, and screeding of the concrete.

If the size of the building required two cranes for its construction, each placing the same amount of concrete per day, greater economy would be obtained by using a larger mixer and heavier cranes, one crane pouring the concrete, whilst the second crane carried out other handling operations. The advantage of using a 1 cu. yd. mixer for greater outputs enables handling costs to be reduced by approximately 50 per cent, but is offset by increased capital or hire charges for more expensive plant and cranes, and is only justifiable on sites requiring a considerably increased daily output of concrete.

3.3 Choice of Structural Type

3.3.1 General

Structural design aims to provide requisite strength, stiffness, lightness and facile erection of structure on foundations which obtain full advantage
of sub-soil properties, and is founded on construction techniques.

Economy of design is influenced by the optimum use of the characteristics of available materials for maximum standardisation of sections, and a minimum of simple repetitive assembly operations with the concentrated use of suitable mechanical plant to speed erection and reduce total construction costs.

The trend towards lighter structures has aggravated problems of noise in buildings, for although higher working stresses for structural materials can achieve slender sections when designed solely for strength, particular attention should be taken at design stage in order to avoid vibration problems arising due to insufficient stiffening of the structure.

There are a number of alternative forms of construction which may be used to satisfy the functional requirements of a given structural problem, but many of these become unexpectedly uneconomical when not used to the best advantage.

Selection of structural type may be complicated by foundation problems, the availability of materials, and labour, and the need to balance relative costs with time required for completion. In 1946, when there was a general shortage of steel following the war period, government legislation provided for public buildings to be designed in reinforced concrete rather than in structural steelwork, and initiated a tendency which still generally persists today.

Different forms of construction generally require fundamental differences of planning. Multi-rise dwellings, which have comparatively small room spans, are usually more economically constructed in concrete of box-shell construction, rather than with structural steel framework. With other building types, the designer is faced with a wider choice of many complex factors.

In general:

(a) length variations with prismatic components such as beams
and columns is less costly than with panels;

(b) Wing panels cast integrally with columns at one or both ends to help stabilise loading;

(c) it may usually be more economical with systems up to five storeys to design a frame structure and select cladding panels which give flexibility of design and appearance from the present wide variety of such components obtainable on the open market;

(d) for structures over five storeys high, the vertical loading becomes much heavier, and consequently the supporting columns are greatly increased in section.

Panel construction takes these loads over a much greater area, but requires additional structural stability against wind forces by bracing with cross walls.

The economic principles of planning steel and reinforced concrete frames have changed. With light loading, floors are more economically composed of units spanning in one direction, but with change of direction in adjacent bays to ensure even loading on beams. With heavier loading, the units are more economically designed to span in two directions. And for economic multi-storey construction, the combination of the maximum utilisation of the best characteristics of steel and concrete is essential.

3.3.2. Steel Frames

Steel structural frame-systems are economically suited to building types requiring horizontal and vertical repetitive units. They can reduce dead weight by transmitting all loads by stanchions bolted at their feet to foundations, save floor space, and provide large areas for flexible planning by allocating load bearing and space enclosing functions to the structural frame, and light cladding. Suitably positioned solid walls required for functional purposes can be designed to withstand wind pressure on the structure, and thus achieve economy in the steel frame.

Where planning requirements permit, standardisation and economy of
sections may be achieved by equalising the loading in different parts of
the frame on the basis of a regular grid layout, with stanchions spaced
as closely as possible, as short span beams cost less per linear foot than
long span beams.

For normal loading, the deepest available standard joist section
with the required strength provides the greatest economy, and even where
excessive may cost less than a shallower but heavier section. For heavy
loading and spans exceeding 50 ft. the weight of steel increases in relation
to the volume of the building, with consequent extra costs.

High tensile steel sections may offset local reductions in size and
weight of sections to save height or floor space which offset the extra cost
of the more expensive material, but such savings may be obviated by packings
required to obtain uniform overall finished sizes in accordance with architec-
tural requirements.

In a multi-storey building, the floors and amount of beamwork per
storey is identical; it is only the stanchions that increase in section to
take the extra loading. Traditional design assumed that the skeleton of
beams and columns supported the concrete floor slabs and wall cladding in
isolation, any fire protection of concrete casing being assumed to make only
a very small contribution to support imposed loading, and normally provided for
variation in section every second storey, as steel sections are bought in
20-ft. lengths. A stanchion size was determined at the top of the structure,
and proceeding downwards, the stanchions were compounded by additional plates.

The introduction of universal steel columns has enabled this design
practice of compounding stanchions to be largely superseded, as there are now
several different weights of U.C. available for every size section in order
to simplify connections. These are more economically made by internal cover
plates, instead of division plates and external cover plates.

The most important single factor influencing the cost of steel framed
structures relates to the selection of the column module, the cheapest frame being that with the least dead weight, and consequently the closest column grid. By this means the supported load is transmitted to the foundations in the most direct way. As the number of columns in a steel framed structure decreases, the total weight of steel remains more or less constant, no matter what the grid module may be. But the weight of the beamwork, which costs less per ton than stanchions, increases as the number of columns decrease when the grid is widened. The mass concrete foundations to isolated stanchions on a normal site is approximately 5 per cent of the total cost of the structure.

Developments in steel framework design have introduced changes in fabrication techniques so that it is generally more economical for details and connections to be shop welded, and bolted at site with friction grip bolts. Where confined space makes these bolts difficult to fix, high tensile R. type bolts form a suitable alternative.

Structural steelwork can be very readily and quickly erected, and provides a more flexible layout than a concrete frame, but cannot be shaped to profile as concrete. A standardised light steel section sufficient to carry shuttering without props in combination with concrete designed to take all loading achieves greater economy than designing sections of steelwork only to support the loading, and casing the steel with concrete for fire protection. Shuttering for beams and columns can be standardised and reused floor by floor commencing at ground level.

Economy in the design of steel frames can also be achieved by minimising the number of stages by which the load is carried (e.g. where user requirements permit, by closing the grid to obviate secondary beams, fewer sections are required to be handled). Columns can be arranged in serial sizes based on the different weights of the same section. For example, based on a 20 ft. x 15 ft. grid, a 30-storey frame could be standardised at the top with 6 in. x 6 in. stanchions, which would serve six storeys; 8 in. x 8 in.
stanchions for 10 lower storeys; 10 in. x 10 in. stanchions for 10 storeys below, and 12 in. x 12 in. stanchions for the lower floors and basements. The effect of increasing the size of the grid is to increase column sizes, but savings would be gained in the fewer bases required for their foundations.

Steel frames for multi-storey dwellings should be designed with (a) relatively low perimeter-plan ratio, and effective integration of the plan to the structural system, (b) rigidly standardised spans, (c) lightweight pre-fabricated cladding units which provide adequate weather, fire and insulation protection. Cladding must be efficiently jointed, and for rapid erection may be secured to the frame in units of three storeys in height, (d) standardised lightweight fire-proof casings, and (e) full utilisation of all repetitive factors.

An economic plan form for multi-storey dwellings 20 storeys high based on wall cladding of not more than 25 lb. per sq. ft., and a maximum wind loading (Exposure B) of 18 lb. per sq. ft. would provide for four three-apartment flats without balconies, two lifts in one shaft, and one staircase per floor. Construction would consist of a simple steel frame with dry casings, standard 5 in. pre-cast floor beams of 9 ft. and 11 ft. spans resting on the top flanges of the steel, and pre-cast floors for light cranage. Costs of such construction would compare with a normal in-situ concrete frame with brick infilling, or a pre-cast concrete system based on rigid standardisation of spans and a limited output of maximum repetition of units.

Factors which tend to narrow the difference in costs between steel and concrete structures for other types of multi-storey structures (e.g. offices) relate to the use of lightweight fireproof cladding, high tensile steel, torque bolting, composite action between steel and concrete, and ultimate load basis of design.
Disadvantages of steel skeleton frame structures are that:

(a) tower cranes cannot be utilised to maximum efficiency due to (i) the extra lifting, slewing, trolleying and dropping required to handle concrete skips or components to positions between the steel frame, and (ii) restrictions of working at wind velocities of 15-20 m.p.h. as compared with wind velocities of up to approximately 35 m.p.h. preventing crane movements handling concrete skips and components; and

(b) the additional labour required to pack and vibrate in-situ concrete between steel sections and shuttering compared with normally reinforced concrete sections.

3.3.3. Reinforced Concrete Construction

(a) General.

Many more systems for multi-storey buildings are being developed in reinforced concrete rather than steel because (a) reinforced concrete structural sections can be pre-cast to combine weather resistance, fire protection, sound and heat insulation, and finished appearance in one operation, and enable more rapid completion of the building; (b) structural sections can be economically formed by standardising shutters or moulds for beam and column sizes, with extra steel reinforcement where required to take heavier loads, and (c) buildings based on steel frame construction generally cost approximately 10 to 20 per cent more than similar buildings based on reinforced concrete frames.

In general, buildings with short spans are more economically constructed with reinforced concrete, and are particularly suited to pre-cast concrete construction. With large spans, the weight of the concrete structure is high in relation to the load carried, the dead weight/imposed load ratio being approximately unity. With steel structures, this ratio is only about one-fifth. This indicates that on sites for large scale developments, economies could be achieved in tower blocks by planning larger buildings.
For reasons of economy and fire protection, the form of structure most currently used for multi-storey building types are (1) in-situ reinforced concrete frames, (2) combination of in-situ and pre-cast concrete frames with panel infillings, (3) pre-cast concrete box-shell construction. Comparatively few structures of steel frame skeletons or composite steel and concrete construction are being constructed for such buildings.

(b) In-Situ Concrete Construction. In-situ monolithic construction has the advantages of (1) reducing deflection in structural members, (2) distributing reduced bending moments more uniformly throughout the structure than in discontinuous pre-cast concrete structures to achieve light members of uniform section which can be sized to the maximum bending moment, thus minimising wastage of material at less highly stressed points, (3) less rapid increase in the dead weight of beams with increase of span, as stress distribution requires extra material over the supports to take up the weight directly without increasing the bending moment (which it would do if placed in the centre of the span), (4) use of mainly unskilled labour for erecting the structure, and (5) utilisation of a variety of light infilling for facades, or the use of white cement and coloured aggregates to combine architectural finish with structural section.

Changes of reinforcement, beam and column sizes, slab and wall thicknesses, size and shape of foundations, and adjustment of formwork can be minimised by standardisation of design. It is generally more economical to design poured in-situ suspended concrete slabs with a higher percentage of steel rather than with a thicker slab and less steel because a heavier slab necessitates larger beams with a higher percentage of steel, and increased loading on foundations.

Taller buildings require higher strength concrete, and where the slenderness of designed columns in a tall building requires a concrete strength of 7500 lbs. per sq. in., which is better obtained under factory
conditions rather than on site, the slump test should be 5" or 6" to avoid the concrete losing some of its workability before it is hoisted to the top of the structure.

The main disadvantages of in-situ reinforced concrete construction relate to the adverse effects of (1) differential foundation settlement causing secondary shearing forces and bending moments in the beams and columns due to the distortion of the frame caused by rigid joints, (2) temperature movement similar to foundation movement, and (3) the time lag between pouring concrete and striking of shuttering. The curing of the concrete delays re-use of the shuttering, and obstructs working areas for long periods, which can be considerably shortened by utilising methods of accelerated curing. Steel reinforcement should be designed to form a stable structure in itself capable of sustaining the load, the added concrete being able to implement the equilibrium quantitatively by connecting the steel bars and absorbing compressive stresses.

Composite construction with poured in-situ concrete walls or stability core and a pre-cast concrete frame has the disadvantages of the in-situ concrete rising at a slower rate than the pre-cast concrete frame, with the result that the site becomes obstructed by formwork, unless sliding shutters are utilised for the in-situ core. Moreover, the distribution of stress in members composed of in-situ and pre-cast concrete may be uncertain and need testing. For example, where pre-cast concrete sides are not continuous throughout the height of a building but are jointed at floor levels, the in-situ core is continuous, and the whole of the composite section is required to be load bearing due to loading conditions, some form of bonding is required to prevent the pre-cast concrete sides buckling away from the core, and the effects of differential shrinkage in lateral and longitudinal directions between the core and the sides must be most carefully determined.

Under these conditions, steel links will be required which project
into the core from the pre-cast concrete sections. Shrinkage can be reduced by designing a fairly dry mix in the core to achieve the same ultimate loads as for the poured in-situ concrete. Fire resistance requirements can be obtained by utilising sintered pulverised fuel ash light weight aggregate in both the pre-cast units and the core.

Economic monolithic in-situ concrete box-shell construction for multi-rise dwellings over 11 storeys high requires formwork designed in as large units as possible with props attached, and loose parts minimised for crane utilisation and rapid erection.

Walls and floor slabs act together as beams because of the total monolithic character of the in-situ construction, which provides full continuity throughout beams, columns and slabs. The particular distribution of stresses and consequent variation in disposition of material permits the production of almost any shape. But the high cost of formwork, which amounts to approximately one-fifth of the total cost, necessitates simple structural shapes so that economical shutters can be repeatedly used.

The basic construction consists of pouring the in-situ monolithic box-shell structure within a rigid module. Formwork is pre-fabricated in storey height panels weighing about 2 tons, with concrete batches arranged so that the skips plus the contents are of about the same weight in order to achieve efficient crane utilisation.

Internal cross walls are poured before the floor shuttering is erected; unskilled labour being generally utilised for placing welded mesh panel floor reinforcement. After the floors have been poured, the panels of shuttering can be jacked down and wheeled towards the outside of the building for handling by crane into the position next required. This method speeds the erection cycle by enabling finishing trades to proceed simultaneously with the main construction. Economy of finishing is obtained by papering walls or spraying with paint, and screeding and finishing floors before the next wall lift proceeds. Staircases, and any projecting balconies are more economically constructed with pre-cast concrete.
An economic method of monolithic in-situ box-shell construction of multi-storey structures for dwellings up to 11 storeys high can be obtained by traditional methods utilising 6 in. reinforced concrete load bearing walls and 6 in. in-situ hollow pot floors for spans of 9 ft., 10 ft. and 17 ft. Cost reductions are achieved by avoiding intensive capital investment for factory equipment and tower cranes, utilising light shutters, and limiting mechanical plant utilisation to (a) 12/18 weigh batch mixers with 4-minute cycles and (b) hoist towers with skips. Concrete is delivered by hoist to required floor level and stored in containers for barrow delivery to required position. The wall shutters are easily struck and formed with 8 ft. x 4 ft. plywood sheets 5/8 in. thick on 4 in. x 2 in. studs spaced at 16 in. centres and stiffened with three rows of 6 in. x 3 in. whalings for handling by two operatives. These shutters are bolted together with 3 in. x 3 in. concrete blocks the thickness of the wall in length, perforated for a 5/8 in. bolt with nut and 3 in. x 3 in. x 1/4 in. plate washers for easy assembly.

The 7-day erection cycle comprises:-

1st day - Erect wall shuttering, place steel reinforcement and pour 3,000 lb. concrete to walls (50 cu. yd.)

2nd day - Strike shuttering to walls.

3rd day - Erect bearers, centres and plywood shutters for floors and staircases.

4th day - Lay floor pots, place steel reinforcement and electrical conduits.

5th day - Pour concrete to floors and stairs.

The concrete to the floors and stairs is left to cure over the weekend, and the cycle commences on the next floor above on the following Monday, the shuttering being struck at the end of the week. Site labour for erection operations comprise a carpenter team of 10 men for the erection of 500 sq. yds. of shuttering, and a team of 12 men for the in-situ concrete operations. The building requires an external scaffolding for the cladding,
and incorporates wet trades for floor, wall and ceiling finishes. The
time taken to erect one 11-storey block of 42 flats is about 18 months, but
the cost per dwelling is extremely competitive.

Lift slab technique is suited to multi-storey buildings of regular
shape. It can provide economies by avoiding complicated formwork and
cranage for floor and roof slabs, which are cast at ground level one on top
of the other, with holes left in so that the slabs can freely slide up the
columns, and kept separated. After the in-situ concrete columns and stabil­
is ing walls have been cured, the slabs are lifted to their respective levels
in the building by hydraulic jacks, and supported on brackets fixed to the
columns.

(c) Shuttering. Good shuttering is of vital importance for economic
poured in-situ concrete construction. Its successive removal subjects the
structure to temporary strains and irregular conditions of loading. The
design of shuttering for in-situ work should (a) provide adequate strength
to take the dead and live loads imposed by the wet concrete, operatives and
plant, (b) avoid excessive deflections, (c) ensure tight joints which prevent
loss of moisture which reduces the ultimate strength of the wet concrete,
(d) be readily constructed, erected and struck, and provide an optimum number
of uses.

Economy is related to the costs of labour (which is the major factor),
materials, type of construction, required finish to face of concrete, ease
of handling, and number of uses obtainable. The cost of shuttering is greatly
influenced by degree of repetition, and the correct phasing of erection and
striking with the curing time of concrete and progress of the works.

For optimum economy, shuttering and scaffolding should be minimised
to enable the structure to be self-supporting during course of construction
so that the structure will be self-supporting as it is being constructed,
and the obstruction to floors due to propping of shutters which slows down
the erection cycle is reduced.
The design of the reinforced concrete may reduce the sectional dimensions of structural members to a minimum whereby the cost of the temporary shuttering required to support them greatly exceeds the cost of the structural members themselves. The concrete should therefore be designed to achieve economic shuttering compatible with minimal section sizes. This can be achieved by:

(a) standardising column sizes to obtain more uses from the forms;

(b) standardising beam depths, so that their projections below slabs are uniform in depth and, where practicable, to modules which permit optimum use of the forms to the sides of the beams;

(c) spacing beams to obtain the maximum use of standardised shuttering to soffits of slabs;

(d) utilising kickers for walls and columns.

(d) Sliding shutters. Economies in shuttering to structures over 60 ft. high may sometimes be obtained by the use of sliding shutters for buildings of simple, regular plan form and cross section throughout their length and height, or for the walls of service cores and lift shafts to be built in advance of the main structure. Such cores often provide the main stability of the building, and their early construction provides the following structure with complete support against wind loads. A very high degree of detailed pre-planning to avoid stoppages, and efficient concrete control, supervision and constant checking are required to ensure that the forms are kept level and in alignment, prevent the continuously moving forms from jamming, and correct immediately any faults that may occur. By such means, a shutter rise of 6 in. or more per hour can be achieved.

The design of the core should be as simple as possible with the minimum of cross walls and boxings for services, etc. To reduce the loading in foundations, weight may be reduced by designing thin cone walls with
heavy compressive reinforcement, although this leads to difficulty in placing the excessive amount and weight of reinforcement in the short construction time available.

The hydraulic jacks, through which 2 in. diameter climbing tubes pass, are bolted to steel vertical frames spaced at 6 ft. to 10 ft. centres around the perimeter of the service core walls. The tubes are 16 ft. to 18 ft. long, and are jointed together with sleeved couplings as the work proceeds. Each jack has two internal clutch mechanisms, with a screw, turning head, and threaded collar, which is fixed to the shutters. As the screw is turned it obtains purchase from the clutch, which bites on the tube under load and raises the collar with the attached shutters. When the piston has reached its full extension, one clutch holds the shutters, while the other clutch and piston are returned by a spring to the original position.
The hydraulic system has a central control to enable the whole of the shutters to the perimeter walls to be raised as a single unit. The jacks are served from a ring coupled to a power unit and booster, and have a working load of 2 to 3 tons, and an operating rate of approximately 1 in. to 10 minutes, based on the setting time of the concrete. At this speed, the height of the shutters is 4 ft.

The core can be erected in the form of a tower so that the carpenter gang can be fully employed, and non-productive time of pre-cast concrete erectors minimised.
When sliding shuttering is used for the central service and lift core of a building 20 storeys high of composite pre-cast and in-situ construction, pouring of the in-situ concrete walls commences from the bottom, the walls being able to rise about 90 ft. high by the middle of the second week of operations. As the structure does not achieve wind stability above 120 ft. to 130 ft., the building would become unstable through the walls having advanced far beyond the rate of casting the floors, unless provision is made for a floor being rapidly cast at the tenth floor to act as a diaphragm. This can be achieved by setting up at ground level and within the structure the soffite shuttering for one floor, and lifting it up to the tenth floor level so that this floor can be poured as quickly as possible to avoid delaying the rapidly rising walls. The slab would have 1 in. diameter holes cast in so that steel wire ropes can be threaded through in order to lower the further soffite for casting the floors below, commencing with the ninth floor and proceeding down to first floor level. To speed erection, a second shutter soffite may be placed on the tenth floor and lifted to roof level, and be subsequently used for pouring the remaining floor slabs, commencing at the twentieth floor level and proceeding downwards to the eleventh floor level.

Such a method of using dropping shutters can achieve very rapid construction time, but is more costly than slower and more traditional methods of construction, which requires the most careful integration of the pre-cast concrete erection cycle with the slower in-situ concrete pouring cycle in order to avoid non-productive time caused by delays in curing concrete and erecting striking shuttering.

Various mechanised methods of shuttering enable whole floors to be speedily decked out, and are easily dismantled after the concrete has been poured.

With composite construction of this type, wind forces are restricted by the in-situ concrete core, and the pre-cast perimeter frame can be tied
to the floor by pre-cast units. Optimum economy is achieved by three or four of the pre-cast perimeter columns being hoisted together in a metal jig and positioned over pre-cast concrete edge beams supporting the floor slabs, the perimeter columns being designed to carry only central axial forces.

One system for high rise housing up to 30 storeys high is based on in-situ concrete cross wall construction using sliding shuttering, the plastic concrete being placed in a slip-formwork assembly and moulded to the structural plan shape. The sliding shutters move upwards at a rate of two and a half storeys a week, and the average labour content, including erecting off-site pre-fabricated components, averages 800 to 900 manhours per dwelling.

The economic use of sliding shuttering depends upon (1) the correct integration of shuttering reinforcement and concreting operations into interdependent co-ordinated processes, (2) utilisation of cranes and mixing plant to achieve outputs of 6-12 cu. yd. of concrete to be placed per hour, and (3) overtime and night work to be undertaken during the construction of the in-situ tower.

In general, the higher the structure, the greater the economy attained by its use due to the high cost of setting up and making the forms.

The main advantage of sliding shutters are:

(1) high speed of construction, with a centralised mixing plant;
(2) reduced costs of shuttering, because only one complete lift of shutters is made for the whole structure, or core, and the cost of handling heavy shutters by tower crane and fixed scaffolding is avoided;
(3) comparatively low man hours required on site;
(4) a jointless structure is obtained with a good finish.
Disadvantages are:

(1) rates of labour are high due to the need for skilled operatives, and shiftwork;
(2) the cost of installing and making the forms is high;
(3) reserve plant and power must be available in case of breakdowns.

(e) Pre-Fabricated Steel Shutters. Some systems are based on precision made steel interlocking shutters designed for transverse walls and plain floor slabs with a finish that permits direct spray painting or wall papering to reduce site labour. The shutters are in the form of tunnels, with sides of one piece steel panels full storey height, and soffite divided at the centre and extending the full span of the floor, each half being jointed to the vertical member to make a right angle bracket.

Location pins, clamps and dowels ensure a true surface; and screw jacks, removable props and quick release clamps with four-wheeled trolleys enable the tunnels to be withdrawn within reach of the erection crane to achieve ease of striking, quick turn round, and minimum damage.

The concrete is cured by means of steam pipes attached to the formwork, temperature being controlled to ensure that the concrete hardens overnight. By these means, a complete floor can be constructed in two days.

Setting out for subsequent floors is eliminated due to a steel kicker incorporated in the shutter for the next wall above. Scaffolding is obviated, as the shutters provide a working platform which follows up the building, and is utilised for wheeling on the tunnels prior to handling by crane to the floor above.

3.3.4. Pre-Cast Concrete Construction

(a) Panel Systems

Industrialised techniques based on the production of pre-cast concrete structural units enable contract times to be greatly speeded with
fewer operatives, but the capital cost of factory plant and equipment does not make them economically competitive without a much higher volume of demand than that normally provided by developments on individual sites.

Additional disadvantages are that:

(a) the pre-cast units are heavy and cumbersome, and require costly cranes for handling to position;

(b) where structural members are joined to others at beam and column intersections, the in-situ connections are complicated and expensive to construct;

(c) there is a delay while the in-situ work matures, tending to offset the time advantage of prefabrication;

(d) the structural units are heavier than steel sections and require more costly foundations and cranage,

(e) flexibility of design is restricted.

(f) Condensation problems are expensive to resolve.

(g) Other defects may arise which have not yet been fully discovered due to the comparative novelty of industrialised building techniques.

Pre-cast concrete box-shell structures with jointed connections capable of resisting both tension and shear stresses approximate to thin wall spatial systems in which every element resists a local load which is transmitted to strong points in the system. Thus floors resist bending out of plane and transmit the load to walls; transverse loaded walls resist compression and transmit loads to foundations and longitudinal walls.

The structural components participate in the three dimensional stressed state of the whole system, which may not always prevail under the local load. The rigidity of the structure depends on the plumbness of the walls and the stiffness of the joints to resist any rocking tendency.

Buildings constructed in this form comprise complex statically
indeterminate systems with composite structures of load-bearing walls pierced with door and window openings, which control noise at party floors, supported on ground foundations. The walls become elongated beams and columns forming an eggcrate, with the facade filled in with a variety of infilling.

Large concrete panels for floors, load-bearing wall units and partition walls can be standardised for economic factory production to achieve speed and simplicity of erection, and a floating floor finish can be used to avoid the impact noise of rigid fixing.

The tendency of large panel techniques leads towards increasing panel sizes to dimensions of two or three rooms to minimise the number of component types and site joints, but requires a vast volume of demand for economic production.

An open plan utilising a minimum number of pre-cast concrete structural units provides an economic basis for the mass production of units without the need for very costly factory plant and equipment to achieve simple site erection. Where the design permits floors to be supported only as external bearings, site erection is further simplified.

Structural design criteria for panel systems is related to (a) the total cubic feet of concrete per dwelling, (b) the percentage ratio of concrete in cladding to structural units per dwelling, (c) the percentage of floor to wall areas and (d) the total number of components per dwelling.

Provision for handling units should be detailed at design stage to ensure that permissible stresses are not exceeded during erection. These lifting devices should be inherently safe, easily inspected and operated, and ensure that the units hang correctly for placing in order to avoid double handling. The handling of units from the moulds may require different devices from those used for hoisting units to position, such as projecting or recessed loops to accommodate standard hooks or shackles, sleeved or plain holes
formed in units, cast in projecting bolts, or vacuum pads.

Factory production with steel moulds enables the concrete to be closely controlled to achieve savings in materials, and improvement in quality. Where concrete surfaces are to be exposed, the production of a satisfactory finish and the installation of service pipes and electrical conduits is facilitated in the moulds.

For high-rise housing, the plan modules used to achieve maximum mould utilisation should be related to a frontage module, determined by the maximum span; a second module for room widths related to the size of moulds used for casting, and a third module related to storey heights.

The optimum room size for most systems based on pre-cast concrete box-shell construction for high-rise structures requires units weighing not more than 8 tons, (i.e. floor slabs 22 ft. x 9 ft. 6", and wall units 22 ft. x 8 ft 6 ins.), but some systems are based on a limiting weight of 10 tons per unit, and utilise heavier cranes.

In order to obtain maximum economy and speed erection operations with the use of tower cranes, basic room sizes should be developed to fit the productivity of the system, and designs should avoid the need for external scaffolding to facades, and utilise pre-glazed windows, cladding panels and curtain walling that can be fixed from inside the building. Balcony units and staircases should be pre-cast, and any work required to elevations (e.g. cleaning off, pointing, decorations) executed off cradles.

One type of pre-cast concrete system for low-rise housing up to 4 storeys in height is based on simple load-bearing structures which can be built up with floor slab panel units and "L"-shaped wall panel units providing considerable stability, as they are equivalent to a wall buttressed by another at right angles, without requiring structural joints between the wall panels. Where wall units abut, the joints are formed with non-structural filling for sound insulation. Openings between walls can be of storey height,
and where located externally are filled in with light infill units of timber framing, which incorporate doors and windows.

The main disadvantages of pre-cast concrete construction are:

(1) continuity and rigidity are more difficult to attain than with in-situ concrete structures. The lowering of a pre-cast concrete unit into its final position is a critical point. Centre lines of gravity must be calculated to ensure that the unit is dropped into position without any other movement than propping. Units must not be dropped on splay, and subsequently aligned vertically, because lateral movements of the crane are dangerous. Any plumb-ing up should be very small, and carried out on props. The erection crane has to hold and steady medium and heavy weight panel units, and handle them into position with a jib attachment based on stays, and bolted inserts cast into the unit, whose weight, shape and position varies the time of crane operations. Thus a wall unit requires a certain amount of staying, a floor unit has to be positioned and levelled, and a staircase unit more delicately so.

(2) Unless there is a sufficient volume and continuity of demand (i.e. for a minimum of approximately 300 dwellings on one site), factory production is uneconomic.
(b) Example of production and erection requirements for a panel system.

Structural components suited to site factory manufacture of units for four 20-storey blocks on one site, each block approximately 100 ft. x 50 ft. on plan, and comprising two 3-bedroom, two 2-bedroom, and one 1-bedroom dwelling per floor would be based on the following panel types (max. 6 tons) per floor:

<table>
<thead>
<tr>
<th>PANEL TYPE</th>
<th>SIZE (Approx.)</th>
<th>No. required</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>7&quot; wall panels</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type A</td>
<td>15ft. x 8ft.</td>
<td>24</td>
</tr>
<tr>
<td>&quot; C</td>
<td>13ft.6ins. x 8ft.</td>
<td>2</td>
</tr>
<tr>
<td>&quot; G</td>
<td>8ft.6ins. x 8ft.</td>
<td>7</td>
</tr>
<tr>
<td>&quot; H</td>
<td>5ft.6ins. x 8ft.</td>
<td>4</td>
</tr>
<tr>
<td>&quot; J</td>
<td>7ft.6ins. x 8ft.</td>
<td>6</td>
</tr>
<tr>
<td><strong>7&quot; wall panel with beam</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type K</td>
<td>7ft.9ins. x 8ft.</td>
<td>2</td>
</tr>
<tr>
<td><strong>12&quot; wall panels</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type D</td>
<td>15ft. x 9ft.</td>
<td>4</td>
</tr>
<tr>
<td>&quot; E</td>
<td>5ft.6ins. x 8ft.3ins.</td>
<td>4</td>
</tr>
<tr>
<td>&quot; F</td>
<td>8ft.6ins. x 8ft.3ins.</td>
<td>1</td>
</tr>
<tr>
<td><strong>6½&quot; balcony panels</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>17ft. x 5ft.</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>11ft. x 3ft.</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>9ft. x 3ft.</td>
<td>4</td>
</tr>
<tr>
<td><strong>6½&quot; floor panels</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>15ft.9ins. x 8ft.6ins.</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>8ft.9ins. x 8ft.6ins.</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>9ft. x 3ft.3ins.</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>16ft.6ins. x 10ft.9ins.</td>
<td>7</td>
</tr>
<tr>
<td>UNIT TYPE</td>
<td>SIZE (Approx.)</td>
<td>No. required</td>
</tr>
<tr>
<td>---------------------------------</td>
<td>---------------------------</td>
<td>--------------</td>
</tr>
<tr>
<td>8in. mullion (2-storeys high)</td>
<td>16ft.9ins. x 1ft.4ins.</td>
<td>22</td>
</tr>
<tr>
<td>16in. corner &quot; (ditto)</td>
<td>16ft.9ins. x 1ft.4ins.</td>
<td>4</td>
</tr>
<tr>
<td>Dust chute unit 2ft. dia.</td>
<td>8ft. long</td>
<td>1</td>
</tr>
<tr>
<td>Ditto floor ring 2ft. dia.</td>
<td>6 ins. high</td>
<td>1</td>
</tr>
<tr>
<td>Single flight stair unit</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>Landing slab unit</td>
<td>-</td>
<td>2</td>
</tr>
</tbody>
</table>

Internal partition slabs would be cast 2\(\frac{3}{4}\) in. thick. Approximately 100 cu.ft. of poured in-situ concrete and 16 cwt. of steel reinforcement per floor would be required for "stitching" joints between units.

Site factory production

The site factory would be sited to accord with erection requirements, and operate with a manager and team of 23 operatives. The production cycle would be based on 24 hours for a weekly output of units for 1\(\frac{3}{4}\) floors, comprising approximately 9,500 cu.ft. of pre-cast concrete working 10 hours per day for 5\(\frac{1}{2}\) days with steel moulds heated by steam to accelerate curing in accordance with the following daily production cycle:
<table>
<thead>
<tr>
<th>Unit</th>
<th>Type</th>
<th>Size</th>
<th>Quantity per unit cu.ft.</th>
<th>Mould Type</th>
<th>Strike, clean &amp; prepare mould Mins.</th>
<th>Fix Electrics Mins.</th>
<th>Fix Steel reinfmt Mins.</th>
<th>Cast Concrete Mins.</th>
<th>Total Time Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>S.0.1</td>
<td>6½ floor slab</td>
<td>15'10x8'7</td>
<td>79</td>
<td>Horizontal</td>
<td>45</td>
<td>30</td>
<td>15</td>
<td>15</td>
<td>1½</td>
</tr>
<tr>
<td>S.0.2</td>
<td>&quot;</td>
<td>8'10x8'7</td>
<td>44</td>
<td>&quot;</td>
<td>60</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>1½</td>
</tr>
<tr>
<td>S.0.3</td>
<td>&quot;</td>
<td>9'0x5'3</td>
<td>17</td>
<td>&quot;</td>
<td>45</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>1½</td>
</tr>
<tr>
<td>S.0.4</td>
<td>&quot;</td>
<td>16'7x10'10</td>
<td>90</td>
<td>&quot;</td>
<td>45</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>1½</td>
</tr>
<tr>
<td>No. J</td>
<td>7&quot; wall units in Battery A</td>
<td>7'7x7'11</td>
<td>4 No. 140</td>
<td>Vertical Battery A</td>
<td>165</td>
<td>105</td>
<td>60</td>
<td>5½</td>
<td></td>
</tr>
<tr>
<td>2 No. H</td>
<td></td>
<td>5'7x7'11</td>
<td>2 No. 52</td>
<td>&quot;</td>
<td>165</td>
<td>105</td>
<td>60</td>
<td>5½</td>
<td></td>
</tr>
<tr>
<td>3 No. G</td>
<td></td>
<td>8'6x7'11</td>
<td>3 No. 117</td>
<td>&quot;</td>
<td>165</td>
<td>105</td>
<td>60</td>
<td>5½</td>
<td></td>
</tr>
<tr>
<td>1 No. K</td>
<td></td>
<td>7'10x7'11</td>
<td>1 No. 36</td>
<td>&quot;</td>
<td>165</td>
<td>105</td>
<td>60</td>
<td>5½</td>
<td></td>
</tr>
<tr>
<td>Total 345</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>60</td>
<td>5½</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. A</td>
<td>7&quot; wall units in Battery B</td>
<td>15'1x7'11</td>
<td>3 No. 210</td>
<td>Vertical Battery B</td>
<td>120</td>
<td>90</td>
<td>45</td>
<td>4½</td>
<td></td>
</tr>
<tr>
<td>1 No. C</td>
<td></td>
<td>13'8x7'11</td>
<td>1 No. 63</td>
<td>&quot;</td>
<td>120</td>
<td>90</td>
<td>45</td>
<td>4½</td>
<td></td>
</tr>
<tr>
<td>Total 273</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>60</td>
<td>4½</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. E</td>
<td>12&quot; and 7&quot; wall units in Battery C</td>
<td>5'7x8'4</td>
<td>1 No. 47</td>
<td>Vertical Battery C</td>
<td>120</td>
<td>90</td>
<td>60</td>
<td>4½</td>
<td></td>
</tr>
<tr>
<td>1 No. F</td>
<td></td>
<td>8'5x8'4</td>
<td>1 No. 70</td>
<td>&quot;</td>
<td>120</td>
<td>90</td>
<td>60</td>
<td>4½</td>
<td></td>
</tr>
<tr>
<td>4 No. A</td>
<td></td>
<td>15'1x7'11</td>
<td>4 No. 220</td>
<td>&quot;</td>
<td>120</td>
<td>90</td>
<td>60</td>
<td>4½</td>
<td></td>
</tr>
<tr>
<td>Total 337</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>60</td>
<td>4½</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Half landing &amp; stair flight</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>36</td>
<td>75</td>
<td>15</td>
<td>1½</td>
<td></td>
</tr>
<tr>
<td>Mullions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>16'8x1'4x8</td>
<td>15</td>
<td>75</td>
<td>15</td>
<td>1½</td>
</tr>
<tr>
<td>6½ Balcony slabs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>17'0x5'0</td>
<td>46</td>
<td>75</td>
<td>15</td>
<td>1½</td>
</tr>
<tr>
<td>11'0x3'0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>18</td>
<td>75</td>
<td>15</td>
<td>1½</td>
<td></td>
</tr>
<tr>
<td>9'0x3'0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>15</td>
<td>75</td>
<td>15</td>
<td>1½</td>
<td></td>
</tr>
<tr>
<td>2½ partitions in vertical batteries B &amp; C.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The floor slabs would be cast and lifted horizontally; wall cladding units would be cast horizontally in tilting moulds; wall and partition slabs cast vertically in batteries with mild steel bars cast in and threaded top and bottom to provide vertical continuity during assembly. The excess bolt length would fit into purpose-made cones in a pocket formed at each end of the wall units, above which a steel rod would run full height and project at the top to form a levelling bolt for the floor above. Threaded lifting sockets would be cast into all units together with the steel mesh reinforcement.

**Erection operations.**

The sequence of erection operations would comprise:

(a) positioning floor slabs on foundation walls with a gap between equal to the wall thickness less bearing steel reinforcement in loops projecting from edges of floor slab and top of foundations. The stitches would be reinforced with lateral steel bars provided to tie the structure together,

(b) pouring in-situ "stitching" concrete into the gaps, and vibrating it to form a joint which ties the structure together,

(c) lining and levelling the nuts on top of the levelling bolts which project through the units from the wall below, and placing a steel washer over each nut,

(d) laying a stiff mortar bed in the recess over the structural joint between the floor slabs where bearing on wall units,

(e) lowering cross wall units onto the washers and levelling bolts,

(f) propping and plumbing the walls,

(g) cleaning off the excess mortar from the base of wall units. About 48 hours later, the levelling nuts would be slightly unscrewed and the pockets filled in flush with mortar,

(h) forming vertical joints between wall units with in-situ concrete poured into opposing serrated grooves to avoid cold bridging effects
through the cladding in which a polystyrene layer is cast.

Horizontal waterproofing of the facade panels may be obtained by inserting compressible butyl foam strips and lightweight flashings.

When all the wall units are positioned, the floor slabs for the next storey above are positioned in order to tie the lower storey units together. After this has been done, the props would be removed, and finishing operations commence.

The following tables indicate average crane times for placing wall units:
### Average times of Crane Placing Wall Units - 12th to 15th floor - in minutes and Seconds

<table>
<thead>
<tr>
<th>Unit</th>
<th>Initial Lift</th>
<th>Level bolts</th>
<th>Set out position</th>
<th>Strike props</th>
<th>Strike floor channel or bks</th>
<th>Fix Channel</th>
<th>Slacken bolts</th>
<th>Load out mortar</th>
<th>Strike cramp or transfer levelling nut etc.</th>
<th>Crane Rig</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>40.64</td>
<td>3.20</td>
<td>6.94</td>
<td>6.44</td>
<td>2.76</td>
<td>2.40</td>
<td>2.14</td>
<td>2.37</td>
<td>4 falls low</td>
<td>66.89</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>41.84</td>
<td>3.20</td>
<td>6.94</td>
<td>3.11</td>
<td>1.50</td>
<td>1.88</td>
<td>2.14</td>
<td>2.37</td>
<td>0.30</td>
<td>&quot;</td>
<td>63.82</td>
</tr>
<tr>
<td>D</td>
<td>33.44</td>
<td>3.20</td>
<td>6.94</td>
<td>7.02</td>
<td>2.88</td>
<td>3.08</td>
<td>2.14</td>
<td>1.18</td>
<td>2.45</td>
<td>2 falls medium</td>
<td>62.33</td>
</tr>
<tr>
<td>E</td>
<td>44.44</td>
<td>3.20</td>
<td>6.94</td>
<td>3.51</td>
<td>1.50</td>
<td>1.88</td>
<td>2.14</td>
<td>1.18</td>
<td>6.39</td>
<td>2 falls low</td>
<td>71.18</td>
</tr>
<tr>
<td>F</td>
<td>50.84</td>
<td>3.20</td>
<td>6.94</td>
<td>3.51</td>
<td>1.50</td>
<td>1.88</td>
<td>2.14</td>
<td>1.18</td>
<td>6.90</td>
<td>&quot;</td>
<td>77.88</td>
</tr>
<tr>
<td>G</td>
<td>37.48</td>
<td>3.20</td>
<td>6.94</td>
<td>3.22</td>
<td>1.50</td>
<td>2.14</td>
<td>1.18</td>
<td>0.30</td>
<td>2 falls medium</td>
<td>57.84</td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>31.52</td>
<td>3.20</td>
<td>6.94</td>
<td>3.11</td>
<td>-</td>
<td>-</td>
<td>2.14</td>
<td>1.18</td>
<td>0.30</td>
<td>2 falls low</td>
<td>48.29</td>
</tr>
<tr>
<td>J</td>
<td>45.84</td>
<td>3.20</td>
<td>6.94</td>
<td>8.36</td>
<td>-</td>
<td>-</td>
<td>2.14</td>
<td>1.18</td>
<td>0.42</td>
<td>2 falls medium</td>
<td>67.66</td>
</tr>
<tr>
<td>K</td>
<td>44.76</td>
<td>3.20</td>
<td>6.94</td>
<td>-</td>
<td>0.75</td>
<td>-</td>
<td>2.14</td>
<td>1.18</td>
<td>0.42</td>
<td>&quot;</td>
<td>59.39</td>
</tr>
</tbody>
</table>

### Placing Walls - 16th to 19th floor - in minutes and seconds of Crane Time

<table>
<thead>
<tr>
<th>Unit</th>
<th>Initial Lift</th>
<th>Level bolts</th>
<th>Set out position</th>
<th>Strike props</th>
<th>Strike floor channel or bks</th>
<th>Fix Channel</th>
<th>Slacken bolts</th>
<th>Load out mortar</th>
<th>Strike cramp or transfer levelling nut etc.</th>
<th>Crane Rig</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>42.16</td>
<td>3.20</td>
<td>6.94</td>
<td>6.49</td>
<td>2.76</td>
<td>2.40</td>
<td>2.14</td>
<td>2.37</td>
<td>4 falls low</td>
<td>68.41</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>43.36</td>
<td>3.20</td>
<td>6.94</td>
<td>3.11</td>
<td>1.50</td>
<td>1.88</td>
<td>2.14</td>
<td>2.37</td>
<td>0.30</td>
<td>&quot;</td>
<td>64.80</td>
</tr>
<tr>
<td>D</td>
<td>35.12</td>
<td>3.20</td>
<td>6.94</td>
<td>7.02</td>
<td>2.88</td>
<td>3.08</td>
<td>2.14</td>
<td>1.18</td>
<td>2.45</td>
<td>2 falls medium</td>
<td>64.01</td>
</tr>
<tr>
<td>E</td>
<td>42.64</td>
<td>3.20</td>
<td>6.94</td>
<td>3.51</td>
<td>1.50</td>
<td>1.88</td>
<td>2.14</td>
<td>1.18</td>
<td>6.39</td>
<td>2 falls low</td>
<td>72.98</td>
</tr>
<tr>
<td>F</td>
<td>52.04</td>
<td>3.20</td>
<td>6.94</td>
<td>3.51</td>
<td>1.50</td>
<td>1.88</td>
<td>2.14</td>
<td>1.18</td>
<td>6.99</td>
<td>2 falls low</td>
<td>79.78</td>
</tr>
<tr>
<td>G</td>
<td>39.16</td>
<td>3.20</td>
<td>6.94</td>
<td>3.22</td>
<td>1.50</td>
<td>2.14</td>
<td>1.18</td>
<td>0.30</td>
<td>2 falls medium</td>
<td>59.52</td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>32.30</td>
<td>3.20</td>
<td>6.94</td>
<td>3.11</td>
<td>-</td>
<td>-</td>
<td>2.14</td>
<td>1.18</td>
<td>0.30</td>
<td>2 falls low</td>
<td>49.17</td>
</tr>
<tr>
<td>J</td>
<td>47.52</td>
<td>3.20</td>
<td>6.94</td>
<td>8.36</td>
<td>-</td>
<td>-</td>
<td>2.14</td>
<td>1.18</td>
<td>0.42</td>
<td>2 falls medium</td>
<td>62.34</td>
</tr>
<tr>
<td>K</td>
<td>46.44</td>
<td>3.20</td>
<td>6.94</td>
<td>-</td>
<td>0.75</td>
<td>-</td>
<td>2.14</td>
<td>1.18</td>
<td>0.42</td>
<td>2 falls medium</td>
<td>61.07</td>
</tr>
</tbody>
</table>
The lifting speeds of the erection crane would be varied to minimise the hoisting time of units positioned at upper floors:

<table>
<thead>
<tr>
<th>Crane Rig</th>
<th>Lifting speed per min.</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-fall</td>
<td></td>
</tr>
<tr>
<td>low gear</td>
<td>33 ft.</td>
</tr>
<tr>
<td>medium gear</td>
<td>85 ft.</td>
</tr>
<tr>
<td>high gear</td>
<td>164 ft.</td>
</tr>
<tr>
<td>2-fall</td>
<td></td>
</tr>
<tr>
<td>low gear</td>
<td>66 ft.</td>
</tr>
<tr>
<td>medium gear</td>
<td>170 ft.</td>
</tr>
<tr>
<td>high gear</td>
<td>323 ft.</td>
</tr>
</tbody>
</table>

Under normal conditions, a static tower crane on concrete beams with sleepers and track, and tied back to the structure at increased heights would be utilised for hoisting all pre-cast units from the stacking areas to required positions in the structure, as well as reinforcement, and the in-situ concrete mixed at ground level for stitching joints between units. The mortar for bedding wall units would be mixed at each erection floor level.

The following tables indicate the average total crane and associated team's times for erecting wall units, including placing, lining and plumbing:
The following table indicates the average total crane and associated team's time for placing and plumbing balcony units:

<table>
<thead>
<tr>
<th>UNIT</th>
<th>Weight in cwt.</th>
<th>Crane time placing unit</th>
<th>Manhours levelling etc.</th>
<th>Total time</th>
<th>Crane rig</th>
<th>Floor level</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>93</td>
<td>66.89</td>
<td>26.66</td>
<td>93.55</td>
<td>4 falls low</td>
<td>12 - 15th</td>
</tr>
<tr>
<td>A</td>
<td>93</td>
<td>68.41</td>
<td>26.66</td>
<td>95.07</td>
<td>&quot;</td>
<td>16 - 19th</td>
</tr>
<tr>
<td>C</td>
<td>84</td>
<td>63.82</td>
<td>26.59</td>
<td>90.41</td>
<td>&quot;</td>
<td>12 - 15th</td>
</tr>
<tr>
<td>C</td>
<td>84</td>
<td>64.80</td>
<td>26.59</td>
<td>91.39</td>
<td>&quot;</td>
<td>16 - 19th</td>
</tr>
<tr>
<td>D</td>
<td>97</td>
<td>62.33</td>
<td>32.32</td>
<td>94.65</td>
<td>4 falls med</td>
<td>12 - 15th</td>
</tr>
<tr>
<td>D</td>
<td>97</td>
<td>64.01</td>
<td>32.32</td>
<td>96.33</td>
<td>&quot;</td>
<td>16 - 19th</td>
</tr>
<tr>
<td>E</td>
<td>80</td>
<td>71.18</td>
<td>10.12</td>
<td>81.30</td>
<td>2 falls low</td>
<td>12-15th</td>
</tr>
<tr>
<td>E</td>
<td>80</td>
<td>72.98</td>
<td>10.12</td>
<td>83.10</td>
<td>&quot;</td>
<td>16 - 19th</td>
</tr>
<tr>
<td>F</td>
<td>71</td>
<td>77.88</td>
<td>12.84</td>
<td>90.72</td>
<td>&quot;</td>
<td>12 - 15th</td>
</tr>
<tr>
<td>F</td>
<td>71</td>
<td>79.76</td>
<td>12.84</td>
<td>92.62</td>
<td>&quot;</td>
<td>16 - 19th</td>
</tr>
<tr>
<td>G</td>
<td>52</td>
<td>57.84</td>
<td>15.46</td>
<td>73.30</td>
<td>2 falls med</td>
<td>12 - 15th</td>
</tr>
<tr>
<td>G</td>
<td>52</td>
<td>59.52</td>
<td>15.46</td>
<td>74.98</td>
<td>&quot;</td>
<td>16 - 19th</td>
</tr>
<tr>
<td>H</td>
<td>34</td>
<td>48.29</td>
<td>17.78</td>
<td>66.07</td>
<td>2 falls low</td>
<td>12 - 15th</td>
</tr>
<tr>
<td>H</td>
<td>34</td>
<td>49.17</td>
<td>17.78</td>
<td>66.95</td>
<td>&quot;</td>
<td>16 - 19th</td>
</tr>
<tr>
<td>J</td>
<td>47</td>
<td>67.66</td>
<td>12.40</td>
<td>80.06</td>
<td>2 falls med</td>
<td>12 - 15th</td>
</tr>
<tr>
<td>J</td>
<td>47</td>
<td>69.34</td>
<td>12.40</td>
<td>81.74</td>
<td>&quot;</td>
<td>16 - 19th</td>
</tr>
<tr>
<td>K</td>
<td>27</td>
<td>59.39</td>
<td>37.66</td>
<td>97.05</td>
<td>&quot;</td>
<td>12 - 15th</td>
</tr>
<tr>
<td>K</td>
<td>27</td>
<td>61.07</td>
<td>37.66</td>
<td>98.73</td>
<td>&quot;</td>
<td>16 - 19th</td>
</tr>
<tr>
<td>Type</td>
<td>Weight</td>
<td>No. Floor</td>
<td>No. Crane</td>
<td>Lifting Time</td>
<td>Placing Time</td>
<td>Line &amp; Plumb. Time</td>
</tr>
<tr>
<td>--------------</td>
<td>----------------</td>
<td>-----------</td>
<td>-----------</td>
<td>--------------</td>
<td>--------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>Balcony</td>
<td>3 to 6 tons</td>
<td>4</td>
<td>12-15</td>
<td>2 falls low</td>
<td>8.06</td>
<td>24.18</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>16-19</td>
<td></td>
<td>8.82</td>
<td></td>
</tr>
<tr>
<td>Balcony</td>
<td>25 cwt. to 3 tons</td>
<td>12</td>
<td>12-15</td>
<td>2 falls med.</td>
<td>6.70</td>
<td>20.10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>16-19</td>
<td></td>
<td>6.83</td>
<td></td>
</tr>
<tr>
<td>Double</td>
<td>ne 25 cwt.</td>
<td>12-15</td>
<td>2 falls high</td>
<td>5.79</td>
<td>17.37</td>
<td>42.48</td>
</tr>
<tr>
<td>height mullion</td>
<td></td>
<td>16-19</td>
<td></td>
<td>6.21</td>
<td>18.63</td>
<td></td>
</tr>
<tr>
<td>Corner</td>
<td>ne 25 cwt.</td>
<td>12-15</td>
<td></td>
<td>7.34</td>
<td>22.02</td>
<td>32.29</td>
</tr>
<tr>
<td>mullion</td>
<td></td>
<td>16-19</td>
<td></td>
<td>7.76</td>
<td>23.28</td>
<td></td>
</tr>
</tbody>
</table>

The following table indicates the average total crane and associated team's time for placing and plumbing dust chute and stair units:
<table>
<thead>
<tr>
<th>Type</th>
<th>Weight</th>
<th>No. Floor Level</th>
<th>Crane Rig</th>
<th>Lifting Time</th>
<th>Placing Time</th>
<th>Line &amp; Plumb.</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dust Chute</td>
<td>ne 25 cwt.</td>
<td>12-15</td>
<td>2 falls high</td>
<td>8.42</td>
<td>25.26</td>
<td>-</td>
<td>33.68</td>
</tr>
<tr>
<td></td>
<td></td>
<td>16-19</td>
<td>&quot;</td>
<td>8.00</td>
<td>26.40</td>
<td>-</td>
<td>35.20</td>
</tr>
<tr>
<td>Floor rings</td>
<td>ne 25 cwt.</td>
<td>12-15</td>
<td>&quot;</td>
<td>3.69</td>
<td>7.38</td>
<td>5.29</td>
<td>16.36</td>
</tr>
<tr>
<td></td>
<td></td>
<td>16-19</td>
<td>&quot;</td>
<td>4.07</td>
<td>8.14</td>
<td>5.29</td>
<td>17.50</td>
</tr>
<tr>
<td>Single flight</td>
<td>25 cwt. to 3</td>
<td>12-15</td>
<td>2 falls med.</td>
<td>8.12</td>
<td>24.36</td>
<td>15.37</td>
<td>47.85</td>
</tr>
<tr>
<td>STAIRS</td>
<td>3 tons</td>
<td>16-19</td>
<td>&quot;</td>
<td>8.47</td>
<td>25.41</td>
<td>15.37</td>
<td>49.25</td>
</tr>
<tr>
<td>Landing Slab</td>
<td>&quot;</td>
<td>12-15</td>
<td>2 falls med.</td>
<td>6.88</td>
<td>20.64</td>
<td>-</td>
<td>27.52</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15-19</td>
<td>&quot;</td>
<td>7.23</td>
<td>21.69</td>
<td>-</td>
<td>28.92</td>
</tr>
</tbody>
</table>

The following table indicates the average total crane and associated team's time for placing and plumbing floor slab units:
<table>
<thead>
<tr>
<th>Type</th>
<th>Size</th>
<th>No.</th>
<th>Crane Rig</th>
<th>Lifting Time</th>
<th>Placing Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>801</td>
<td>15'10 x 8'7</td>
<td>19</td>
<td>4 falls med.</td>
<td>9.12</td>
<td>30.36</td>
</tr>
<tr>
<td>802</td>
<td>8'10 x 8'7</td>
<td>5</td>
<td>&quot;</td>
<td>9.12</td>
<td>27.96</td>
</tr>
<tr>
<td>803</td>
<td>9'0 x 3'3</td>
<td>5</td>
<td>4 falls high</td>
<td>7.96</td>
<td>23.88</td>
</tr>
<tr>
<td>804</td>
<td>16'7 x 10'10</td>
<td>7</td>
<td>4 falls low</td>
<td>12.43</td>
<td>34.71</td>
</tr>
</tbody>
</table>

**Erection Cycle of Operations**

The erection cycle for a typical floor (12th to 15th) would be based on the following sequence of operations:
<table>
<thead>
<tr>
<th>OPERATION</th>
<th>Quantity per floor</th>
<th>Site Labour Team in Hours</th>
<th>Crane Time in Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Place and plumb walls</td>
<td>54 No Units</td>
<td>77.5</td>
<td>58</td>
</tr>
<tr>
<td>ditto balconies</td>
<td>12 No</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>ditto floor slabs</td>
<td>36 No</td>
<td>14</td>
<td>5.5</td>
</tr>
<tr>
<td>Load out 2(\frac{3}{4}) partitions and place and plumb</td>
<td>42 No</td>
<td>6.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Place and plumb stair flights &amp; landing slab</td>
<td>2 No</td>
<td>2</td>
<td>1.5</td>
</tr>
<tr>
<td>ditto dust chutes</td>
<td>1 No</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Stitching steel in joints</td>
<td>16 cwt.</td>
<td>5</td>
<td>0.5</td>
</tr>
<tr>
<td>In-situ concrete in joints</td>
<td>97 cu. ft.</td>
<td>7</td>
<td>1.5</td>
</tr>
<tr>
<td>Place and plumb mullions</td>
<td>4 No</td>
<td>17.5</td>
<td>10.5</td>
</tr>
</tbody>
</table>
The following graphs summarise the associated crane times and sequences of erection operations, and indicate that:

(a) The differences in crane time hoisting units from 10th to 20th floor does not vary by more than approximate 10% increase from the time required for hoisting units to lower floor levels due to quickening the speed of the crane's lift by changing to a faster gear. However, this advantage may be obviated to a certain extent by more frequent high winds delaying crane working at increased heights.

(b) All departures from standardised units involve a greatly increased time for placing. For example:

(i) Wall units cast with a cantilever beam to form a corridor opening (unit K), and one levelling bolt instead of two, take longer to level because the beam rests on another seating and tends to pivot and skew when lined;

(ii) Mullion units require two men working on different floor levels to balance their ends and line them both horizontally and vertically.

(c) The heaviest floor slab units (127 cwt.) bear on a greater number of wall units, and consequently require increased time for levelling and placing. In addition, their extra weight necessitates more manhours pushing and pulling the units into position whilst still being held in position by the erection crane.

(d) The additional weight of a wall unit is of lesser significance, because this type of unit can be dropped into position, and then propped.
(c) Frame Systems

Designs for building types based on pre-cast reinforced concrete structural frames should enable the high cost of the precision made steel moulds required to produce standardised beam and column units with close tolerances to be economically viable by repeatedly utilising the same basic sections a sufficient number of times to enable the capital investment required for factory production to be recovered within a comparatively short period, and achieve savings in cost and time.

Standardised moulds for pre-cast concrete frames can provide scope for the expression of individual designs in a variety of ways. Grids can be varied to provide any chosen module, e.g. 4 ft. or 5 ft. so that external mullions can be spaced at 4 ft., 5 ft., 8 ft., or 10 ft. etc., centres. The structural frame can be exposed and manufactured with white cement and aggregates to obtain an acceptable architectural finish. External work can be brought off the grid by cantilevering the floor out to carry a curtain wall or other chosen elevation in any kind of materials (brickwork, timber frames, exposed aggregate wall panels, etc.) and thus achieve variation in pattern, texture and colour.

Floors can be standardised, or patent types of construction utilised. Greater economy could be obtained, particularly in view of the coming change over to the metric system, if their dimensions were also to be standardised. Columns, edge beams and spine beams can be cast to any length consistent with the span/load limitations. The whole framework can be tied together by a structural floor screed, which helps the floor to function as a horizontal diaphragm by transmitting wind loads through to shear walls.

Factors which affect the economy of pre-cast concrete frame systems relate to:

(1) maximum number of repetitive units;
(2) minimum amount of times each unit can be handled;
Erecting frame units
(3) availability of site facilities for production and stacking of units without impeding erection operations;
(4) the gearing of factory output to erection requirements, and efficient stacking to minimise damage and cranage;
(5) methods of yoking groups of units together to facilitate hoisting to position;
(6) efficient cranage for handling units;
(7) type of factory production and moulds;
(8) jointing techniques.

Pre-cast frames are about 20 to 30 per cent cheaper than steel frames encased in concrete and comparable in cost with uncased steel frames, which require the additional expense of fire protection with other materials, thus reducing speed of erection operations. They avoid most of the disadvantages of in-situ work, benefit from some of the advantages of steelwork, and permit extensive unification of structural units for building types with relatively large areas and spans on the basis of a modular system. High tensile reinforcing steel, high strength concrete, pre-stressing techniques, and improved ratio of height to span enables dimensions to be increased for the economic factory production of standardised pre-cast beam, column and curtain wall panel units, which can be rapidly erected by cranes. Improved moulding methods provide facade surfacing of units with smooth or textured weatherproofed finish externally, and smooth inner surfaces ready for direct spray painting.

Five main component types are required to carry superimposed floor loads and provide for the stability of the structure:

(1) exposed external, and internal columns;
(2) beams - these may be visually absent, as in flush slab construction;
(3) floors - solid, hollow and T-section;

...
(4) stairs - flights and landings;
(5) stability walls - independent, or forming part of lift or staircase walls.

The stability of the frame depends largely on the stability walls, so the loading of vertical components can be isolated to form racking forces by using internal walls, but joints between the frame are extremely vital, so that visible signs of any movement in the structure should be controlled to occur only at these points.

Reduction in the weight of the structure can be achieved by (1) lowered strength characteristics and close control of materials to improve quality of concrete, (2) standardising a minimum number of beam and column sizes, with varying loads taken up by alternative reinforcement, the joints between beams and columns being load-transferring, (3) light cladding of maximum size for efficient cranage, (4) pre-finishing units in the factory to reduce the work of other trades.

3.3.5 Jointing Tolerances

(a) Generally. The design of pre-cast concrete units for factory production should ensure that variations in dimensions after manufacture will be taking up in site jointing, which influence the systems' success and speed of erection due to problems affecting the handling, weight limitation, and ready assembly of structural elements, and the durability and ease of joint repair.

As the most critical parts of pre-cast concrete structures occur at the joints between units, where some of the highest forces occur, such joints must be capable of transferring forces without undue deflection or deformation, with a minimum of support.

The physical limitations of concrete are such that precise connections can only be achieved by the interaction of concrete with other suitable
media. Any in-situ mass concrete filling that may be required at the joints should be easily handled to position, poured, and compacted. Joints with steel reinforcement, bolts, and plates are much more costly, and delay the speed of erection operations.

(b) Joints in panel systems. Panel systems avoid the bending moment induced by the load in a frame system, and require only one joint made with direct loading. Such systems tend towards casting with close tolerances the largest possible units to minimise site joints, and omit traditional finishings to mask inaccuracies. The larger the units designed, the greater will be the movements that occur, with consequent demand on sealants used at the joints of facade panels, which will vary according to height of structure.

Joints between structural panel units taking stresses vary with the type (wet or dry) and position of the joint, and should be designed to include for tolerances and creep. Close tolerances are costly to achieve, but joints become more difficult to make as tolerances increase.

Problems relating to the design of joints between structural panel units taking stresses include:

(i) Tolerances, which may need to be acceptable for structural, aesthetic, waterproof, thermal and sound resistance purposes. A joint may be required to accommodate tolerances due to manufacture and setting out on site, as well as allowances for working loads; exclude weather, allow for thermal and moisture movements, preserve sound and thermal insulation, and withstand factors due to manufacturing techniques and methods of site assembly, e.g. sandwich facade panel units formed with a cavity to reduce noise and increase insulation between two skins; and designed with structural and weather resistant qualities, and half the weight of dense concrete.

(Drawings 1 and 2).
Fig. 1

**Horizontal joint in Facade unit**

- Facade unit
- Polystyrene
- Mortar bed
- In situ concrete
- Stitch
- Sealing strip
Fig. 2

VERTICAL JOINT IN FACADE UNIT
(ii) Creep. Temperature creep and shrinkage in pre-cast concrete structures necessitate movement joints designed to function without damaging units. Facade sandwich panels and other structural units, which vary the line of action of their loads as the temperatures of the inner and outer skins vary, should be designed to ensure uneven distribution which avoids overstressing.

Roof movements due to temperature creep can damage walls. Where possible, insulation with a light reflective surface should be provided above the structural roof slab. Creep deflection of floor slabs can damage partitions and finishes, and must be avoided.

(iii) Type of Joint. Wet joints are costly and delay the erection cycle. Designs should provide for a stable structure to minimise propping units, and enable any grout jointing or "stitching" to be carried out when required, and not during erection operations. Units should be designed with bearing areas capable of accommodating reasonable tolerances without spalling at edges, so that they can be placed without fouling any projecting reinforcement.

(iv) Position of Joint. Joints between plain structural elements such as floor and wall units usually have in-situ concrete "stitching" poured around additional steel reinforcement to provide continuity and fire protection, and prevent the slabs from sliding apart and forming potential crack lines which may reduce sound and thermal insulation, fire resistance, and structural strength. (Figs. 3 and 4).

The function of vertical joints between wall units is to prevent one wall sliding against another, and a "frog" is provided to prevent this occurring.

Horizontal joints between wall units should be in compression to minimise the cost of steel reinforcement. Where tension occurs, spliced reinforcement joints are more economical to form than joints with plates,
bolts and nuts levelled on the lower unit and adjusted when the upper unit has been plumbed, as this form of joint delays the cycle of erection operations. (Fig. 5).

One economical method of avoiding costly joints at the internal angles of buildings of T plan shape consists of forming the angles with poured in-situ concrete to fit the grid module to avoid difficult jointing and weatherproofing of the internal angles.

Landing units and stair flights should be sealed with the minimum of bearings to facilitate levelling operations.

(v) Propping and Strutting, which requires minimising for optimum speed of erection. Units should be designed for sufficiently firm assembly which stabilises the structure and supports their dead weights, and construction loads. Attempts to reduce the erection crane's holding time whilst wall units are being fixed include the development of a free-standing storey height unit L-shaped on plan, 8 ft. long x 4 ft. long on return.
Joint of floor slab to wall unit.

In situ concrete "stitching."
In situ concrete "stitching."

**Joint of Floor Slabs**
(c) Joints in Frame Systems.

The necessity to develop the load-carrying capacity of reinforced concrete frame members through the site joints requires special provisions to be made at the ends of members to transmit forces from the reinforcement, and attention must be paid to the jointing medium.

The construction of pre-cast reinforced concrete frames based on storey height columns is such that the eccentricities can be imparted by the tendency to rotation of the edge beams sandwiched between the column ends, which may impart additional bending stresses to the column ends, causing them to disrupt at an earlier stage than when subject to pure axial load.

In order to counteract this tendency, it is necessary (1) to improve the resistance to bursting of the ends of heavily reinforced columns in order to provide a better margin of safety against cracking, and in addition, make the failure load at this point equate to the strength of the column shaft in order to improve the overall carrying capacity, and provide an additional margin to contribute to the bending stresses that might arise from edge beam rotation, and (2) to improve the condition of the load application by (a) the introduction of a soft bedding joint (e.g. epoxy mortar), which will permit rotation, or (b) limiting the area of bedding to more nearly accord to a pin end, and thus restrict the eccentricity and moment that can be induced.

Care must be taken to ensure that reinforcement is not displaced during casting, and that ends of bars are covered to required tolerances which permit easy erection, and maintain an acceptable finished building (e.g. ± 1/4 in. in 10 ft. for lengths of columns). Closer tolerances (e.g. ± 1/16 in.) require very much more expensive moulds. Vertical joints should allow for additional lengths of tolerances, and horizontal joints allow sufficient tolerance on the height of the building to maintain
Horizontal joints between column and wall units can be divided into:

(a) joints of units in which the concrete can bear the load, and reinforcement is nominal because the units are not required to resist high bending moments, and

(b) joints of units in which reinforcement is required for compression or tension, and some form of coupling is required.
Section of Columns & Edge Beam

Foot of column

3/8" dia. hairpin

Floor slab (ribbed)

7/16" (0/4)

Edge beam

1/8" dowel bar cast in

3/16" dia. stirrups & 6" c.c. closed to 3" c.c. at ends for 12".

12" x 12" storey height column

4 No. 1/8" dia. bars

1" dia. grout holes

2" x 2" pocket 12" long

Joint in pre-cast concrete

FRAME UNITS
The stability of the structures for pre-cast concrete systems needs to be checked on site, as they do not usually include the additional safeguards of continuity and rigid partitioning achieved in traditional building.

Industrialised system buildings based on pre-cast concrete construction are of too recent construction to enable much information to be gained about the most sensitive parts of their structures - grouts in vertical and horizontal joints. But at present, there are no serious grounds for considering their life to be lower than that of traditionally constructed buildings.

3.3.6. Box Construction

In the U.S.S.R., one form of this type of construction is used for constructing multi-rise blocks of flats up to 12 storeys in height with pre-cast concrete room size boxes weighing 20 tons each and hoisted to position by portal cranes straddling the blocks.

In Canada, another form of box construction has been used by pre-casting three dimensional load-bearing units, each 17 ft. 6 ins. x 38 ft. 6 ins. x 10 ft. high of 5000 lbs. concrete, steam cured in steel moulds for the construction of 158 centrally heated and air-conditioned single family dwellings which vary from one-bedroom dwellings of 600 sq. ft. to four-bedroom dwellings of 1700 sq. ft., built up into a multi-storey project.

The units weigh 70 to 90 tons each, and are handled by stiff leg derrick cranes supported by a 70 ft. x 70 ft. base on a moving track 70 ft. wide, to a finishing area, where most of the components, including completely pre-fabricated kitchens and bathrooms are installed in an assembly line method before the roof is connected. A sub-floor space in the unit contains all plumbing and electrical services, including a fan coil unit supplied with hot and cold water from a central plant for conversion into warm and cold air and distribution through thin slots in the edge of the floor.
The units are erected one on top of the other, carry most of the load through walls and piers, are connected together by post-tensioning and bolting, and incorporated into the structure so that adjacent walls, floors and ceilings of adjoining houses are separated to achieve a high level of insulation from sound and vibration. Further structural support is provided by 10 ft. high horizontal walkways, which contain the mechanical services, and horizontally transmit part of the load to vertical elevator and stair cores. Overall stability for wind and seismic conditions is provided by the action of the box units and side walks.

The project incorporates shops, offices, covered parking areas, and a network of surrounding playgrounds and parks, the all-in cost of which is approximately £27,750 per unit. More than half of the cost is taken up by mechanical handling and factory plant costs, and the learning time required for erection operations. It is anticipated by the designers that increased production for outputs of 25,000 dwellings would reduce the all-in unit cost to £7,000, but in view of the appearance of the project (Photograph ), it appears unlikely that this volume of demand will ever be required.
3.3.7. Composite pre-cast and poured in-situ concrete construction.

Systems for dwellings which are based on composite pre-cast and poured in-situ reinforced concrete construction have the advantage of obviating complex vertical jointing of pre-cast structural elements by designing pre-fabricated vertical load-bearing units to support poured in-situ concrete floor slabs which compensate for tolerances in the erection of the vertical units, distribute loads evenly over the units they bear on, and provide bracing to the structure.

Vertical units can be cast (a) to form insulated facade panels and all load-bearing walls so that non-structural partitions can be designed with light materials to reduce dead loads,

(b) with projecting hooks at the top for the steel bar reinforcement of the poured in-situ floor slabs to pass through and help tie the structure together, and

(c) to form complex structural bathroom and kitchen units of shell type construction which can be designed to incorporate ducts, flues, air inlets, waste stacks, services, and all requisite fastenings and attachments in the moulds for the simple installation of equipment on site.

Design flexibility can be obtained by adapting the in-situ concrete floors to suit variations in the planning of different dwelling types based on the standardised wall units, and varying surface treatment and fenestration of facade panels incorporating windows, which can also function as load-bearing walls.

Some "closed" systems pre-fabricate (a) standard plywood shutters on light steel adjustable props which provide 50 to 60 uses for supporting the poured in-situ concrete floors, and (b) vast steel bar reinforcement cages with services incorporated at ground level and hoisted to position in one operation by a spreader frame attachment of the erection crane.

Other systems are based on pre-fabricated steel shutters with built-
in services attached to the steel reinforcing bars, and utilise steam pipes to accelerate the concrete maturing, with controlled temperature to ensure that the concrete hardens overnight. By such methods, a complete floor can be constructed in two days.

3.3.8. Composite Steel and Concrete Construction.

Until recently, the design of composite beams in structural steel and reinforced concrete was based on elastic concepts assuming a modular ratio \( Z = m/f \) to determine the transformed section of the concrete area into an equivalent steel area on the hypothesis of complete interaction between the two materials, although (a) horizontal slip at the interface cannot be completely stopped, and (b) no allowance is included in the theory for concrete creep and shrinkage affecting the stress condition within the beam.

The more economical current approach of ultimate load design based on a specified load factor, provides difficulties when selecting a suitable steel beam which balances the concrete slab to give required moment of resistance, as there are normally six basic parameters to be considered for the ultimate load design of a composite section having the plastic neutral axis in the slab, but enables large reductions to be achieved for the design of steel columns as composite construction with reinforced concrete. By this means, savings of approximately 45 per cent in the weight of the steel columns can be achieved, the volume of concrete remaining constant. A code of practice relating to this method of design is in course of preparation. C.P. 117: Part 1 permits beams to be designed in accordance with this approach, so that full advantage may be taken of the plastic resistance of the steel and the capacity of the concrete casing to take up part of the load and reduce the weight of the steelwork.

The economic design of a steel column to act in conjunction with concrete casing achieves savings in costs by assuming that the yield strength
of the steel is reached simultaneously with the crushing value of the concrete, so that both the steel and the concrete casing take their part of the loading in the most economic manner.

Plain beams (i.e. those not stiffened with a concrete casing) in steel skeleton frames require a dry casing for fire protection, and a mechanical connection between the top flange and a concrete floor slab. When the whole joist is in tension, and works in conjunction with the concrete slab in compression, an economic section is obtained when the neutral axis lies within the thickness of the slab.

With composite construction based on elastic theory, concrete cased steel beams can be economically designed by deliberately proportioning the composite sections so that the neutral axis coincides with the junction of the underside of the slab and top flange of the steel joist. When based on ultimate load theory, the beams are usually designed without concrete encasement in a similar manner.

Present design rules do not rationally take into account the concrete casing to the columns of a multi-storey frame as contributing adequately to the increased strength and stiffness of the encased stanchion. This results in differences of design requirements for a reinforced concrete column and an encased steel stanchion of the same size, which are considerable.

When a steel beam is designed to act in conjunction with the concrete floor slab, part of the slab must be included as part of the beam in order to achieve economy by reducing the size of the beam. A more economic concept for a structural steel frame would be to assume that only all the floor loads are supported by the beams and columns, wind forces being resisted by the floor slabs, and transferred back to suitably positioned stability walls. These would either take the form of flank walls, or walls forming staircase approaches; or lift shaft and staircase walls could be integrated to form stiff cantilever core structures in reinforced concrete designed to accommodate all the
wind forces, the perimeter structural steel columns and beams trimming back to the core.

The main difference in design approach between this country and the U.S.A. is that in the States the stanchion grid is opened out (e.g. 80 ft. x 35 ft.) to provide uninterrupted floor space which permits open planning. The deep beams that result from such grids increase storey heights, the space between the beam and floor soffite being utilised for running mechanical and electrical service installations. This method of design makes the use of structural steelwork much more economical than reinforced concrete, because the volume of concrete required to support such large spans would be excessive compared with the required steelwork, with consequential increase of dead weight and foundation sizes.

The box-shell design of composite construction with steel framework and in-situ reinforced concrete provides for contribution to load support and transverse stability from ancillary elements of the structure, each medium depending on the other for individual stability, and influencing the other in their combined operations.

The problems of design relate to the effective interaction between the beams and the slab, their extension to the design of the whole structure, and the economic utilisation of all the elements of the structure which can effectively contribute to the stability and support of the applied load. This includes the steel skeleton of columns and beams, as well as the floor slabs and walls. Much of the simplicity of the framework is lost where the stiffness required to stabilise a tall building is confined to the skeleton alone, as this leads to cumbersome and costly beam to column connections.

Stability is effectively achieved by transferring the distributing forces through the floors to the walls, and thence to the ground, thus simplifying the beam to column connections which are made with only nominal stiffness, and can be economically joined with friction grip bolts. The floors are
arranged to act as horizontal girders between strong points, generally achieved by continuity of the membrane. Additional reinforcement is not usually required to stiffen the slab for this purpose.

The strong points are formed from the walls enclosing the stairwell, service area, or permanent partitions, which act as vertical cantilever girders anchored to the foundations. These elements are conveniently designed with the stanchions and cross-beams acting as tension members enclosing concrete or brick panels, which provide the complementary compression. Beams are formed jointly with the floor slab in compression acting compositely with the steel joists.

Composite construction of structural steel sections with concrete floors and walls becomes economic when full advantage is taken of the maximum strength available in the combined materials. Where steel beams and concrete floor slabs are designed as a structural unit, the columns must be sufficiently rigid to withstand gravity and wind loads in order to reduce deflection and floor thicknesses. Alternatively adjacent bays or cantilevers must be provided to ensure semi-rigid construction acting between the limits of design assumptions.

Savings can be achieved by (1) allowing for the concrete casing protecting steel members to be taken into account when computing their carrying capacity, (2) providing additional steel reinforcement to obtain smaller steel sections and reduced volume of concrete casing, or (3) using composite stanchions, e.g. two opposing channels filled with vibrated in-situ concrete can save up to 50 per cent of steel in normal stanchions.

When designed on the ultimate load basis, composite action between the steel floor beams and concrete floors may be economically achieved to obtain smaller sections by welding upstand shear studs to the top flanges of the joists and pouring in-situ floor concrete around them so that when the superload is applied, interaction takes place between the beam and floor by transmission
of the horizontal stress through the studs. Alternatively, epoxy resins can be used as reliable and safe sheer connectors to withstand either static or dynamic long-term loading. When the steel beams are not completely buried in the floor, exposed sections vulnerable to fire can be cased, asbestos sprayed, or protected by false ceilings.

In general, the intensity and type of superimposed loading determines the most economic span for a chosen floor type, the spacing of beams being dependent upon the maximum economic floor span and the loading of beams and columns. Standardised sections can be minimised if the loads can be transferred axially downwards from the point of application, instead of horizontally.

Floor thicknesses and column and beam sizes are influenced by the method of wind bracing or stiffening walls adopted. Thus a two-way continuously reinforced floor slab with four edge supports results in a thinner and lighter slab when (a) load and span conditions permit a square structural grid or (b) the larger side of the bay does not exceed $1\frac{1}{2}$ times the length of the shorter side.

Multi-storey structures up to 20 storeys high with short spans and lighter loadings may be economically developed as flat plate construction. By this means, reinforced slabs with additional steel reinforcement to take increased stresses, and directly supported by columns without beams can achieve a smaller total volume of concrete than beam and slab floor construction. The absence of beams and aprons simplifies formwork, reduces floor to floor heights, and enables pipework and ducts to be run without obstructions. If design requirements necessitate beams, pre-cast units are generally more economical than those cast in-situ, especially at the perimeter. Freedom of spacing columns is obtained, and maximum economy is achieved by standardising bay sizes to a module.

The erection of a composite steel frame for a multi-storey building
necessitates full integration with the building programme. Independent steel frames erected complete as a self-contained component on prepared foundations before cladding or floor operations commences lose their potential advantages of speed in erection by introducing a time lag before the follow-up trades start, and the need for fire protection. A fully erected frame does not necessarily speed building operations, particularly in conditions where floors and cladding cannot be handled by tower cranes through the steel frame. Moreover, the skeleton frame requires temporary bracing, which may become extensive when the frame is erected before the floors and stabilising walls.

It is more economical to erect the steel frame for multi-rise composite structures in (a) vertical sections up to a definite height, the frames being erected by the steel erector, plumbed, temporarily braced, and released successively in pairs to the general contractor, with a neutral bay between the sections being erected and that being clad, and (b) horizontal sections, so that work on lower floors can be completed before work commences on the upper framework.

The operations of casting floors and constructing the stabilising walls on the storey below must be closely integrated with releasing the temporary braces to the steel frame, four lower floors usually being completed before work commences on the upper framework. The "umbrella" floor and the steel skeleton can support polythene covers suspended from the frame and provide protection in bad weather.

Composite construction, with partial prefabrication of floors and dry casings enables site labour to be reduced and can speed erection provided the erection of the steel skeleton is effectively integrated with the associated construction programme.

3.3.9. Extraneous Factors Influencing Construction Costs.

Many unforeseeable extraneous factors can influence construction
costs, for example: national and local shortages of labour and materials; credit "squeezes"; abnormal rainfall during the period of tendering which causes a rise in the water level, sudden increases in the cost of building materials, coal and petrol; change of political party; a greatly increased volume of building commencing, or proceeding in the area of the proposed works.

Costs are also influenced by general factors relating to:

(a) contract conditions (e.g. time for completion);

(b) many items termed "preliminary particulars" in Section B of the Current Standard Method of Measuring Building Works, which can represent a substantial proportion of the total construction costs.

One recent building contract of approximately £1,350,000 included over £150,000 for such preliminary items, another similar contract of approximately £4,500,000 included over £510,000. Such high costs may be due to uncertainties in the estimator's mind at tendering stage due to the unrealistic current methods of obtaining tenders based on "accurate" quantities of "fully described" unit items of "measured" work which ignore the economics of site mechanisation, methods of factory production, and construction techniques. Such quantities when priced do not take into account the effects of repetitive operations on labour output, nor provide designers with any conception of the effects of design detailing on costs, because the "accurate" quantities for different types of work only relate to volume or area, and not to the particular difficulty of individual jobs, e.g. changes of wall profiles and openings in poured concrete walls;

(c) the various obstacles to large-scale planning in cities, such as multi-ownership of land, mixture of land uses, high cost of land, intricate planning requirements, and obsolete building legislation, all of which inflate construction costs;
(d) price fluctuations in costs of materials and rates of wages which disturb "fixed" contract prices;
(e) ground with poor load bearing capacity, which can abnormally increase the cost of similarly planned projects on different sites;
(f) maintenance requirements. Decorations are a significant factor of maintenance costs, and where two different owners pay separately for the initial cost of a building and its subsequent running costs, there may be a tendency at design stage to favour a low initial construction cost with a known high maintenance cost, or vice versa.
PRINCIPLES OF ECONOMIC COMPONENT DESIGN

4.1 Components for "closed" and "open" systems.

General factors influencing the design of standard components for "closed" and "open" systems suited to a particular building type, and with limited applications to other similar building types, relate to:

(a) type of component;
(b) materials, and performance specifications;
(c) size, shape, weight, and number of components suited to the system;
(d) amount of pre-finishing and incorporation of different trades and services in one unit;
(e) junction details;
(f) degree of standardisation;
(g) variations on standard designs;
(h) factory production methods;
(i) site erection requirements;
(j) maximum application to different building types;
(k) required serial runs for economic production.

Economic component design should avoid over specification, restrict variations on standardised units to a minimum, utilise the best properties of selected materials to the utmost, and comprehend suitable methods of factory production and the full capacity and continuous operation of site mechanical handling plant and equipment in order to:

(a) achieve a minimum number of simple standardised repetitive units and their essential variations as suited to each particular building type, or combination of appropriate types, with the least amount of alterations to moulds, shuttering, standardised methods of factory production, jointing
techniques, and site assembly;

(b) reduce industrial operations by sizing units as large as possible in order to reduce handling, cutting and fitting, and jointing;

(c) control accuracy of component dimensions within required tolerances;

(d) ensure safe and rapid site assembly with a minimum number of operations for each part of the building in accordance with the requirements of differing erection techniques;

(e) avoid non-productive time on site due to (i) one team waiting for another to finish, or (ii) more than one team working on one operation at the same time, by minimising differences of materials and construction techniques, avoiding division of trades, and incorporating components in a pre-finished state with the maximum integration of different trades and services in one unit.

4.2 Classification of Component Types.

Components may be classified as:

(a) universal components valid for all building types, individual buildings, and groups of buildings, (e.g. bricks);

(b) components limited to one or several types of buildings, (e.g. pre-cast concrete load-bearing facade panels);

(c) structural and non-structural components;

(d) multi-purpose assemblies, and sections connecting individual structural units with the finished building (e.g. service cores, curtain walling);

(e) less complex, standardised and smaller components suited to the varying requirements of different building types (e.g. doors, windows).

Structural elements do not lend themselves to standardisation as interchangeable components to the same extent as do many types of non-structural components (e.g. baths) due to the great differences of storey heights, finishes, and foundation and structural requirements affecting design. Quite
different structural elements are required for (i) one to three storey buildings, (ii) four to thirty storey buildings, and (iii) buildings over thirty storeys.

In general, component types should be related to:

(a) the size and features of especial importance in a building, e.g. structural elements - columns, beams, load-bearing walls, floors, roofs, staircases;

(b) non-structural parts, e.g. cladding units, partitions, windows, doors;

(c) fittings, e.g. sinks, shelving, cupboards;

(d) services;

(e) degree of pre-finishing;

(f) the integration of different trades into one unit;

(g) maximum application to different building types.

4.3 Materials

Climatic conditions and available sources of local materials influence component design in several ways:

(a) in countries with long extended cold winter months, e.g. the U.S.S.R., pre-cast concrete component production is carried on in factories during the winter period for erection in the comparatively short summer months;

(b) In the U.S.A., timber is plentifully available, and most low-rise dwellings are constructed of timber framing, which is simple to fabricate, whereas in Great Britain, most timber has to be imported, and is comparatively costly compared with brickwork and concrete for the structures of low rise dwellings;

(c) In cold climates, materials which are poor heat conductors are better suited to components such as cladding units, whereas in hot dry climates, buildings which are not air-conditioned should be constructed with materials which provide heat equalisation.
Traditional materials, such as plaster and slates are not suited to mechanised methods of component production. Current advances in the design and manufacture of plastics, laminated skin structures, and pressed metals are insufficient to render them more attractive economically for structural demands than concrete, steel and timber. Technology is making possible the utilisation of raw materials and waste products previously considered unsuited to building technology, but it is essential that any such materials used for component production are of high and uniform quality comparable with concrete, bricks, metals, plastics and timber.

New materials tend to be more expensive than traditional materials because: (a) they are based on capital intensive methods of production, (b) they may be a monopoly production of one firm, or a group of firms, (c) sufficiently long serial runs have not yet been produced for cost economy, and (d) current advances in their methods of manufacture are not yet adequate to render them more attractive economically for structural elements than concrete, steel and timber. But as the tendency in Great Britain over the past years has been for the cost of skilled labour to increase at a faster rate than the cost of manufactured traditional materials, designers are provided with a more possible economic selection of light new materials, such as plastics, aluminium and sheet steel provided that their site erection costs are sufficiently reduced; for example, by designing pre-fabricated insulated plastic panels which can be delivered to site in units 3-storeys high for handling to position and fixing between 10th and 15th floor levels within 40 minutes.

4.4 Size, Weight and Finish of Units.

Functional requirements limit the selection of dimensions for components which comply with more than one building type. The size and weight of a unit influences handling and transportation costs, and the amount of site jointing. Large heavy units reduce site erection, handling and jointing, but necessitate cranes and other costly mechanical equipment. Smaller and less complete units
require more site assembly, fitting, jointing, and increased work of finishing trades. Components should be suited to the full capacity and utilisation of site mechanical handling plant and be designed to achieve simple and repetitive units which ensure continuity of site assembly with the minimum number of operations for each part of the building.

In general, the more that components can be pre-finished and assembled into complex elements in the factory, the more site operations and labour can be reduced. A timber-framed cladding panel which incorporates load-bearing functions with cladding, insulation, internal and external finishings, minimises site sorting, handling and erection, and also eliminates time required for drying out wet trades.

However, unless such components are integrated with the whole sequence of construction, and do not involve considerable expenditure in assembly, jointing and making good, these advantages are lost.

4.5 Junction Details

There are considerable obstacles to the attainment of standardised junctions for a variety of components, because joint details vary with the material and thickness of a component according to type and structural requirements, and may also necessitate the adjoining component either contributing a joint part of varying thickness, or else none at all (e.g. a cladding unit embedded in concrete).

In view of the current trends towards the greater use of pre-fabricated components, the British Standards Institution is in the course of preparing a new Code of Practice for "the Control of Inaccuracy in Building", which requires that tolerances should be dealt with explicitly, and not implicitly as at present. The aim of the Code is to enable design requirements to be realised in terms of accuracy in production and assembly.

The type, material and joint dimension of an interchangeable component constitutes a serious limitation to standardised mass production. In general, components and their junction details should be designed:
(a) with modular co-ordination and unification of joints, in so far as practicable;

(b) with acceptable conditions and realistic understanding of tolerances to meet the performance requirements of each structural and building type;

(c) according to the suitability of the particular building type for complete standardised prefabrication;

(d) in relation to the number of storeys, as junctions influence structural design and determine the size and other features of structural equipment;

(e) with an increase in the installation requirements of sanitary and electrical equipment;

(f) to suit site erection requirements.

4.6 Variations on Standardised Components

Variations on standard designs relate to:

(a) user requirements;

(b) site conditions and environment;

(c) building regulations;

(d) function and performance requirements, which determine number, size, materials and finish of components;

(e) available materials and skills;

(f) type of factory production.

Variations in the assembly of standardised components for "closed" systems need not necessarily slow down the erection cycle provided the number of different component types is minimised, and their basic shape, weight, and method of jointing is similar. For example, 4 or 5 heavy structural units can be hoisted to position and fixed in any ordered sequence within a definite planned period so long as they are dimensioned to fit the erection crane's tackle and capacity, and are similarly assembled and jointed.

But variations in construction techniques may delay erection operations,
thus the assembly of pre-cast concrete standardised beams and columns when combined with poured in-situ concrete floor construction may be considerably slowed down due to the obstruction of working areas caused by supports to shutters, and the time required for pouring and curing concrete, and erecting and striking shuttering.

Any design which breaks the rhythm of the erection cycle increases the non-productive time. Thus, a type of cladding unit which needs scaffolding for erection should not be used with another type that requires handling by crane.

4.7 Relation of Component Standardisation to Safety and Speed of Erection Operations

Conditions favourable to standardisation of component production and repetition of site erection operations for increased labour outputs include:

(a) architectural and structural plans which assure maximum identity of operations,

(b) adequate sized developments which permit sufficient specialisation, and adequate site space for erection teams to work without getting in each other's way.

When the design of a pre-cast concrete system obviates the use of external scaffolding for component erection, protection must be provided around the perimeter of the buildings at each working level. Concrete elements for perimeters should be designed for erection within the building before inner walls are positioned in order to provide a safe working level as early as possible. When no permanent balustrade or cladding units can be fixed at this stage (e.g. metal windows, or timber panels to fill in openings) provision for some form of temporary guard rail will be required.

Other factors that influence the speed of the site erection relate to:

(1) the stage of the building programme at which the components are to be introduced;

(2) the limitations imposed by permissible tolerances;
(3) user requirements affecting component selection and flexibility; and
(4) the amount of standardisation of non-structural components;
(5) the degree of simplicity of standardised jointing techniques.

The later in the building programme components are delivered and erected, the more serious will be the effect of delaying the cycle of site operations.

To achieve economy, design solutions of production and site erection requirements should provide the best relationship between costs of construction and user value of a building, and a wide choice of standardised interchangeable components of varying sizes suited to alternative treatment of the heights, elevations, and appearances of buildings.

4.8 Standardised Open Components suited to a variety of building types

The design of more flexible and interchangeable components than those currently produced for "closed" and "open" systems should enable an optimum number of selected and variable materials, shapes, colours, and dimensions to achieve an adequate differentiation of heights, masses, surfaces, structures and elevations for each particular building type, so that industrialised "system" building can advance to "component assembly" based on a severely restricted number of essential elements and their variations.

The general principles of component design for the factory production of vast outputs of such standardised interchangeable units are based upon:

(a) the inter-relation of the essential common factors of as many different building types as possible to achieve the maximum flexibility of a minimum number of necessary components. The value of a building will be diminished if it includes any components which are superfluous for its use and aesthetic appearance;
(b) the fulfilment of performance and user requirements common to as large a variety of building types as practicable;
(c) the provision of acceptable junction details, joints and tolerances.
4.9 Increased application of standardised "open" interchangeable components to a wider variety of building types.

The standardisation of interchangeable components should be related eventually to their increased application to a wider variety of different building types in relation to:

(a) building types with identical requirements, e.g. dwellings;
(b) building types with similar requirements, e.g. offices, factories, schools;
(c) buildings with special requirements, e.g. hospitals;
(d) the effects of building heights on structural design, e.g. low-, medium- and high-rise buildings.

Selected interchangeable components could be designed to suit each particular building type, and be gradually extended to comprehend as many different building types as possible in one component, including housing. Thus:

(a) a limited number of building type requirements, (e.g. schools, hospitals, factories, offices) could be inter-related with a similar number of components (e.g. structural frames, partitions, external cladding, doors and frames, etc.);
(b) performance requirements and preferred basic dimensions of the selected components could be related to the selected building types;
(c) similar and differing performance requirements could then be divided for all the selected types;
(d) these performance requirements could finally be related to those for housing.

4.10 Ultimate Component Unification

The final development of the economic mass production of "open" interchangeable units is based on the unification and eventual standardisation of
buildings and components, their methods of assembly and jointing, and the maximum application of these standardised designs to as many different types of buildings as practicable. This necessitates:

(a) the achievement of more components and varied sizes so that differences in heights, masses, facades and surfaces can be readily obtained by designers through the selection of materials and dimensions which comply with the performance requirements of various types of buildings;

(b) the solutions of many problems affecting the harmony of architectural and structural requirements;

(c) the determination of methods of assembly that can be used advantageously on site, and modified to the individual requirements of a building; and

(d) effective economic production in relation to the quality of buildings, and their environment, climatic conditions, service life, and maintenance.

Although the full unification of components is not practical, nevertheless size, degree of finish, and other universal qualities and functional requirements of components necessitates a certain degree of unification of design. And until industrialised building techniques advance to the mere assembly of standardised "open components", and Government policy provides for a long term demand for a very large and continuous volume of building, industrialised building systems for limited volumes of production will generally achieve speed of erection rather than substantial economy of cost when compared with techniques based on traditional methods using more site labour without the factory production of standardised structural elements.
CHAPTER 5
PRINCIPLES OF ECONOMIC COMPONENT PRODUCTION

5.1 General.

The production of most materials and component parts of buildings is related to capital intensive organisations. One of the achievements of industrialised system building is that it replaces site labour by the economic production of factory made structural elements and components which can be handled and erected by mechanical plant, and does not necessarily involve contractors in very greatly increased capitalisation, unless limited to one particular type of system based on high serial runs of pre-cast concrete elements mass produced by semi-automated processes in permanent factories to satisfy a vast and continuous demand.

Building contractors' resources are usually widely dispersed, and not limited to any one particular kind of construction anywhere, so that they can hire plant and employ sub-contractors as required for their various contracts, thereby reducing the need for extensive fixed assets and capital. A major part of contractors' costs are direct costs, and quickly recovered from their Employers by monthly interim payments on account.

Even when sponsoring a system based on the site factory production of pre-cast concrete components, required capital investment per operative employed is considerably less than that needed in other industries, e.g.

<table>
<thead>
<tr>
<th>Industry</th>
<th>Approximate Capital Investment required per Operative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical</td>
<td>£7,000</td>
</tr>
<tr>
<td>Motor car</td>
<td>£3,000 to £3,500</td>
</tr>
<tr>
<td>Site factory system</td>
<td>£1,400</td>
</tr>
</tbody>
</table>

5.2 Non-Structural Components

5.2.1. General

The design of factory produced non-structural components should attempt to correlate the requirements of demand, transportation limits,
planning areas, and the required speed of factory productivity by automated processes. Transport is an essential link between high volume factory production and rapid site erection, and can be simplified provided the type of component manufacture does not require a complex ordering problem in the factory.

In theory, component production should be based on the estimated over-all number of standardised universal components related to a nationally planned building programme in order to achieve the mass production of huge series, with resulting economies due to the variety reduction achieved by optimum standardisation.

In practice, this aim is unattainable on account of changes of user during the life of a building, adjustments required by new materials and techniques of construction, the transportation problems that would result from an extended national market, the special requirements of major individual developments, the difficulty of maintaining vast production runs due to the changing demand for different types of buildings, and the whole structure of the building trade and its allied industries. These industries have to provide for the site erection of large buildings constructed from component parts of varying materials, sizes and complexity, which are obtained from many different sources and assembled in close physical association to achieve functional integration. In addition, savings obtained by mass production are substantially off-set by the high proportion of final costs already represented by materials, labour, factory production, and transportation costs, and conditions best suited to component production may not necessarily be the best from the point of view of site erection.

The output and overhead costs of manufactured products depends upon scale and length of series run, and tend to rise when a factory operates at a low level of production due to the high proportion of fixed costs. The development of a building technology based on the flexible assembly of
standardised and selected interchangeable components obtainable in the open market requires the development of assembly-line and semi-automatic methods of production, pre-packaging, and the acceptance of dimensional co-ordination and interchangeable jointing.

Present problems of the mass production of standardised units include (i) functional requirements limiting selection of dimensions, and degree of unified finish. These depend upon whether components are to be introduced completely finished by mass production methods, or assembled individually in workshops from mass produced semi-products; and on methods of site assembly, and (ii) methods of site assembly and jointing.

5.2.2. Factors influencing mass production methods and costs of components.

(a) General. The mass production, in vast series, of carefully selected materials and "open" interchangeable standardised components related to long-term National building programmes necessitates:

(i) component designs which correlate the requirements of demand, planning areas, transportation limits, the effective utilisation and combination of the best properties of the selected materials, and the required speed of factory assembly as necessitated by the high serial runs achieved by automated processes,

(ii) low cost methods of automation, and the development of semi-automated processes of varying degrees;

(iii) the creation of new process-dependent industries which will lead to substantial reductions in labour requirements similar to those already achieved in the aircraft industry; and

(iv) vast capital investments (e.g. one polythene factory built in Hungary cost £27 million at 1965 prices).

Building contractors may be considered as effective organisations conditioned by their ability to finance and undertake construction works, but most competent and allied manufacturing industries require intensive capitalisation of their assets to operate successfully.
(b) **Categories of mass-production methods.**

There are three main categories of production:

(i) components produced by the transformation of materials by formation processes of (i) machining to specified dimensions, (ii) pre-casting (e.g. concrete) and (iii) heat or chemical treatment to change physical properties;

(ii) components produced by the above methods and assembled into complex units (e.g. curtain walling, service cores, box construction);

(iii) components mass produced on site (e.g. pre-cast concrete units, timber infill panels).

Types of manufacturing plant include:

(i) fixed machines with manual control,

(ii) ditto with fixed control programme,

(iii) ditto with cybernetic programme,

(iv) complex machines with computerised programme of control,

(v) other degrees in the scale of operations.

(c) **Low cost methods of automation.**

Automated methods of increasing productivity at lower costs cover all types of industries, and can provide an economic and effective factor in simplifying production methods by obviating the drudgery of repetition handling in order to benefit workers on the shop floor.

For example, the process involving operatives seated at benches, and picking up and placing pins and studs into holes all day, can be very simply automated at low cost by a vibratory hopper feed. The pins and studs could be correctly orientated from the exit point, fed to a parts placing unit, and married up with the unit part required to accept the pins or studs and the whole arrangement could then be time-cycled for assembly at a predetermined rate to achieve considerable savings on this type of operation, with increased productivity of the complete assembly and release for other
work of the operatives employed on the bench.

Automatic assembly and machine loading, and the design and development of special purpose machines need not necessarily involve vast capital expenditure for economic installation provided that all elaboration and unnecessary refinements which tend to cause trouble when the machine is in actual operation are eliminated.

(d) The Development of semi-automated processes.

The development of manufacturing methods for semi-automated processes and short cycle times involves such processes as ultrasonic techniques for bonding, photo-electric guards for the arrestor mechanisms of machinery, electromagnetic devices such as tape controlled processes to eliminate hand fitting, and other ingenious devices which substantially reduce labour requirements. But great reliability of increased mechanisation is essential in order to avoid stoppages of production. For example, even one or two insignificant fasteners could shut down an assembly line.

(e) Factors influencing production costs.

The costs of mass production methods for high serial runs of components relate to:

(a) type of production, optimum size of plant, and size of serial runs;
(b) volume of composition of demand, and future developments;
(c) degree of automation required for production;
(d) investment costs;
(e) sources of raw materials, and transport network available;
(f) technical possibilities of processing raw materials;
(g) power requirements;
(h) direct and indirect costs, and number and skill of available manpower;
(i) maximum and minimum sizes of components, type of finish, and tolerances and dimensions of finished products;
In general, the higher the capital cost of plant utilised for vast scale productions, the greater the productivity achieved per unit of plant.

For example, a single centralised factory with advanced methods of production and transportation related to its high outputs can achieve a quicker amortisation of capital costs than a similar factory operating with a lesser degree of automation.

The main issues involved are:

(a) to economically relate mass production methods to required outputs, e.g.

(i) a minimum output of 10,000 complete steel dwellings is essential for the economic utilisation of press forming methods of production

(ii) a simple air-operated clamping system introduced into a joinery works achieved a 500 per cent increase in outputs of window frames, and a more rigid and better quality product;

and (b) to balance production against capital expenditure on plant in order to amortise investments within a sufficiently limited period, and obtain required profits on the total capital employed, and on turnover.

5.3 Pre-Cast Concrete Structural Components.

5.3.1. General

The economic production of pre-cast concrete panel units capable of arrangement into a load-bearing and wind resisting structure is based on:

(a) general factors which create the environment in which a particular system operates, e.g. the existence of a special or more general market, scale of output, volume of demand anticipated, economic life of fixed assets, required
return on investment;

(b) the achievement of a variety of building types, layouts, and appearances which provide flexible architectural design integrated with structural needs, and satisfy user requirements. Building details and concrete unit profiles should satisfy performance criteria for at least as long as factory costs have to be amortised.

(c) the minimum number of standardised units required for maximum repetition of production and simple jointing techniques;

(d) size and weight of units. Large panels 20 ft. long, or over, of standardised storey heights necessitate too many complicated casting processes for site manufacture. Heavy units over 6 tons each require rail transport;

(e) type of factory production and mechanisation dependent upon the extent to which the component design lends itself to advanced mechanisation for high serial runs. Degree of automation for off-site productions should be related to required outputs and amount of flexibility for variations. Any changes in size and detail of standardised units are costly, and can only be made economically for large projects. Requirements of local authorities for variations in standardised systems to suit their individual artistic demands can increase the costs of their dwellings by as much as 33\(\frac{1}{3}\) per cent.

(f) location of factory, which affects transportation costs and risk of damage to units in transit;

(g) minimising handling and transportation in the factory and on site;

(h) programming and phasing daily outputs to integrate with erection requirements.
5.3.2. Off-site factory production

(a) Location of Factory

When possible, an off-site factory should be located in public areas near good roads, within 25 to 40 mile radius from sites to be served, and with ready access to public utility services in order to avoid additional costs for providing requisite 500 K.V.A. electricity supply. Access to the factory should be provided for incoming deliveries of materials and outgoing transportation of units to sites, with different spaces allotted in factory areas for loading and manoeuvring trailers to avoid traffic jams.

A high proportion of transportation costs relate to loading and unloading trailers, approximately one hour for each operation. Thus the difference in cost of transporting units to sites 1 mile and 25 miles distant from the factory relate to the time passed en route; 4 loads being made to the sites 1 mile distant as compared with 2 loads to sites 25 miles away.

When comparing comparative merits of off-site and on-site factory production methods, transportation costs from the proposed off-site factory should be compared with (a) the cost of handling units by a site factory crane to erection cranes located near adjoining structures, and (b) the cost of site transport from the temporary factory to distant blocks.

(b) Type of mechanisation

Off-site factory production is based on semi-automated assembly floor-line processes with highly specialised operations carried out at successive working stations. A quick turn around in the cycle is observed by lifting units from the moulds into the stacking yard as rapidly as possible without re-handling.
In order to avoid over-capitalisation in factory mechanisation due to over-estimated volumes of demand in relation to economic production, new factory buildings should be laid out on the approximate basis of double the amount of existing outputs, with only sufficient machinery installed to satisfy current volumes of demand. By so doing, there will be at least a sufficient requirement for economic single shift production if the estimated demand falls below anticipated peak periods after the factory is in operation. If too much costly semi-automated machinery has been installed, necessitating high-volume production with two shift work in order to obtain an economic return on capital investment, a fall in demand will result in decreased outputs with the machinery working at under capacity, and consequent loss of profit.

Costs of installing a permanent factory for the manufacture of precast concrete panel units can vary from approximately £60,000 to £600,000 and upwards according to scale of production, and degree of mechanisation and automation utilised. A factory to be set up on production line basis for manufacturing pre-cast concrete panel units requires a minimum of machinery and plant sufficient for the sustained production of approximately 600 dwellings, with daily outputs of 2300 cu. ft. of units based on 30 to 36 component types. Successful production on this basis can enable total site labour of all erection teams to be reduced to approximately 800 manhours per dwelling.

(c) Methods of maintaining continuous semi-automated production.

Production based on daily castings to achieve de-moulding after 24 hours requires factory layouts based on some form of transverse and multiple through bays, with special cranes to ensure the smooth and continuous handling of units. More rapid results can be obtained in factories which maintain continuous operations with accelerated concrete curing and two shift work. By using semi-automated self-stripping and erecting multi-panel precision made steel battery moulds fitted with electrical heating elements, and
working three shifts, continuous production can be maintained of single units such as plain wall and floor panels with a tolerance of 1/16 in.

In cold winter months, continuous operations are ensured by pre-heating the mixing water at night to provide a concrete placing temperature at 60°F. The moulds are heated to maintain the rapid production of units for de-moulding after 24 hours (or less). Subsequent maturing is effected on storage racks.

Manufacturing bays, moulds, and air, water and electrical services should be suited to the techniques required for producing each different type of unit. Transverse bays with offices, stores and workshops can be located where required in the production bays, and added to suit expansion of the factory. The main batching and cement site equipment should be planned normally along one end of the factory, with a rail mounted conveyor belt and a receiving hopper for direct off-loading from lorries to feed aggregate to ranges of storage compartments. These should be of different size for several weeks continuous production.

Although inspection and close concrete quality control is essential, a deviation of 500 lbs. per sq. in. to the next highest standard mix may be provided when a lower strength mix is specified, as the extra cost of the cement is negligible compared with the costs of more effective quality control.

(d) The Stacking Yard

For daily outputs not exceeding 3,000 cu. ft., the factory stacking yard would be normally of sufficient area to take several weeks stock of units, plus an additional two weeks "buffer" stock, and be of approximately similar area to the factory production bays. Six or seven trailers would suffice for daily deliveries to sites of the units produced.

The phasing of deliveries should ensure the units being off-loaded direct from the trailers and hoisted into position without the need for a stacking yard on site, and consequent double handling. Allowances should be
made in delivery times for hold-ups due to breakdowns and traffic jams. If efficiently timed, deliveries should be normally up to within 20 minutes of scheduled times.

(e) Example of economic production for daily outputs of 2,300 cu. ft. of panel units.

The production cycle for internal wall panels would be based on a team of 12 to 15 men working one shift, with a concrete conveyor delivering mixed concrete from the batching plant to required positions on the roller line. This line produces the units as it moves along the production bays, each operation taking approximately 15 to 20 minutes.
The factory team would comprise 12 to 15 men, working one 8 hour shift.

Production line roller track, on which the moulds are placed, with a stationery machine tilting table A, which demoulds the units. The empty moulds are cleaned and reinforcement placed as they move to B.
The cycle of operations would normally take 2 to 2\(\frac{1}{2}\) hours, and comprise:

(a) placing the mould filled with cured concrete on the roller line;
(b) de-moulding the concrete;
(c) cleaning and oiling the mould;
(d) placing reinforcement;
(e) placing electrics and other inserts in the mould;
(f) pouring concrete;
(g) placing topping mix;
(h) finishing surface of topping.

The concrete would be cured by ambient temperature maintained in the factory at 65\(^0\) to 70\(^0\)F by oil fired warm air heaters to provide good working conditions, or similar means, in order to permit natural concrete curing on a 24-hour cycle.

The cycle of operations for the production of floor panels would be similar to that for the wall panel units, but without the finishing operation, if screeded on site. The operations for the production of facade panels would vary according to (i) external finish, (ii) type of insulation, (iii) type of unit, i.e. whether plain flank wall unit, or a unit with a window opening; and take approximately 4 to 5 hours.

When standard units have to be varied to suit architectural or structural requirements, the team of 12 to 15 men would need to be doubled.

Higher outputs for panel systems with units 20 ft. long necessitate larger factories with more costly machinery, and site erection cranes with greater lifting capacity. But total factory production costs would be similar to within approximately 10 to 15 per cent.

5.4 Site Factory Production

5.4.1 Location

The most efficient location for the installation of a site factory and stacking areas is related to (a) shape of the site, (b) available space, (c) building layouts, (d) access for materials deliveries, (e) required
volume of production, (f) type of construction, (g) mechanical plant utilisation, and (h) required finishes.

The main problems include minimising double handling, and integrating production with erection requirements, normally solved by siting the factory within reach of the buildings, and setting up the batching plant near the site entrance. Where space is restricted, ready-mixed concrete can be used to supplement limited batching plant, or even for all castings.

The ideal position for the factory is at a central, or other convenient position, so that the factory portal handling crane is within reach of the erection tower crane to ensure as direct a lift as possible from the factory into stacks adjoining the buildings. This does not present a difficulty on sites developed with only single or multiple tower blocks. But for sites with low-rise or mixed developments, transportation of the units will be required, and stacking areas should be located immediately adjoining the factory, the furthestmost blocks being completed first to avoid transportation problems through finished areas.

5.4.2. Factory Requirements

The introduction of a site factory in a centralised area for manufacturing pre-cast concrete panel units, some of which are to be transported and erected on other sites, brings it within the terms of the Factory Act Regulations. These involve certain additional requirements to the Building Regulations, and include reporting the existence of the factory to H.M. Inspector, displaying Factory Forms 1, 43 and 31 on site, installing fire alarms in the factory, obtaining certified means of escape in case of fire, providing hot water for washing, and incorporating practical safety precautions, good drainage facilities, and clear gangways between moulds. The site factory should contain adequate shelters, manufacturing bays, and services suited to the production techniques for each type of unit. Layouts of moulds and stacking areas should be carefully checked against the radius and lifting capacity of the factory cranes to ensure maximum utilisation.
Major plant requirements comprise mixers, moulds, subsidiary plant for curing concrete, steel fabrication areas when reinforcement is not delivered to site ready cut and bent, and shelters which vary according to the type of factory to be installed.

The main types of lifting plant are tower cranes, overhead travelling cranes, and portal cranes.

In order to provide efficient equipment and conditions for curing cubes and undertaking sieve analysis and other tests, a small size laboratory should be set up with the site factory, and liaison established between the factory and erection teams regarding quality, improvements, and availability of units.

5.4.3. Size of factory in relation to required outputs

An approximate method of estimating required factory manufacturing bays for preliminary programming may be calculated on (i) an assessment of 3 to 4 times the total floor areas of the buildings to be erected each week, and (ii) a basis of mould utilisation averaging four castings per week. For example:

Floor areas of buildings to be erected: = 5400 sq. ft.

Maximum weekly rate of erection: = 5400 x 1.2
 = 6500 sq.ft. (approx.)

∴ Approximate area of factory bays = 6500 x 3.50
 = 23,000 sq.ft.

In order to determine the size of the factory more accurately, a schedule of the units required each week should be compiled, upon which the number of moulds may be calculated on the general basis of 5 castings per mould per week. Some moulds would be based on 6 castings per week in order to attain 6 repeats when required, and avoid unnecessary mould duplication. Where only a few units of a particular structural type are required, they can be made in a single mould to make up the number to 4 repeats, thus permitting one free day for mould modifications.

These calculations can be improved as casting and erection teams become fully trained. On contracts planned with experienced teams, it is
practicable to work on 10 castings a week of structural units, but with shift working to achieve such higher production rates.

The percentage of covered space to the factory production lines should be normally approximately 60%, varying according to the time of year when pre-casting is at its peak. If during the winter period, this percentage might need increasing to 75%.

For limited volumes of production on single sites, standard manufacturing bays should be set up with a series of 30 ft. wide x 20 ft. long mobile shelters to run on rails, and formed of light steelwork covered with any suitable material. Electricity, water and steam services constructed with appropriate outlets would be provided alongside the moulds. The rails on which the shelters run can be secured to timber inserts cast in the oversite concrete to enable two men to move the shelters along the rails and away from the moulds when the operations of placing steel reinforcement, concreting, and lifting units from the moulds are proceeding.

Careful attention should be given to the electrical installation for the factory. Socket outlets to mould beds should be positioned to minimise cables trailing from sockets to vibrators. Electrical intake and switch gear housings should be placed clear of portal and tower crane tracks to prevent a trap being formed between the housings and moving cranes.

Steam installation pipes need lagging to prevent operatives contacting hot pipes, and control cocks designed to prevent accidental operation.

A good psychological effect on site operatives is obtained by their working in a factory which is not too stuffy, with facilities provided for washing and change of clothes. As some men may be allergic to mould oil, oil spraying should not be permitted, and barrier cream and neoprene (or similar) aprons and gloves provided.

5.4.4. Relation of rate of production to crane utilisation and erection requirements.

Factory crane requirements for a single tower block are comparatively simple, as both the casting and erection cranes can usually provide adequate
coverage to all moulds. With multiple tower blocks on one site, the main problem is to site the factory within reach of each block. Part of the factory lifting equipment should include a tower crane with an extended track to reach the stacking areas for adjoining blocks.

Such methods are unlikely to enable all blocks to be reached directly when more than three tower blocks are to be constructed on one site. Under these conditions, transport should be provided to deliver the cast units to required locations for erection operations.

The choice of a factory portal or tower crane depends on comparative cost economies, and the space available on site for stacking and casting units.

Portal cranes have several advantages where site space is not too restricted:

(a) Cranes up to 6 tons lifting capacity can perform along the production bays all concreting operations, including casting, striking, placing and lifting units.

(b) In the initial stages of a contract, the crane can be used for the erection of the production bays, and also for the erection of the building up to the first five or six storeys;

(c) the crane can be turned through 90° to increase its portability and flexibility, and be easily transported across a site for re-positioning;

(d) Setting up and erection time is much faster than that required for a tower crane of comparable performance, and is consequently less expensive in terms of manhours;

(e) the crane does not require such a heavy track as a tower crane;

(f) Portal cranes avoid the lifting problems normally associated with cantilevered jibs, i.e. wind interference; diminishing permissible load with outward travel of the hoist; and inherent structural dangers.

Overhead travelling cranes can provide a useful secondary support in sites where a tower crane is utilised as a major factory lifting appliance, and are generally used over battery pits.
The speed of the erection cycle determines maximum crane utilisation and rate of factory production. This erection rate, and the design of the type, size, number and finish of the units to be manufactured, influences (a) the number and type of moulds required, (b) methods of casting, (c) type and amount of factory plant and equipment, (d) duration of the casting cycle for each unit, (e) the nature of shift work, and (f) size of production bays, stacking, and storage areas.

The layout of moulds and stacking areas should be carefully checked against the radius and lifting capacity of the proposed tower crane to ensure its maximum utilisation, and the displacement of the factory cranes should provide coverage to all moulds and mixing plant so that in the event of a power failure, some continuance of work to the moulds is provided.

On sites with a single tower block of box-shell construction, the key factor to output is mould utilisation. Economic casting speed would be about 4,000 to 5,000 cubic feet per week, with one factory crane for casting purposes used to the maximum, supported by the erection crane, which would tend to be under-utilised.

On normal sites with two or more tower blocks, and erection rate of 8 dwellings per week, at least two factory cranes are necessary. One should be a tower crane used for delivering the finished units within reach of the erection cranes, or for loading on to trailers. The other crane should be a portal or overhead travelling crane set up over the 30'0" factory production bays, and used solely for concreting and initial stacking. To avoid problems of clashing, a tower crane can be used with a shortened jib.

The work loads between the two cranes needs to be carefully balanced between the following operations:

(a) Concreting horizontally-cast moulds;
(b) Concreting vertical moulds;
(c) Striking and stacking horizontals;
(d) Striking and stacking verticals;
(e) Striking and stacking tilttings;
(f) Lifting and loading to trailers horizontal and vertical units.

When an increased rate of production is required (e.g. for 10 to 12 dwellings per week) for two different types of tower blocks, the factory should be divided into two parallel production lines, one for each block type, with an additional crane common to both sections for loading and stacking units.

Vaster production series require the installation of a more permanent type of factory with heavier cranes for casting large and more complex units with a greater degree of pre-finishing.

5.4.5. Production Costs.

(a) General. Production costs are influenced by:

(i) installation, running and dismantling costs of the temporary factory, plant and equipment;

(ii) mould costs, affected by (a) increased utilisation due to accelerated maturing of concrete and (b) shift work to increase outputs;

(iii) materials costs, affected by surface treatment and final colour of the units;

(iv) labour costs, affected by the integration of the casting and erection cycles;

(v) type, size, finish, and number of units.

Plain and simple units can be economically cast on site. Those of intricate design are better suited to off-site production under more controlled conditions. Unless the same shaped units are used on every floor, additional costs will be incurred for altering moulds for any different units to be used at various floor levels.

Large panel units reduce the number of joints required for smaller units, but involve increased time and costs for:
(i) more extensive cutting, shaping, and accurate location of steel reinforcement in the moulds;
(ii) more accurate casting and working of larger area facade panels with a facing mix, sandwich layer, and adjoining backing mix;
(iii) costly precision made steel moulds capable of supporting the dead weight of a panel weighing several tons;
(iv) cranes with comparatively high lifting capacities to handle and stack units.

In general, optimum economy is obtained by standardising moulds for a minimum number of units, accommodating variations of span and loading in standard basic profiles by adjusting the amount of reinforcement within the sections to achieve design requirements, and varying lengths with stop ends.

(b) Materials. Materials costs are influenced by:

(i) availability and type of aggregates, the use of local aggregates and sand provides maximum economy;
(ii) type of cement. Ordinary cement is very much less costly than white cements used for finishings.
(iii) design of concrete mix, and quality control;
(iv) amount and type of steel reinforcement; (bar or mesh), method of fabrication (cage or mat) and placing in the mould, technique (ordinary reinforcement or pre-stressed), and number and type of inserts;
(v) type of materials for insulated panels.

(c) Concrete Outputs.

In general, the following types of batching plant is suited to normal on-site concrete productions:

(i) For outputs up to 6,000 cu. ft. per week, a Benford Silover or Simesa type mixer with Dalli scraper and electrically driven three compartment aggregate storage, or similar
### Production Costs

The production costs are influenced by the following factors:

- **Installation, Running, and Dismantling Costs**
  - Degree of Mechanisation
  - Volume and type of required production
  - Contract time
  - Speed of outputs, influenced by the erection cycle & max crane utilisation for structural units, and the finishing trades cycle
  - Methods of constructing reinforcing and curing units
  - Available space on site for stacking units

- **Materials Costs**
  - Availability and types of aggregates
  - Type of cement
  - Design mix
  - Quality control

- **Mould Costs**
  - Type, shape, size and number of units
  - Incorporation of fittings and services

- **Labour Costs**
  - Time required for learning operations
  - Required methods of casting
  - Integration of casting and erection cycles

### Table of Factors Influencing Costs

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<td>Speed of outputs, influenced by the erection cycle &amp; max crane utilisation</td>
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<td>Volume and type of required production</td>
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An 18/12 mixer is suited to plain structural concrete units, and a 10/7 mixer to exposed aggregate mixes.

(ii) For outputs over 6000 cu.ft. per week, a 21/14 gyramixer with automatic drag line, leading boom, and 5-compartment aggregate storage bins, or similar equipment. This type of plant can produce a batch of mixed concrete in 20/30 seconds, with a mix output of 30 cu.yds. per hour. As the feed rate of the boom is only 15 to 26 cu.yds. of aggregate per hour, two automatic loading booms are needed to feed the aggregate into to obtain maximum utilisation of the mixer, which requires a 30 to 40 ton cement silo to serve it.

The capacity of the storage bins should be 50/60 cu.yds. of which 20 cu.yds. is dead storage, and a minimum area of approximately 60 ft. x 55 ft. should be allowed for the plant, excluding lorry access.

The mixer may be completely operated by one man, who can control all the aggregate handling and mixing operations.

Where more than five aggregates are required to cover exposed aggregate mixes, staircase and other special units, an additional mixer should be provided. On sites where space is extremely limited, ready-mixed concrete can be economically used, either for all castings, or to supplement outputs of limited batching plant.

(d) Surface Finishes

The final colour of a concrete unit depends (i) more on the colour of cement and fine aggregates used than on the coarse aggregates, and (ii) on the treatment given to the surface of the unit. The colour of the cement is of lesser importance with some exposed aggregate finishes, as the proportion of cement to aggregate visible may be relatively small, and only affect the general tone value of the slab. But with an ex-mould casting, where the surface is untouched after release from the mould, the cement is the dominating factor.

Natural aggregates vary greatly in colour and cost. Crushed brick, tile, and other manufactured materials (e.g. glass) are even more expensive than coloured natural aggregates, as they require crushing and grading.
The type of surface texture to be produced depends upon:

(i) Scale of texture,

(ii) Size of aggregate related to viewing distance,

(iii) Aspect of facade related to weathering,

(iv) Particle shape and surface characteristics of the coarse aggregates. These affect weathering, and the reflection of light from the surface,

(v) Whether the finished surface is untouched from the mould, or further treated, e.g. by grit blasting. This process removes laitance from the finished surface and minimises risk of crazing from too rich a mix, or too high a water/cement ratio.

The surface pattern of the slab is related to (i) size and shape of unit (e.g. in general larger aggregates and profiles should be used on large units, and smaller aggregates and profiles on smaller units), (ii) texture and colour of surface, (iii) arrangement of slabs and joint treatment, (iv) the use of profiled effects produced either by casting against relief moulds, or in sand, or moulding clay, and (v) the use of exposed aggregates.

The number of faces each unit is required to be finished affects methods of casting and costs. Where only one exterior finished face is required, it can be readily achieved by casting a thinner facing of the required facing material, with a backing of ordinary mix concrete. If one or two return faces are required to be finished in addition, these can be readily obtained from the returns of the facing mix, provided the width dimensions are not greater than the thickness of the facing. If all faces of a unit are to be finished (e.g. white to imitate Portland stone), either the mix for the casting can be made of (i) special white coarse and fine aggregates, and white cement where a textured or exposed aggregate finish is required, or (ii) of ordinary coarse aggregates and white fine aggregates, and white cement where the surface is untouched after finish from the mould. But in the latter case, any subsequent removal of laitence from the ex-mould surface will expose the ordinary aggregate and spoil the finished appearance of the unit. If a mottled surface is required, it can be obtained by
utilising coloured coarse aggregates, white fine aggregates, and white cement.

The finish to external wall panels, beams and columns is more economically obtained in the moulds rather than by mosaic, tile or other finishes applied later, as a self-finish costs less, and the shrinkage of the concrete tends to cause applied finishings to fall off, or else crack.

(e) Reinforcement

Steel reinforcement depends on the type of unit to be produced, and may be either delivered to the factory cut and bent to required shapes ready for placing in the moulds, or else be cut and fabricated on the site by factory flow-line methods of production. Cages of reinforcement should be detailed to enable the cranes to pick up the cage, place it in the mould without distortion, and correctly fit it to maintain specified concrete cover.

Internal wall panels are normally cast without any reinforcement other than that required for handling. Floor panels are usually reinforced with mesh fabric, which although more costly than steel bars, requires less site labour for fabrication and placing.

The removal of cast units from the moulds, transportation, and handling operations may require special reinforcement and different lifting points or devices from those used for placing the units. Irregular shaped units involve problems in handling stresses during de-moulding, for as the unit is lifted off the crane, a great deal of weight is put on one corner.

(f) Moulds

(i) General. Mould costs are based on the number of castings to be obtained, plus the direct costs of: (a) cleaning and preparing each mould after casting, (b) placing the concrete in the mould, (c) curing it, and (d) lifting and handling the unit to the stacking yard.

For economic productions, (a) all units should be cast as large as possible with minimum tolerances for handling by suitable cranes, (b) be pre-finished in the moulds to minimise wet trades such as plastering and screeds, and (c) the casting of the units should be based on the assembly of pre-formed standard parts for placing in the mould. All pre-formed inserts
should be ready before casting in order to avoid changes in the mould.

The optimum number of moulds required for site factory casting is related to (a) the total number of castings obtainable from each mould, (b) the contract period, and (c) the number of daily castings required to suit erection requirements or stock piling.

When the volume of demand is such that a larger number of moulds would be uneconomic for production, the units should be produced in fewer moulds well in advance of erection operations commencing on site, e.g. during site preparation and foundation works.

Inserts for the pre-cast units, whether bolts, service fittings, or cores for holes must be carefully fixed and rigidly held in the moulds to avoid any displacements or twists during casting the concrete, as any slight irregularities can seriously interfere with the erection programme.

Vibrators used for vibrating concrete in metal moulds should be designed to vibrate vertically in order to prevent segregation, and vibration should be carried out to each pour of concrete from the skip to the moulds.

Concrete which has a low slump to provide high early strength should be discharged direct, so that the rate of flow can be regulated or stopped at any point of discharge where units are being built up in the moulds.

A typical economic mould layout for the site casting of panel units for box-shell construction should be based on:

(a) Production lines 30 ft. wide, with a maximum length of 200 ft.;
(b) minimum working space around all moulds of 2 ft.;
(c) moulds of standardised sizes grouped under battery-cast walls, standard floor slabs (horizontal), standard wall slabs (horizontal) and tilting moulds), exposed aggregate units, and units with special finishes. Battery moulds requiring large pours of concrete should be placed nearest to the batching plant.
Moulds for casting panel units are necessarily constructed of heavy steel to withstand constant vibration, maintain accurate tolerances, and provide required surface finishes for large volume production, and can cost approximately £12,000 each (and upwards) according to type. Variations in modular sizes of wall panels can be obtained with extendible moulds and stop ends to vary lengths of panels standardised in height.

The accuracy of finish in site casting varies according to the accuracy of the moulds, but normally enables 1/8" textured plaster to be sprayed on direct to concrete ceilings, and 1/4" to 3/8" thick wood floated rendering to be applied direct on concrete units. Units with wider tolerances require less expensive moulds, but involve additional jointing media, and take longer to erect.

(ii) Mould Design

Mould designs for non-automated site factory production are based on:

(a) number and types of moulds required for the design of panels required by the system;
(b) number of moulds of each type according to the correlation of panel types provided by the possibilities of the system. This determines the weight and radii at which the panels have to be handled, and the total number of panels required for a project;
(c) detailed designs of mould bodies and mechanisms;
(d) detailed designs of incorporation provisions needed in moulds for entrances and canopies, access balconies, staircases, fire protection requirements, lifts, internal and external finishes, plumbing, heating and electrical installations, and fittings;
(e) assembly details of the above units relating to mould versatility;
(f) details of foundations and jack pits required by moulds;
(g) details of hydraulic, mechanical, electrical, heating, water
and compressed air installations and equipment required for each mould and injector;

(h) layout of service mains in the factory, including welding plugs and crane power.

Current developments of mould design for panel production include:

(a) the extension of battery casting techniques to curved and patterned cladding, and other types of shaped panels;
(b) the evaluation of the "Chevron" technique to produce self-supporting L-shaped elements of varying sizes and thicknesses to eliminate awkward corner jointing; and
(c) methods of spraying and pressing concrete units.

Both curved and grooved cladding panels which are insulated and lined internally, are being produced on a London site in battery moulds, with special lifting gear, and a belt conveyor for handling concrete from the mixer to the moulds.

(g) Methods of Casting

The shape of the units to be produced determines their methods of casting, and all pre-formed inserts should be available before casting operations to avoid damage in the moulds.

Tilting moulds for horizontally cast floor panels subject to wash and spray techniques achieve a more rapid turnover from the mould before the slabs have gained sufficient strength for horizontal handling. Floor panels can be economically cast with electrical conduits run in, and screeded off ready to receive a vinyl or similar floor finish.

Battery moulds for vertically casting plain panels enable a series of units to be cast with two finished faces, and can be achieved economically by casting the panels in series with two parallel smooth faces free from blow holes for lifting directly into the building from the mould. By these means multiple handling, transportation costs, and expensive finishing operations are avoided. With horizontal casting, the slab has to be picked up before placing in its vertical position. On one current project, panels up
to 18 ft. long and weighing 6 tons each are being battery cast and handled by travelling tower cranes on specially constructed rails.

Moulds for external load-bearing facade panels which incorporate (a) door and window frames, (b) intermediate insulating layers, (c) a variety of internal finishes, and (d) raised, sunk, or exposed aggregate finishes to provide flexibility of appearance, present a problem. Economical methods of vertical battery casting for this type of panel, which requires sufficient space for pouring and vibrating the concrete on either side of the sandwich layer, have not yet been developed by mould manufacturers.

Insulated wall facade panels are usually cast horizontally face down to:
(a) obtain a relatively thinner and more expensive concrete finish,
(b) obtain a profiling from a template for external patterned finish,
(c) utilise sand bed techniques for exposed aggregate finish, and
(d) accord with the particular shape of the unit, and its erection requirements (e.g. positioning of starter bars, incorporation of fixings and other inserts).

The panels are alternatively cast horizontally face up when it is required to:
(a) obtain an internal face which is very accurate in plane and free from irregularities and marking;
(b) accord with required unit shape, e.g. a ribbed panel incorporating structural steel, with a dished centre to lighten weight;
(c) enable the aggregate to be exposed by spray and soft brush techniques; or
(d) profile by sculptured techniques.

One economic method of vertical battery casting such facade units can be achieved by profiling the divider plates, or grit blasting the external face of the panel to expose the aggregate after de-moulding, and
applying an insulating skin to the internal face of the unit either in the factory, or on site.

Systems which incorporate complex structural core units use more costly moulds which enable (a) ducts, flues and service stacks to be cast with requisite pipework and attachments for fittings, and (b) load-bearing components forming kitchen and bathroom units to be cast which combine in one mould many operations that would be separated in traditional building, with an accuracy of production which enables requisite equipment and fittings to be readily installed on site.

Steel moulds for casting beam and column units for frame construction are of lighter steel. In order to obtain more open planning, moulds can be standardised for repetitively casting sections to the maximum of their load-bearing capacity, any increase of column spacing required being obtained by pre-stressing techniques.

(h) Electrical Inserts

The lighting system for dwellings constructed of pre-cast concrete panel units can be economically provided by integrating a complete wall lighting scheme in the wall panels. The method of fixing the pre-fabricated electrical conduits within the moulds necessitates dimensions of repetitive conduits not varying by more than 1/8 in. All holes in accessory outlet boxes, except those required for fixings, should be taped over, and all open ends of conduits corked or taped during casting.

Boxes for switches, socket outlets, wall brackets and similar fittings should have rotary adjustable lugs to overcome any casting errors, and prevent any distortion caused during concreting operations from affecting the fixing centres.

Points should be located on the socket outlet ring circuit to avoid extensive deviation from a perimeter ring current, and standardised types of conduit cast in the moulds.

Socket outlets should be of a type where the twin unit has two horizontal fixing holes for use in conjunction with the rotary adjustment
Wall bracket lighting outlet boxes should be fitted after casting with a 3-way through-connection block of 10-amp. rating, with terminals suitable for 2 x 7/0.029 cables. Bracket fittings can be wired with 23/0.076 flexible cord, and connected to connector blocks inside the outlet box, the third terminal in the connector block being used for earth wire.

Some composite systems based on pre-cast concrete wall panels and poured in-situ concrete floors integrate a radiant heating system which is fabricated in a template at ground level, and integrated with the steel reinforcement for the poured in-situ floors. The electrical wiring system for lighting is fully integrated in the structure by casting in the wall panels flexible plastic type cables and outlet boxes, and assembling in the site factory all wiring required for the in-situ floor slabs.

5.4.6 Factors influencing speed of site factory production.

(a) General

The main factors influencing speed of factory production relate to:
(a) methods of constructing and reinforcing units;
(b) speed of concrete curing;
(c) the different daily outputs required for each type of unit;
(d) the number of daily shifts required to be worked for each separate casting cycle; and
(e) available space on site for stacking units.

The optimum curing cycle will vary according to design mix and type of materials for each element. In order to maintain long-term strength and durability, panel units should generally be kept moist throughout the curing cycle, and for some time afterwards. But with some types of structural units, it may be more advantageous to ensure that a large proportion of shrinkage has taken place before their incorporation in the structure. Thus some loss of moisture would be desirable during curing, the choice depending upon the position of the unit in the building.
(b) **Methods of fabricating units**

The cycle of operations and the approximate times for a team of 4 men employed on the production of sandwich facade panels 8 ft. x 12 ft. and 12 ins. thick, formed with a 2" insulation sandwich layer between 6" structural and 4" backing concrete, and cast horizontally in steel tilting moulds would be:

<table>
<thead>
<tr>
<th>Operation</th>
<th>Time (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Striking mould from previous unit</td>
<td>1</td>
</tr>
<tr>
<td>Cleaning mould</td>
<td>1</td>
</tr>
<tr>
<td>Applying mould oil</td>
<td>1/2</td>
</tr>
<tr>
<td>Placing inserts</td>
<td>1/2</td>
</tr>
<tr>
<td>Fixing steel reinforcement</td>
<td>1/4</td>
</tr>
<tr>
<td>Placing 6&quot; structural concrete</td>
<td>1/2</td>
</tr>
<tr>
<td>Cutting and placing insulating panel, and</td>
<td>1</td>
</tr>
<tr>
<td>spacing and fixing ties</td>
<td></td>
</tr>
<tr>
<td>Packing 4&quot; concrete backing</td>
<td>1/2</td>
</tr>
<tr>
<td>Exposing aggregate surface</td>
<td>1/2</td>
</tr>
<tr>
<td>Stacking panel in yard</td>
<td>1/2</td>
</tr>
<tr>
<td>(after curing)</td>
<td></td>
</tr>
<tr>
<td>Cleaning exposed surface with acid (after</td>
<td>1/4</td>
</tr>
<tr>
<td>stacking)</td>
<td></td>
</tr>
</tbody>
</table>

The concrete would be left to cure in the mould overnight, and the stacking and cleaning operations carried out the next morning.

The casting cycle and approximate times required for manufacturing internal wall panels 15 ft. x 8 ft. x 7 ins. thick in vertical batteries of 5 or 6 would be:

<table>
<thead>
<tr>
<th>Operation</th>
<th>Time (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Striking mould from previous unit</td>
<td>1 to 1 1/2</td>
</tr>
<tr>
<td>Cleaning mould</td>
<td>2</td>
</tr>
<tr>
<td>Applying mould oil</td>
<td>1</td>
</tr>
<tr>
<td>Placing inserts, e.g. fixing blocks, electric</td>
<td>3 1/2</td>
</tr>
<tr>
<td>conduits, inserts for holes</td>
<td></td>
</tr>
<tr>
<td>Fixing steel reinforcement</td>
<td>1</td>
</tr>
<tr>
<td>Placing concrete in mould</td>
<td>1 1/2</td>
</tr>
</tbody>
</table>
Curing concrete 5 hours
Stacking panels in yard 1 hour
Treating surface finishes in yard (next morning) 1 hour

Under normal conditions, factory operations would be staggered for 2 single shifts of 8 1/2 hours each per day in order to obtain 2 casts from the moulds. One team commences at 6.0 a.m., and the other team at 8.30 a.m. The teams would be engaged in preparing reinforcement and inserts when waiting for the concrete to cure in the moulds.

With production requirements based on a 3-minute cycle mix of concrete from a 1 cu. yd. capacity mixer to place the concrete into its mould within 20 minutes, the casting cycle and approximate times required for manufacturing floor panels 10 ft. x 12 ft. x 6 1/2 ins. thick with one team of 3 men working one daily 8 hour shift to complete horizontal casting operations of one panel would be:

- Striking mould from previous unit 10 to 15 minutes
- Cleaning mould 10 minutes
- Applying mould oil 2 minutes
- Placing inserts 6 to 7 minutes
- Fixing steel reinforcement 15 minutes
- Placing concrete in mould 20 minutes
- Surface treatment 20 minutes
- Curing concrete 6 hours
- Striking concrete from mould 10 to 15 minutes
- Stacking panel in yard 10 minutes.

(c) Accelerated Concrete Curing

The turn round of moulds for constant use is economically based on a 24-hour cycle, so the design of a concrete mix should provide sufficient strength for de-moulding at 24 hours, with a strength of 1,450 lb. per sq. in. at 18 hours.

The casting and curing of concrete at high temperatures (i.e. over 50°C) provides a quicker handling of units, and enables two daily casts
to be obtained from steel moulds, but with strength loss of up to 50%.

This loss can be compensated by using a richer mix with more cement.

Rapid turnover without loss of strength can be obtained at temperatures up to approximately 50°C. The minimum casting per mould requires temperatures above 15°C for both casting and curing. Below this temperature, gain of handling strength would be insufficient for daily turnover.

It is desirable that no violent changes should occur during the casting and curing cycles. For example, concrete should not be cast at 20°C and then rapidly cured at 40°C. If conditions necessitate casting at a considerably lower temperature than that required for curing, temperature increase should be gradual.

Steam curing (i) accelerates concrete maturing by causing it to expand, and (ii) achieves increase of productivity by enabling the moulds to be used more frequently for casting concrete, so that two or more mould casts can be obtained in one shift. As the costs of materials and labour are constant for each casting, the economies achieved relate to the more rapid casting and striking from the moulds. For example, a 13 ft. x 8 ft. wall panel can be steam cured in half an hour, and then de-moulded, a process which normally takes from 2 to 5 hours.

Some Continental systems are based on methods of battery casting and high temperature concrete curing with double shift work in order to obtain five pre-finished units from the moulds which are ready for stock piling in 16 hours. By these means, utilisation is achieved of only one fifth of the number of moulds that would be required for horizontal casting with an output of only 1 or 2 units per 16 hours.

Two economical types of steam plant for the site factory curing of concrete are:

(a) a mobile steam generator unit which provides a steam output of 550-572 lbs./hour at a pressure of 142 lbs. per sq. in., with a fuel consumption of 5.5 Imperial gallons/hour of diesel
or gas oil Type B.S. 2869: 1957 Class A. This type of generator requires an electricity supply of 440 V 3-phase, and a water supply of 59.4 Imperial gallons/hour, and is suited to production requirements up to 3,000 cu.ft./week during winter months;

(b) a unit with a vapour boiler and fuel capacity of 1,000 gallons, and giving a 1,000 lb./hr. steam output at 150 lbs. p.s.i. for larger production requirements of 6,000 cu.ft./week and over.

Fuel consumption is about 9.2 Imperial gallons/hour of diesel or gas oil. The unit requires a 440v 3-phase electricity supply, includes water softeners and electrical time switches, and should be contained in an enclosed shelter. An insulated tank at high level should be provided through which steam may be used to heat the mixing water. The capacity of the tank should vary with the production of concrete from the mixers. Approximately 28 gallons of water is required for each cubic yard of concrete mixed.

(d) **Shift Work**

It takes approximately 2 to 3 weeks for new operatives to learn the various manufacturing techniques required in a temporary site factory. A team of 13 experienced men engaged in the site factory production of large panel units for the box-shell construction of dwellings on one site would have a normal weekly output of approximately 4,000 to 8,000 cu. ft. of pre-cast concrete units, working one daily shift of 8½ hours.

In theory, it would appear more economical for the teams to work two shifts per day in order to increase their productivity, but this would not result on sites to be developed with only one to three tower blocks unless:

(i) sufficient stacking area was available on the site for the simultaneous production of the units required for all the blocks;

(ii) the additional erection cranes required could be economically utilised; and

(iii) adequate team strengths were available for the finishing
trades to follow up erection of the structures.

Site factory outputs are limited by (a) the finishing trades' cycle of operations, and (b) optimum utilisation of mechanical plant and equipment for handling and erecting the pre-cast concrete structural elements.

When increased weekly outputs (e.g. 10,000 to 12,000 cu.ft. per week) are required for larger projects, economic single shift work could still be maintained, but an additional factory crane would be required to deliver the factory finished units within reach of the erection cranes and trailers. Economic shift work is dependent upon the careful balancing of manufacturing techniques with daily production requirements for each type of unit. For example, a daily output based on the production of x interior wall panels, y facade panels, and z floor panels should be geared to the required ratios by determining whether to utilise more moulds with less shift work, or fewer moulds with increased shift work, according to:

(i) type, size and construction of each unit,
(ii) required output of each type,
(iii) any limitations imposed by erection equipment, layout of buildings, and space available for stacking finished units;

and (iv) the overall contract period.

In general, shift work may be economical on a private development project in order to obtain a quicker return on the employer's capital investment in the form of rents. But on Local Authority developments, where subsidies are required to be paid out when the dwellings are occupied, there is not the same drive for rapid erection, and construction is usually based on the more economic but slower construction and completion of one single block followed by a second block, trade by trade.

(e) Stacking and Transportation of Pre-cast Concrete Units

In order to ensure safe handling, concrete units should (i) reach a satisfactory stage of their curing before removal from the moulds (e.g. 1,500 lbs. per sq. in., or 40 per cent of their 28 day strength), and (ii) be identified
with their date of manufacture in order to prevent green units which have not reached their design strength being built into the structure.

Efficient stacking of units is essential for the safety of site operatives. Stacks should not be positioned close to moving plant such as cranes so that a trap would be formed between the fixed stack and the crane; a minimum clearance of 2 ft. is essential for safety.

Odd units should not be placed outside the normal stacking areas, as they may impinge upon crane tracks and access ways, and can be caught up by another unit whilst being slung into position by the erection cranes.

Units should be supported at suitable points in the stacking yard to avoid permanent deformation due to their low strength of concrete at this stage of their maturity. Direct and bending stresses in the lifting loops, bars or bolts should be checked, as units damaged in stacking can be dangerous when lifted from the stack by cranes.

Proper packing is essential in order to prevent damage and fracture to the units. Floor panels which are stacked horizontally should be separated by such means as timber packing placed one above the other up the stack, with sleepers positioned over the bolt holes when the slab is even. Good access should be provided to the top of the stack. On long runs of vertically stacked wall units, an elevated walkway the entire length of the stack should be provided to ensure quick and safe access to any position.

The transportation of units around the site necessitates considerable care. Hard standings for trailers should be provided at loading or unloading points, as vehicle wheels may sink into soft ground and unbalance its loads. All units should be chained to their transport vehicles, and units travelling vertically on "A" frames should be well secured with clamps.

5.4.7. Factory Production of Pre-Cast Concrete Panel Units for 400 Dwellings.

The following example indicates the procedure required for setting up a factory on site for the production of pre-cast reinforced concrete wall, partition and floor slab units suited to the box-shell construction of
multi-storey dwellings on an assumed basis of 400 dwellings planned in 4 twenty-storey blocks for completion within a period of 100 weeks.
Plan of site for factory

- **Crane track + rails.**
- **Portal Crane.**
- **Mobile Shelters.**
- **Concrete paving.**
- **Bed of ashes.**

**Services duct** for temporary drainage, plumbing, steam & electric services.

**A** = steel battery moulds in pit for external wall slabs.

**C** = Ditto for internal wall slabs.

**B** = Steel moulds for floor slabs.
The floor of the factory indicated comprises pre-cast paving slabs bedded in sand around the moulds, with a service duct in the centre, and a bed of ashes laid between movable polythene framed shelters and the portal crane track. About 40 cu. yds. of concrete would be required for supporting the steel moulds and battery pits, and bedding the portal crane tracks.

Plant requirements

The plant required would include a 70 ft. portal crane, a 21½ mixer, a steam generator, and stacking racks. The work load of the portal crane would be based on lifting approximately 280 units per week to provide a 15½ day erection cycle per floor geared to daily factory outputs of 850 cu. ft. of pre-cast concrete units.

Production Requirements

The floor slabs would be produced in horizontal moulds, and the wall slabs in vertical battery moulds.

The pre-cast units required for each floor would comprise:

- 100 floor slabs
- 30 cladding units
- 50 internal wall panels
- 5 staircase panels
- 45 internal partition wall units.

Total 280 units per floor, comprising a total of 13,000 cu.ft. of pre-cast concrete.

5.4.8. Factory Production of Pre-Cast Concrete Panel Units for 1,000 Dwellings

The type of site factory for a larger volume of output (e.g. for 1,000 dwellings) would necessitate differently planned manufacturing bays and a more permanent type of temporary structure (e.g. metsec columns and framing for walls, and sliding roof, timber framed cladding), additional cranes, and increased areas of production bays and stacking yards as indicated in diagram X:
Plant requirements for the factory would include one portal crane for each production bay, and mobile tower crane spaced to control all movement of units, one 18/12 concrete mixer with track for two skips serving each portal crane and the tower crane, one steam generator unit, and approximately 2,000 sq. ft. of stacking area made available adjoining the track of each portal crane.

In addition, approximately 5,000 sq. ft. of further stacking space should be allocated in a convenient area of the site.

5.4.9. Factory Production for Larger Outputs of Panel Units

Increased volumes of site factory production necessitate more highly intensive capitalisation for:

(a) larger and more permanently constructed factory buildings, with maintenance sheds for vehicles delivering units from the factory to required locations on site;
(b) a greater degree of mechanisation for production, requiring more costly machinery, plant and equipment;
(c) large areas of handstandings and stockyards;
(d) fencing, gates;
(e) additional staff, e.g. foreman, quality control inspectors, production planning and materials ordering staff, concrete engineers, plant and cost clerks.

A housing project comprising 4,000 low- and high-rise dwellings of composite pre-cast and poured in-situ concrete construction would be based on site factory production of wall units for yearly outputs of 1,000 dwellings working one shift per day. Capacity would be provided for increasing outputs to units for 1,500 dwellings working two shifts per day. The type of factory installed on site would have a closed roof, and an internal gantry crane, with two bays of sliding roof provided at one end, for handling the units and placing them in the stacking yard. The layout of the manufacturing areas would include two casting halls, one for floor panels and horizontal facings, and the other for vertical complex units, staircases and
miscellaneous units. Stores, welding shops, a boiler house, carpenters' shop, and fully equipped fitters' shop would be provided, and approximately twenty trailers required for transporting the units to required positions on site.

All moulds for pre-casting would be of precision made steel which provide flexibility for varying lengths of standardised wall units by the insertion of stop ends. The curing of units would be by steam. External wall panels would be cast with a polystyrene insulation sandwich layer, and fittings, doors and windows inserted in the moulds. Once the panels have been cast, they would remain in a vertical position to simplify handling operations. Horizontal moulds would be jacked up vertically to avoid stressing, and lifted into the trailers by crane for transporting and hoisting to final positions in the various buildings.

Average daily outputs of pre-cast concrete units based on 2 castings a day would vary from between 3,000 to 4,000 cu. ft. of concrete, according to site erection requirements. The average time required for producing one unit would average approximately 2 2/3 to 3 hours, excluding 12 minutes for inspection and making good pinholes in finished surfaces. Average times for cranes to handle one unit to position would be 15 minutes, and for a team to erect, joint and point the unit, 3/4 hour.

5.4.10. Effects of Scale of Production on Costs

The effects of increased scale of outputs on factory production costs of pre-cast concrete panel units is relatively insignificant within fairly confined limits. The following assessments of site factory costs are averaged over all types of large panel units for the box-shell construction of dwellings based on weekly outputs of 8,000 to 10,000 cu. ft. of concrete units for 300 dwellings, the minimum volume of demand for economy.
Factory installation, maintenance and dismantling 9.
Steel moulds 1. 0.
Casting 7. 0.
Plant 1. 0.
Concrete sandwich materials 4. 6.
Steel reinforcements 2. 6.
Factory staff 9.
Insurances 6.

Add Handling and transporting unit to position and erecting 2. 0.

Add Contingencies, overhead charges and profit, say 25% 5. 0.

Approximate total cost per cu.ft. of concrete unit produced and erected in position 25. 0.

By doubling such outputs, a saving of approximately £100 per dwelling could be achieved on the total cost of system built housing, approximately 33\(\frac{1}{3}\) per cent of which relates to traditional site and foundation works. Increased outputs for 1,000 dwellings would probably achieve a saving of approximately £125 per dwelling. This would be a limiting reduction, because vaster outputs necessitate either a much larger or more expensive type of site factory, or else a second factory to maintain speed of assembly and erection.

Other effects of increased outputs relate to additional requirements for heavier and more costly types of cranes and transport vehicles to handle larger and more pre-finished units to keep pace with erection requirements.

The main advantages to be gained from the increased scale of production for pre-cast concrete panel units relates to a certain limited economy of construction costs, and to the advantages obtainable from:

(a) the construction of large numbers of dwellings of a higher standard than those built by traditional methods due to the greater precision and better finish achieved by factory
methods of controlled production;
(b) more rapid construction with less site manhours;
(c) improved labour-management relations due to (i) better working conditions and more opportunities of obtaining increased bonus payments, and (ii) the beneficial psychological effects achieved from operatives readily seeing the quick effects on output of their increased efforts.
CHAPTER 6

PROGRAMMING AND CONTROL OF SITE MECHANISATION
AND ERECTION OPERATIONS

6.1 Programming

6.1.1. General

Traditional building construction is a labour intensive activity, the speed of craft operations being mainly determined by the ability and drive of the operatives related to effective bonus schemes, availability of work and materials, and the design of the buildings to be erected. The productivity of industrialised system building is also influenced by these factors, but more especially by:

(a) the detailed design of mechanical plant and equipment used for semi-skilled operations;
(b) the general sequence of erection operations;
(c) the composition and strength of erection teams for specialised trades geared to the mechanical plant serving them; and
(d) the integration of factory outputs with more rapid erection requirements.

The speed of system building is determined by the critical operations of the floor to floor erection cycle, which is mainly influenced by type of structural design. For example, (a) where several teams are employed on in-situ concrete operations based on crane handled shuttering and concrete skips, maximum crane utilisation may result in one or more of the teams being idle at times, or (b) where central core construction is planned to proceed well in advance of general floor construction, attempts to increase the speed of other operations may only result in more idle time.

Effective pre-planning and site control of all phases of industrialised system building is essential to (a) integrate rapid factory production outputs and materials deliveries with erection requirements, (b) ensure that all erection teams are fully occupied and can move freely from one operation
to another without delays in order to maintain continuity of construction and plant operations, and (c) minimise non-productive time and site on costs.

The most careful consideration should be given to the sequence, timing and most economic method of erection operations (e.g. the use of simple erection devices to plumb, level and line pre-cast concrete units for jointing), and the comparative advantages of manpower or suitable mechanical plant and its positioning in order to achieve uninterrupted construction.

The momentum of system building output depends on (a) optimum utilisation of plant and labour, (b) efficient safety and welfare measures, (c) provision of artificial lighting during winter months, (d) adequate protection for the men during adverse weather conditions, (e) facilities for servicing and repairing mechanical plant and (f) effective bonus schemes.

In general, the fewer separate erection operations required and the more standardised and repetitive they are, the easier will be the organisation and progression of erection processes.

In order to achieve a high labour output, equitable bonus targets should be established for the phased operations of all trades and sub-contractors' men integrated with the planned erection cycle. This programme may require frequent revision during the progress of the works to suit changed conditions (e.g. shortage of materials and labour, alternate methods of construction), bad weather, and other unforeseen circumstances.

Slower building with less mechanical plant and equipment tends to reduce idle time, but increases overhead costs, and delays the return on Employers' capital investments. The use of more mechanical plant to replace site labour combined with efficient control over materials, component deliveries, labour and mechanical plant can minimise non-productive time, and result in faster construction which achieves savings in overheads, and provides a more economic return on capital investment and turnover.

Non-productive time can be reduced to a certain extent at design stage by standardising components, and erection and simple jointing techniques.
The specialisation of erection tasks enables labour output to be increased by the operatives' improved facilities of carrying out the same operation repeatedly.

In order to achieve maximum economy of labour and speed site erection, architectural and structural plans should provide (a) a maximum repetition of standardised site erection operations with sufficient working space and access to operatives inside the building so that specialised teams can handle and erect the optimum number of standardised pre-fabricated components, and (b) site layouts which permit adequate manoeuvrability of cranes and earth moving equipment, continuous operation of all cranes, and efficient utilisation of all other plant and equipment required for total construction operations.

System building has brought the construction industry more into line with manufacturing industries by the introduction of factory methods of production and industrial problems of the shop floor. These profoundly affect the control of a contractor's profits, the main control ratios being (a) Profit/Total capital employed, which indicates the efficiency of assets utilisation, and (b) Total capital employed/Turnover, which indicates the efficiency of expenditure of circulatory capital, largely obscured by the allocation of fixed capital in the ratio which is not turned over during the financial year.

A contractor's organisation based on a building system requires the control of both finance and production due to the rapid speed of construction, which is strongly responsive to the introduction of capital. Increased receipts, which are influenced by rapidity of earnings, should be related to return on capital as well as market demands, and required profits on capital investments should be established in relation to planned productions.

The following table indicates how the introduction of capital and speed of construction should be controlled by financial planning:
<table>
<thead>
<tr>
<th>Period of Contract</th>
<th>Value of Contract £</th>
<th>Gross Profit 10% £</th>
<th>Assets Employed £</th>
<th>% Return on Assets</th>
<th>% Earned per Week</th>
<th>Cash Earned per Week £</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>30</td>
<td>50,000</td>
<td>200,000</td>
<td>25%</td>
<td>.83%</td>
<td>1,667</td>
</tr>
<tr>
<td>A2</td>
<td>20</td>
<td>50,000</td>
<td>220,000</td>
<td>22.7%</td>
<td>1.135%</td>
<td>2,500</td>
</tr>
<tr>
<td>B1</td>
<td>18</td>
<td>50,000</td>
<td>230,000</td>
<td>21.74%</td>
<td>1.20%</td>
<td>2,778</td>
</tr>
<tr>
<td>B2</td>
<td>18</td>
<td>500,000</td>
<td>230,000</td>
<td>14.94%</td>
<td>.83%</td>
<td>1,909</td>
</tr>
</tbody>
</table>

**TABLE ILLUSTRATING METHOD OF PLANNING**

**TO CONTROL CAPITAL INVESTMENT IN RELATION TO SPEED OF CONSTRUCTION**
In Example A2, capital of £20,000 (a second erection crane) was introduced to reduce the contract period to 20 weeks. By obtaining this speed of construction it would be possible to reduce the gross profit on turnover to 7.3% and yet still obtain the same weekly return on capital employed of 8.3% per week i.e. the estimated profit can be reduced to £13,580 (i.e. the difference between 10% and 7.3%) and still be improved by reducing the contract time.

In Example B2, increased assets yields a proportionally much smaller decrease in contract time, but as the amount introduced is relatively smaller, the % return earned per week is increased. This represents greater earnings in terms of cash flow per week. Thus a contract price which yields 6.8% on turnover yields the same return on capital (i.e. .25%) as obtained in Example A1. Thus the speed of a project should be related to its profitability in terms of total capital invested, or turnover, and capital and speed of construction utilised to achieve the optimum return on capital investment.

6.1.2. Phasing Materials and Component Deliveries to Suit Erection Requirements

The ordering of phased deliveries of materials and components (e.g. for 500 dwellings) should be based on the delivery of structural units and cladding direct to the erection cranes, and the delivery of materials and non-structural components to storage compounds for packaging into dwelling types and storing until required for (a) lifting into the buildings at shell erection stage, or (b) carrying in at a later stage.

The speed of industrialised building requires corresponding business efficiency aids to management, and computer techniques are used for accelerating management decisions and speedily evaluating a complex series of unrelated data in detail. Computers can be used to cut down the work in preparing lists of units for developments with a considerable variety of dwelling types and units, e.g. 50 different cladding units painted five different colours, i.e. 250 types of this one type of unit alone.
An effective computer system can aid rapid and flexible control over pre-planning and costing by taped programmes for (a) ordering materials to phased deliveries, (b) comparing estimated costs with the current costs of all jobs in progress by a detailed breakdown which forms a pre-expenditure control budget enabling all price variations between estimated and actual costs to be readily determined, (c) rapidly ascertaining payments and outstanding balances due to sub-contractors on the basis of coded budget programmes, and (d) readily obtaining monthly efficiency reports which provide detailed information about differences in costs and quantities of materials used on site, labour, plant costs, and sub-contract works.

Computerised forward weekly delivery lists can be prepared for materials to be sent to storage compounds, allocated into (a) list of materials to be carried into buildings from storage compounds, (b) list of building types (in weeks), and (c) list of materials to be delivered direct to the cranes.

Materials lifted in at erection stage should be included in the weekly erection lists and ordered in a fixed number of weeks ahead equivalent to the period of stock held in the storage compounds (e.g. erect on week No. 10, stock held for 3 weeks, deliver on week No. 7).

Materials to be handled into the buildings after erection stage can be timed by (a) adding on the period from erection to fixing time, and (b) deducting the stock period (e.g. erect on week No. 10, handle into the building 7 weeks later, stock held for 3 weeks, deliver on week No. 14).

Materials delivered direct to the crane involve a more laborious process, as a sequential list should be prepared for every unit in order of erection, analysed into loads.

All these methods of scheduling materials deliveries can be computerised by feeding the computer with (a) a list of dwelling types, and the amount and numerical code numbers of each type of unit, (b) a list of the units' numerical code numbers against the equivalent design code numbers,
and (c) a list of week or day numbers, and the amount and type of dwellings in each day or week.

Five basic types of schedules for dwellings are required for computerised production control:

1. A delivery schedule on a time basis, giving the amount and types of units required each week;

2. An erection schedule of units delivered direct to the crane, giving a sequential list of units in order of erection broken down into trailer loads, with delivery dates against each load;

3. A quantity schedule for each block, or part of a block, giving a list of the units required for that particular portion of the project;

4. Labour content schedules with the total manhour content of each dwelling type and component, as a basis for assessing bonus payments;

5. Price schedules, or cost plans, with the prices of various components for each dwelling type.

6.1.3. Pre-Planning the Erection Cycle

In the complex network of concurrent, overlapping and interrelated site operations, (a) speeding the time of a single operation may actually increase costs without decreasing the contract time, because other critical operations have not been speeded up as well, and (b) quickening the time of all the operations may well result in excessively increased costs being incurred in relation to the reduced time achieved.

The critical path and method of sequence analysis aids pre-planning by making it possible to establish which particular operation, or sequence of operations can be speeded in order to obtain the most economic reduction of time by:

(a) isolating those operations whose starting and finishing times are critical, and must be strictly kept in order to complete
the contract to date;

(b) evaluating the amount of flexible time ("float") included in each non-critical operation, within which it can be started later, or be completed more slowly than originally programmed without affecting the completion date. By this method, (i) non-productive time can be minimised by adapting the speed or sequence of non-critical operations to maintain the steady full employment of the planned labour force over prolonged periods, (ii) mechanical plant and equipment can be continuously operated, instead of being utilised to complete operations in spurts followed by idle times, and (iii) uneconomic utilisation of additional equipment being brought on to site to meet short peak loads can be avoided.

6.1.4. Site Layouts

Site layouts should be flexibly planned to co-ordinate and control access, movement, plant, service runs, traffic routes, and factory administrative and work areas in relation to the different phases of construction and the contract time, in order to ensure a smooth flow in the cycle of operations.

Administrative areas should provide adequate temporary offices, stores and welfare units which avoid obstructing work areas, and maintain free access to storage compounds and points requiring maximum labour control.

Site factory and stacking areas should be determined by available space, access for deliveries, required output, type of construction, and layout of buildings and plant in order to minimise double handling, and integrate production with erection requirements. The main problem is to site the factory within reach of the blocks, with the batching plant set up near the site entrance. Where space is restricted, ready-mixed concrete
can be utilised to supplement limited batching plant, or even for all castings.

Construction areas should be sited to minimise movement and handling, and permit storage of the least amount of materials and components required for the erection operations.

Administrative areas should be sited to maintain free access to storage areas and points requiring maximum labour control. On large development schemes in city areas, economy can be sometimes achieved by allocating a separate storage area for sub-contractors' deliveries, the general contractor being responsible for their transportation to required locations on site in order to avoid lorries waiting before being able to enter the site.

Transportation routes and temporary roads should be effectively located to avoid restrictions on earthworks, service runs, and movements of mechanical plant, either by planning two-way traffic systems, or by one-way circular routes with turn rounds and passing bays according to the site layout and phased operations. Vehicles for transport should be related to power, surface condition of planned works, capacity, and shape, size, and weight of units.

Wet sites necessitate tracked machines, whereas sloping sites may obviate the use of rail mounted cranes. A site surrounded by adjoining tall buildings may require a derricking jib crane, rather than a horizontal crane, in order to clear the buildings as it slews round.

Passenger hoists should be located around the structures of multi-storey buildings to speed the time of operatives moving to and from work positions, and be related to the number and location of canteens provided in order to minimise the non-productive time of men leaving their work positions from upper storeys at meal breaks, and at the beginning and end of the day's work.

On sites to be developed with several multi-storey blocks based on the site factory production of pre-cast panel units, the most economic but
The slowest method of site erection relates to single block construction:

(a) the foundation team constructs the foundations, and moves to the next block when its work has been completed;

(b) the "non-repetitive" teams then construct the work from ground to first floor, or such floors as are "non-repetitive";

(c) During this period, the site factory will have produced the units required for the three floors above, and these are erected next;

(d) The finishing teams then follow on in the floors erected.

This cycle of operations continues, so that by the time the roof is placed on the first block, all the units for the three first floors of the second block have been manufactured and erected.

Where a development provides for six or more blocks, more economical construction would be based on doubling factory production outputs and cranage, and similarly erecting two blocks at a time, because the time for completion of all the blocks, and their numbers and layout influences the choice of structural type and team strengths related to cranage.

In general, in-situ concrete construction is more economical than pre-cast concrete construction for (a) limited volumes of production (e.g. 250 dwellings on one site), (b) non-repetitive designs, and (c) widely separated blocks, because such site layouts and small volumes of demand do not justify the costs of setting up a site factory.

Economic pre-cast concrete construction requires (a) more adequate volumes of demand, (b) efficient design of structural elements and jointing techniques, and (c) block layouts spaced sufficiently closely for rapid erection operations. For example, blocks should be laid out so that (i) 2 cranes and 2 erection teams can operate three blocks, or (ii) 3 cranes and 3 teams can operate six blocks.

When completion of all the buildings is required at the same time, the most efficient site layout would take the following form:
so that when block 1 has been completed, the erection teams can proceed to blocks 2 and 3.

But if the blocks were to be widely spaced apart as indicated in the following diagram:

Alternative track for mobile crane.
Static tower cranes

X Tower Crane

X Tower Crane

X Tower Crane
It would be more economical to construct them with in-situ poured concrete, and 3 cranes and associated erection teams.

On sites where only one block of dwellings is to be constructed with in-situ concrete, one crane and erection team of 10 men could complete one floor of five dwellings each week. This would involve a certain amount of non-productive time (approximately 20 to 30 per cent) according to circumstances, and would not provide the operatives with sufficient incentive to increase their efforts in order to gain a bonus for improved output. But when two similar blocks are to be developed on one site, and suitably positioned so that they can be served by one crane, the outputs of the associated erection team can be increased to achieve weekly completion of one floor in each block (i.e. a total of two floors per week). This method of procedure minimises non-productive time, because the operatives can fall back very readily from the first block to the second without disorganising the team, and provides the men with an incentive to work harder with the opportunity of increasing their productivity from approximately 50 to 70 per cent in order to obtain a good bonus.

When three similar blocks are to be developed on one site and suitably positioned for erection with two tower cranes, three associated teams will be needed, one for each block. If only two teams were operating, the men in each team would be split up in order to fall back on the third block, and by so doing, would lose their integrated output. By operating three teams the situation becomes similar to that when only one block is to be developed on a site, and there is insufficient incentive for the men to increase their efforts to gain a bonus.

When four blocks are to be developed on a site, it is more economical to operate with two cranes and two associated erection teams of 15 men each and thus achieve a situation similar to that required for the economic construction of two blocks.

It is generally more effective to construct long blocks for a mixed
development scheme comprising low- and medium-rise dwellings up to 4 storeys high with a small portal crane on tracks, rather than tower cranes. But if the buildings to be constructed were taller, greater economy could be achieved by using two climbing tower cranes suitably positioned, because:

(a) the cost of laying the track and sleepers for the portal crane is avoided;
(b) two tower cranes provide more versatility in handling different kinds of materials and components, and can more readily keep the operatives fed in order to speed the erection cycle.

6.1.5. The Preliminary Erection Programme

After determination of the building, plant, services, and site factory layouts, a preliminary overall erection programme can be determined on the basis of a bar chart which indicates separately:

(a) all the principal repetitive erection operations of the system which are to be undertaken within the contract time;
(b) all non-repetitive work in the sub-structure and above up to the level at which repetitive system building commences.

By this means, cost comparisons can be made of the most economic alternative methods of construction (e.g. by utilising climbing tower cranes rather than static cranes, or sliding shutters instead of pre-fabricating shutters in large sizes for handling by crane). When the broad overall programme has been decided, critical path planning can be introduced to indicate the amount of spare time each operation includes before the starting and finishing times of "critical" operations which cannot be delayed or prolonged without extending the contract time.

The most economic cost to time relationship of erection operations is that best suited to the total labour, plant and materials requirements for the whole of the programmed works in order to (a) optimise the contractor's return on his investment in the contract works, and (b) lead to a reduction in competitive tender prices.

Construction costs tend to decrease as output per team of operatives
and related mechanical plant increases. Ill-planned speeding of erection operations can result in higher costs being incurred to (a) overtime, (b) shift work, (c) over-sized erection teams, (d) unnecessarily large or additional mechanical plant, and (e) different and more costly methods and techniques of construction.

One advantage of industrialised system building is that site work can be split into well defined operations capable of being carried out by various types of teams without their interfering with one another. This method of procedure replaces the traditional "criss-crossing" of teams from house to house on low-rise development schemes by a train of teams following one another around the site, their work having been pre-planned so that no one team can proceed slower or faster than its neighbours. The leading erection team determines the speed of the whole cycle of operations, and is separated by a "buffer" period of about one week from the succeeding teams, which are each similarly separated in time one from the other. These "buffer" periods act as a safety valve to achieve day by day variations without involving non-productive time, as where the labour content of different dwelling types vary, one team will tend to catch up with, or fall too far behind the team in front.

The following comparison of traditional building methods with industrialised system building techniques indicates how the latter can minimise non-productive time being incurred on site:
<table>
<thead>
<tr>
<th>Day</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Carpenter</td>
<td>Electrician</td>
<td>Plumber</td>
<td>Carpenter</td>
<td>Plasterer</td>
<td></td>
<td>Carpenter</td>
<td>Electrician</td>
<td>Plumber</td>
<td>Carpenter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>House no:1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>House no:2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table of Trade Teams for Two Traditional Houses on a Low-Rise Housing Development.
This table of trade teams, which is not based on any particular form of traditional construction, indicates the planning of trades where each trade is intimately connected with all the others. The carpenter team is represented as completing its first task in house no.1 by day 3, and moving into house no.2, where its task is completed by day 6.

By this time, the following team of electricians has completed its task in house no.2 on day 5, but cannot start work in house no.2 until day 6 because the carpenters are still there. The electrician team either has to wait a day, or else be occupied elsewhere.

Similarly, when the carpenters have finished in house no.2 on day 6, they are unable to return to house no.1, as it is still occupied by the team of plumbers.

These situations result in a confusion of trades either waiting on their predecessors, or else holding up their successors. When multiplied on a large development project by several hundred houses, site management is presented with a typically confused problem which can only be solved with traditional methods by building much more slowly.

With industrialised system building:

(a) for low-rise developments of dwellings, mobile erection cranes become the leaders of a series of teams which follow the cranes around the site, so that the operatives can carry out their pre-planned tasks at a fixed speed. Each crane and its associated team composed of a crane driver, banksman, and two erectors, is completely isolated from the other cranes, and must erect and finish their dwellings to programme. In so doing, each operator will receive a bonus payment at the end of the week;

(b) for high-rise developments, the cranes are selected and laid out with sufficient mobility to bring the required materials and components to the waiting erectors stationed at planned positions.
In programming the erection of operations of industrialised building systems, the optimum effects of repetitive tasks on labour outputs can be achieved best by dividing the whole of the contract works into a large number of simple, well co-ordinated processes based on effective, satisfactory bonus incentives. By these means, a high degree of specialised tasks can be achieved for the assembly of standardised components geared to a common rate for the erection cycle by independent teams of operatives freely moving between different working areas of the building in accordance with the general work rhythm.

All the separate tasks should be listed, and the most important key operations selected on the basis of their regular occurrence (e.g. pouring concrete into large pre-fabricated shutters), for which time cycles are estimated. The planning of the remaining operations should be based on these cycles to provide a rhythm for the various teams to follow in an integrated sequence, with only one team occupying each defined work area in order to avoid interference of one team with another. Sufficient space should be made available so that all the different teams can work simultaneously without any loss of time, and commence work on the next floor above as soon as their work on the preceding floor below is completed.

Properly planned and co-ordinated factory production and site operations reduce the working space for teams inside the building, which can be reduced when components are delivered pre-finished. Wet processes entail more space, which if not made available (a) slow down the whole erection cycle, (b) reduce productivity, and (c) adversely affect the operatives' bonus payments, thereby damaging good labour-management relations.

The general rhythm of work may have to be adapted as occasion arises in order not to break up the erection teams, or re-employ additional men. When key operations depend upon a technological process (e.g. the time required for concrete to harden), or the hoisting capacity of mechanical handling plant and equipment, the number of men can be reduced.
With work carried out in a closely organised and sequential manner, the interruption of some operations will affect the whole process, and secondary delays may occur as subsequent trades overtake those originally stopped (e.g. heavy rainfall over the weekend which delays earthworks and concreting operations programmed for the following week).

Non-productive time due to bad weather can be reduced by (a) transforming as much site work as possible to factories in order to obtain the optimum dry assembly of pre-fabricated components, (b) adopting methods of construction which enable the shell to be rapidly roofed in, (c) taking into account monthly data supplied by the meteorological office covering the duration of weather capable of stopping or delaying operations.

Adverse weather conditions can delay the cycle of erection operations and increase the costs of construction due to:

(a) operatives being prevented from working. High winds exceeding 33 m.p.h. can delay the working of tower cranes, and heavy rain can hold up concreting operations, and the in-situ jointing of floor to floor connections. But the operatives mainly affected by bad weather are bricklayers and general labourers;

(b) Additional manhours required to make up reduced productivity in bad weather; and

(c) making good damaged work.

The approximate times allocated to erection operations when pre-planning a preliminary overall programme would normally include:

10% site installations (e.g. huts, cranes, services, batching plants, roads, fences, preparation of shuttering etc.)

8% Excavations, foundations, drains

3% Traditional works

44% Site erection of pre-fabricated structural units

20% Internal finishings and services

2% External finishings
10% General site works (e.g. maintenance of plant and equipment, safety measures, clearing and tidying site, storing and checking materials etc.)

With good site management, non-productive time can be reduced to within approximately 10% to 15% of the total manhours employed. And effective bonus incentive schemes can reduce non-productive site service time to within 20% of the total effective operational time.

6.2 Effects of Repetitive Operations on Labour Output

The repetition of identical site operations reduces construction time by increasing labour output, and achieves savings in (a) indirect costs by the greater utilisation of mechanical plant and ancillary works (e.g. cranes, hoists, scaffolding), and (b) on-costs by the increased use of such items as stores, site offices, and temporary roads.

The processes of repetition relate to the organisation and specialisation of methods of site assembly and jointing, and involve (i) a learning phase and (ii) a routine acquiring phase, which gradually induce increased speed of operations dependent upon:

(a) degree of accuracy required for an operation;
(b) type, size and number of components to be erected;
(c) techniques of construction and jointing;
(d) type of mechanical plant and equipment utilised;
(e) the number of men forming the erection team. Larger teams require more time to learn an operation, and greater effort is needed to co-ordinate their work; and
(f) bonus incentive targets.

Increase of labour productivity is disturbed by:

(a) operational discontinuity, due to non-identity of operation;
(b) executional discontinuity caused by a break in team sequence, or changes in teams;
(c) process restrictions; and
(d) bad weather.

Decrease of operational costs is not directly related to increased labour outputs because wages are based on bonus schemes and incentive payments, which may not be linked to actual increases of labour productivity. This dissociation may become a source of difficulty when bonus payments for all the different teams on a site are pooled together and distributed equally amongst each man, instead of the payments being made to individual teams on the basis of their increased outputs.

When calculating the gradual improvement of labour due to repetitive operations, (a) the number of men required for undertaking the different operations may be taken as constant, and (b) the time taken by each process gradually decreased in order to reduce the number of operatives whilst maintaining a constant speed for the whole cycle of operations.

The effects of repetitive operations on labour outputs comprise only a part of the results due to introducing large series of standardised components into building operations. Other factors which affect the time of individual erection operations depend upon (a) the design and methods of prefabricating and transporting units, (b) the locations of factories manufacturing materials and components, (c) scale of production, (d) contract time, (e) restrictions imposed by site conditions, and (f) site organisation.

6.3 Factors Impeding the Erection Cycle

Some of the adverse factors that delay erection operations are outside the contractor's control (e.g. traffic jams in city areas holding up deliveries to site, components damaged in transit, winter darkness). Other factors relate to:

(a) weight of components; the heavier the unit, the more time required for handling to position;
(b) over-complicated jointing details;
(c) failure of the factory, or outside component manufacturer,
to maintain planned production targets;
(d) inefficient selection of mechanical plant and related erection teams;
(e) breakdown of plant, and power failures;
(f) dissatisfaction of the operatives with their bonus targets.

Some adverse conditions which delay the speed of erection operations only come into effect as the number of storeys in the building increases:

(a) men take longer to reach and leave their work positions;
(b) handling and hoisting of materials and components to increased heights takes longer;
(c) movement becomes more difficult as wind strength increases and affects the handling of lighter materials and components;
(d) propping requirements for structural elements become more stringent;
(e) weather conditions at heights of 50 ft. and above become more unfavourable.

6.4 Bonus Incentives

Bonus incentive schemes for site bargaining were introduced in the immediate post-war conditions of a vast reconstruction programme and acute shortage of skilled labour in order to permit payments over the standard union wage rates to be made to operatives, provided that they were strictly related to increased labour productivity. The intention was to afford operatives an opportunity of increasing their earnings, and at the same time, increasing their output of work.

At present, there are no nationally agreed target times or standard methods of measuring work for bonus payments that can be applied to industrialised building projects for several reasons:

(a) In some areas, national bye-laws can be superseded in favour of local bye-laws, which may institute different
conditions with easier task requirements;

(b) Craft methods of working differ in different parts of the country;

(c) Contract periods vary, so that men employed on a 6-month contract require quicker results from their work than men employed on 2-year contracts, who can be educated to understand that their bonus targets are truly profitable. This enables tighter targets to be operated on long-term contracts than on short-term contracts.

As a result of this lack of uniformity, national rates of wages are of but little importance in most areas throughout the country, because bonuses may not be factually related to productivity, and whilst increasing operatives' earnings, undermine the standard rates on which their bonus earnings depend.

The Trade Unions' retention of a rigid traditional craft structure in the face of continuing changes in work content due to mechanisation and new techniques of construction can lead to inefficiency and delay. For example, the erection of an industrialised building designed with a structural pre-cast concrete frame and poured in-situ concrete floors may be slowed down by a Union rule which prohibits labourers during breaks in the cycle of assembling and erecting pre-cast concrete units from assisting other labourers working with carpenters on shuttering operations.

Before the 1939 war, strict inter-craft and craft labour demarcation lines reflected real divisions in building operations, and served to provide a measure of work security and wages for labour. Thus a plasterer will pick up mortar with a trowel, but not with a shovel, as it is a labourer's job to mix the plaster and place it on the plasterer's spot board.

New techniques and mechanised processes require new levels of skills, in many cases capable of being carried out by labourers upgraded to semi-skilled status with adult re-training. Yet the Union structure
does not permit any process requiring a specialised technique, however limited, to be performed by anyone other than a craftsman trained through traditional apprenticeship, often with attendant labourers. As a result:

(a) skilled men are frequently under-employed, the shortage of craftsmen is aggravated, and the savings in labour that can result from new mechanised processes may not be fully obtained because craftsmen may have to be re-trained for each new operation; and

(b) the production of concrete is in the hands of unskilled and semi-skilled labour instead of apprentice-trained artisans. This necessitates improvement in both the production and finishing of site concreting operations, and can involve additional materials costs for extra cement to ensure specified strengths, as well as technicians to attempt the effective quality control of site mixed concrete.

Industrialised building employs a new type of operative termed an "erector", whose knowledge and skill is considerably less than that of a craft tradesman, but requires a knowledge and awareness of mechanical plant, the sequential operations in the erection cycle, and an understanding of the way components must fit together. A recent agreement on balanced teams of craftsmen and labourers for industrialised system building operations enables experienced erection teams to be built up on a site to a certain extent, but necessitates some erection operations which are basically continuous to be divided in order to accommodate two or more unions. Moreover, such teams when established on a site do not usually remain for other jobs.

Efficient system building can achieve high labour productivity with human satisfaction through the reduction of adverse effects on labour operations due to heavy physical labour, dust, bad weather, isolation, and lack
Of the several different types of financial incentive schemes operated in the Building Industry (i.e. profit sharing, piecework, hourly plus rates, and earned bonus), that normally best suited to system buildings with accurately scheduled and established times of repetitive operations relates to team bonusing based on standard and measurable performances. Payments made on the basis of "in lieu bonus" or "inspired" guesswork due to lack of bonus surveyors may well bear no relation to production, and become a mere increase of rates.

Although bonus schedules are usually drawn up at the start of most large industrialised system building projects as a basis for negotiation, less than half of the skilled labour force may be covered, so that serious problems can occur which eventually lead to strikes, as on the Barbican and Horseferry Road sites. Where several specialist sub-contractors are employed on a site, each firm may have its own different incentive scheme. This can result in the Union representatives' demands for equal or pooled site bonuses, to which skilled operatives and craft tradesmen object. When forced into operation, such incentive schemes can slow down the work of skilled men, and lead to output targets becoming so costly that a job may close down, even when operatives are earning double the average national earnings with their bonus payments.

A well operated bonus incentive scheme is essential for the full benefits of costly factory production and mechanical plant to be obtained, and should be related to (a) the outputs of the whole cycle of erection operations, (b) measurable targets which the men can check each week, and (c) provide an equitable return to all operatives employed, irrespective of whether they are craftsmen, labourers, or employed on non-productive work such as unloading, cleaning out latrines, or assisting storekeepers, as all these operatives indirectly increase the general productivity of the works.

The targets for each individual task should be negotiated
separately for each erection team and contract, but certain basic principles apply:

(a) the method of calculating bonus payments should be fair, easily understood by all the teams, and enable operatives to obtain approximately 50% of the benefit derived from any time that is really saved;

(b) the tasks and their targets should be clearly specified, issued in advance of work commencing, and remain unaltered except by mutual consent. It is essential that goodwill is maintained by scrupulous integrity.

(c) Should a technique involving additional plant be introduced to speed erection, targets should be adjusted so that the related operatives can gain 50% of the increased saving, otherwise the men will tend to slow down their rate of working;

(d) No maximum should be placed on earnings, and allowances should be made for delays which are outside the teams' control. A target may be fairly assessed, but prove unprofitable to the operatives due to inefficient management. For example, carpenters working on second fixings may find their work continually held up by delays in obtaining materials, or the uncompleted work of other trades.

(e) An economic balance should be made between productive operatives and non-productive operatives (e.g. unloaders, site service operators) indirectly serving them, which can only be maintained if both groups of operatives put forth equal efforts to increase their work outputs.

(f) All bonus payments due should be paid regularly on the next pay day after the work has been assessed.

(g) In general, the size of a contract should control the targets
set for a particular duration so that the operatives can look forward to a measure of continued bonus earnings, and not incline to slow down their efforts through fear of being unemployed when the contract is completed.

A good bonus incentive scheme should:

(a) entail the observance of all safety, health and welfare requirements;
(b) maintain required standards of workmanship and efficient plant utilisation;
(c) minimise wastage of materials and temporary services;
(d) permit the continued training of apprentices; and
(e) enable site service operators to earn higher wages based on increased outputs that are only indirectly related to increased productivity of the contract works.

If a bonus scheme does not satisfy men employed on tasks which are not directly productive, their cost of serving tradesmen may be increased from about 13\% to as much as 33\frac{1}{3}\% due to a lack of incentive to increase their outputs. For example, four men who "couldn't care less" might be unloading materials where only two men were required to undertake the job in the same time, because their weekly bonus payments amounted to 10/-, whereas their craftsmen brothers were earning weekly bonuses of £10.

Mechanical aids, stock piling, extra delivery transport, and a high level of organisation can enable productive operatives to maintain a constant high level of output, and high bonus earnings. But the balancing of their increased outputs with the outputs of the service operatives necessitates all the non-productive site labour making comparable efforts, otherwise the number of men required for site servicing can become out of all proportion to the number of productive operatives, and prevent them from earning a reasonable bonus.

Target schedules should therefore be agreed so that
(a) the increased efforts of site service operatives achieves a reduction of the men so employed;

(b) productive operatives do not profit at the expense of site service operatives by the introduction of methods which increase their output and require additional site service; and

(c) all operatives are encouraged to co-operate and understand the costs involved and bonus earnings obtainable by their combined efforts.

One method of achieving these results is for an agreed percentage of the average productive operative's bonus to be assessed as between

(1) operatives of direct service to teams, including unloaders nominated by the site works committee at, say, 60%, (2) fitters, and drivers etc., at say 50%, and (3) other site service operatives nominated by the Committee at, say, 30%. Such a method provides the site service operatives with a keen inducement to maintain strong efforts, as they stand to lose approximately four times as much as the productive operatives. By making the site works committee and bonus surveyors responsible for agreeing the actual names of men to be included in any particular group, they are kept informed of new operatives entering the site service teams.

In order to improve the general level of welfare in the Building Industry, instead of casual employment and incentive schemes, more permanent labour forces should be built up and receive payments based on length of service bonuses, pensions, and profit sharing. These inducements would help to create contentment, staff loyalty, and encourage operatives to do their best, instead of tending to slacken off their efforts towards the end of a contract through fear of working themselves out of a job.

6.5 Site Control

6.5.1 General

Economic system building necessitates "flow-line" methods of
production and erection to simplify site management and enable daily assembly operations to be controlled through a "management by exception" technique. This consists of checking to ensure that each erection team is up to required strength, and fully equipped with materials and information to carry out its planned tasks for the day. Teams which are under strength in labour or ability can be especially dealt with, and the remaining teams left alone to carry out their planned tasks at definite speeds geared to factory production in order to ensure that the men will not run out of units to assemble.

Efficient site organisation and control can reduce costs and ensure continuity of erection operations with a minimum of non-productive time by providing:

(1) Adequate safety precautions. These should be provided at floor edges wherever practicable by (a) components designed as cladding units, or (b) balustrades cast in with any balcony units.

When the design of a system does not comprehend such units, falls are possible, and temporary guard rails must be provided with the first operations of the erection cycle. Holes in floors, and lift shafts should be protected with suitable covers, and rails positioned across lift door units. Immediately staircase units have been placed and provide working access they should be fitted with temporary handrails.

Tower cranes are potentially the most dangerous machines used in building, and involve hazards relating to (a) the erection and dismantling of the crane where site contours are uneven, (b) wind effects, (c) access to driving positions and for maintenance, (d) human failures under working conditions, e.g. careless or incompetent driving, incorrect signalling or slinging, risk of overloading, and (e) several different firms of sub-contractors working together.

(2) Passenger hoists around the structures of tall buildings to speed the time of men leaving and returning to their positions at meal breaks.
and the commencement and end of work periods.

Some systems suited to high rise dwellings utilise a small mobile canteen which is hoisted by crane to each erection floor level; one man being detailed to fetch all meals required for the team. Larger labour forces which require increased canteen facilities may necessitate one canteen at ground level and a second canteen installed on the 10th floor level of structures over 20 storeys in height to minimise non-productive time.

(3) **Artificial lighting** for outside work during months of winter darkness in order to reduce loss of time during shorter working weeks. The approximate costs of installing a temporary flood-lighting system are £100 per tower, plus 10/6d. per 100 sq. ft. of site space illuminated. These costs can be reduced when some of the initial equipment is reused on other sites.

The well planned use of flood lighting can (a) guarantee a full working week plus overtime to a planned labour force, (b) aid site security, and (c) provide greater safety during hours of dusk during early morning and evening.

(4) **Efficient mechanical plant utilisation and servicing** to ensure continuous operation of all items of plant at their maximum capacities.

(5) **Tools and materials stock piled** and readily available for use as and where required. This necessitates careful regulation to (a) avoid impeding access to working areas, and (b) minimise double handling, which can be reduced by unloading deliveries as near as possible to required positions for erection.

Timber and similar materials should be protected from the weather, and fragile materials placed where least likely to be damaged. A stack of soft facing bricks placed on unsuitable ground can result in 25 per cent breakages due to settlement.

Aggregates should be stored where they can be fed by road transport,
and adjoining batching plant without need of further handling. This prevents careless operatives allowing the materials to spread and become trampled into the ground during mixing operations. Wherever practicable, long bank runs to and from mixers should be avoided by the use of skips handled by cranes.

Steelwork should be stacked near erection areas and delivered to site in correct order of units to suit erection requirements.

Components should be suitably grouped near cranes and hoists so that they may be handled and hoisted where required in one operation with a minimum change of the crane's position. The lengthy site storage of components increases risk of damage, and they should be erected as soon as possible after delivery to site.

6.5.2. Plant Utilisation

(a) General

The efficient utilisation of site mechanical plant and equipment increases production and labour outputs, and speeds erection operations at reduced overall construction costs by (a) performing work that cannot be readily undertaken manually, (b) eliminating heavy physical work, and (c) maintaining production when labour is scarce.

The type and extent of site mechanisation for a particular project will be influenced by:

(a) the nature and amount of the work to be undertaken;

(b) the time in which it is required to be completed;

(c) site conditions, e.g. ground contours, soil strata, degree of wetness;

(d) the layout, type, size and heights of the buildings to be constructed;

(e) the sequence of erection operations as determined by structural design, techniques of construction; and number, size and weight of components to be handled;
(f) the technical skills required for operating the machines;

(g) the type of craftsmen and quality of unskilled labour available for site erection operations, and

(h) the capital costs or hire charges for the plant.

Efficient site mechanisation obtains when:

(a) all plant is being utilised in conditions which enable it to provide continuous optimum performance,

(b) the apportionment of operatives to plant ensures that both the machines and related teams of operatives are kept actively employed to maintain steady output, with a minimum of idle time, and

(c) the tasks of handling and fabricating components are separated so that teams undertaking a limited number of specialised repetitive tasks can work freely and continuously on site to rapidly assemble and erect standardised pre-fabricated components.

Manual labour can be employed economically on more isolated operations, but conditions may arise on site when it will become more advantageous to utilise machines in order to produce a superior result, or avoid costly delays, even if the plant selected cannot be used to provide a saving in costs over the same operations if carried out by manual labour.

The planned work load of any separate item of mechanical plant should be balanced and integrated with the working of all other plant on site in order to fit in with the overall construction programme, as the actual output of a machine does not solely depend upon its own potential, but also on the limitations which follow. For example, (a) the effective output of a concrete mixer is limited by the rate at which the concrete can be poured, and will be lower for placing in columns than is mass foundations;

(b) the work loads and layouts of tower cranes need careful planning
to achieve their full capacity with a minimum number of movements. Specially designed attachments, such as concrete skips and brick cages can extend the range of items which they can handle, with remote control for operation from a position which provides the best view of the construction areas.

According to the particular conditions of a site, operational efficiency may be obtained by:

(a) selecting a machine to fulfil a number of functions (e.g. a crawler mounted mast crane with vertical boom and fly jib),
(b) meeting peak load requirements in a different way (e.g. by using ready-mixed concrete deliveries),
(c) utilising a range of machine sizes, or accepting a lower rate of efficiency for separate operations by selecting a compromise size of machine to reduce plant costs by raising the level of its use.

Work study techniques can establish correct methods of matching and operating equipment at maximum efficiency, and the accurate information obtained used for comparing alternative methods of construction, and forecasting work schedules to improve site organisation and avoid wasteful tasks.

(b) **Plant Costs**

It is essential for economy that the most suitable items of plant are selected for each particular operation. If not available in the contractor's yard, plant should be especially hired or purchased for a particular project, as it is not economical to use an item in stock which is not adequately suited to the work to be undertaken.

In addition to the rate of hire, plant which is hired from an outside firm incurs transportation costs and the overhead charges and profits of the hirer. Even when these appear economical, it may not be necessarily advantageous to hire if suitable plant were available in the contractor's yard.

Factors influencing decisions to purchase outright or hire items of
plant for the period of a contract are related to:

(a) initial cost;
(b) period and amount of use required;
(c) maintenance and repairs, and
(d) available storage space off-site when the plant is not in operation.

Most types of mechanical plant have a comparatively short life with optimum capacity in relation to their high cost - generally about 5 years, but 2 to 3 years for dumper trucks and concrete mixers. Their cost has to be recovered by work outputs plus profit or interest on invested capital. The actual productive time worked each year of the plant's life is approximately 1,600 to 1,800 hours dependent upon (a) efficient maintenance and (b) the normal working periods of building operatives being limited to 39 weeks of 42 hours per annum. Machine drivers and operatives may be required to work an extra half hour per day before and after normal working hours for starting up, servicing, and maintaining their machines. But the actual outputs of mechanical plant items seldom match up to their rated or calculated outputs, on account of difficulties of achieving continuous optimum efficiency on site due to:

(a) Breakdowns and running repairs;
(b) non-productive time, e.g. waiting upon other plant, setting out work, refuelling, meal breaks, power failures, starting delays in cold weather;
(c) manoeuvring about the site, re-positioning during progress of the works, restricted access space, and
(d) adverse weather conditions.

The capital cost of each item of plant should be set against the savings in labour and other costs achieved by its use, and its economy based on:

(a) standing costs (i.e. annual capital or hire charge) related
to type and size of plant which provides optimum utilisation
for each particular operation;

(b) transportation and erection costs, fuel consumption, and total
operating costs in relation to hourly output and completion
time. An adequate supply of power should be readily available
on site at an economic price for operations;

(c) Working conditions and availability of skilled operators. For
economic operations, there should be sufficient work to be per­
formed of a nature for which the plant is designed in order to
keep it continuously operated as near to its maximum capacity
as possible;

(d) Unit cost of operation performed. The comparatively higher
rates usually charged by plant hire firms do not necessarily
reflect such operating costs, which in respect of a contractor's
own plant are determined by (i) the plant's estimated working
life and total utilisation, (ii) depreciation, (iii) interest
on capital investment, (iv) maintenance, insurances, licences,
and plant function overheads, and (v) the skill of operators
driving the plant;

(e) the efficient matching of the plant where more than one item is
involved in one operation, e.g. a mobile crane delivering units
to a static tower crane in order to minimise idle time;

(f) manoeuvrability about the site, amount of re-positioning, and
any restrictions of working space;

(g) the correct allocation of labour to plant;

(h) efficient and regular cleaning;

(i) availability of maintenance servicing, repairs and fuel storage.

The more machines are used to increase productivity, the more
serious are the consequences of their breakdown in delaying the
cycle of erection operations.
The effective use of mechanical plant and equipment on a recently built high-rise office building with low-rise podiums for shopping areas constructed on piled foundations and involving extensive demolitions in a crowded city area included the use of tower cranes, compressors, pile frames, concrete batching plant, and sliding shutters. By these means, savings of approximately 50 per cent in time and 20 per cent of total construction costs were achieved in comparison with traditional and less mechanised methods of construction utilising more site labour.

In general, the more working hours that can be achieved from an item of mechanical plant during each year of its life, the lower will be its operational costs. In the U.S.S.R. and most European countries with a "controlled" economy, longer working periods and considerably less safety and welfare provisions for site operatives than required in Great Britain, plant is operated for a very much longer time each year (e.g. approximately 7,000 hours per annum for a tower crane) over periods extending from 8 to 10 years, or until the machine is no longer serviceable.

Such increased use of plant does not (a) achieve economy in total construction costs without efficient overall planning and site control, or (b) result in increased human welfare and happiness.

(c) **Mechanical Aids to Labour**

The development of profiles, jigs, hand-powered tools and mechanical aids to both skilled and unskilled labour can achieve considerable savings in time and costs, e.g.

(a) compressor tools and hand-powered tools for cutting, drilling, sawing, hammering and plugging;

(b) spraying machines for painting, and pumping mortars and plasters;

(c) bricklaying machines capable of laying 800 bricks per hour, which is equivalent to a bricklayer's output in one working day. One type of machine travels along a track of scaffold
tubes to lay bricks at rates varying from 10 to 20 per minute, the mortar for jointing being gravity fed from two hoppers in a continuous operation. The machine requires an operator, and a skilled bricklayer to supervise it and point the brickwork. The degree of plumb and evenness of the work is dependent upon the accuracy in positioning and levelling the track. Completely automatic brick panel building machines can (i) prefabricate brick panels 6 ft. or more wide and of storey heights for handling and transporting to site in steel jigs, and (ii) incorporate a pneumatic machine which picks up bricks direct from the production line, and transports them for loading into the machine's tray. Horizontal and vertical jointing of the panels is relatively simple, and avoids structural complications;

(d) Automatic machines for high speed application (150 ft. per minute) of industrialised joinery primers and undercoats to all types and shapes of straight timber with sections up to 12 in. wide x 6 in. high.

(d) Earth Moving Plant and Equipment

(i) General

One of the main factors influencing excavation costs in Great Britain relates to the serious effects of soil and weather conditions on the productivity of mechanical and earth moving plant and equipment. The natural moisture contents of earth fill materials are usually relatively high, and rainfall and low evaporation during winter months normally limits large excavation works to periods from March to October, or less.

The economics of digging by machines is affected by (a) the composition and properties of the soil to be moved, (b) the form and dimensions of the soil-cutting tool, and (c) the engine power of the machine related to its operating cycle and capacity.
The weight of materials to be excavated is affected by the moisture content of the soil in its natural state. This strongly influences the capacity of load and working performance of the excavation plant, as the heavier the material, the greater the motive power required to move it. Some materials (e.g. clay) can be bulldozed or loaded into a scraper in their natural state, other materials require loosening, or even blasting before removal, and their increase in volume for removal after excavation varies considerably.

In general, the soil-cutting tool of an excavator is acted upon by the force of the resistance offered by the soil to the digging, and may be considered as the sum of the reactions exerted by (a) the soil on the cutting tool, the magnitude and direction of which depend upon the type and design of the tool, (b) the shape and size of the cross-section of soil excavated, and (c) the kind and state of the soil.

In order to reduce the effects of wet weather to a minimum, (a) soil should be excavated from a vertical face and transported to the fill or disposal area by plant whose operation is not critically affected by the wetting of the ground surface, and (b) all filling should be placed in the thickest possible layers, and compacted immediately.

The output of mechanical plant such as tractors, scrapers, bulldozers and shovels is strongly influenced by site conditions. These also affect the internal site transportation of spoil, as lorries and dumpers tend to become bogged down on wet sites, and have to travel with reduced loads, but the outputs of heavy excavating plant are not affected to the same extent.

Excavations should normally be carried out so that dig and disposal operations are continuously maintained with the minimum of waiting time and the most economical form of earth support or method of raking back earth sides, in relation to site conditions.

Choice of plant and equipment is influenced by:

(a) loadability, weight, moisture content, swell and degree of
hardness of the materials to be moved;
(b) total quantities of earthworks;
(c) method of soil disposal;
(d) correct balance of the number and size of haulage units in
relation to the number of excavators as required by the
building programme;
(e) haulage distances to tips and spoil heaps;
(f) weather conditions;
(g) time available to undertake the work;
(h) the experience, skill, and bonus targets of operators; and
(i) efficient maintenance and repair facilities.

These factors determine the average outputs of plant per unit of time.

Earth moving machines may be classified according to (a) purpose
and (b) nature of working operations.

(ii) Types of machines
(1) Earth moving machines which handle the soil as the machine
moves forwards, e.g. bulldozers;
(2) grading machines which shape excavations to required formations,
e.g. powered scrapers;
(3) Compacting equipment such as rollers, tampers, and vibrators;
(4) Excavators which dig the soil and load it on to trucks or other
transporting facilities for disposal to a place of deposit, e.g. crawler-
mounted shovels, digger-loaders, draglines; and
(5) 'Universal purpose' machines which cover a variety of digging
and loading operations, and can also be used as cranes.

(iii) Working Operations
Powered machines which operate:
(i) intermittently, e.g. excavators, scrapers, bulldozers; and
(ii) continuously, e.g. trenchers, rollers, vibrators.

Bulldozers. These machines provide a great variety of uses such
as stripping off turf or top soil; removing bushes, stumps, small trees;
spreading and levelling earth filling; pushing spoil from excavated areas to spoil heaps; back filling trenches and pits. They can also be used for auxiliary jobs such as clearing a path for scrapers and dumpers, or helping scrapers forward when their bowls are filled.

Scrapers. This type of machine is most usefully operated on moderately wet sandy soils and loams which fill the bucket to full capacity, but are not economical in use on (a) loose sand, which does not adequately fill the bucket, (b) soils containing large stones, (c) very heavy soils which require ripping up before utilising a scraper, or (d) moist clay or earth, as the soil sticks to and clogs the walls of the bucket.

The low speed of crawler tractors limits the operating ranges of towed scrapers according to site conditions. Self-powered scrapers with a travelling speed two or three times higher than crawler vehicles are more efficient for longer distances. With good ground conditions, a rubber-tyred tractor scraper unit which requires push loading can move more excavated material at less cost than a track type unit, whereas a loaded scraper moving over a sandy surface requires a crawler tractor.

The earth moving capacity of modern scrapers has increased to the extent that a fleet of three scrapers can provide a capacity of 1,000 cu. yds. an hour over a 6,000 ft. haul. Dump trucks with diesel electric drives are manufactured in ranges up to 240 tons, and scrapers with diesel engines producing a total of 1,900 horse power in ranges up to 78 cu. yds. capacity for use on large development schemes.

'Universal purpose' Excavators

Powered revolving excavators with intermittent operation and several different readily fitted working attachments are manufactured as 'universal' machines to provide a variety of digging and lifting operations. The main parts of the machine comprise:

(a) Front attachment, e.g. face shovel, back actor, dragline, grab bucket, trencher, crane mast. Dragline attachments are used
for (i) excavating deep cuts, from spoil heaps or 'dumplings',
and (ii) generally in conditions where a large outreach is
required, as the boom of the dragline is twice and even more
times longer than that of a digger-loader. Digger-loader
attachments with a pivoted loader-beam and bucket are used for
excavations below the level on which the machine stands. They
can provide an increased reach over a normal bucket attachment,
with a fast lift and dump which speeds the loading cycle.
Detachable trenchers with buckets and pivoted loader-beam
extension for hydraulic operation are capable of excavating
trenches up to 3 ft. wide x 11 ft. 6 ins. deep, and grubbing
up any tree roots encountered.
The operating member in the form of a bucket, shovel, drag line
eetc. excavates the soil, carries it a short distance, and dumps
it into a pile or on to transporting facilities, and returns
the operating member back to the digging face to complete the
machine's cycle of operations. Under average working conditions,
a shovel type excavator will fill and empty its bucket about
44 times an hour, and the back-actor about 30 times an hour,
outputs varying according to the nature of materials to be
excavated, and depth and type of dig.
(b) Turntable, which carries the power plant, engine, or winches,
and operates at a faster speed when used with digging attach­
ments than when operated as a crane. The machine is usually
powered with either diesel engines, electric drive powered from
an electricity supply, or diesel electric drive. Increase of
engine speed and power of lifts can be obtained with hydraulic
action, and operational control of a machine quickened with
compressed air.

(c) **Lower Frame**, which takes the weight of the turntable mechanism and operating equipment; and

(d) **Running Gear**, (i) Crawler mounting for operation on ordinary soils; (ii) widened caterpillar tracks for soft, very moist or boggy soils, or (iii) truck mounting with air-tyred wheels designed to carry the excavator on a normal or reinforced chassis.

When the machine is used as a crane, a hydraulically operated jib mast is fitted instead of the excavating arm, the positive movement of the hydraulic cylinders in both directions resolving the problem of jib hoisting with a suspended load. The jib is raised by the hydraulic ram used for raising the excavating arm, and provides the excavator with manoeuvrability and load lowering operations controlled by engine speed.

A multi-purpose crawler mounted excavator with crane attachments, instead of two machines, can achieve economies on smaller sites after excavations have been completed provided that the crane capabilities of the excavator are adequate for the handling work to be done. Such a machine can be used for levelling out small slopes, and its hydraulically controlled movements make it possible to use the machine for stripping or finishing operations, which until quite recently had to be undertaken with a high input of manual labour.

(iv) **The Relation of Haulage Units to Excavating Plant**

When undertaking earth moving operations, an excavator generally works with a dumper truck or tipping lorry for the disposal of the spoil, so that the cycle times which the machines take to complete their operations must be related to layouts, contours, strata, and surface of the site.

The motive power of vehicles transporting spoil to places of fill or deposit is influenced by weight of load, ground resistance, the retarding force of gravity when pulling up hill, and the surface of the ground over which it travels. Where higher power is required over short haulage
distances and ground conditions make scraper utilisation difficult, bulldozer equipment can be used economically up to approximately 100 lin. yds. push. But for hauls up to a maximum of 450 lin. yds., tractor drawn scraper units are more economical.

Where the nature of the excavated materials or haulage distances preclude the use of scrapers, it is usually more economical to utilise wheeled transport. Dampers are uneconomical on long hauls, and are not generally utilised at distances over half a mile from excavation to tip. However, it may be sometimes advantageous for a vehicle to travel a longer distance over the site following ground contours, rather than travel a shorter distance over rough ground.

(e) **Concreting Plant and Equipment**

The selection of plant for site concreting operations presents problems of:

(a) quality control,

(b) speed of production; and

(c) handling and transportation of mixed concrete, dependent upon the nature of the contract, site conditions, and the building programme.

All plant selected, and its related teams of operations should (a) ensure the continuous production of good quality concrete to specified mixes in relation to (i) the inflow of material and (ii) subsequent movement of the mixed concrete to points of placing, and (b) be capable of conveying and placing the mixed concrete in relation to the speed of production and locations required by site conditions.

Detailed planning to determine (a) the capacity of site mixing plant and rates of concrete outputs, and (b) handling requirements throughout the contract period, should be related to the total volume of concrete required, and fluctuations in demand during the construction period. The size of any one mixer should be related to the capacity of the plant needed for
transporting and placing the mixed concrete so that the mixers can be discharged as quickly as possible.

Automatic weighers, mechanical loading of mixers, and cement silos for large volume productions can increase outputs by 20 to 40 per cent, although they necessitate mechanical placing by conveyors to ensure continuity of outputs, and deliveries to required work points.

The mixing time of concrete varies according to type of mixer, but it is the number of revolutions of the machine (generally about 20) that determines adequate mixing.

Batch mixers have an optimum cycle time of 2½ to 3 minutes based on:

(a) the minimum time for loading the dry materials into the mixing drum, adding water, and properly discharging the drum, and (b) a method of handling concrete which enables the batch to be discharged at maximum speed as soon as properly mixed.

A wide range of powered dumpers, mono-rail transporters, feed hoppers, belt conveyors, and mechanically operated pumps are available for transporting concrete at high speed to positions of placing. Their selection depends upon the nature of the contract and prevailing site conditions. The final selection of concreting plant and equipment should be related to the handling of all other materials and components required by the overall programme for construction. Thus although maximum economy for a large volume of concrete production could be obtained by utilising automatic weighers and a 14 cu. ft. capacity mixer with a related team of operatives composed of a driver and one labourer in order to minimise non-productive time when the demand for concrete became intermittent, other site conditions might determine greater overall economy by using a skip hoist and a smaller capacity mixer, because various components had to be handled by crane.

Where conditions permit, maximum economy and ease of supervision can
be achieved by selecting one mixing plant strategically located to produce average concrete production requirements throughout the period of the contract, supplemented by deliveries of ready-mixed concrete to serve occasional peak periods of increased demand. But if the contract works are widely dispersed, greater economy might be obtained by setting up several smaller plants at strategic locations.

Ready-mixed concrete can be used to speed productions when pre-planned so that each delivery truck can be discharged rapidly direct into position, normally in foundations, or at ground level. Where concrete is required to be placed beyond the limited reach of the delivery truck’s discharge chute, a belt conveyor with chute attachment can be fitted to the truck-mixer in order to place concrete at a 25 ft. radius from the truck, or at heights of approximately 10 ft. without the chute.

Advantage can be obtained of the high discharge rate of truck mixed concrete for large volume productions in foundations over short construction periods by setting up concrete pumps and several chains of belt conveyors to achieve high outputs for daily placing. But it is uneconomical for deliveries to be taken at a higher rate than they can be placed, and methods should be adopted for reducing the site operating time of the trucks by:

(a) decanting loads into a wet hopper so that the concrete can be drawn at rates suited to site handling equipment,
(b) providing (i) sufficient skips for handling by crane, or (ii) detachable type bodies for handling by dumpers; and
(c) providing trailer skips for transportation of complete truck loads by mono-rail.

In circumstances where the concrete can be off-loaded direct into chutes for placing in mass concrete foundations, deliveries of 6 cu. yd. trucks at 8-minute intervals can achieve the placing of 450 cu. yds. of concrete per day. By increasing deliveries to 4-minute intervals, outputs can be doubled to 900 cu. yds. per day.
The siting of mixing plant in relation to the layout of multi-storey buildings determines the erection tower crane's times of slewing, trolleying, and hoisting. It is essential to match skip capacity to the mixer and crane, because when working at high speeds the rate of hoisting becomes a critical factor in the concreting cycle. Time may be saved by hoisting two mixes in one skip, rather than by hoisting two mixes in two skips. The type of skip most economically utilised should be (a) easy to control manually whilst discharging its contents, with side discharge for vertical members and bottom discharge for horizontal slabs, (b) easy to clean, and (c) of strong construction.

The speed of erection for a composite concrete system based on precast concrete structural vertical elements and poured in-situ concrete floor and roof slabs needs careful adjusting to the rate of concrete productions. Where structural requirements demand a high continuous output of concrete over long periods and site conditions permit, economic production can be achieved by the use of a large central mixing plant located in the most suitable position for minimising deliveries to pouring points.

The hoisting and use of shuttering for the in-situ concrete are key operations. The optimum number of shuttering units which are used in regular rotation provide a definite and readily controllable operational floor. During bad weather, electricity heated panels fixed to the shuttering can keep the supported concrete at regulated temperatures to eliminate delays in curing.

(f) Handling Plant and Equipment

(i) General

The economic handling and complete movement cycle of materials and components on site requires

(a) the co-operation of manufacturers with the contractor to achieve an economic system of delivery so that units can be (i) delivered pre-packaged or pre-palleted for quick unloading, or (ii) delivered on vehicle platforms left on
site for collection after the units have been hoisted to their required positions;

(b) the use of selected mechanical aids and equipment to off-load lorries which require manpower for unloading; and

(c) the efficiently planned operation of integrated and well maintained handling plant and equipment, dependent upon the optimum use of its limited capacities, in order to achieve economic construction.

The problems of hoisting are complicated by wide variations in the nature, shape, size and weight of materials and components incorporated into a system, e.g. steel bar reinforcement, heavy concrete panels, pre-fabricated shutters, sheet metal trunking of all shapes and sizes, sanitary fittings, bricks, heavy plant and machinery.

The off-loading of lorries can be speeded by:

(a) the delivery to site of manufactured units packaged, crated or strapped together in standardised weights and sizes in non-returnable packings, e.g. palletised bricks; packaged concrete blocks; packaged flooring in 'house sets' containing the exact square feet of flooring per dwelling, ready to lay without further covering. Each set can be packaged in heavy duty polythene, and fastened with tough nylon bands, the edge of the pack being protected by wooden slats so that the boards can be unloaded by crane and handled direct to required positions.

(b) small gantries to off-lift heavy loads by block and tackle to support efficient cranage;

(c) the use of machines and mechanised equipment to facilitate loading and off-loading, e.g. (i) portable elevating belt conveyors for handling bricks, tiles etc. to higher scaffold
levels; (ii) high lift rough terrain fork trucks with lifting capacity of 35 cwt. to height of 30 ft.;

(d) machines such as 'humpers', which can be used to off-load packaged and palletised materials and distribute them over the site;

(e) steel "stillages" and racks designed to take large built-up components (e.g. cladding units delivered in 3-storey heights) conveniently located for direct off-loading and handling to position by crane;

(f) the provision of adequate temporary roads and lighting for night deliveries;

(g) Cranes. A number of tower crane attachments have been developed to meet special handling requirements, e.g.

(i) hoppers for bulk materials such as aggregates. A crane can unload a full 5 to 8-ton load in a few lifts and transport the loaded hoppers to required positions with comparative ease;

(ii) patent devices such as 'portaforms' to facilitate handling table forms to position;

(iii) light weight concrete skips of aluminium alloy or thin gauge sheet steel which enable a crane to lift batches of concrete at the required radius;

(iv) lifting cages to take packaged pre-cast concrete blocks and bricks, multi-tine crane forks which can enter the cavities of 12 in. x 12 in. hollow flooring blocks so that a stack weighing 1 ton can be off-loaded direct from lorries delivering to site;

(v) mechanical aids to enable pre-cast concrete units to be lowered slowly and gently into their final positions with accurate positioning and alignment.
Where two mast cranes are utilised for erection operations the arcs of their jibs must intercept in order to obtain complete coverage of the building and stacking areas for materials handling. Adequate precautions must also be taken to avoid their jibs and hoist ropes colliding as the cranes slew round by the horizontal booms of any tower cranes set at different levels.

The critical point in movement handling occurs when the direction changes from horizontal to vertical, and vice-versa. Materials for the sub-structure and ground floor of a building (e.g., hardcore, concrete, steel reinforcement, shuttering, bricks, mortar) require horizontal rather than vertical handling, and where practicable should be performed (a) by lorries delivering loads to the site for placing in the final positions direct from the vehicles, and (b) with versatile machines such as "dumpers" or "humpers".

Vertical handling is of greater importance with tall buildings, where units should be stacked fairly close to the base of the buildings in order to reduce distances of horizontal handling.

In general, the distribution of small units to localised stock piles is essential to maintain continuity of erection operations, whereas larger units can be normally off-loaded from trailers and handled direct to position, or else remain in a storage area until required for erection.

Improved methods of handling materials and components conserve the operatives' physical energy, and release them for other duties. All unnecessary movements of materials and components should be eliminated, so that they are moved to positions via the most direct practical routes by means of suitable handling equipment with as high speed as possible in relation to capital cost and operating efficiency.

(ii) Horizontal Handling Plant

Plant for horizontal handling includes motorised barrows, mobile cranes, dumpers, trucks, railed transporters, conveyor belts, ready-mixed concrete trucks, and pumps for moving large quantities of concrete.
The horizontal handling and movement of materials and operatives on site is strongly influenced by:

(a) the layout of buildings.

(b) Site restrictions. Wet sites necessitate tracked machines. Sloping sites may obviate the use of rail-mounted cranes. Confined sites may not provide sufficient space for mixing plant, so that truck-mixed concrete will be required. Limitations of access may reduce the size of plant that could have been economically utilised for large volume productions of concrete, or site factories.

(c) Output of handling plant, determined by (i) type of construction works, (ii) rate at which units can be moved, (iii) speed of operation to which the plant contributes, (iv) locations of pick-up and delivery points, and (v) type and weight of load to be handled. In general, the ratio of weight of equipment to load carried should be the minimum for maximum economy.

Horizontal handling on site can be economically speeded where ground conditions are bad, or access to work positions limited by

(a) mono-rail transporters with power-driven vehicles, which can tow wagons of \( \frac{1}{2} \) cu. yd. capacity filled with concrete at speeds of 100 lin. yds. per minute on a single rail supported by adjustable stands. This type of machine does not require a driver, and can be started by the mixer driver and stopped automatically;

(b) Where there is a regular and continuous flow of materials between fixed points, a simple type of wire rope for conveying palletised bricks off-loaded from fork-lift trucks can be utilised for their direct transportation to required work points;

(c) A simple type of electrically operated fully conveyorised
plant with outputs of over 80 cu. yds. per day can be used for pre-casting various types of pre-finished concrete units. The machine requires only two men to operate the batching and conveying plant from two main points, and can be laid out with parallel steel joists between which the moulds are cramped. Concrete is fed from the batching plant into a 120 ft. long mechanised conveyor system.

(d) Types of narrow-belt conveyors run at a fast speed have a high output in relation to their weight, and can be joined together in series to carry concrete to placing points. A train can be readily set up and dismantled when each length of conveyor is articulated, and on wheels. In order to ensure concrete being fed from the mixer at a steady rate, a short length of conveyor with a wide belt running at low speed, and a large receiving hopper can be utilised. By these means, a complete batch of concrete can be discharged from the mixer to feed a series of narrow-belt conveyors at a required and steady rate.

(e) Mechanically operated pumps can be used for conveying large quantities of concrete: (i) piston-type pumps to deliver a steady flow of concrete through a pipe line which remains full when the pump is stopped by insertion of a stopper in the end of the pipe. Compressed air from a container can be used to push the stopper and concrete out of the pipe line; (ii) pneumatically-operated type pumps to blow a batch of concrete from a vessel at high velocity down a pipe to a baffle which reduces the velocity at placing points. The pipes should be cleaned out after each batch has been shot. Both types of pumps can deliver concrete a distance of several hundred feet horizontally and about 100 ft. vertically.

(f) Overhead runways can be economically utilised for certain operations, e.g. paint spraying, pointing facades when no
fixed scaffolding has been erected, and where the frequency of materials flow does not necessitate a conveyor, or it would not be economic to install one.

(iii) Vertical Handling Plant

Plant required for the vertical handling of materials and components includes small mobile platforms, barrow hoists, platform hoists, elevators, and cranes.

Hoists

A variety of platform hoists with speeds ranging from 175 ft. per min. to 250 ft. per min., according to height of building, have been developed for carrying (a) goods only, (b) goods and/or passengers, and (c) concrete in self-tipping skips for continuous pouring operations.

Self-contained hoist assemblies are manufactured to accommodate electrical floor limit switches, and gates with self-supporting pre-fabricated tubular towers carrying (i) a centre-slung type combined platform/automatic concrete elevating plant, or (ii) a passenger hoist, with complete interchangeability of respective hoists within one basic tower.

Twin hoists operate on a counter-weight principle, with geared electric winches up to 5-ton capacity, and controlled speeds of ascent and descent arranged for remote control. They are particularly suited to handle pre-cast concrete units and facade panels with precision and accuracy of landing.

Types of hoists manufactured with one cage ascending as the other cage descends, comprise one tower with:

(a) one cage forming a passenger hoist, and the other a concrete hoist,

(b) one cage forming a concrete hoist with a tipping skip one side, and the other a materials cage, or

(c) two concrete skips.

Passenger hoists can travel vertically almost as rapidly as tower cranes, and have the advantage of not being held up by the high winds which prevent
cranes working. Operatives can normally reach their work positions in
a multi-rise building up to approximately 10 storeys in height by means
of the staircases as constructed. Structures above that height require
(i) hoists for operatives and (ii) cranes for hoisting components, irres­
pective of structural type.

The comparative advantages and disadvantages of utilising tower
cranes or hoists of similar economic range for handling materials and
components on medium-rise structures relate to:

(a) the comparative costs of hiring or purchasing each type of
plant, providing skilled drivers, power, hauling the equip­
ment to site, and erecting and dismantling it;

(b) possible effects on techniques of construction, e.g. simplifi­
cation of shutter design, possibility of more economic assembly
of steel reinforcement on ground and rapid hoisting to positions;

(c) comparative savings in labour, e.g. (i) versatility of crane to
hoist shutters, fabric reinforcement, steel bars, and feed brick­
layers, (ii) increased labour productivity per floor constructed
achieved by efficient cranage to eliminate manhandling materials
and components from the top of the hoist to points of fixing;

(d) programming labour requirements, e.g. comparison of the number
of men required to carry out operations without idle time utilis­
ing hoists or cranes;

(e) comparative efficiency by the determination of which type of
plant entails the simplest method of carrying out the works, e.g.
whether 2 hoists instead of 1 crane necessitate more supervision
to ensure the efficient distribution of materials and components;

(f) site overheads, e.g. comparative costs of temporary works such
as scaffolding in relation to each type of plant.

The most careful consideration of the particular merits of each
individual project is required. In general, platform hoists with lifting
speeds up to 300 ft. per min. are suited to placing materials within the
shell of a structure when required in positions out of reach of the erection crane. Some systems based on in-situ concrete construction with simple pre-fabricated standardised shutters for structures up to 10 storeys in height can be economically constructed by utilising hoists without a tower crane.

Cranes

(a) General

The economic handling of materials and components by cranes is based on minimising crane movements in both horizontal and vertical planes, and relating work loads to the crane's lifting capacity in order to minimise the number of lifts, and speed erection.

Efficient crane utilisation depends upon:

(a) the correct selection of cranes for each particular programmed work load,
(b) the skill of the crane driver,
(c) continuously maintained crane working at each particular assembly operation. Delays and extra costs are incurred when a job on hand is left for another and returned to later,
(d) the provision of safety devices,
(e) regular and efficient maintenance; and
(f) the correct matching of the erection teams and other related mechanical plant with the crane's operations.

(b) Tower Cranes

General. Electrically operated tower cranes are required for the erection of tall structures. They are constructed with:

(a) a support in the form of a tapered gantry or flat frame which carries the travelling mechanism,
(b) a mast of (i) lattice steel framework, (ii) large diameter steel tubes, or (iii) telescopic pattern, fabricated in several sections to facilitate erection and dismantling;
(c) a revolving structure and boom. By providing a trolley to travel along the boom, large pre-cast panel units may be readily and precisely set in required positions;

(d) a counterweight, which compensates for the weight of the boom and part of the load weight being lifted; and

(e) controls.

The operating members of the crane comprise the boom, hoisting pulley, and load handling attachment, with hoisting, slewing, travelling, luffing, and jib mechanisms. Tower cranes are designed as:

(a) free-standing static cranes with a fixed base, and the turntable and counterweight mounted at the top,

(b) mobile cranes on rail tracks with a highly manoeuvrable boom, and all mechanism and counterweights arranged at the base on the turntable, which revolves together with the tower in order to improve stability and simplify erection and dismantling operations. The winding gear provides for a horizontal movement of the load as the boom changes the angle of inclination, thus facilitating the placement of the load. The load winch is equipped normally with a mechanism which ensures loads being smoothly set at low speeds.

(c) telescopic cranes with hydraulic climbing gear. The drive is built in, and provision made for adding sections to the mast. When operating inside a building, the mast can be fitted into a steel floor frame device for support.

The main factors that influence the versatility, selection and costs of tower cranes relate to:

(a) type of crane,

(b) length of boom,

(c) height of free-standing mast,
(d) lifting capacity in relation to working radius,
(e) speed of lift,
(f) type of control (remote or cabin),
(g) type of chassis,
(h) power and safety requirements,
(i) building layouts,
(j) type and height of structure to be built,
(k) site restrictions,
(l) the building programme.

Safety Requirements

Tower cranes must be designed to obviate the risk of being tipped over by an excessive load or load moment in accordance with the requirements of B.S.S. 2573 and 2799.

One type of safety device utilised automatically changes the safe load-lifting capacity of the crane while keeping the load moment constant. This makes it possible to increase the weight of the load at shorter jib lengths. Other types of weigh load indicators show the load weight on the hook and maximum permissible load at any radius by black and red pointers on a dial; when the two pointers coincide, danger point has been reached and the alarm is given.

Statutory safety requirements include the testing of crane slings and lifting gear (a) by the manufacturer before use, and (b) every subsequent six months.

One of the most critical factors of effective crane safety and maintenance relates to regular lubrication of the crane's wire ropes throughout their working life. It is essential to ensure that the size of the wire ropes is exactly suited to the dimensions of the pulleys and rope grooves in the sheaves of the drum, as the rope will become trapped and damaged if there is not a fit.

Current design assumptions are based on a crane operating 105 cycles
at maximum safe working loads throughout its life.

Power Requirements

On sites where the Area Electricity Board may be unable to provide sufficient power for site requirements (which can exceed 300 K.W.A. for a single factory), one or more temporary transformer stations may have to be provided on site, with cable ducts carefully located to minimise abortive runs.

The required motive power for electrically driven tower cranes varies:

<table>
<thead>
<tr>
<th>Tower Crane Plant</th>
<th>Horse Power Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hoist motor</td>
<td>3.0 to 80</td>
</tr>
<tr>
<td>Slew motor</td>
<td>1.5 to 15</td>
</tr>
<tr>
<td>Travel motor</td>
<td>1.0 to 10</td>
</tr>
<tr>
<td>Grab or derricking motor</td>
<td>1.0 to 10</td>
</tr>
</tbody>
</table>

Lifting Capacity of Tower Cranes in Relation to Height and Working Conditions

In order to select the correctly sized tower crane required for handling large heavy units to any great height, it is essential to establish:

(a) the maximum load to be lifted to its maximum height,
(b) the maximum free-standing height of the static mast under the lifting hook, both when in operation and not working;
and (c) the safe lifting capacity of the crane in relation to its working radius.

The smaller the tower crane, the lower the free-standing height of its mast. Beyond this critical point, special steel tie-off frames must be fitted to connect the tower mast of a static crane to the structure for greater stability, and increase the effective height of the crane around a fixed point.

The lifting capacity of the crane is greatly reduced when it trolleys
beyond the stay bars or ropes, due to the bending moment induced on its jib.

Types of tower cranes at present manufactured are designed to accommodate the varying requirements of approximately 150 different systems, with maximum unit loads varying from 5 cwt. to 13 tons, and available ranges varying from cranes that can lift a few cwt. at 30 ft. radius to those capable of lifting several tons at 100 ft. radius or more.

The following examples indicate the range of variation in lifting capacity of a static type tower crane with a maximum free-standing height of 174 ft. under the hook:

<table>
<thead>
<tr>
<th>Radius in ft. at centre line of mast ft.</th>
<th>Lifting Capacity of crane in Cwt.</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>200</td>
</tr>
<tr>
<td>59</td>
<td>144</td>
</tr>
<tr>
<td>80</td>
<td>101</td>
</tr>
<tr>
<td>99</td>
<td>76</td>
</tr>
<tr>
<td>118</td>
<td>60</td>
</tr>
</tbody>
</table>

At heights above 174 ft. the crane would have to be tied back to the structure for support, and above 300 ft., the crane's capacity would have to be slightly de-rated to the weight of the rope on the hoist drum.

**Speed of Crane Lift**

Required speeds of lifting are influenced by the (a) total tonnage to be hoisted, (b) the nature of the site, (c) the height of the structure to be erected, and (d) the building programme. This determines the size and number of cranes needed to maintain the speed of the planned erection cycle. Work loads should be accurately calculated, and not based on average lifts and average theoretical time cycles, because in practice delays inevitably occur in lifting and placing loads, and a load of insignificant weight may have to be lifted to maintain continuity of the erection cycle.

The crane's rig determines its hoisting capacity and speed of
lifting. Greater lifting capacity can be obtained by changing the rig from 2-fold to 4-fold, an operation which only takes a few minutes. A 2-fold rig can achieve a faster speed, but with only a small percentage of the maximum load taken by a 4-fold rig at reduced speeds. Lifting speeds with a 2-fold system involve a winch with two 40 H.P. motors to obtain lifts in high gear up to 30 cwt. at 328 ft. per min., and lifts in low gear up to 100 cwt. at 132 ft. per min. Beyond these capacities, the requirements of B.S.2799: 1956 provide for a safety factor of 6:1 on the hoist rope's breaking strength. This requirement necessitates a 4-fold system to obtain lifts up to 60 cwt. at 132 ft. per min., and up to 200 cwt. at 66 ft. per min.

The weight, shape, and position of a unit affects the time of crane working. Pre-cast concrete wall units have to be propped, floor units positioned and levelled, and staircase units similarly but more delicately handled.

Simple erection devices to plumb, line and level pre-cast concrete units are essential for economy. The final lowering of a unit into its position is a critical point. It must be dropped without further movement other than propping in order to avoid too many lateral movements of the crane, which has to hold and steady the unit, as well as handle it into position.

The difference in crane time hoisting units above 10th floor and up to 20th floor levels does not vary by more than approximately 10 to 15 per cent increase of the time required for hoisting to lower levels, because the speed of the crane's lift can be quickened by changing to a faster gear. However, wind velocities are greater at high levels, and can hold up the crane's operations to delay the erection cycle.

(c) Mobile Mast Cranes

Mobile mast cranes are particularly suited to low-rise developments, and can provide (a) versatility of operation by fitting requisite attachments for excavations, (b) convenient self-erection, and (c) a realistic
load/radius with a comparatively small base machine, without wasting working area.

The working load and radius of these cranes are governed by the proportion of base machine stability (crawler size and counter weight) to mast height/fly jib length. The use of high tensile steel for the masts can double normal lifting capacity. Cranes may be classified by:

(a) power source,
(b) mode of power transmission,
and (c) load-carrying capacity.

Rubber-tyred and truck mounted mast cranes are provided with outriggers which (i) increase the bearing surface of the crane, (ii) completely relieve the springs and wheels of the load, and (iii) increase the load-handling capacity of the crane. Crawler and rubber-tyred mast cranes are driven by an engine mounted on the turntable; truck mounted cranes are similarly powered but with a separate motor for driving the running gear. When travelling, the crane is operated from the driver's cab, and for load handling by the motor mounted on the turntable.

An economical type of machine on low-rise developments would normally be crawler mounted, able to handle 5 to 6 tons at 80 ft. to 90 ft. radius, and up to 8 tons at reduced radius, with the ability to self-level and minimise the need for preparing working platforms on sites sloping at 1:10.

(d) Portal Cranes

Electrically operated portal cranes with a lifting capacity of up to 20 tons can travel at creep speed on two widely spaced rails with a fixed span and height. They have the advantages of (a) constant load/reach characteristics and (b) operation unaffected by high winds. No counter balance is employed, and as the load is spread over four points, maximum wheel loading is lower than with other forms of lifting equipment. The crane can be adjusted to variable spans and heights before erection through
standardisation of the legs and beam. On sloping sites, the crane's tracks should run parallel to the line of contours, with its legs extended on the downhill side.

Attempts to obtain both the full use of a standard tower crane and the performance features of a heavier type of overhead crane at an economic cost have resulted in the manufacture of a tower/gantry crane which consists of a standard 15-ton tower crane model converted into gantry operation by introducing an auxiliary mast. The boom of the basic crane is slewed and positioned on top of the auxiliary mast to form a portal crane with a capacity of 15 tons throughout an effective straddle span of 125 ft. with lifting heights up to 195 ft. The auxiliary tower can be removed in order to free the machine for normal tower duties.

(e) Crane Utilisation in Relation to Building Layouts and Site Restrictions

Cranes should be sited on a work load and movement basis to cover as much of the construction area as possible. Their positions are influenced by the accessibility of loading and unloading points, and the effective radius at which the loads can be safely lifted.

The arrangement of an unloading area within the crane's working radius should be determined to minimise double handling, and enable the crane to unload and hoist programmed deliveries of maximum weight as planned with suppliers. Materials and components should be hoisted into position, and not placed within the minimum radius of the crane's hoisting capacity.

On sites with limited storage space for stacking materials and components, economy can be achieved by feeding the main erection tower crane for the structure with a small mobile crane which ferries components from a main stacking area located elsewhere, the crane area being restricted to stacking for daily lifts.

To achieve optimum economy, all cranes should be sited to (a) achieve optimum coverage from access roads and materials stacks to placing positions in the building, and (b) permit vehicles to be unloaded on or adjacent to
roads, instead of entering a site and becoming bogged down in wet weather.

The road access to low-rise developments influences the selection of the type of crane to be utilised economically. Where the buildings are sited close to a road so that a crane can function from it, rubber-tyred mobile mast cranes may be suitable. But if a crawler-mounted mast crane is selected, the distance of the buildings from roads is not of such importance. This type of crane normally operates on firm level ground; slight deviations may tend to make the machine unstable, but do not radically affect its boom stresses. These conditions have the reverse effect on mobile tower cranes, as off-level working is more critical.

The following examples indicate how economies in time and manpower can be achieved by the use of strategically positioned cranes for unloading and handling materials to required locations in a building.

(i) Palletised bricks in packs of 400 can be off-loaded from delivery lorries and handled to position in approximately 50 minutes with 1 crane and 2 slingers, a total of 2\(\frac{1}{2}\) man-hours, as compared with 165 minutes and a total time of 10 manhours if the bricks were (a) to be unloaded manually by a team of labourers, (b) stacked on the ground, (c) loaded on to pallets from the stacks, and (d) hoisted to position in a cage lifter;

(ii) A small mobile crane with a contractor's standing hire charge of approximately 17/6d per hour (or a hire charge from an outside firm of 28/- to 38/- per hour) including operator, can lift a half-ton load (or over) to a height of 50 ft. at a working radius of 50 ft. every 3\(\frac{1}{2}\) to 5 mins., and provide a hoisting capacity of approximately 7 tons per hour at a cost of 17/6 or 30/- per hour. The same work undertaken by a team of labourers would cost approximately £3 to £4 per hour.
(f) Crane Utilisation in Relation to Type and Height of Structure

Cranes for system building can be divided into those suited to high-rise or low-rise structures, and their operational analysis determined by (a) maximum weight to be lifted, (b) maximum height of lift in relation to working radius, (c) whether or not the crane should move under load, (d) how long it will be situated in one place, and (e) the type of ground to be traversed by the crane in order to proceed to its next work position.

In general:

(a) Free-standing static tower cranes are suited to co-ordinate handling around tall structures. They require a fixed base and involve extra costs for (i) concrete foundations and (ii) tying back the mast to the structure at increased heights.

(b) Telescopic tower cranes cost less than static tower cranes, can climb to any height, and are particularly suited to tall structures on sites where movement of mechanical plant is restricted. Their disadvantages include (i) incurring additional costs every time the crane is raised, and (ii) impeding the erection cycle due to the necessity for filling in openings left for their climb when installed inside a structure.

(c) Rail-mounted mobile tower cranes are able to achieve the optimum use of their hoisting capacity when travelling on straight or curved tracks, and can be utilised for tall structures where the finished height of the building does not exceed the free-standing height of the crane.

(d) Tower cranes of medium capacity are suited to point block multi-rise buildings up to 15 storeys in height. Taller buildings with larger and wider plan shapes require heavier cranes capable of covering 100 ft. x 60 ft. working areas with a 4 1/2 ton lift.

(e) Taller buildings, such as 30-storey point blocks can be served by rail-mounted mobile tower cranes manufactured to travel with a load under hook at a height of 268 ft., and lifting capacity of 4 tons at 135 ft. working radius increasing to 15 tons at 47 ft. radius. Such cranes have
(i) a hoist winch with six hoisting and lowering speeds varying from 400 ft. per min. to a slow micro-controlled speed of 6 ft. per min., selected when in motion under load from a portable remote control box, and (ii) a jib trolley with speeds varying from 0 to 160 ft. per min. By providing progressive acceleration and deceleration when traversing, the tendency for the load to swing is obviated.

(f) Crawler or truck mounted mobile mast cranes are not suited for work on tall structures due to (i) their limited working radius as building height increases, and (ii) site restrictions which limit access around the structure. There are certain exceptional conditions when this type of mobile crane with a very long jib might be suitably applied, but in general, it is more suited to low-rise developments.

(g) Portal cranes are not suited to buildings which are short in length, and under 3 storeys or over 10/12 storeys in height. They are economically suited to long buildings within these height limitations, and for use with extendable main beam and overhang as a complementary machine to tower cranes utilised for systems based on the site manufacture of pre-cast concrete panel units for long medium-rise buildings.

Free-standing static tower cranes and telescopic tower cranes can provide a variety of uses for structures based on poured in-situ concrete construction, and can switch continuously from materials and component handling to hoisting pre-fabricated sections of shuttering as necessitated by the erection cycle.

A system based on the site manufacture of pre-cast concrete panel units requires cranes capable of (a) lifting panels into position from trailers or stacking yards and holding the units steady whilst being levelled and lined, (b) erecting the units furthest away from the crane on the top-most storey, and (c) lowering units gently and slowly for the last few feet into their final positions in order to facilitate easy handling and accurate positioning and aligning.

The height and width of a pre-cast concrete structure, and the
size, weight and number of its structural elements influence (a) the type, size and number of cranes required on site, (b) the size and composition of the related erection teams, and (c) the time required to erect a given number of components each day. The free standing height, lifting capacity and working radius of the cranes should be suited to the structure, component production, and stacking requirements so that they can lift the maximum total load per day, with allowance for the extra load imposed by the adhesion of any pre-cast concrete units to the mould.

Steel framed structures are normally erected with pole or guy derricks by the steel erectors before concreting and cladding operations commence, and provide support for the erection cranes and/or hoists subsequently installed for handling materials and shuttering.

(g) Crane Utilisation in Relation to the Building Programme

Most building projects are divisible into (a) a structural phase, and (b) an internal finishings and services phase which are partially integrated, yet programmed separately. Cranage facilities should start on site as soon as construction permits, and end shortly after completion of the structure.

The cranes should be subordinate to the erection cycle, and normally governed by concreting operations or the placing of pre-cast concrete units. Crane layouts should be carefully planned in relation to their work areas, as these are governed by the effective radius at which loads can be safely lifted, and space allocated may not be available at completion of the works to enable the crane to be readily dismantled and removed.

A radial type crane is restricted as regards maximum load and area coverage by the length of its jib, whereas a derrick type crane, which is essential for effective operation on sites surrounded by tall buildings, is limited to a 270° sweep for its operating area, but has the advantage of gaining a high lifting capacity from its anchorage.

Mobile cranes with a vertical boom and fly jib for convenient
self-erection, and a load radius of 5 to 6 tons lifting capacity can provide versatility of operation suited to the building programme of low-rise developments, as the base machine is able to:

(a) enter a site before access roads have been laid out, travel up inclines of 1:4 gradient, and operate long boom drag line or grab crane excavating equipment,

(b) operate on roads or virgin site on inclines of 1:20 with complete mobility around buildings,

(c) operate as a standard jib crane for heavy lifting of plant and structural units delivered to site.

On smaller low-rise developments, a truck mounted telescopic jib crane with lifting capacity of 8 tons at 65 ft. height and working range of 20 ft. reducing to 1½ tons at 55 ft. may provide versatile use. The crane can be erected within a few minutes, and is able to:

(a) alter the length of its jib to reach across the width of a building, or change its lifting capacity by telescopic action in a matter of seconds, thus obviating the dismantling time for a mast crane utilised for similar operations,

(b) move rapidly and safely on sloping sites by reducing the length of its jib.

When the crane has finished operations for the day on a particular site, it can be rapidly transferred to other sites at a travelling speed on roads of 35 m.p.h.

(h) **Crane Costs**

Tower cranes are the most expensive kinds of cranes utilised in system building. Their basic costs relate to:

(a) type (i.e. static, mobile, telescopic),

(b) jib length,

(c) height of mast,
(a) hoisting capacity and working radius,
(b) speed of lift,
(c) type of control and chassis,
(d) erection and dismantling costs; and
(e) for static cranes, foundation costs and extra costs of
tying back to the structure to gain increased heights.

Approximate costs of heavy static tower cranes vary considerably,
e.g. from approximately £11,000 with 130 ft. mast height and 6 tons basic
lifting capacity to approximately £25,000 with 210 ft. mast height and
15 tons lifting capacity.

Portal cranes compare favourably in cost with tower cranes when
used for work involving similar lifting capacity. A tower crane capable
of lifting a load of 10 tons at a realistic working radius costs at least
double that of a comparable portal crane, plus much higher erection costs.

The optimum life of a crane varies according to its purpose and
degree of maintenance and repair. Slow moving infrequently dismantled
and re-erected portal cranes have a longer potential working life than
faster operating and more lightly constructed and frequently used tower
 cranes. But unless a crane can be operated over a sufficiently long period
to justify its purchase (i.e. at least 45 per cent utilisation of a normal
potential of 1,800 to 2,000 hours per annum throughout a working life of
5 years), it will be more economical to hire rather than purchase.

The cost of efficient crane utilisation on low-rise projects for
housing depend on the speed of the erection cycle, but normally should not
exceed £30 (approx.) per dwelling. But this cost will be increased out ofall proportion by (a) inefficient planning of crane operations, (b) inconsist-
sent flow of components to site, and (c) complicated jointing details
which entail long waiting periods when the crane has to hold the units in
position whilst they are being fixed.

Restrictions on contract time may necessitate a crane working
overtime and thus help to reduce site on-costs. But if subjected to
excessive travel, and unskilfully operated, the wheels, gears and motors
of rail mounted tower cranes, which are only intended for short occasional
travel, will wear in a similar manner to the plates, pins and gears of
crawler cranes. And when mobile cranes are utilised for travel on uneven,
rocky, or water-logged ground, the replacement or rebuilding of their
running gear can become necessary with one half or one third of their
normal working life.
CHAPTER 7
SIMPLIFIED TENDERING AND CONTRACT PROCEDURES

7.1 General

Economic industrialised system building necessitates the early co-operation of designers and contractors for the efficient pre-planning of a project in all its aspects in order to commence and complete construction works with a minimum of delay and variation from completed drawings and specifications. As a result, more effective methods are essential for obtaining competitive tenders to substitute present costly, time-wasting and ineffectual methods now generally adopted.

When several tenderers are selected to submit lump sum prices on the basis of substantially inaccurate drawings and bills of quantities, clients are unnecessarily adding to the costs of building, because:

(a) every contractor has to adjust his prices to comprehend
overheads incurred in unsuccessful attempts, or else take
part in the organisation of a price ring, which defeats the
whole object of competitive tendering;

(b) considerable time and cost is wasted, and the commencement
of works on site delayed pending the preparation of "accurately measured" and "fully described" bills of quantities
subject to a virtual re-measurement of the billed items for
"the adjustment of variations";

(c) final balances of payments to contractors and nominated
sub-contractors and suppliers are withheld for years pending settlement of "final accounts", which invariably greatly
increase original 'lump sum' contract prices obtained from
'accurately measured' and 'fully described' bills of quantities based on incomplete 'contract drawings' and specifications
(if any).

Competitive tenders which are really competitive, and not just
arrangements made by members of price rings, are necessary to maintain economic costs, but they should be obtained in a form which:

(a) minimises the considerable abortive costs of unsuccessful tenderers by being based on simple, concise bills of quantities adequate for tendering purposes,

(b) enables estimators to price the bills sent out with the tendering documents in a reasonably short period of time,

and

(c) include bills based on a simplified method of measurement and adequately completed drawings and specifications which obviate the need for re-measuring contract works in order to "adjust variations", and inflate the contract sum.

The information which estimators require from a bill of quantities in order to submit keenly competitive tenders is entirely different from the information required at post-tendering stage, and cannot be included in tendering documents. Moreover, economic construction necessitates that a contractor should be selected at the initial stage of a project in order to fully co-operate with the design team preparing the working drawings, and advise on alternative techniques of construction to achieve savings, which a "professional adviser" quantity surveyor is incapable of assessing due to his lack of education, knowledge, and experience of mechanical plant utilisation, network analysis, programming works, site control, and computerised costings of contractor's current projects.

Early selection of a contractor can be readily made by obtaining competitive rates on the basis of a budget figure based on initial sketch plans, outline specifications, and a comprehensive schedule of items covering the proposed works. The tendered schedule rates can be subsequently used for pricing bills of quantities prepared in accordance with a simple and realistic standard method of measurement from completed drawings and specifications.

The information contractors require after tendering stage cannot be
prepared at tendering stage because it relates to:

(a) the purchase of materials (which are measured net in the tender bill),

(b) pre-expenditure control, which requires budget assessments for ancillary items such as site offices, small tools, welfare and safety requirements,

(c) selection of mechanical plant and outputs in relation to labour teams and manhour production for 8-hour shifts,

(d) sub-contract purchases, and organisation of sub-contractor's work,

(e) valuation of interim certificates, and

(f) Bonus targets.

Such information needs to be incorporated in several documents, one of which being a working document in the form of an analysed estimate budget to (a) minimise wastage and facilitate pre-expenditure control, (b) separate labour from materials, and schedule each separately, with labour requirements in a form which enables work to be planned on site, (c) plan daily tasks for teams and individuals and make provision for comparison of daily and weekly outputs, (d) amend estimates of tasks on the experience gained from the contract, and (e) schedule work loads of all items of mechanical plant and equipment.

Experienced estimators, who habitually base their lump sum prices for (a) industrialised building systems of pre-cast panel construction on rates for the total quantities of concrete, steel, and inserts required for a project, and (b) major construction works such as factory, office and housing developments on the basis of a rate per sq. ft. or cu. ft. and a study of the drawings and specifications, are not assisted by the innumerable items and long-winded descriptions unrelated to the economics of construction as presented to them in bills of quantities prepared in accordance with the current standard method of measuring building works. And instead of wasting
weeks of their valuable time in attempting to price such minutiae, they frequently prefer to take a price from the ring, and save their efforts for more useful and remunerative work.

The increasing tendency towards larger scale developments on vast sites let on the basis of fixed lump sum 'package deals' ensures that the main function of the professional quantity surveyor as an adviser paid (a) one fee for preparing "accurately" measured and "fully described" bills of quantities based on the current S.M.M., and (b) a second fee for virtually re-measuring the works already measured all over again in order to determine final accounts long after completion of the contract works, becomes increasingly wasteful of time and the Employer's capital investment. For the economic cost of a building project does not only depend upon obtaining an initial competitive tender figure, but also on effective (a) critical path scheduling, (b) pre-expenditure control based on a cost budget, (c) resources planning to ensure the most economical use of available labour, materials and plant, and (d) programming the works to obtain the most effective return on the Employer's capital, functions which are normally left as an exercise for the "unprofessional" contractor's surveyor to perform.

To become really effective, the "professional" quantity surveyor should be competent to carry out these functions, and also be in a position to (a) take into account all the different elements contained in the contract bill and record all results achieved on similar contracts, (b) develop plan resources in relation to cost estimates and site programmes with the necessary flexibility for efficient minimum cost expenditure, (c) control the critical path method of site operations, and (d) optimise each situation as it arises during the course of construction, process feed back the information and (e) ingest it into a computer for consideration against actual progress, forecasting future trends, and re-assembly of all previous experience.
The present Ineffectiveness of the Quantity Surveying Profession

Some years ago, after contractors first decided to cut down overheads by employing one man to compute their quantities for competitive tendering, they helped to evolve an increasingly complicated method of measuring to ensure payment for authorised works undertaken which were not clearly shown or described in the documents sent out for tendering purposes.

Today, great savings in time and man's mental and physical labours have resulted from the use of comptometers, computers, mechanical plant and equipment, powered tools, modern techniques of construction, and many other ingenious devices. Yet, despite all this, such savings are more than discounted by the vast daily wastage of time and labour drained away on the production of unnecessary paperwork in respect of

(a) the preparation of vague and incomplete drawings and specifications used as a basis for "accurate" bills of quantities sent out to tenderers;

(b) the preparation of "accurate" bills of quantities based on a complicated, inflexible and unrealistic method of measurement and incomplete data, and subject to innumerable "adjustments for variations";

(c) the pricing of thousands of items contained in such bills;

(d) the checking of their arithmetical computations;

(e) the more or less practical re-measurement of the bills for the adjustment of variations;

(f) the pricing and agreement of final accounts containing these adjustments;

(g) the technical audit of such final accounts;

(h) the negotiation and settlement of contractual and ex-contractual claims arising out of such documents regarding claims for delay and other matters - delays that prevent works commencing on site for months and years, hold up progress of the works, and
eventually delay payment of outstanding balances due to contractors for similar periods.

Long-winded descriptions of minutiae, and innumerable differentiated items of quantities contained in current bills of quantities sent to tenderers, despite tower cranes, mechanical plant, powered tools, British Standard Specifications and Codes of Practice, frequently do not represent the extent of completed contract works, or all the conditions under which they are to be carried out, and usually result in very considerable and costly delays.

Civil engineers refuse to countenance such an unsatisfactory state of affairs, for they well understand the importance of mechanical plant and construction techniques in relation to site problems and costs, and the vital necessity of providing tenderers with adequately completed drawings and specifications at tendering stage, or else a bill of quantities which does not pretend to be more than a schedule of prices. The current Standard Method of Measuring Civil Engineering Works enunciates the basic principles that (a) a bill of quantities should be as simple as possible provided it adequately covers the work to be done, and (b) descriptions in a bill should be as brief as possible, and only in sufficient detail to ensure identification of the work covered by the respective items with that shown on the contract drawings and described in the specification, which is required to make clear the exact nature of the work to be performed.

No matter how great a complexity of measurement, nor however "standardly phrased" a description may be, unless the drawings and specifications from which the bills are prepared make clear the exact nature of the work to be carried out, they are of but little value.

A bill of quantities forming part of tendering documents based on the R.I.B.A. conditions of contract is prepared for the express purpose of enabling building employers to obtain firm competitive lump sum prices which represent the actual and final cost of their proposed enterprises. Nevertheless, the extent to which such prices do so depends upon the extent to which the drawings and specifications sent out to tenderers represent the
actual scope of the proposed works, as well as numerous complex factors, some of which may be quite unknown at the time of tendering. As a result, employers are frequently called upon to pay much larger sums for their building projects than represented by the "firm" lump sum prices obtained by competitive tender.

Building operations involve many different persons over considerable periods of time, are subject to changes of mind, human errors, weather conditions, economic booms and depressions, unforeseen happenings, and other uncontrollable influences which can impede continuity of the works, and thereby increase construction costs. These costs are also affected by such diverse matters as variations in price levels of other industries, credit squeezes, the sudden imposition of unforeseen tax legislation, and shortages of all kinds of labour and materials. No amount of "accurate" measurement of "fully described" items can adequately comprehend these factors, or the vagueness of tendering drawings and specifications which fail to indicate the full extent and nature of the proposed works.

"Accurate" bills of quantities prepared in accordance with the current Standard method of measuring building works which form part of tendering documents, contain no provision for the effect on costs of position in the works, or of the effects of repetition on labour output. Moreover, the R.I.B.A. conditions of contract expressly state that "as and when from time to time it may be necessary, the architect shall, without charge to the contractor, furnish him with two copies of such drawings and details as are reasonably necessary either to explain or amplify the contract drawings, or to enable the contractor to carry out and complete the works in accordance with the contract conditions."

Exactly what drawings and details are to be considered reasonably necessary is left undefined. But the meaning of this clause ensures that if, on signing the contract, a contractor were to ask for details of holes and chases for engineering services on the 18th floor of a multi-storey building
(the design of such services having been sub-let by the architect to specialist firms or consultants), the reply permitted under the terms of the clause would enable the architect to refuse the request on the grounds that such details were not necessary at this initial stage of the proceedings, as there was plenty of other work for the contractor to undertake.

Such a lack of detailed information prevents the contractor from being able adequately to pre-plan a job on the basis of flow-line production, and consequently increases his costs of building. If such information is not available for the contractor, it would not have been furnished to the surveyor preparing the bills of quantities, and consequently the contract quantities cannot have been accurate in respect of this work, although doubtless covered by inflated "provisional quantities".

Thus the very conditions of contract preclude the possibility of a really accurate pre-measurement of the works, let alone all those unforeseen happenings and variations that frustrate even comparatively well planned schemes.

The present emasculation of the quantity surveyor's work into that of (a) "professional advisers" incapable of advising design teams on the cost of construction problems due to alterations in design approach involving different techniques of construction and plant utilisation, and (b) "unprofessional" contractors' surveyors with sufficient knowledge to provide such advice, not only prevents Employers from obtaining the most economic use of their capital investments in building projects, but also puts the real benefits of computer aids beyond the reach of most professional advisers. For these benefits can only be obtained by their adequate utilisation with other mechanical aids capable of expressing coded quantities from drawings on to a tape in order to obtain (a) quantified descriptions for feeding in with taped prices relating to the requisite quantities, (b) programmes of coded labour, (c) materials and plant constants integrated with the building programme in order to obtain a schedule of fully priced quantities and programme of operations under separate headings, broken down into labour,
materials and plant so that all expenditure can be related to the capital sums involved, and not merely to the tender price in isolation.

As developments become larger and increased amounts of capital are required for:

(a) external works, garages and public utility services,
(b) mechanised handling and site factory plant and equipment, and
(c) other items which do not yield an adequate return on capital until completion of the works,

a more realistic form of valuation for interim payments is essential in order to obtain a more profitable use of the Employer's investment.

The economics of building relates to both the Employer's and the Contractor's capital investments, yet although both have the same aim of obtaining the maximum yield on their investments, the means by which each may obtain such a result is entirely different. The employer's risk is limited to obtaining an effective economic tender from a competent contractor, whereas the contractor's risks are spread over many different sources of capital investment, overheads, labour, materials, plant, unknown circumstances. The present unrealistic standard method of measurement for building works does not provide either party to a contract with adequate assistance to achieve their aims.

7.3 Present Unrealistic Methods of Measurement

Certain principles laid down in the current standard method of measurement make it improbable that work "accurately" measured and "fully described" in the bills of quantities will relate factually to the works as carried out. For example:

(i) Rule WI(c) requires painting material applied by a particular method (e.g. from cradles) to be so described, stating the method of application. But when, as at present, contractors tendering are not present during the design stage of the building, the use of cradles depends on the tenderer's eventual decision as to whether or not it will suit him better to utilise
external scaffolding according to the particular techniques of construction he may wish to adopt, and not on the quantity surveyor's imagination at the time of preparing the bills.

(ii) Various rules which affect the accuracy of "accurate" quantities by requiring non-existent excavations and concrete to be "accurately" measured merely for the sake of complying with theoretical rules regarding working space,

(iii) the whole basis of measurement, i.e. net quantities of work in position, ensures the inaccuracy of the "accurate" quantities measured because such quantities (a) do not represent the factual extent of the works undertaken, (b) do not include any quantities for increase in bulk for the disposal of excavated materials, or to compensate for the shrinkage in volume of "wet" materials such as concrete, or for wastage of materials in cutting to required sizes.

In addition, the "accurate" quantities included in the bills for formwork, and measured in accordance with nearly forty different "principles" of measurement, do not enable estimators to price the items measured without the need for their taking off all the formwork again in order to determine the number of times it can be utilised. And all this despite the work having been "fully described" and "accurately" measured in accordance with the fifth edition (revised) of the Standard Methods of Measuring Building Works.

In reality, S.M.M. "accurate" quantities are not, and cannot be really accurate, and the "full" descriptions required to be given in accordance with that document are not really comprehensive. Thus according to the rules of measurement, a comparatively simple item such as a pre-cast concrete panel unit would be enumerated and described in such terms as:

"6 in. Pre-cast concrete (4,000 lb. - 3/4 in. max. aggregate)
wall panel size X by Y, reinforced with Z rods at B centres,
and bedded in cement mortar (1:3)."

Not a word is required by the S.M.M. principles of measurement to be
given regarding the height above ground level at which it is placed - which might be 2 ft. or 200 ft.

In what sense is such a description to be considered "full", when it is not only silent about the height to which the panel has to be hoisted, but is also mute regarding its method of production, i.e. "Strike mould for previous panel".

Clean mould.

Re-assemble mould.

Apply mould oil to ditto.

Cut and bend steel for mould.

Fix steel in mould.

Place concrete in mould.

Cure concrete.

Strike concrete.

Stack panel in yard.

Handle panel to position.

Hoist panel.

Line and level panel.

Strike props to panel.

Lay mortar bed to panel.

Strike off excess mortar to panel.

And so forth, and so on.

One clarification of the current S.M.M. issued recently by the Standing Joint Committee states that "it is most important that the specific words or phrases of the S.M.M. are used."

But if this advice were to be strictly followed, considerable confusion would result. For instance, rule D6 (e) states that "excavating in rock shall be described as excavating in rock", rock being described as "any material met with in excavation which is of such size or position that it can only be removed by means of wedges, compressed air or other special plant, or explosives".
And rule D13 states that "breaking up concrete, reinforced concrete, brickwork and the like met with in excavation shall each be given as extra over the various descriptions of excavations".

But it can happen, and in fact sometimes does happen, that when excavations are proceeding for major projects in large cities, hidden concrete foundations of old buildings are encountered on site of sizes in the region of 50 ft. in length x 7 ft. wide and 9 ft. deep.

It is quite useless attempting to remove such large concrete foundations with compressors - they merely chip the surface of the concrete and do not break it up. The use of explosives or special plant is required to fracture such concrete and fragment it into sufficient sizes for compressors to be subsequently used.

How then is the categorical demand of using the specific words or phrases of the S.M.M. to be obeyed? Is the removal of such foundations "excavating in rock" under rule D6(e) - because it is a material that requires to be removed by explosives or special plant?

Or is its removal to be described as "Extra over excavations for breaking up concrete" - under rule D13, because it is concrete? Or should it be fully described as both at once? Clearly, a clarification of the clarification is needed here - and so ad infinitum.

The S.M.M. "principle" of providing net quantities of unit items does not relate to the actual realities of modern methods of production and techniques of construction. It is based on outdated pre-1914 conditions, when operatives were more susceptible to control, materials costs were of greater importance than relatively stable labour costs, horses and carts were used to remove surplus excavations from sites, and there was comparatively little mechanical plant and equipment available to aid man's physical efforts.

The vastly increased replacement of human labour by machines has achieved remarkable results for many years which greatly affect construction
costs, but are not reflected in the current S.M.H. of measuring building works. Even the unmeasurable positioning and layout of cranes on a site vitally affect construction costs (and very considerably more so than do the measurable "stop ends" on plaster cornices), because the cranes' travel determines the locations for unloading materials, setting up concrete batching plants, pre-casting concrete units, assembling sections of shuttering, and many other site operations. Moreover, many of the S.M.H. principles of measurement are rendered entirely meaningless by construction techniques such as sliding shutters and icosdiaphragm walls.

A radical change from the Current Standard Method of Measuring Building Works is essential for economic construction because:

(a) the principles of measuring enunciated therein include those which are contradictory, meaningless, require measurement of non-existent work, and are not related to construction costs,

(b) the majority of the "accurate" quantities billed are meaningless, as they are based on inaccurate drawings and specifications, and have to be re-measured all over again for the "adjustment of variations",

(c) the method of measurement relates to unit rates based on manhour production, whereas in fact labour is increasingly being replaced by machines, and the only practical method of estimating labour is on shift team output related to mechanical plant,

(d) the unit rates do not:

(i) take into account the effects of repetitive operations on labour output,

(ii) reflect the way work is carried out, and so cannot reflect the actual costs of construction,

(iii) enable designers to have any conception of the effects design detailing is having on construction costs,

(iv) take into account the effect of position of the work in relation to costs of handling and hoisting, and
take into account all those factors termed "preliminary particulars" in Section B of the S.M.M. These "particulars" can amount to hundreds of thousands of pounds on large contracts, and cannot be scientifically or accurately related to all the innumerable "accurately" measured and "fully described" minutiae which inevitably follow later in the bills.

The total contract price is based on unit rates which provide tenderers with the opportunity of taking advantage in order to obtain a high final contract sum in relation to the original tender figure by (i) pricing low those items which it is anticipated will be reduced in quantity, and (ii) pricing high those items which it is anticipated will be increased in quantity (e.g. foundation works, cutting holes and chases for engineering installations, hardcore under roads);

The work billed results in an adjustable tender figure in isolation, without relating the Employer's expenditure to the various capital sums involved in the most economic manner,

an estimator has to base his rates on many unmeasured and undescribable factors not included in the bills which affect the whole of the price level for a job, such as (i) the availability of labour and general level of skill and output, (ii) the degree of bonusing in each trade, (iii) the degree of mechanisation practical for a job, (iv) the type, nature and most effective utilisation of mechanical plant, (v) the volume of other construction work proceeding in the area which may be causing a shortage of labour, (vi) shortages of local sources of essential materials such as ballast, and (vii) seasonal difficulties.

The claim has frequently been made that bills prepared in accordance with the current S.M.M. are the most suitable kind to assist estimators price tenders, and employers obtain firm competitive prices for the cost of
their building enterprises. In actual fact, such prices do not represent these costs. And the bills on which they are based do not (i) include quantities which enable contractors to order materials other than formless materials in bulk, (ii) provide information regarding (a) utilisation of formwork, (b) the sequence of operations for setting bonus targets, or 
(c) programming a job into teams working in sectionalised areas in order to benefit from the effects of repetition on output. So despite all the "accurate" measuring and "fully" describing, the contractor's estimator, manager, and bonus surveyor have to take off the quantities all over again to suit their particular purposes.

Instead of "fully described" "accurately" measured, unrelated-to-reality quantities, tenderers require (a) simple bills which present the basic information they require in a form which enables them to make their own breakdown of costs into:

(i) materials schedules;

(ii) assessments of gang strengths and mechanical plant requirements in order to obtain weekly and total outputs for their jobs;

(iii) separation of repetitive work from non-repetitive work for assessment of improved efficiency as work proceeds above first floor level;

and (b) as many sets of the tendering drawings and specifications as they may require in order to obtain competitive prices for their sub-contract trades.

Contractors who finance their own speculative development schemes would not dream of using anything more formidable than a simple form of bill to serve their purpose of building at a minimum cost.

Government departments limit the estimated costs of their projects by the simple expedient of setting a rate per square foot of building.

Experienced surveyors who keep cost records for various types of
construction over long periods and are constantly supplied with information obtained from computerised feedbacks for their current projects which readily enable them to determine wastage and errors, are sufficiently well informed to be able to submit firm lump sum tenders for major projects on the basis of an examination of the drawings and specifications, and at rate per square foot of building, because such estimates are (a) based on the experience of other contract works, and (b) the average tendency produced by the variation of all relevant factors influencing costs is likely to be found within fairly narrow limits as indicated by the Central Limit Theorem of Probabilities.

In the United States of America, where building costs have remained relatively stable over the past 10 years in comparison with ours (a) variations on contract sums are practically unknown, (b) firm contract prices remain firm, and (c) tendering procedures are based on a very simple form of bill, and at least 30 sets of the tendering drawings and specifications.

The highly competitive context of the American building industry (which lacking fully measured and detailed bills of quantities, also lacks price rings) results in a bridge between contractors and manufacturers. The architect's drawings and specifications describe some materials and components by performance specifications, and others by specifying a particular manufacture, or equal. The responsibility for the selection of manufactured items rests with the contractor, who is himself selected by real competitive tender and is under extreme pressure to defend the economic viability of his position.

The contractor arrives at his final selection of manufactured items by a 'dutch auction' between alternate sources of supply, and manufacturers attempt to avoid the direct impact of this price war by giving their product special 'appeal' to the contractor which will lead to their selection for
reasons other than price alone, e.g. baths may have thin moulded plastic inserts dropped in for protection during handling to save time spent in cleaning off their rival competitor's paper tape protection.

American contractors cannot introduce any innovations which would restrict their ability to compete for work as designed, but they can utilise short cuts and devices which enable the work shewn or specified to be undertaken more effectively (e.g. re-designing woodworkers' standard overalls so that they can reach nails in their pockets when stooping), as opposed to introducing materials or components of a special kind.

Although such procedures may not be suited to the British way of life, nevertheless no Building Industry in any country should be burdened with such time wasting and costly phenomena as "fully described", "accurately" measured bills of quantities prepared in accordance with the S.M.M., despite the fact that such ineffective bills permit architects to send out to tenderers incomplete specifications and drawings with the comforting assurance that they are afforded financial protection by so doing.

Contractors put up with the procedure for a variety of reasons, one being that by this means they can obtain payment for work undertaken but only vaguely or incompletely indicated or described in the contract documents. As for Employers, they are merely required to pay the bill, plus the quantity surveyor's two fees, one for preparing "accurate" quantities, and the other for virtually re-measuring the contract works all over again in order to adjust "variations" in the contract.

"Risk bearing" forms of "lump sum" contracts during periods of boom, when the volume of work unleashed on the building industry becomes greater than it can adequately cope with, are more or less subject to the law of supply and demand, instead of that law of the jungle which operates during periods of depression. Consequently, the usefulness of bills of quantities prepared during these times for the express purpose of obtaining competitive lump sum tenders are not only related to the extent that the drawings and specifications upon which they are based make clear the exact nature of the
work to be performed, but also upon the extent to which tenderers are prepared to submit keenly competitive prices. The truth of this "law" may be evidenced, for example, by a comparison of the differences between the highest and lowest tenders obtained during a "period of expansion" with those obtained during a "period of recession". Or by comparing the difference in tendered rates during the two periods for "basement excavations not exceeding 5 ft. deep" and those "exceeding 5 ft. and not exceeding 10 ft. deep" - a remarkable difference made in times of boom, despite the fact that mechanical excavators in operation do not usually discriminate between such niceness of measurement.

Quantities are but one facet of the diverse information required for keenly pricing tenders for risk bearing lump sum contracts - there are many other vital factors bearing on costs that require assessment which by their very nature are unmeasurable. And not only all those "preliminary particulars" and the like which are set out in Section B of the current S.M.M. Building Works. Or those contingent and potential causes of expenditure classified as "contractor's risks" in the current S.M.M. or Civil Engineering Works.

Some of these factors involve considerable costs, which estimators are left to assess without the guidance of any quantities, and relate to (a) the most advantageous and economic use of mechanical plant and techniques of construction; (b) the economic implications of varying site conditions such as ground and water levels; (c) the comparative advantages and disadvantages of transporting men daily to and from a site instead of erecting a huttered camp; (d) site restrictions limiting the movement of mechanical plant and the storage of materials; (e) police regulations limiting the period for unloading materials at site or imposing the operation of one-way streets.

Other unmeasured factors relate to the economic implications of design such as the height and shape of the proposed building, the amount of prefabrication possible, the amount of repetitive work at each floor level,
and the like. And other factors relate to (a) general circumstances prev­
vailing at the period of tendering, (b) the availability or otherwise of
labour in the district, (c) national shortages of materials, (d) impending
change of government or rate of bank interest, (e) inclement weather, (f)
the international situation, and (g) many other unmeasured and unmeasurable
factors.

No matter how complex a method of measurement may be, it cannot
adequately take into account such factors, and its inflexibility may well
prevent estimators from exercising their skill to achieve economies when
tendering by adopting alternative methods of construction to obtain savings
which could be passed on to the building employer.

7.4 A Simplified Method of Measurement

A simple, flexible and effective method of measurement for both
Building and Civil Engineering Works related to drawings and specifications
which made clear the exact nature of the work to be performed, and provided
estimators with the bulk "all-in" quantities of the main elements of con­
struction, would undoubtedly enable bills of quantities for risk-bearing
lump sum contracts to be more readily, economically and usefully prepared.

When for one reason or another, only incomplete drawings and specif­
ications were available at the time of tendering, such a method of measurement
would enable Schedules of Rates to be prepared as a basis for competitive
tendering and the assessment of a final contract sum based on a single measure­ment
of the works as executed.

"All-in" quantities are those which are deemed to include in the
measurement of work undertaken all contingent and temporary works, expenses,
liabilities, risks, and everything else necessary for the proper execution
and completion of the work measured, in accordance with the contract documents.

The measurement of excavations and earthworks, and some of the factors
influencing their pricing is influenced by the moisture content and nature
of the soil, and the wide variety of excavating and earth moving plant and
equipment available in the open market. The type, nature and extent of
timbering or sheet steel required to uphold the sides of excavations is
affected by such factors as the nature of soil, site water level, weather
conditions, and the comparative economies of battering the sides of excava-
tion rather than upholding them. A total "all-in" measurement of the net
cubic contents of the voids to be formed, classified (a) according to the
nature of soil (soft, hard, or rock as defined in the Conditions of Con-
tract), and (b) the type of excavation (shallow surface, bulk in open,
cuttings, trenches, pits, etc.) would suffice to enable estimators to
exercise their skill. All such incidental items as increase in bulk, allow-
ances for working space; disposal of soil; multiple handling; differing
depths (in most cases); planking and strutting; grading, levelling and ram-
ming bottoms; keeping site free from water, etc., would be deemed to be
included in the rates for the "all-in" unit items of excavations, billed in
cubic yards.

Such inclusions would suit experienced estimators, who are used to
assessing such unmeasurable items as the economic impact of complying with
all the limitations, restrictions and difficulties of working on a confined
site located in the centre of a busy city thoroughfare, and are able and
willing to tender competitive rates per superficial foot as the basis for
lump sum contract prices based only on drawings and specifications for pro-
jects of over £1 million.

Items such as stripping turf, breaking up pavings and foundations,
and the like, would be measured as "extra over" items, and exceptional
depths of certain types of excavations given separately in cubic yards.

As regards brickwork, there is no point in the current S.M.M. requir-
ing "facework to returns 9 in. wide to be given in superficial yards" as
opposed to "fair ends to one brick wall faced both sides in linear yards",
whilst at the same time making no distinction whatsoever between (a) walls
built between cill level and window head over, and (b) those built between
window head and cill level above. Or for that matter, between walls built at first floor level and those built at twenty-first floor level.

Contractors who have sublet brickwork to piecework teams, and paid them liberally for building the perimeter walls of a building from footings up to ground floor cill level, are well aware of such undifferentiated variations in cost when they discover that the team has not arrived for work on the following and successive days.

Instead of stuffing bills full of innumerable items of measured brick minutiae without separating brickwork according to (a) location as regards window openings and (b) position as regards heights, tenderers should be provided with bills of quantities based on drawings and specifications which make clear the exact nature of the work to be performed, and include "all-in" quantities of the main elements of construction.

Such simplified bills would not only avoid (a) holding up works starting on site, (b) disorganising building programmes due to variations, and (c) delaying payments of final balances of accounts, but would also enable estimators to use time wasted in pricing thousands of minutely measured details by the more useful thorough study of the tendering drawings, specifications, and site conditions with a view to achieving economies, a most essential task which in times of boom is practically eliminated.

Moreover, building employers would be saved (a) the expense of innumerable costly variations necessitated by a method of measurement which requires the raising of a variation order every time the architect changes his mind over the merest trifle, (b) claims for delays, and other contractual and ex-contractual claims, and would be enabled to gain possession of their completed buildings more speedily, and at far less expense.

Concrete operations are now increasingly expedited by the use of batching plant, pumps, conveyors, vibrators, truck mixed deliveries, sliding forms, new methods of pre-casting and pre-stressing, tower cranes, and many
other innovations, and it is high time that a more effective and simple method of measurement is adopted to replace the innumerable "principles" laid down in the current S.M.M. of Building Works for measuring concrete. It is true that the rules of measuring enunciated in the current S.M.M. of Civil Engineering Works are much fewer and more simple, yet these great boons are more or less cancelled by General Conditions of Contract which deem quantities measured in accordance with these rules not to represent the actual and correct quantities of work shown on the contract drawings and specifications required to make clear the exact nature of the work to be performed.

Stonework, no matter how minutely classified, nor how many separate labours be measured on it, is invariably lumped together as one total foot cubage for the job, and priced at one and the same unit rate on the basis of the estimator's experience and examination of the drawings. The current S.M.M. for Building Works unwittingly recognises this fact at times, despite its voluminous principles of measuring natural stonework, by giving up the attempt to measure labours separately on tracery. And after requiring labours on superficial items of stonework, such as rebates, sinkings, chamfered angles and the like to be given separately in linear feet with the further separate measurement of their stops and mitres, the S.M.M. permits these very same labours not to be measured separately on superficial items of stonework, provided they are included in the description with the word "rustications".

A simplified and single method of measurement for both Building and Civil Engineering Works is urgently needed to unify the present unnecessarily complicated situation whereby (a) the current RIBA Form of Contract for use with quantities requires the S.M.M. of Building Works to be adopted, (b) the current Conditions of Contract for Works of Civil Engineering Construction require the S.M.M. of Civil Engineering Works to be adopted, and (c) the Institution of Structural Engineers' current general Conditions of
Contract for Structural Engineering Works require the S.M.M. for Building Works to be adopted.

Much simpler bills than those prepared in accordance with the current S.M.M. of Building Works are vitally necessary to assist the nation's economy, and should contain general clauses such as the following to assist tenderers:

(1) In submitting a tender the contractor will be deemed to accept the method of measurement and description adopted and used in this Bill of Quantities.

(2) The lump sum price submitted by the contractor is to allow for all elements of cost in completing the works, as the rates, prices and total amounts of the items and net quantities included in this Bill shall be deemed to include everything set in place and fixed complete, including all expenses and liabilities set forth in the General Conditions of Contract, Specification and drawings, as well as for everything necessary to be used during the execution of the works and for the proper completion in a sound and water-tight condition and maintenance thereof for the period stated in the Appendix and in accordance with the General Conditions of Contract.

(3) The volume of the building is ... feet cube, and the total floor area (measured between inside faces of external walls) is ... feet super.

(4) The descriptions of materials and workmanship, general trade preambles, preliminary particulars and insurances contained in the Specification on pages x to y shall apply to the works as a whole, and the contractor is to allow hereunder, the separate sum or sums he may require for compliance with their provisions as listed below:

A simplified National Standard Method of Measuring Construction
works for either building or civil engineering contracts could take the following form:--

Demolitions and Alterations

The responsibility for the safety of the existing and adjoining structures shall be the sole responsibility of the contractor during the entire contract period.

The contractor is to visit the site, take all necessary dimensions and particulars, and allow, where listed below, for executing and completing the whole of the demolitions and alterations as indicated on drawings nos. x and y and described in the specification on page Z:--

Excavation and Earth Works

The total "all-in" quantities of excavations and earthworks shall be given in yards cube and classified according to the nature of soil as in soft ground, hard ground, or rock as defined in the conditions of contract, and sub-divided into the following categories:

- shallow surface excavation;
- excavation in bulk or in dumplings between trenches;
- cuttings for roads;
- pits and pier holes in stages of 10 ft. depths;
- trenches in stages of 5 ft. depths.

Planking and strutting, disposal of spoil, grading, levelling and ramming bottoms of excavations and all other incidental expenses, including keeping the site free from water, should be deemed to be included in the rates for excavation, with the sole exceptions of the following items, to be measured as "extra over" excavations for:

- stripping turf (in yards super);
- breaking up pavings (in yards super);
- breaking up brick and concrete foundations, or similar obstructions (in yards cube).

Hardcore. The total "all-in" quantity of all hardcore filling and beds of over 12" consolidated thickness shall be given in yards cube. Beds under
12" consolidated thickness shall be given in square yards, and blinding the surface of hardcore to receive concrete shall be given as an "extra over" item in yards super.

Piling.
The total feet run of all pre-cast and bored piles and driving shall be given, with a description of the super-imposed load per foot super, and average length of pile.

The total yards super of all sheet steel piling and driving shall be given, with a description of the thickness, average depth, and type of pile.

Concrete Work.
Concrete work shall be generally classified according to (a) type (e.g. in-situ, plain, reinforced, pre-stressed, pre-cast), (b) quality or mix, and (c) position as regards in foundations or superstructure, sub-divided according to location in the structure (e.g. in walls, slabs, beams, columns, panels, mullions).

The total "all-in" quantity of the various types of concrete shall be given in yards cube, all concrete not exceeding 12 in. thick being kept separate.

Bush hammered and other types of special finish to concrete surfaces shall be given in yards super.

Expansion joints and similar items shall be given in yards run.

Where the cross section of in-situ concrete is reasonably uniform throughout its length, shuttering shall be included in the rate for the concrete. Alternatively, shuttering for in-situ concrete may be measured separately and classified as wrought or sawn and sub-divided into shuttering to:

(a) soffites, with lengths of strutting over 15 ft. kept separate in stages of 15 ft. (in yards super);

(b) walls and vertical surfaces of foundations, etc. separated into walls not exceeding 12 in. thick, walls 12 in. to 2 ft. thick and walls over 2 ft. thick (in yards super);
Reinforcement for all types of concrete shall be given separately according to type (bar, square twisted, mesh fabric, etc.) and size, and the total "all-in" quantities of each type shall be given separately in tons or cwt.

Components of Industrialised Buildings

The total "all-in" quantities of components fabricated in factories shall be given as numbered items according to description, or by reference to manufacturer's catalogue.

Hollow Block and Hollow Beam Construction

The total "all-in" quantities of slabs and beams shall be given in yards cube according to description.

Brickwork and Blockwork

The total number of each kind of brick shall be given in thousands, separated only according to (a) different mortars, (b) whether in sub-structure or superstructure, (c) position in work, and (d) shape and contour, e.g. general brickwork, walls with battered face, circular on plan, chimney shafts, manholes, arches.

The total "all-in" area of brick face work and fair face shall be given in yards super.

The total "all-in" quantities of (i) all blockwork shall be given in yards super according to thickness, manufacture, and mortar.

(ii) damp proof courses and similar items shall be given in yards super;

(iii) cills, brick reinforcement and similar items shall be given in yards run;

(iv) fireplace surrounds, chimney pots and similar items shall be enumerated.

Underpinning

The total "all-in" quantities of all underpinning shall be given in yards.
run according to description, and shall be referred to the detailed sections and lengths shown on the architect's drawings.

**Masonry and Rubble Walls**

The total "all-in" quantities of all stonework other than cills, curbs and similar items of small cross-section shall be given in yards cube according to material and mortar. Cills, curbs and similar items shall be given in yards run.

**Asphalt Work**

Generally, asphalt work shall be separated into:

(a) damp proofing and tanking;
(b) paving;
(c) roofing;

and the total "all-in" quantities of each shall be given in yards super according to thickness.

The total "all-in" quantities of skirtings and the like shall be given in yards run according to heights in stages of 6 in. measured to the nearest 6 in.

**Roofing**

The total "all-in" quantities of

(i) the areas of roofing shall be given in yards super according to material and description.

(ii) individual items such as eaves, verges, valleys, hips and the like shall be given in yards run.

(iii) metal aprons and flashings shall be given in yards super according to type and weight.

**Carpentry**

Generally, carpentry shall be separated into:

(a) wrought and sawn timber according to material;
(b) framed and unframed timber;
(c) sections above 4 sq. in. and sections below 4 sq. in.

The total "all-in" quantities of
(i) all timber shall be given in foot cube according to location (e.g. roofs, floors, etc.) and the foregoing categories.

(ii) all boarding shall be given in yards super according to thickness and description.

(iii) all grounds, fillets, battens, etc. shall either be given in feet run per sectional inch, or alternatively shall be reduced to a total feet cube.

The plugging of timber to any type of surface shall be measured in feet run.

Joinery

Generally, joinery shall be separated according to material into:

(a) flooring;

(b) linings, casings, partitions and the like;

(c) doors and windows, including frames and architraves, and related to the architect's door and window schedules;

(d) skirtings, cornices, mouldings and the like;

(e) fittings, staircases and similar items.

The total "all-in" quantities of (i) flooring shall be given in yards super according to thickness and description;

(ii) linings, casings, and partitions, etc., shall be similarly given;

(iii) framed partitions, borrowed lights etc., including frames and architraves shall be given in feet super;

(iv) skirtings, cornices, mouldings etc., shall be given in feet run per sectional inch;

(v) fittings, staircases and the like shall be enumerated.

Ironmongery

The total quantities of ironmongery shall be listed in accordance with the Architect's schedule of ironmongery.
Structural Steelwork

Generally, structural steelwork shall be separated according to method of fabrication into the following categories:

(a) grillages and girders;
(b) stanchions, columns and portal frames;
(c) roof members, braces, struts and rails;
(d) bolts and sundry items;

and the total "all-in" quantities of each category shall be given in tons and hundredweights.

Metalwork

The total "all-in" areas of (i) plates, duct covers and the like shall be given in feet super according to description or Manufacturer’s catalogue,

(ii) frames, bars, handrails, etc., shall be given in feet run according to section,

(iii) sheet metalwork shall be given in feet super according to description,

(iv) metal windows and doors, etc., shall be enumerated according to type and size,

(v) curtain walling shall be given in yards super according to description,

(vi) balustrades, railings, gates, ladders, etc. shall be similarly given in feet run.

Plumbing Installations

Total "all-in" quantities shall be given for plumbing installations according to the following categories:-

(a) gutters, rainwater, soil and plastic pipes shall be given in feet run according to description and size;
(b) copper, lead, mild steel and cast iron pipework shall be given separately in tons and hundredweights. Bends and other fittings shall be enumerated and described;
(c) hopper heads, valves, connections to mains and the like shall be enumerated and described;

(d) sanitary fittings shall be similarly enumerated and described according to manufacturer's catalogues.

**Insulation**

The total "all-in" quantities of insulation to (i) pipework shall be given in yards run according to material and size of pipe.

(ii) boilers, etc., shall be enumerated and described.

**Engineering Installations**

Each individual installation, such as heating, hot water, ventilation, gas, electrical, lifts, compressed air etc., should be adequately shown on the architect's drawings and described in his specifications, and the contractor referred to these tender documents and instructed to obtain competitive lump sum estimates with priced quantified schedules of items from a list of approved firms nominated by the architect.

**Builder's Work in Connection with Plumbing and Engineering Installations**

The total "all-in" quantities of (i) holes shall be given in numbered items according to description,

(ii) floor chases, wall chases, duct covers and casings, etc., shall be given in feet run according to description.

All other sundry items of builder's work shall be included for by the tenderer in accordance with his knowledge and experience as a percentage of the cost of the particular engineering, etc., installation.

**Plasterwork and Other Floor, Wall and Ceiling Finishes**

Total "all-in" quantities shall be given according to the following categories:

(a) floor finishings and beds in yards super according to thickness and material,

(b) wall finishings and screeds shall be similarly given, including keying,

(c) ceiling finishings shall be similarly given, including keying,
(d) skirtings, cornices and similar items shall be given in yards run according to materials and description,
(e) finishings to staircases shall be enumerated according to materials and description.

Only the quantities of such labours as arises; quirks, etc., considered by the surveyor to be of sufficient value to be measured separately shall be so measured.

Glazing

The total "all-in" quantities of (i) glass and patent glazing shall be given according to kind, quality and description.

(ii) velvet or wash-leather strip shall be given in yards run.

Painting and Decorating

The total "all-in" quantities of painting, polishing, etc., shall be given in yards super according to preparation, material, and number of coats (measured overall windows and doors).

External Works and Drainage

Generally, external works shall be measured in accordance with the principles given in the foregoing sections.

Drainage shall be measured and total "all-in" quantities given in accordance with the following categories:-

(a) trench excavation for pipes in yards run in stages of 1 ft. depths;
(b) concrete beds in yards run according to width of trench and thickness;
(c) pipes in yards run according to material and size;
(d) pipe fittings, manholes, sewer connections shall be enumerated and described.

The total "all-in" quantities of fencing shall be given in yards run according to description, and shall include excavation and filling or concreting post holes. Gates shall be described and enumerated as "extra over" items.
Simplified bills of quantities based on completed drawings and specifications and the foregoing methods of measurement would enable competitive tenders to be obtained with no less "firmness", but with very much less expenditure of time and money than those obtained by present outmoded procedures. But they could not attempt to resolve inter-related problems of construction, cost planning, bonusing, and cost control, the solutions of which require a computer programme of multi-variant and adaptive overall type.

Nevertheless, they would provide basic data in a simple form which enabled estimators to assess their total materials costs, labour and plant output for a job, leaving them free to exercise their skill in determining, from a close examination of the drawings and specifications, the most economic use of labour and mechanical plant suited to their firm's particular expertise.

Operational and Activity Bills are just as complicated as S.M.M. bills, and attempt too much. Being based on artificial and theoretical analysis of the work quite unrelated to actual site conditions and contractor's particular organisations, they are of about as much use as S.M.M. bills, and cost more.

Simplified bills should be based preferably on a National Simplified Standard Method of measuring Building and Civil Engineering Works agreed upon by all the relevant organisations and authorities. But they could be prepared without such approval. In cases where tendering documents were vague and incomplete, the quantity surveyor should not prepare any kind of bill at all. Instead, he should spend his time on (a) pre-expenditure control, and (b) checking the prime cost of the works on site.

The rates for items in Simplified Bills prepared for tendering purposes would not apply to variations, which should be kept to a minimum by furnishing tenderers with complete documents. Any essential variations that arose later would be priced individually on their merits.
Simplified Bills would be divided into "sub-structure", "superstructure", and "non-structural" sections, with "repetitive" works on multi-storey buildings defined and kept separate from non-repetitive work in trade sub-divisions. Carpenter and joiners' work would be separated into first and second fixings. The final summary would comprise sub-structure, superstructure (non-repetitive work), superstructure (repetitive work), non-structural works, external works, and a percentage addition to be filled in for preliminaries.

One master of the nineteenth century, whose rational theory of architecture revolutionised design at a time when the permutations of the Romantic movement were deteriorating under their own complexity, describes his method of estimating a large building in the following terms*:

"The surface covered by the main building comprising the vestibule, which has only a ground floor, is approximately 1,060 square yards. Reckoning the cost of the building at £37 per square yard, as the building has only one floor of cellars, a ground floor and a first storey below the attics, we should be well within this rate. The principal building will therefore require a sum of about £39,200.

The outbuildings cover a surface of 800 square yards. These buildings have cellars under part of the ground floor, and one storey in the roof. Their average cost would be £14 per square yard at most, which comes to about £11,200. Adding for drains, paving, water, lighting and accessories £10,000, this gives a total sum of £60,400."

Experienced surveyors, like Viollet-le-Duc, still adopt this principle for assessing approximate costs from preliminary drawings, but require the use of simplified bills of quantities to obtain competitive estimates from fully detailed drawings and specifications in order to submit firm tenders which will represent factually the final cost of proposed works.

* Eugene Emmanuel Viollet-le-Duc, in his "Discourses on Architecture", lecture XVII, 1860.
CHAPTER 8
FUTURE TRENDS, CONCLUSIONS AND RECOMMENDATIONS

8.1 Future trends

Present research into structural and metallicised plastics, adhesives to replace cement for binding aggregates, synthetic aggregates, load-bearing steel sandwich panels, processed volcanic earths and waste products, and the development of pre-stressed concrete and other materials may introduce a new scale of dimensions and structures by greatly increasing flexible spans, and eventually lead to new types of larger and lighter structural elements that will revolutionise present industrialised building techniques.

The development of economic systems for district heating based on a large central heat source from which heat in the form of hot water or steam can be piped to dwellings over vast areas, with computer control of temperature may provide (i) physiologically correct adjustment of heat radiation and movement according to location and time of day, and (ii) electrical action upon the ventilated air to enhance it with a real and natural impression of freshness.

The increased use of automated methods of factory production, with consequent reduction of employees will tend to replace present standard north light structures with windowless buildings entirely lighted and ventilated by artificial means.

The development of suitable mass production methods such as the following for vast outputs of selected standardised interchangeable components in relation to an organised national volume of demand in order to achieve substantial economies of construction costs:

(a) the development of manufacturing methods for semi-automatic operations and short cycle times which involve such processes as:

(i) ultrasonic techniques for bonding,

(ii) photo-electric guards for the arrester mechanisms of
machinery,

(iii) electro magnetic devices such as tape-controlled processes to eliminate hand fitting, and reduce assembly time,

and (iv) other ingenious devices.

(b) the creation of new process dependent industries leading to reductions in labour requirements similar to those achieved in the production of aircraft.

The development of mechanised construction techniques such as the following in order to reduce site labour requirements and speed erection:

(a) the development and greater use of light conveyors for handling materials and components to required positions at successive floor levels,

(b) the development of road/rail vehicles for transporting heavy structural elements to sites distant from factories,

(c) the improved design of soil cutting tools and use of vibratory techniques to reduce the resistance of soil in front,

(d) the use of hovercraft principle to reduce ground pressure under the wheels of haulage plant to allow earth moving machines to operate effectively over a wider range soil and weather conditions,

(e) the economy of crane design due to (i) more uniform techniques of construction and (ii) revision of current design assumptions in relation to crane fatigue,

(f) the development of an excavating machine which concentrates a high proportion of its power into a high-speed rotary cutting tool operating on a small excavating face.

8.2 Conclusions

The modernisation of construction, and increase of the whole level of building productivity is dependent upon integration of the currently divided professions, management, technicians, craftsmen, and manual workers
into a team supported by the economic mass production of a sufficient number of suitable standardised interchangeable "open" components manufactured by semi-automated production methods in relation to a planned National volume of demand and delivery to sites as and when required for rapid erection in buildings of all types.

At present, (a) manufacturing industries tend to compete with one another when they could more economically operate in combination, and (b) too many different types of systems and components have been designed in relation to a comparatively small, discontinuous, and un-organised volume of demand. This prevents the full benefits of industrialised system building to be obtained.

Economic component production depends upon (a) the vast scale manufacture of effectively designed and suitably selected standardised "open" interchangeable components with a minimum of essential variations related to available supplies of materials, labour, suitable mass production methods, and simple jointing techniques, (b) a more effective combination of the characteristic properties of steel and concrete for structural elements than provided by current methods of reinforced concrete, and (c) planned long-term and continuous volumes of demand for high serial outputs of the selected components.

The economy of the site assembly and erection of standardised interchangeable components suited to a variety of building types is strongly influenced by jointing techniques, efficient programming and site control, and satisfactory bonus incentive schemes related to increased outputs which benefit both labour and management.

The main problems relate to:

(a) the elimination of many existing "closed" systems which are similar in type, but not economically viable,

(b) the increased simplification and more severely restricted
standardisation of ranges of selected "open" interchangeable components with jointing techniques suited to the performance and user requirements, and flexible design of each particular building type, (e.g. non-structural components for hospitals as distinct from dwellings),

(c) the further development of such selected components for interchangeability to other building types (e.g. cladding units suited to both hospitals and dwellings),

(d) the development and increased use of light weight materials to achieve taller buildings with savings in foundation costs where building land is scarce and density ratios high,

(e) the more open planning of "multi-type" buildings capable of extension in height and facile remodelling to suit future improvements in living standards and changed user requirements,

(f) the preparation and completion of fully detailed drawings and specifications before contract stage to facilitate the efficient pre-planning of projects, gear materials and component deliveries to erection requirements, and minimise double handling and non-productive time on site. Once such documents have been prepared for standardised buildings, drawing office costs can be substantially reduced,

(g) the simplification of tendering and contract procedures to enable (i) a contractor to be selected at preliminary planning stage and (ii) competitive tender prices to be obtained at contract stage which factually represent the final cost of a project.

The building industry is (a) moving from a craft industry towards a more intensively mechanised industry based on the substitution of
machinery, factory labour and semi-skilled labour for craft trades, and
(b) passing through a transitional stage of "system building" before
(c) entering a final stage based on the site assembly of factory pro-
duced standardised interchangeable components mass produced in vast
series for a variety of building types in relation to a planned long
term volume of demand. The efficient re-organisation of the industry
will necessitate increased standardisation of component production and
construction techniques, modular co-ordination, improved communications
and management, integration of demand and production, and the re-education
of all concerned.

8.3 Recommendations

8.3.1. Simplification

The simplification of present unco-ordinated and complex designs
and conditions affecting system building is essential for economy by:
(a) standardisation of a comparatively few structural elements
of high strength/weight ratio and light non-structural com-
ponents suited to interchangeable assembly for a variety of
building types,
(b) standardisation of simple jointing and erection techniques
to simplify the design of mechanical plant and equipment,
(c) central and regional government long-term planning of build-
ing related to national and local needs and capacities,
(d) preparation of fully detailed and completed drawings and
specifications before contract stage based on standardised
structural elements and components and related to annually
priced national Schedules of Components,
(e) a National simplified standard method of measuring building
and civil engineering works,
(f) amendment of building regulations, bye-laws, fire regul-
atations, codes of practice, design codes, and standard
specifications to obtain unified procedures and performance requirements based on reality and present day needs,

\((g)\) integration and gradual co-ordination of the many separate, competing, conflicting, and duplicating industries, organisations, and professions into coherent and efficient units organised for effective economic production and service.

\((h)\) strategic siting of new industries and factories in relation to planned National and Regional development and transportation. For example, sufficient space could be made available in Hyde Park for siting temporary factories mass producing pre-cast concrete structural elements for Ministry and Council developments in London.

8.3.2. Adaptability of Construction to Future Changes of User Requirements and Living Conditions

Pre-cast concrete panel and frame systems are unadaptable to future changes of user and living conditions. Many new office buildings recently erected in crowded urban areas based on these forms of construction will become obsolete in the comparatively near future due to lack of requisite floor space and improved standards of air conditioning, sound insulation and other technological improvements. At present, we build for a 40 to 60 years unchanged environment, but should base our thinking on designs that will provide (a) structural stability to take increased loading from future user requirements, (b) bigger spans to enable removable non-structural units forming rooms to be utilised for increasing living and working space within the building, and (c) enable curtain walling and other forms of cladding to be readily altered to suit changed user requirements.

The increase in population that is expected to take place within the century and continue into the next will inevitably affect design requirements so that:
(i) the present scarcity of land will tend to increase, thus necessitating higher buildings, and
(ii) sewage problems may arise in densely populated urban areas.

Advances in building technology will also affect design solutions in view of:

(i) the psychological needs of mankind for larger living, working, and recreational areas, (ii) the utilisation of gas from under the North Sea, which may render uneconomic the use of electricity for domestic purposes, (iii) the more general use of new lightweight materials for non-load bearing walls in place of brickwork and concrete.

Current tendencies to seek quantity and speed of erection while passing over the quality that must inevitably come from the advances of technology, if unchecked will eventually lead to the creation of more slums, and the unnecessary and costly demolition of dense reinforced concrete structures capable of lasting hundreds of years, yet too confined in area and lacking current living standards to justify their continued existence on valuable land.

Design requirements should attempt to provide solutions to such problems by:

(1) providing "multi-purpose" buildings with sufficient foundations to take future increases of loading from increased storey heights and additional floor loading due to change in user requirements;

(2) utilising some form of frame construction which will achieve more open planning to provide for (a) change of building type, e.g. from offices to dwellings, (b) the future incorporation of new and lighter materials to facilitate replanning of internal rooms and alterations to facades to accord with changed user requirements;

(3) provision of pipework in service ducts for future installations
utilising cheap gas, and some form of ducting in substructures to accommodate future sewers.

But good design alone is not sufficient to solve these problems and attain the undoubted advantages that could be gained from industrialised building and more sophisticated techniques of construction. Present unnecessary and artificial factors inflating building costs, such as unnecessarily stringent fire grading regulations, and obsolete methods of tendering procedures suited to another age, must be swept away, and better methods of educating all those concerned with building construction be introduced.

8.3.3. Improved Use of the Best Characteristic Properties of Steel and Concrete

Reinforced concrete does not provide the most effective and economic use of the best characteristic properties of steel and concrete for industrialised system building due to:

(a) the low strength/weight ratio of concrete, its need for tolerances in joints, instead of precise connections; and hidden deficiencies, (b) dependence upon ancillary works such as shuttering, moulds and scaffolding, (c) the need for efficient quality control of mixes and finishes produced by unskilled labour, (d) the need for adequate site space and capital investment for the economic factory manufacture of pre-cast concrete structural elements, (e) the liability of steel to rust and weaken under fire, and (f) the need for more rational and economic design rules which relate to the consideration of a set of limit states with suitable margins of safety, so that design could be based on a semi-probable basis.

The more economical design of standardised interchangeable structural elements and cladding units for flexible assembly into a variety of multi-purpose tall buildings providing ready adaptation to future changes in user requirements or improved living standards necessitates:

(a) the maximum repetition of comparatively few light structural
elements which satisfy performance requirements, and combine requisite strength, stiffness, lightness, fire protection, heat and sound insulation, and a variety of pleasing external and internal finishings with precise joints.

(b) Standardised cladding units of light materials pre-fabricated in vast series for rapid erection in multi-storey units, incorporating plastic, aluminium or other lightweight material windows to reduce loading and minimise maintenance requirements.

Reduction in the weight of tall structures can be achieved by designing:

(a) light steel frames, utilising high tensile steel for framing to lower storeys, and ordinary mild steel for framing above,
(b) light weight load-bearing cladding units incorporating windows, and pre-fabricated in multi-storey heights,
(c) locating structural partitions in positions to minimise loading,
(d) light weight removable non-load bearing internal walls and partitions,
(e) steel staircases,
(f) higher strength concrete for structural elements to lower storeys, and lower strength concrete for elements to storeys above,
(g) pre-stressed light weight aggregate pre-cast concrete floors and roofs.

The development of steel frames with central access and service cores, pre-stressed light-weight aggregate pre-cast concrete floors, and plastic or other light weight materials which eliminate maintenance painting of facades would (a) simplify stress problems by utilising floors to provide stability through acting as beams to bring loads to a central
stiffening core, (b) provide (i) a light steel frame to act both as a reinforcement and template for setting out the final construction, and (ii) rapid under cover working for all trades, (c) lighten loading on foundations, and (d) enable a faster erection cycle to be worked with less ancillary works based on 3 storey lifts and simple precision jointing techniques.

8.3.4. **Standardised Steel Girders and Pre-Fabricated Dropped Shuttering for Tall Composite Steel and Concrete Structures**

(a) **Standardised steel girders**

Reduction in the weight of the steel frame can be achieved by standardising light steel sections (e.g. 6 in. x 3 in. steel tees) for all girders, and encasing them in light weight aggregate concrete of standard profiles with a variety of finishings or facings obtained in the shutters.

Increased loading and spans can be readily achieved by:

(a) additional steel reinforcement,
(b) enlarging the concrete casing,
(c) pre-stressing the reinforcement to the concrete casing.

The joints of the tee girders to the steel columns of the frame can be formed by welding on steel plates to the ends of the tees for bolting to the columns.

(b) **Standardised dropped shuttering for in-situ concrete roof and floor slabs**

Standardised pre-fabricated shutters of steel designed as indicated in diagram would support loads, avoid propping and hoisting to floor levels, and provide many uses. Pulley blocks and chains at the four corners of each shutter enable them to be lowered down inside the building from the roof steelwork, thereby providing (i) clear working areas, and (ii) use on all successive floors without cranage.
PREFABRICATED DROPPED SHUTTERING
for in situ concrete slabs & beams
Roof Slab — Detail A below.

Tee girders
Stanchions
Elevation

Pulleys
blocks
Prefabricated Shutters

Plan

Hinge
Friction grip bolt
Metal clamp

Detail at A.
(c) Standardised Shutters to Girder Casing with Pre-Cast Concrete Floor and Roof Construction

With pre-cast concrete floor and roof construction, the standardised pre-fabricated shutters to the steel girders can be designed to support the ends of the pre-cast units as indicated in diagram.
2" Structural screed reinforced with fabric.

Poured in situ concrete casing to girder

Precast floor slabs

Standardised girder (6m x 3m tee)

Crow props temporarily supporting steel frame

STANDARDISED SHUTTERS for in situ concrete casing to girders.
(d) The Erection Cycle

The erection cycle for the structure would be based on three-storey lifts, with the central services and access core proceeding three storeys in advance of the main construction to stabilise the frame during erection, and act as a temporary hoist for materials and operatives.

The tee girders can be temporarily supported for the full height of the structure on "Acrow" props left in until the concrete roof slab is cast as indicated in diagram.
Diagram illustrating method of erecting frame.
Concreting operations commence at roof level, so that the standardised pre-fabricated shutters can be lowered to the next floor 36 hours after pouring, or in less time with accelerated methods of concrete curing. At the third floor below roof level, props are inserted, and the suspension device for the shutters is re-positioned on the floor underneath to enable the roof and two successive floors below to be released for finishing trades.

The cycle of erection operations could be planned to take four days per floor so that by the end of four weeks, four floors would be concreted, and two floors finished complete ready for handing over to the Employer a few months after commencing works on site.
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