

PRECAST BUILDINGS

DESIGN AND IMPLEMENTATION OF THE PRECAST METHOD

PER KJAERBYE & POUL MORK



APPLIED TECHNOLOGY
GROUP OF COMPANIES

Australia • New Zealand • Hong Kong • Malaysia • Singapore

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- Industrialised Building and Modular Design
Henrik Nissen, 1972
- "Arkitekten" (Periodical for the Federation of Danish
Architects)
- CIDB/BCA Singapore
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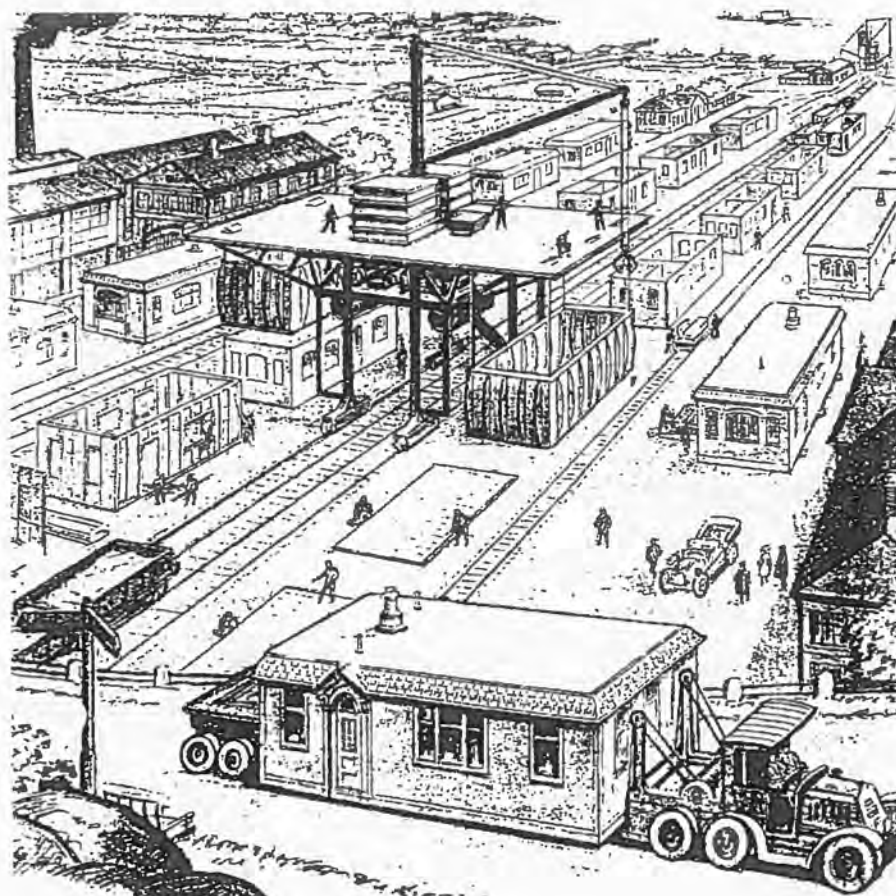
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Left:

A very early American dream of prefabrication of boxes for housing.

The illustration shows an assembly belt production plant with access to roads as well as to the sea for transportation.

Bottom left:

Pictures showing Coalbrookdale Bridge, which is the first bridge structure using cast-iron.

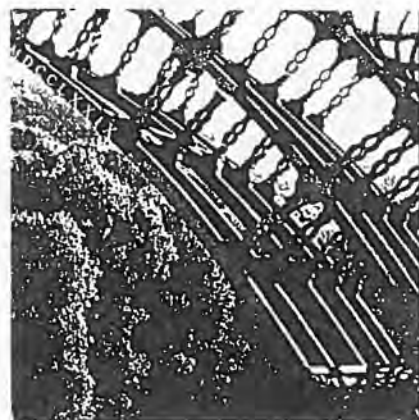
The arches are made of precast-iron members.

The bridge was built in 1779 and spans 30 meters across the Severn River.

Bottom:

Timber-framed, modular coordinated house building, where bays could be added in standard execution.

Such structures were common in North-Europe around year 1700.



1.1 INTRODUCTION

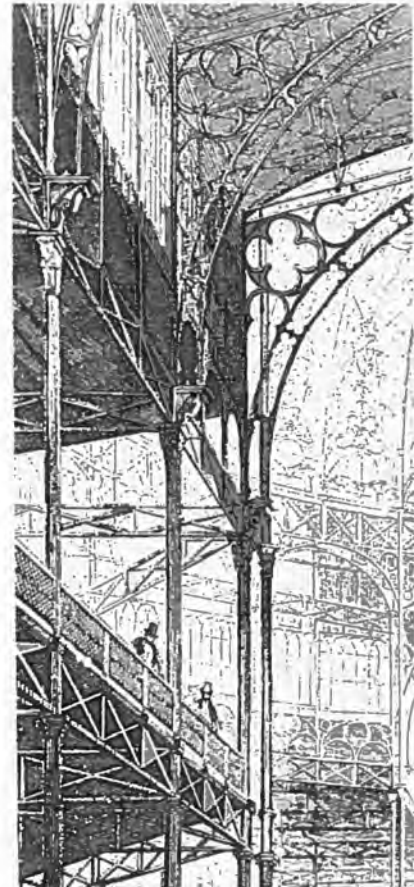
1.1.1 PC-History

Large scale prefabrication of major building parts, such as walls, slabs and facade components, started in countries which had already obtained experiences from industrializing other industries.

Assembly belt production of cars in the United States and the rationalized textile industry in the United Kingdom are often proclaimed as forerunners for the industrialization of the building sector.

The building industry in USA very early planned to produce a kind of turn-key pre-cast houses as a box system, and in UK the well-known Crystal Palace represented the first fully dimensional coordinated, prefabricated building system based on cast-iron members covered with a climatic screen made of glass.

A real step-forward for the prefab housing technique took place in Europe shortly after the end of the second World War. It was a change in peoples demands for housing and also a change of family pattern which influenced the building sector. People were prepared to pay for more living space and at the same time youngsters wanted to move out from their parents home much earlier than before. The Building Authorities in many European countries, especially in Finland, the Netherlands, France and Denmark, realized that the only way to overcome the lack of housing facilities due to the increasing demand was to industrialize the production of houses. Such a concept would also ensure that a rapidly growing building sector could still produce houses of high quality and at the same time with an increasing productivity.



Above:
Crystal Palace in UK and the New York Crystal Palace in USA were both impressive examples of prefabricated buildings, using structural members of cast-iron. The picture shows the New York project, built in 1853, destroyed by fire in 1858.

Left:
A large precast housing project, Broendby Strand, built in Denmark 1969-74, consists of 12 blocks in 16 storeys, 66 blocks in 4 storeys and 8 terraced houses in 2 storeys. The project comprises 2.728 flats plus 122 supplementary rooms. Total floor area is approx. 288.000 m².



In Denmark the implementation of precast modular housing systems were launched in 1958. In the first 9 years from 1958-67 the total storey area built went up from 3.55 mill. m² to 8.87 mill. m², and at the same time labour productivity for new buildings increased with 65%.

The reason for these impressive figures was mainly due to the fact that a clause was put into the Danish Building Regulations, saying: "Dwelling houses erected for rental purposes shall be designed in accordance with Modular Regulations for Building Works", defined in Danish Codes.

With this clause it was mandatory to make a modular design, but still voluntary whether to use prefabricated components. This very soon had a great impact on the construction business. As most projects were now prepared for the use of modular components a new market was created and it became tempting for contractors to invest in factories producing precast components for residential buildings.



In the very beginning the precasters and the structural engineers more and less dictated the shape of the precast buildings. The architects could only be allowed to play with the outer 2-3 mm facade skin for profiling, pattering or colouring. This created many examples of boring buildings. But these conditions have changed now.

Nowadays, developers of PC-building systems surely have recognized the benefit of implementing the integrated design concept, meaning a strong cooperation between architects, structural and mechanical engineers, precasters and contractors from the very first design stage.

For several years now durable and nice-looking buildings have been designed and constructed all over the world using prefab technology for the structural system and for the cladding components as well.



Industrialized housing technology opens up for great variation in shape and colours.

To the left an early example of a industrialized housing product is shown.

After a while the designers met the challenge to work with the precast facade and with precast systems.

The result has been a huge number of completely different buildings, each with it's own expression.

Here f.inst. curved facades, cantilevered storeys, balcony structures, facade columns, and unusual corner solutions.





Early HDB precast pilot projects with facade patterns and tile cladding.



1.1.2 PC HISTORY IN SINGAPORE

During colonial times prefabrication in Singapore was mainly restricted to steel and cast iron components. Cavenagh Bridge was prefabricated in Scotland and later some military installations were prefabricated after standard designs.

At the turn of the century when construction of shop-houses increased rapidly, standard designs and dimensions were developed and prefabricated plaster castings and special tiles were often used for external decorations.

In 1960, the government through HDB launched an extensive public housing program. With this program, the traditional construction method provided for a large number of jobs for the fast-growing population then. The construction industry expanded rapidly and it became necessary to employ an increasing number of foreign workers to meet the demands.

In the late 70s and early 80s, efforts were made towards turning Singapore's production and manufacturing sector from low-skilled, labor-intensive industries to more capital-intensive and high-skilled industries. Emphasis was also put on higher productivity. It was during this period of transition that precast construction method was introduced in Singapore as a way to increase productivity and quality in the construction sector, and to reduce its reliance on foreign workers.

The statutory boards spearheading this development are Housing and Development Board (HDB), Public Works Department (PWD), Jurong Town Corporation (JTC) and Construction and Industry Development Board (CIDB) later renamed Building & Construction Authority (BCA). While the first three were involved in the actual assessment and application of the precast method, CIDB/BCA provided a flow of information and incentives, training and spreading awareness within the construction industry. It also helped to formulate design and construction practices adapted to the local conditions.



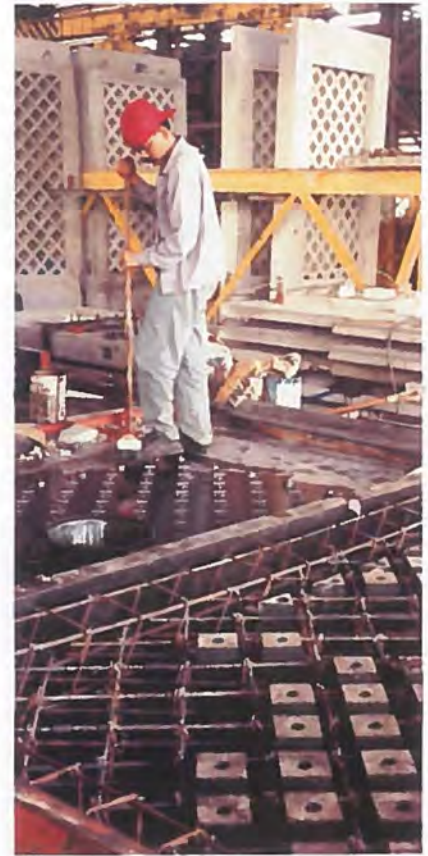
HDB's architects and engineers have since the beginning of the 80s developed PC building components with standardized designs and dimensions which fit into the individual public housing projects. Also in the 80s, four designs of housing projects with all load bearing elements precast were tested in Yishun (P1 - P4). The designs included, however, a large number of internal precast concrete walls and the limited flexibility in the interior layout was not well suited to the local practice of extensive flat renovations when an owner took over the flat. The system was hence abandoned. However, the development of precast facade panels has continued and has expanded to include cast-in tile claddings, window sills and canopies. The standard design for HDB multi-story car parks now include large span precast hollow core slab components.

During the 90s, the government undertook an extensive programme for upgrading of older precincts. Full advantage of the precast method has been taken in this upgrading programme by adding new rooms complete as precast components to existing housing units.

The most labor-intensive and waste generating work in the construction is the casting of the load bearing system : scaffolds, steel binding, shuttering and casting of columns and beams become more and more difficult as the building rise. HDB is constantly testing construction methods to overcome this: 3-4 story high precast columns, standard precast and pre-stressed slab components and the latest, a precast load bearing panel system with good flexibility in the layout of the apartments.

To test new methods and provide "hands-on" training, a Precast Research and Development Centre have been established by HDB. The Centre is fully equipped with production and testing facilities.

PWD has paralleled HDB in the use of components and the precast method, introducing an increasing number of precast components in the civil works. These include storm water drains, overhead bridges and pre-stressed beams for flyovers.



Precasting test facilities and double height columns for an industrial development.





Precast elements: Stairs, internal light partitions, balustrades and road beams.



Lately the extensive schools building programme is mainly based on precast designs.

JTC is primarily dealing with industrialized and commercial buildings. Whenever possible, the designs are incorporating the ready available precast components such as pre-stressed and hollow core slab components.

The private construction sector is mainly using PC for facade panels where granite or marble facing is cast in the surface. Hollow core slabs are frequently used but the constraints in design due to irregular sites and special building programs such as variations in story heights and very high constructions have delayed introduction of fully prefabricated construction methods. A number of condominium projects have however, been successfully completed with extensive use of precast components.

Precasting factories have been established in Singapore since the 80s and are constantly developing their production equipment and skill to meet the demands for the market. Especially the designs from HDB have enhanced the development and enabled a sound economic base and a healthy competitive climate for a precasting production industry. Approximately 20 local factories are able to supply a variety of standard and special components on a competitive basis.

Research and Development of the precast construction method is encouraged and funded by the Singapore government through several channels:

- CIDB/BCA have annually since 1986 presented awards to the Best Buildable Designs evaluated with emphasis on the following criteria:

- Standardization through repetition in dimensions and grids, component sizes and installation details.
- Simplicity with uncomplicated building systems and installation details
- Designs that combine related components into a single element that can be prefabricated.



- In 1989 a Construction Quality Assessment System (CONQUAS) was introduced that provides contractors with high scores with a leading advantage of up to 5% for public sector contracts.

- Additionally, CIDB/BCA has developed a method to calculate the "Buildable Score" of projects based on a detailed evaluation of the design and construction process with special emphasis on the advantages in the precast method. It has been considered to give preference to projects with a high Buildable Score when issuing building permits.

- Seminars, courses and lectures on the precast method are organized and sponsored by BCA and the latest developments (local and overseas) on the prefabrication construction method are published on a regular basis.

This Handbook is part of the overall effort to increase the productivity in the construction industry in Singapore by promoting the use of the precast method.



Fully precast HDB housing project and painted and tile clad facade examples.



1.1.3 PC-Presentation

When using prefabricated components for buildings, for instance, precast members, normally the designers have much more freedom and many more choices in the architectural as well as in the structural design.

Of course some rules have to be followed, it could be standards about dimensional coordination or information about preferred sizes, it could also be economical consequences of using not square components, special colours or grooves in unusual shapes.

Many times it is claimed that prefabrication leads to standardised and to some extent boring buildings. Maybe this was true when the industrialisation processes were implemented in Europe in the late 50's. Looking back it seems that the reason for this must have been very strong statements from the structural engineer and from the precasting pioneers about what was possible and what were the costs.

After a while the structural engineer and the architect started to work closer together in the PC-design process, and this cooperation was soon extended also to incorporate the precaster and if possible the contractor as well.

In other words, the design philosophy was changed from a separated design concept to an integrated design concept which very soon led to much more variation in precast buildings.

This chapter presents a number of PC-examples from Europe and Asia showing the great variation in shapes and colours which is possible to obtain in a precast building project, especially when the PC-design has been made by experienced professionals.

It should be noted that the majority of Danish examples are 2-7 storey buildings due to the local plot ratios, traditions and preferences.

With regards to the layout design and technical qualities of the PC elements the actual height of the building does not, however, play an important role.

Terraced Houses, 4 Storeys

Precast Components:

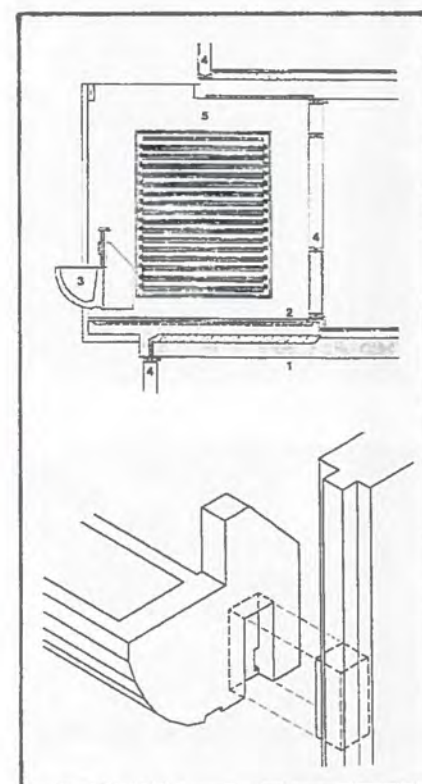
Hollowcore Slabs, Sandwich Gables and Internal Solid Cross Walls, Stairs and Balcony Components: Slabs, Walls & Parapets

Prefab Components:

Timberbased Facades, Lightweight Concrete Panels, Roof Cassettes, Windows and Doors

Structural System:

Load Bearing and Bracing Cross Walls, plus Bracing Stair Well



New Apartment System, 5 Storeys

Precast Components:

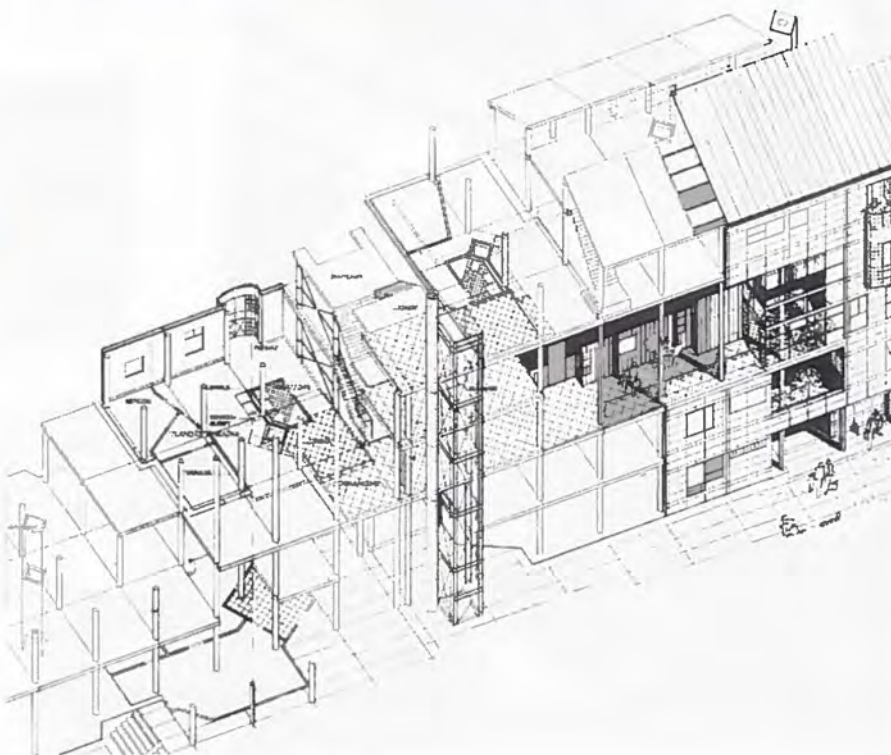
Columns, Slabs, External Sandwich Walls,
Stairs and Balconies

Prefab Components:

Timberbased Cladding along Access Balconies, Glass in Steel Frames as Stairwell Cladding, Internal Walls as Lightweight Concrete Panels or Gypsum, Windows and Doors

Structural System:

Load Bearing Columns and External Walls
as Bracing Members



School, 4 Storeys

Precast Components:

Hollowcore Slabs, Columns and Beams,
Gable Walls, Staircases

Prefab Components:

Light facade parts, Roof Trusses,
Windows and Doors

Structural System:

Columns and Beams with Bracing Walls





Apartment Blocks, 5 Storeys

Precast Components:

Hollowcore Slabs, Sandwich External Walls with cast-in Bricks, Load Bearing Internal Walls and Stairs

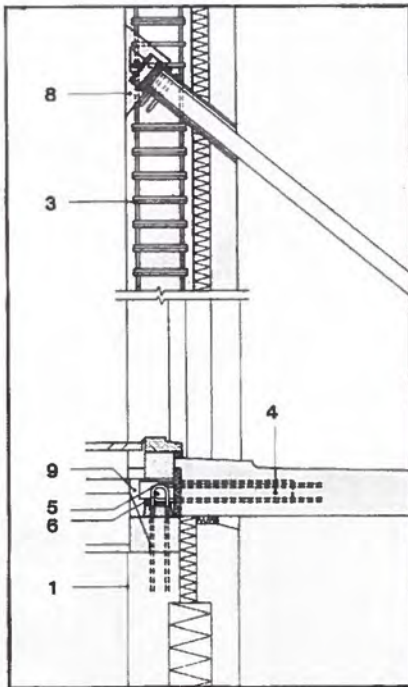
Prefab Components:

Internal Walls as Lightweight Concrete, Roof Trusses and Roof Gables in Timber, Windows and Doors

Structural System:

Load Bearing and Bracing Cross Walls and Gables plus Bracing Facades





Apartment Blocks, 3 Storeys

Precast Components:

Hollowcore Slabs, Facades and Gables as Sandwich Walls, Partition Walls, Stairs and Balcony Slabs

Prefab Components:

Lightweight Concrete Internal Walls, Steel Roof Trusses, Steel Roofing, Steel Cladding at Stair Well, Windows and Doors

Structural System:

Load Bearing and Bracing External Walls, Balcony Supports as Steel Bars





Apartments, 15-storeys:

Precast Components:

Facade panels with cast-in tiles
Parapets, Stairs, Refuse Chutes, Slabs
and Internal Partitions in lightweight
concrete

Prefab Components:

Doors and Windows



Senior Citizens Flats, 5 Storeys

Precast Components:

Hollowcore Slabs, Cross Walls and Gable Walls plus Stairs

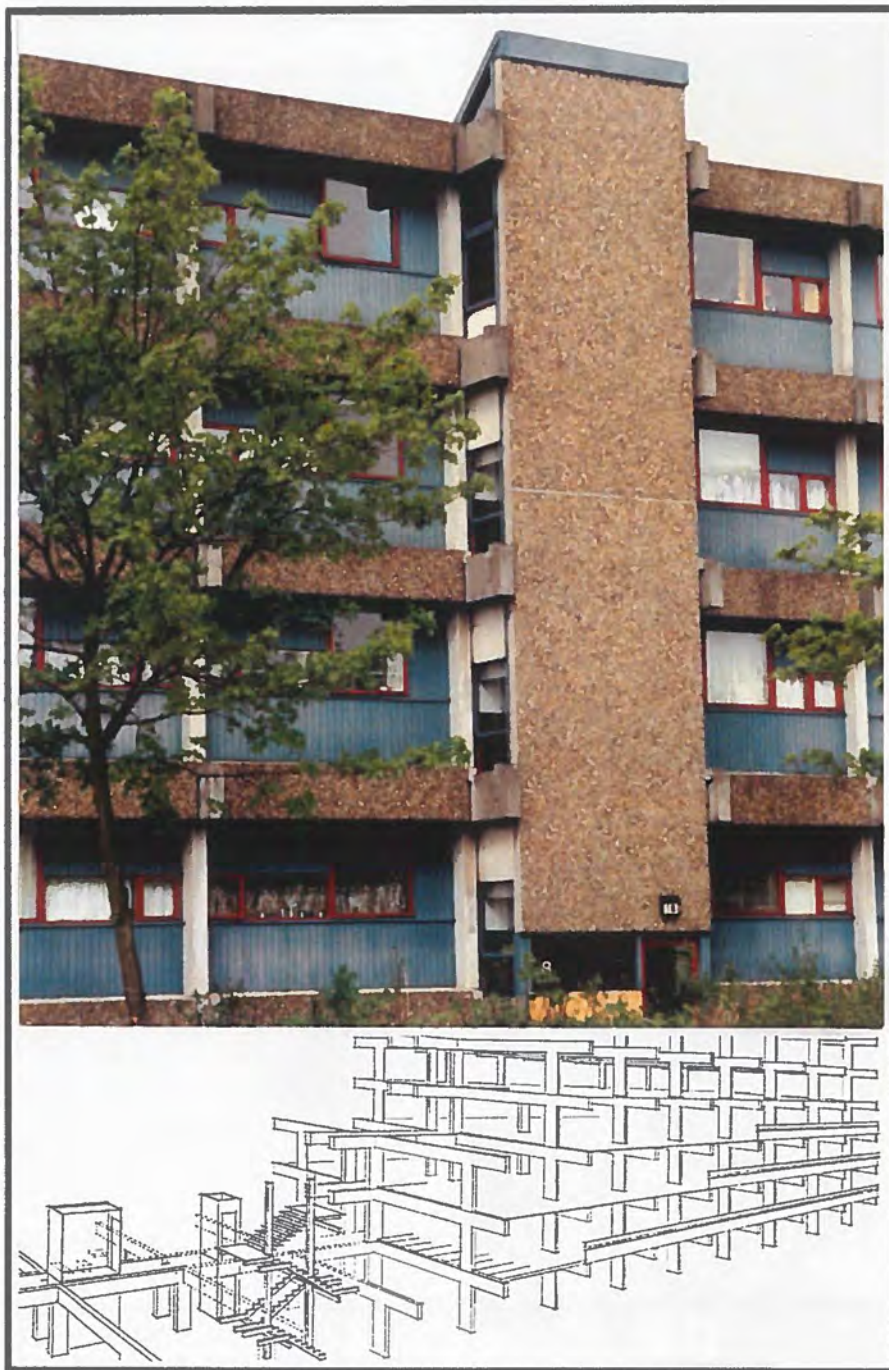
Prefab Components;

Timberbased Facades, Lightweight Concrete Internal Panels, Fiberreinforced Balconies: Slabs and Parapets, Windows and Doors

Structural System:

Load Bearing and Bracing Cross Walls and Gables plus Bracing Stair Well





TVP Apartment System, 4 Storeys

Precast Components:

T- and V-Shaped Frames, Slabs, Gable Sandwich Walls, Balcony Slabs and Parapets, Stairs

Prefab Components:

Timberbased Facades and Lightweight Concrete Panels as Partition Walls

Structural System:

Load Bearing and Bracing Concrete Frame System



Industrial Complex:

Precast Components:

12m Columns, Beams and Hollowcore Slabs

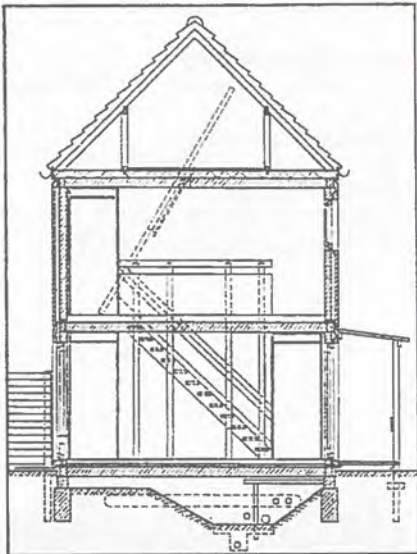
Prefab Components:

Windows, Doors and Internal Walls

Structural System:

Restraint Connections between Columns and Beams, Simply supported Slabs





Terraced Housing, 2 & 3 Storeys

Precast Components:

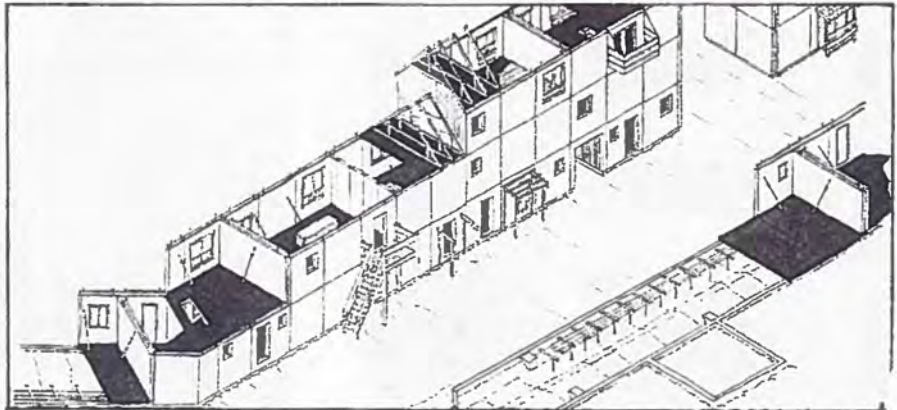
Hollowcore Slabs, Sandwich External Walls, Partitions as Double Walls

Prefab Components:

Internal Walls as Lightweight Concrete, Roof Trusses and Stairs as Timber Structures, Windows and Doors

Structural System:

Load Bearing and Bracing Facades, Bracing Gables





Office Blocks, 3 Storeys

Precast Components:

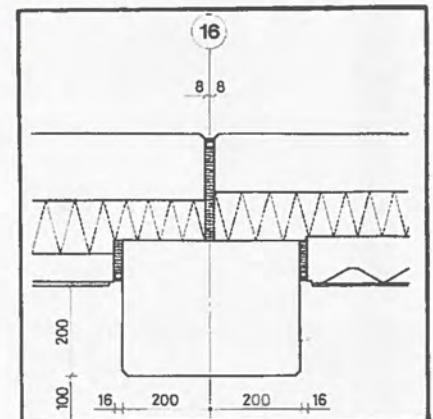
Hollowcore Slabs, Columns, External Sandwich Walls, Stair Walls, Internal Stairs

Prefab Components:

Internal Partitions as Lightweight Concrete Panels and Gypsum Walls, External Stairs as Steel Structures, Glazing and Windows and Doors

Structural System:

Load Bearing and Bracing Facades, Bracing Stair and Cross Walls plus Gables





Apartment Blocks, 20 Storeys

Precast Components:

Slab Planks, External Walls, Internal Loadbearing Walls, Parapets, Staircases, Refuse Chutes

Prefab Components:

Internal Walls in light-weight concrete, Windows and Doors

Structural System:

*Loadbearing and Bracing External Walls plus Loadbearing Internal Wall
Under construction, 1997*

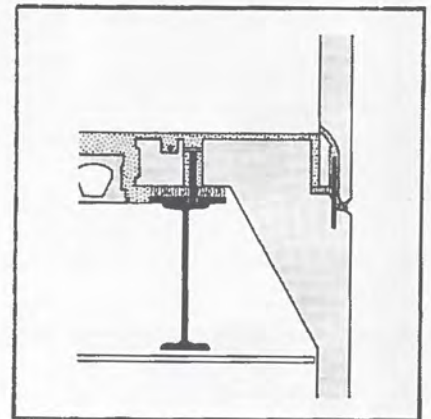
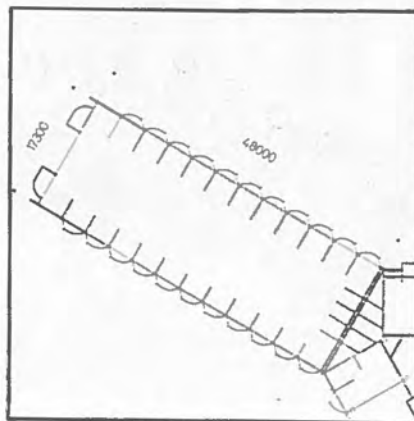
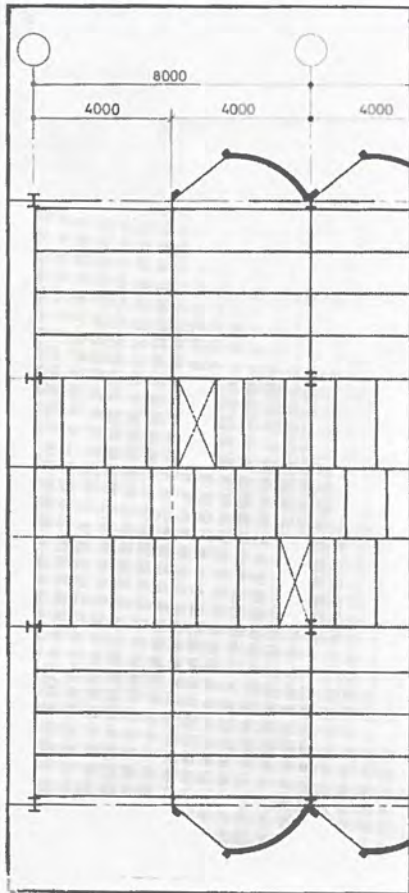




Hotel, 7 Storeys

Precast Components:
Hollow Core Slabs, Curved Facades,
Gable Walls and Stairs

Prefab Components:
Steel Columns and Beams, Curtain Walls,
Partitions Walls as Lightweight Concrete
Panels, Doors and Windows
Structural System:
Load Bearing Steel Structure with Slabs
and Stair-Lift Cores as Bracing Structures





Office Blocks, 4 Storeys

Precast Components:

Hollowcore Slabs, External Sandwich Walls, Stair Well Walls and Stairs

Prefab Components:

Partition Walls as Gypsum Boards, Glazing, Roof Trusses in Steel, Steel Roofing, Doors and Windows

Structural System:

Load Bearing and Bracing External Walls plus Bracing Stair Walls



Stadium + Office Blocks, 8 Storeys

Precast Components:

Columns, Beams, Double-T's and Hollow-core Slabs, External Sandwich Walls, Stairs

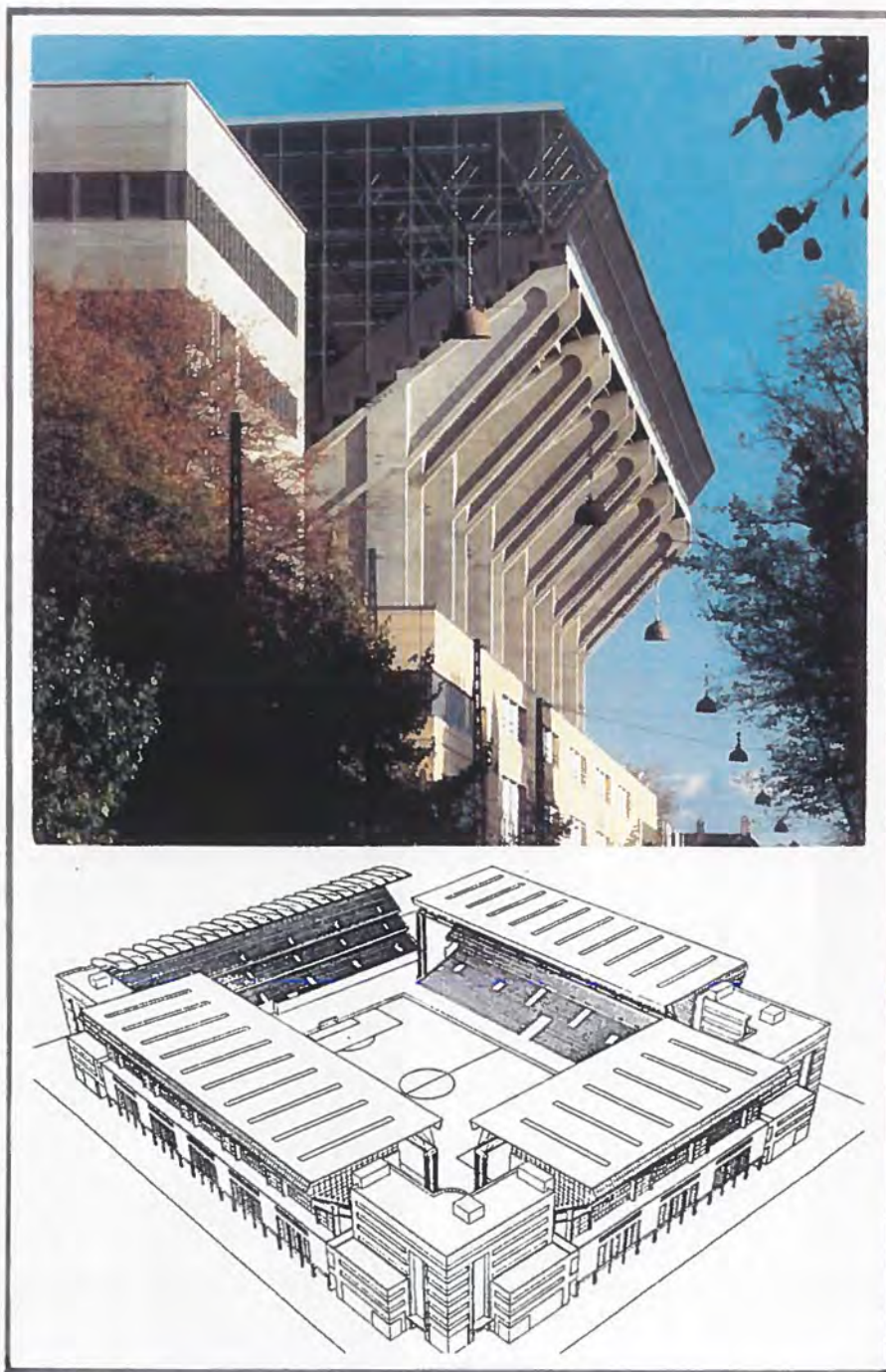
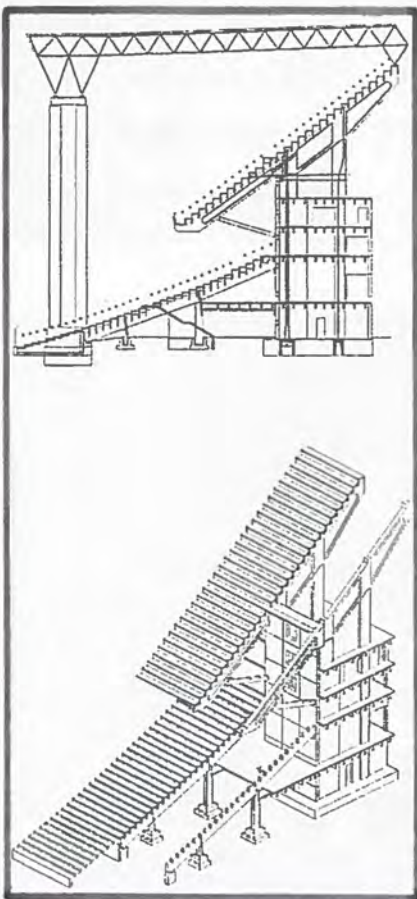
Prefab Components:

Steel Columns, Steel Roof Girders, Internal Walls as Lightweight Concrete Panels and Gypsum Boards, Glazing, Windows and Doors

Structural Systems:

Load Bearing Beams, Columns and External Walls

Bracing Cores for Stand Structure, Bracing External Walls and Stair Walls in Office Blocks



Power Station, 6 Storeys, 30 meter

Precast Components:

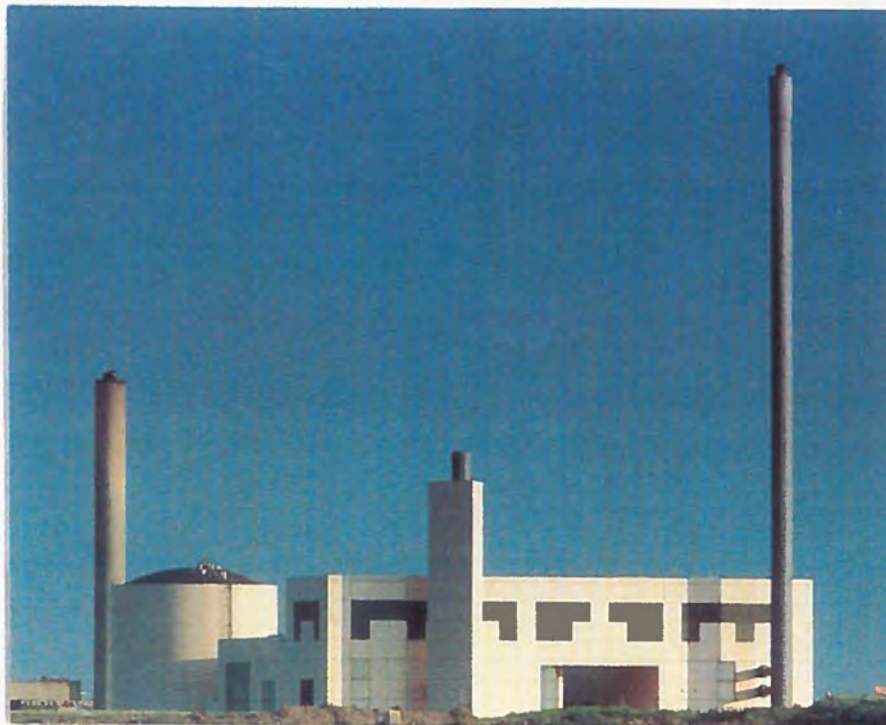
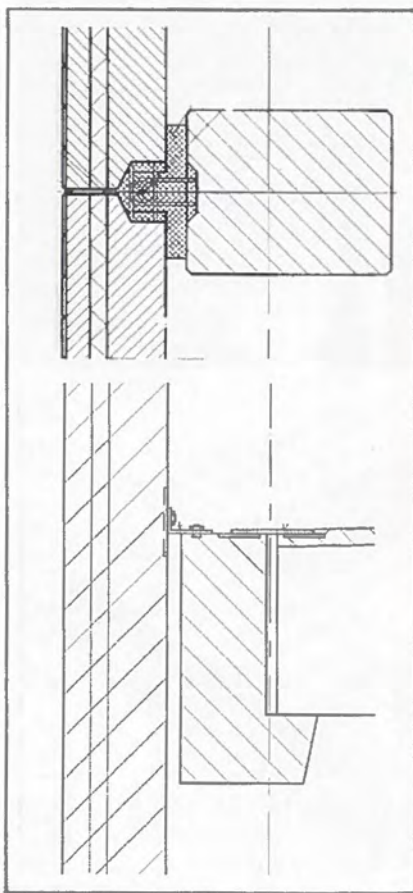
Columns, Beams, Double-T's and Hollow-core Slabs, Claddings and Stairs

Prefab Components:

Steel Columns, Girders and Stairs, Lightweight Concrete Panels, Gypsum Walls, Windows and Doors

Structural System:

Load Bearing Concrete and Steel Columns, Bracing Stair Walls and Steel Cross Bracing



Commercial Multi-storey Project

Precast Components:

Facade Elements with granite facing

Parapet Elements with granite facing

Stairs with tile finish

Prefab Components:

Reinforcement cages

Structural System:

In-situ cast Columns and Beams with standard dimensions and standard steel shuttering





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1.2.1 Consultants and the Precast Method

For the planner, design architect and structural engineer the precast (PC) method offers a wide range of design possibilities. The physical characteristics of concrete can be exploited to the maximum benefit when consultants work together to incorporate layout, structure and architecture in a PC project in an integrated design process

The use of precast concrete components such as facades, walls, columns, beams, slabs, stairs, etc., is relatively new in the construction industry. It was developed mainly after World War II, and the architectural possibilities and structural calculation principles are still under development.

The feasibility of using precast concrete elements in a project depends on many factors. The architect, the structural engineer, the developer/client and possibly the contractor must carry out suitable investigations and conclude in joint evaluations to use the PC method based on the following considerations:



Top:
Hospital - Repetitive character, size and design well suited for PC.

Right:
Industrial Building - Well suited for simple standard PC components.

Bottom:
Administration Building - Uniform and repetitive design for PC plus glass components.

Far Right:
Public Building - Composition of standard PC components and special PC designs.



A. Type of building:

The PC method is most feasible for repetitive design with uniform spans and floor heights. It can be used for residential developments whether semi-detached, terraced, slab blocks or point-blocks, for schools, office buildings, dormitories and other public buildings with a repetitive character. Industrial buildings with standard spans and multi-storey carparks can also be designed for the PC method.

When a project includes special functions such as concert hall, cinemas, etc., a combination of in situ construction for the special functions and PC method for the support facilities such as the offices, etc. should be considered.

Precast concrete cladding elements can, of course, be used under similar conditions as natural stone or tile cladding. It will give the architect maximum freedom in detailed facade design within a reasonable budget.

Buildings up to approximately 20 stories in height have proven feasible for standard PC loadbearing structures.



Simple, uniform PC design on large scale project.

Element storage on site - directly besides the building construction.

Main construction of standard PC components. Variety by claddings and additional components.



B. Scale of the project:

Since the investment in the moulds for the casting of elements are distributed on the number of elements cast, a large number of similar or almost similar elements will minimise the cost of mould per element.

It should, however, be noted that the traditional in-situ casting in principle only uses the relatively costly mould one time and that a simple plywood or timber mould for precasting elements can be used several times if designed and handled with care.

A single steel mould can be designed for casting different elements by moving the sides and thereby distributing the manufacturing cost on a larger number of elements.



C. Site location, local conditions:

The site location, its size and accessibility will determine the possibilities for organising the precast method regarding production, storage and erection.

A remote site location with long and uncertain transportation conditions will normally be organised with batching plant, element production and storage on site or on available land nearby.

In a residential or industrial area with good transport access but limited size of site, some elements, e.g.. facade panels, can be produced on site and stored in limited numbers, while other types of elements, e.g.. slabs, will be produced in a factory and brought to the site for a short storage time before erection.

When the available free area on site is too small for production and even storage of elements, all elements will have to be delivered on the transporters and directly lifted to the construction applying the "just-in-time" method.

Location, capacity and experience of the PC factories have, of course, to be taken into consideration.

D. Human resources and expertise:

Using the PC construction method can substantially reduce the labour manhours per square metre compared to the conventional construction method. A reduction of 50% has been experienced. However, this substantial increase in productivity is dependent on the availability of experienced manpower or training.

Design architects and structural engineers must work together in an integrated design development. All personnel involved, clerk of works, supervisors and foremen together with the skilled and semi-skilled workers, must understand the simple but crucial principles employed in the PC construction method.

E. Construction time schedule:

Construction time for a PC loadbearing system can be reduced by 25-35% compared to the traditional cast in-situ construction, without any loss in quality level.

F. Economy:

Estimates and budgets for precast element construction can be worked out from material and manpower consumption, in collaboration with the PC factories. It should be noted that while the traditional fairfaced or plastered brickwall might be cheaper, it cannot match the precast concrete wall with regards to quality, durability, possibilities in finishes and architectural features.



A few skilled workers can install large components in a short time.

No element storage on site - All elements arrive "just in time".

Complicated in-situ castings can be avoided in a well-designed PC project.





Accurate curves and crisp profiling.

Coordination of form and dimensions.

Architectural features and surfaces.

Combination of proportions, profiling, surface and construction method.



1.2. Architectural considerations in Precast Designs

Architecture is the art and science of building design based on aesthetic and functional criteria. It combines planning, massing, surface, proportions and the use of appropriate materials to present a contemporary "visual language" that is pleasing to the eyes.

In the last 50 years, concrete has been increasingly used in the construction industry because of availability, workability, compression strength, fire and sound resistance quality, cost effectiveness and the extensive architectural possibilities in design.

Structural precast components are being used more and more as a contemporary material and method. By following a few simple guidelines and rules, the architectural opportunities are expanded. The architectural use of concrete have developed from designs imitating natural stone to organic three-dimensional forms adding new dimensions to our architectural environment.

In the traditional construction method, the concrete is poured into a mould in the construction itself and casting after casting gradually form the finished building. As the building grows, the works on steelbinding, shuttering, pouring and demoulding become more and more difficult and hence the forms and designs have to be kept simple. In contrast, when casting is done on ground level in a controlled and sheltered environment and in accurate moulds only a few simple rules limit the architectural possibilities.

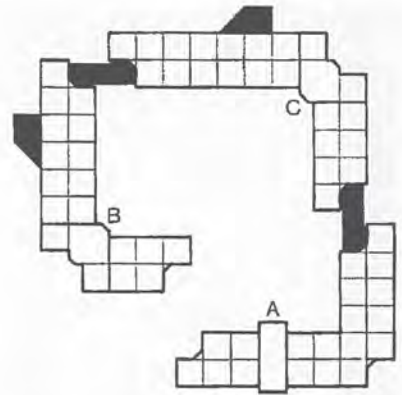


Planning

When the initial decision to use PC construction or cladding is taken, the architectural planning and layout must be guided by a modular set of grids with consistent and standardised dimensions evaluated and chosen with respect to the programme and function of the development.

It is very important in the initial sketch and planning stage to work on the basis of a grid system. This will allow later elementation and initial structural system definition and calculations to be easily done without major amendments and redesign.

Site layout plan should be based on and dimensioned to the grid system lines. And all other information from the different fields of consultancy must be coordinated according to this system too.



Administration and Light Industries Complex.

Layout plan and building layout based on a 6x6 metre grid with standardised corner and gable designs. Variety and flexibility achieved with two types of access designs and two glazed building components.

The 6x6 metre grid will define the structural system and the elementation. Variety achieved with standardised components and a strict grid system.

Top:

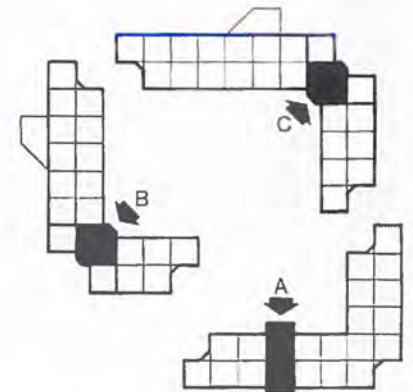
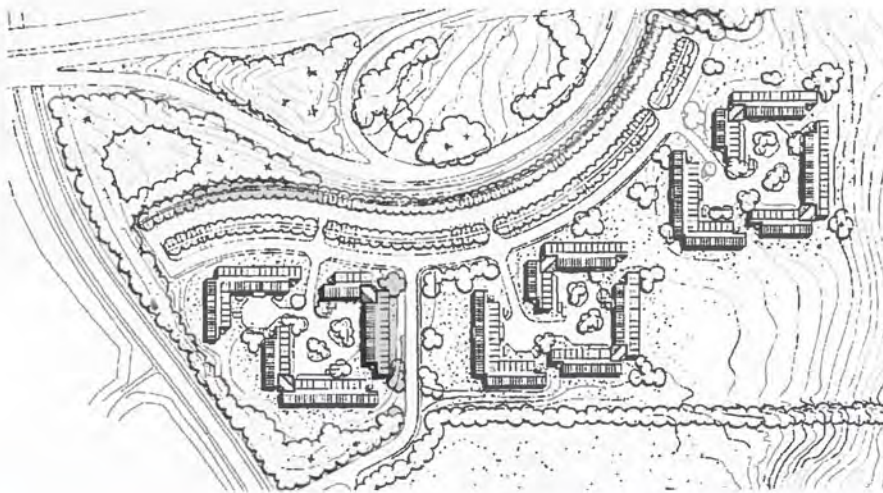
Glazed building components

Bottom:

Access components

Right:

Layout plan





Massing

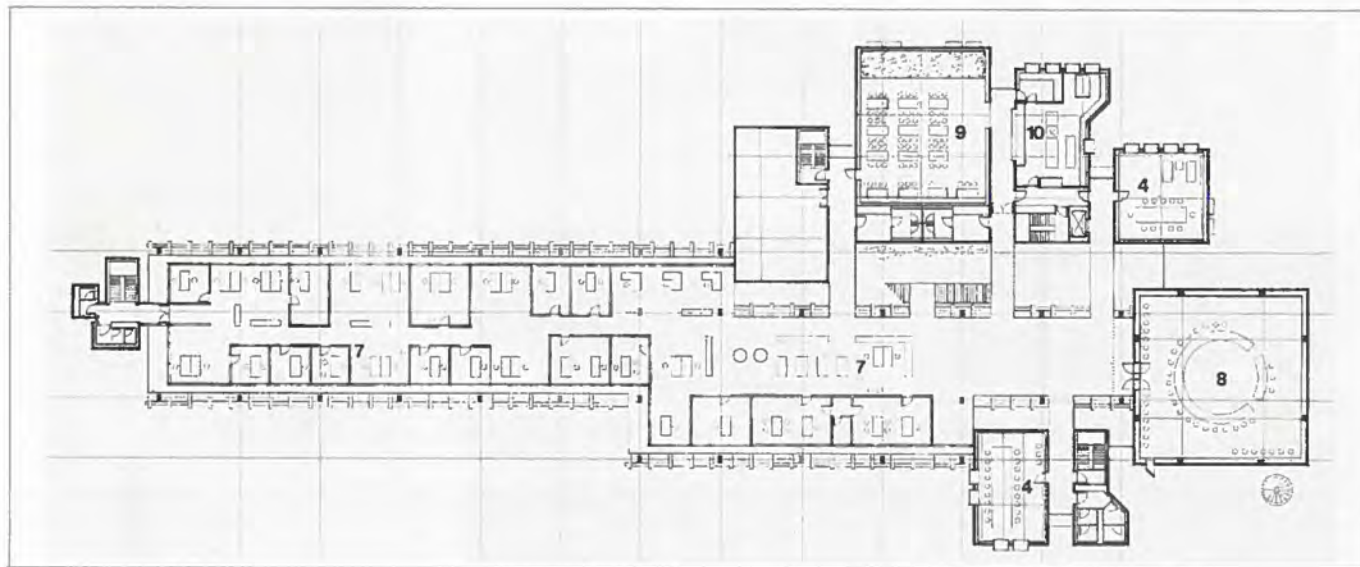
The architects' massing of a development where precast concrete panels in some form are to be used will determine the complexity and number of different elements required. A development with a number of different building elements composed into one organic mega-structure will lead to a large number of non-standard connection details and elements and complicate the whole design and construction process.

Organic building structures should be designed according to a few standard connection details providing the parameters for the design development.

Simple geometric forms are well suited for a precast component method and can be combined into an organic structure and connected by special design balcony elements, stairs and lift towers.

Massing is related to the building programme: In this public building the different functions are separated in the layout - but all dimensions are based on a 600mm module. In the office wing, the main grid is 7.2 metre and in the cores, 2.4 metre. The layout is suited for prefabrication.

Standard "off the shelf" columns and beams and special design wall components.



Surface

The surface of the finished PC component building will gain the architectural character from the integrated design of the panels and the joints.

Horizontal or vertical lines can be emphasised with profiles or grooves in the panels and the joints can be incorporated in the designs or stand out as a special feature.

The final facades will more or less reflect the construction method of joining component to component and a successful design will show in proportions of elements, location and design of joints, corner details and surface designs for light and shade.

In a climate with heavy rains care should be taken to incorporate dripnoses and design the profiling so water is easily led down on the facades and away from the joints.

In a humid climate, fungus and algae will start growing on rough and porous surface and result in discolouring. Only very dense and smooth concrete can be left fairfaced without treatment and have to be cleaned frequently depending on local conditions.

Paint with anti-fungus additive has normally to be applied to ensure no discolouring. Surface areas with shimming and patching are especially vulnerable to discolouring.



*Top:
Joint, dripnose and profiling*

With a thorough coordination of the elementation and the profiling, character and harmony is obtained.

Geometry defined by surface profiles and joints.





The surface of concrete elements can be polished after casting but before erection. The polished, smooth surface is much more resistant to algae and fungus growth and the polishing will also enhance the aggregates' colours and present a surface similar to terrazzo or marble.

A polished concrete surface resembles granite cladding in durability and visual quality - but at a much lower price.

The choices of colour for the polished surface are wide: white cement can substitute the normal grey, white cement concrete can be brightly coloured by additives, and grey cement concrete coloured nearly black. The colours of the crushed granite or sand aggregates will be clearly visible when polished and give a distinctive "natural" look to the surface.



Top:
Partly polished

Left:
Exposed green granite, fair-faced
coloured concrete and polished areas -
all combined on the same element.

Below:
Polished and exposed granite on
cladding.



The surface of the element can also be covered by a layer of granite or marble gravel bonded into the concrete surface during the casting process: Before the concrete is cast a liquid "retarder" - preventing the cement on the surface from hardening - is applied on the mould and the required gravel is sprayed over the surface. The concrete is cast and immediately after de-moulding the surface with the gravel is washed free from cement, leaving a surface of packed bonded gravel similar to the finish of the "Shanghai plaster".

Experience have shown that the growth of fungus and algae is reduced considerably on this surface and the different colours of sand, granite and marble provide a large number of choices for the architect.

All forms of cladding, full face or partly, can be incorporated in the casting of the component: The items are located and fixed in the mould before casting. The choice is wide: Natural stone, ceramic tiles, metals such as stainless steel, aluminium rolled or cast sheets, bronze plates and enamelled plates.

On a project with PC facade elements all the work on the facade is done at ground level in a protected environment. Accurate patterns and elaborate details can be thoroughly worked out and supervised under ideal conditions thereby expanding the design possibilities and increase the quality of the finished building.



*Top:
Proportions and corner design enhanced
by the surface treatment.*

*Left:
Pattern of cast-in tiles*

*Bottom:
Contrast in the surface highlights the
windows.*



Surface



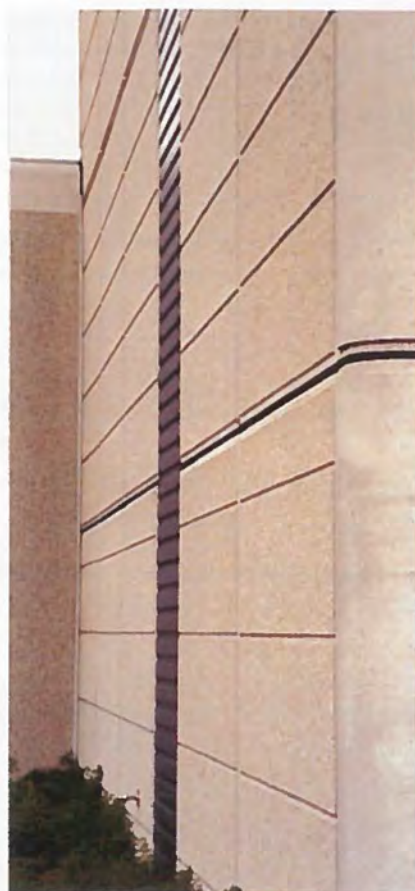
Rough and durable exposed granite on industrial building.

Smooth and "warm" facade on an administration building.

Coordination of PC surface and surroundings.

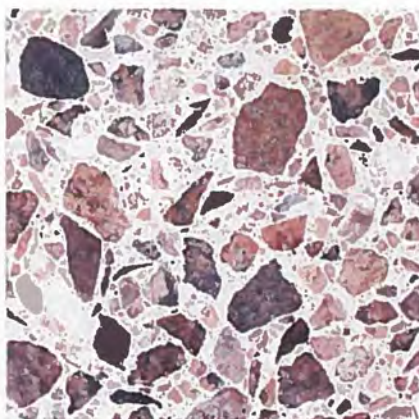
A range of surface possibilities exhibited at the PC factory.

Coloured concrete and fine exposed granite.





Exposed marble



Polished granite and white cement

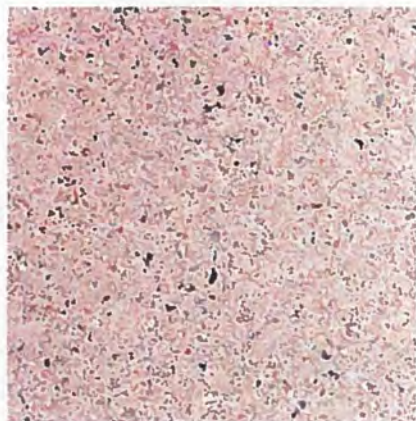


Polished sand

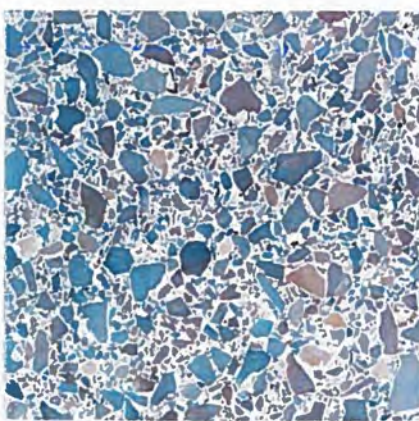
Examples of surfaces in scale 1:1

When materials are exposed on a concrete surface, it must be ensured that they can withstand the local atmospheric and climatic conditions and not bind water and resulting in growth of algae and fungus.

Sand, coloured concrete, sandblasted

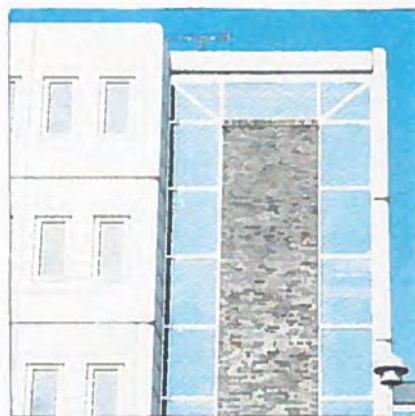


Polished flint



Granite cast in the element





Architectural Precast Cladding

External claddings and internal non-loadbearing wall of precast elements are basically a finish application and the elements are not to be part of the structural system in the building.

The advantages are that the surface finishes on the panels can be worked out in factory conditions with high accuracy, little waste and high durability. Bonding between cast-in tiles or natural stone and concrete can be ensured and quality control performed.

The cladding can be installed at any time when the main loadbearing construction is up.

In precast claddings design, special care must be taken in the method of fixing, tolerances, and water-proofing of joints.

When cladding a cast in-situ main structure, special consideration must be taken with regards to the scaffold which normally will block the installation of the panels.



*Top:
Cladding works on in-situ construction*

*Far Right:
Concrete panel cladding with cast-in
granite surface*

*Right:
Concrete panel cladding with tiles*

*Below:
Cladding component with exposed
granite*

*Bottom:
Other PC components than cladding can
be incorporated in the facade.*





Waterproofing

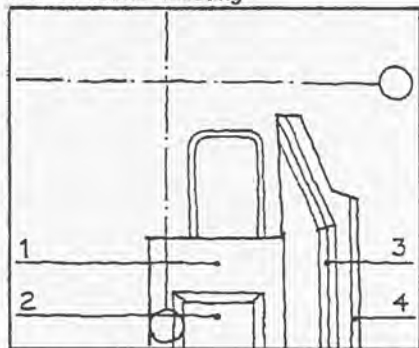
Joints between elements are finished in the construction when the elements have been finally located either by casting or filling with cement, by filling with special joint components such as mastic or with mechanical attached coverings and flashings.

Externally the joints must be able to withstand heavy rain in combination with strong winds which means that water on some occasion is running upwards.

The inner part of external joints must be wind-tight to minimise the pressure.

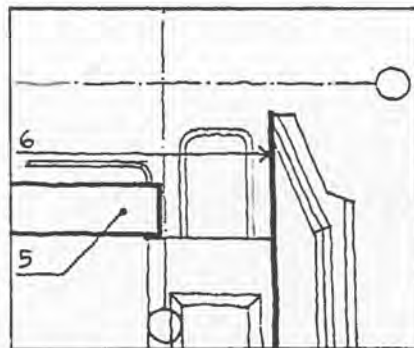
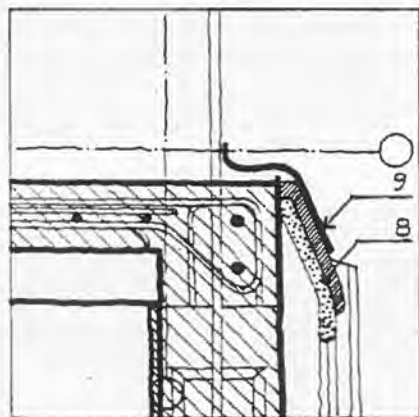
Internally, extensive use of water for cleaning must be expected in nearly all areas and internal waterproofing of slab and wall connections will therefore be necessary.

Water Proofing - Work Sequence In Facade Joints' Meeting



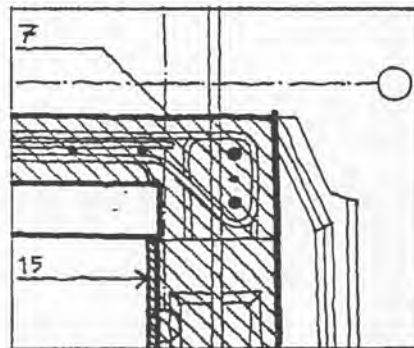
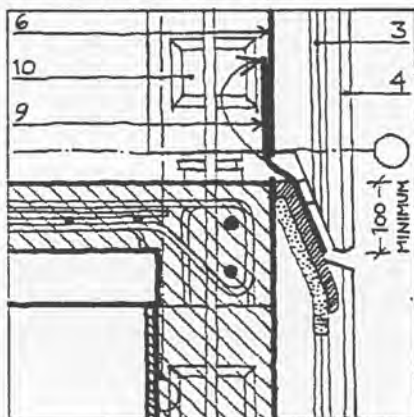
A. Facade element positioned

D. Proofing of top vertical joint



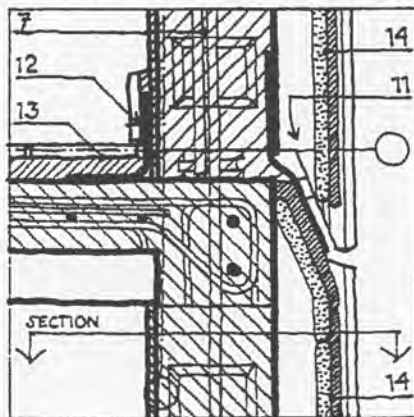
B. Slab and internal proofing of vertical joint

E. Next storey element, connection of water proofing of vertical joint



C. Casting of joint and topping

F. Joint casting. Final internal and external proofing



External Horizontal Joints

The detail should be designed as an "open joint" where the upper element's edge is designed to overlap. To prevent water from entering beyond the joint under pressure from strong winds the vertical overlap must not be less than 100 mm.

The open horizontal joint between facade panels has proved to be feasible under severe weather conditions all over the world and is widely recognised. However, it is very important to establish complete air tightness at the inner side of the joint.

The open horizontal joint provides a practical mean to drain away the water that might penetrate the vertical joints, out to the surface of the facade.

An open joint can also be designed using flashing such as stainless steel or aluminium but special care must be taken in the method of fixing to obtain water tightness by overlapping sheets of flashing.

Horizontal joints could also be sealed with mortar or mastics, but this method prevents water, that might have penetrated the vertical joints, to be drained away. Eventually water trapped in a facade joint will find its way into the building and result in damages. A sealing will also call for more repair work and more maintenance due to temperature movements and climatic exposure.

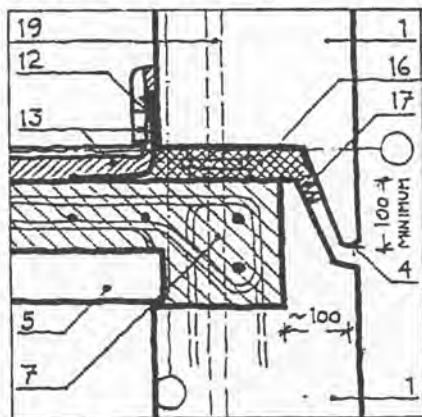
Internal Horizontal Joints

The joints between floor slabs and PC concrete walls, weather facade walls or internal walls must be provided with a water tightening strip before tiling and skirting due to the relative porous character of the mortar bed and the possible excessive use of water during cleaning.

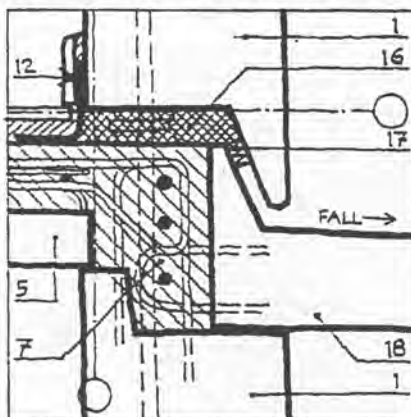
Water Proofing - Key For Numbers On Drawings:

1. PC element, facade panel or internal wall
2. Shear lock, vertical joint
3. Groove for joint backing strip
4. Chamfer, 15 mm
5. PC slab component, "plank"
6. Vertical water proofing strip
7. Reinforcement & casting of joints
8. Backing strip & sealing
9. Water proofing sheet
10. Facade element in shims
11. Vertical joint's drain
12. Continuous internal water proofing strip
13. Screed, tiles & skirting
14. Backing and sealing from outside (gondola)
15. Plaster on recessed casting
16. Grouting
17. Stopping
18. Balcony PC element
19. Vertical tiles

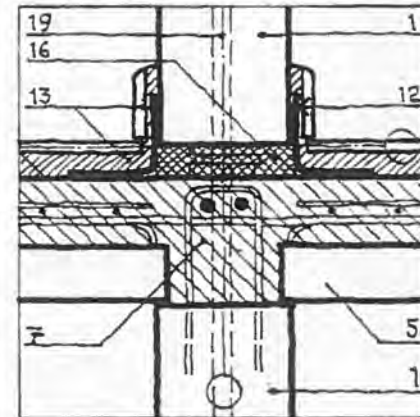
Vertical section in facade joint



Vertical section with PC balcony slab

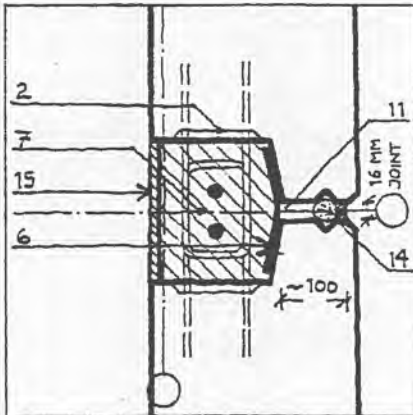


Vertical section, internal wall





Horizontal section in facade joint



External Vertical Joints

Vortical joints can be closed mechanically or sealed with mastic or mortar depending on the detailed design of the whole external joint system. If a mastic sealing is used, it is necessary to drain the horizontal joints.

Bonding between the sealant and the elements must be ensured by proper cleaning and priming and by providing a suitable backing for the joint material.

Tolerances in the casting of elements and the location of elements in the construction will be very visible in the vertical joints. The detailed design must take this into consideration, e.g., generous chamfers and profiling of element edges will minimise the visual effect of variable width of joints.

- Mastic joints, even when carefully made, do not provide a complete sealing of the joints and are vulnerable to the ultra-violet rays of the sun. It should be noted that the manufacturer's guarantee will normally be only a maximum of 8 years.
- Mortar joints can neither be expected to form a complete tight sealing due to shrinkage and hairline cracks, but will have a long life span.
- Backing for joints must be made of water-repellent material such as foam profiles with closed cells or bitumen impregnated.
- All vertical joints must be designed with two-step sealings : 1) External weather proofing by mastic, mortar or flashing and 2) a drain behind, able to lead possible penetrating water out to the facade. Behind the drain a water/wind tight sealing must be provided.

Roofing

The waterproofing principles for roofing in connection with PC concrete construction are similar to those of buildings constructed by the traditional method. Only waterproofing of the top of the vertical joints needs special design with flashing or PC component cover.

Water Proofing - Key For Numbers On Drawings:

- | | |
|--|--|
| 1. PC element, facade panel or internal wall | 11. Vertical joint's drain |
| 2. Shear lock, vertical joint | 12. Continuous internal water proofing strip |
| 3. Groove for joint backing strip | 13. Screed, tiles & skirting |
| 4. Chamfer, 15 mm | 14. Backing and sealing from outside (gondola) |
| 5. PC slab component, "plank" | 15. Plaster on recessed casting |
| 6. Vertical water proofing strip | 16. Grouting |
| 7. Reinforcement & casting of joints | 17. Stopping |
| 8. Backing strip & sealing | 18. Balcony PC element |
| 9. Water proofing sheet | 19. Vertical tiles |
| 10. Facade element in shims | |



Detailed architectural design for PC should reflect the construction method of stacking components and respect and emphasise the structural principles.

Examples Shown:

T.T components, main beam and column.

Columns, top and bottom

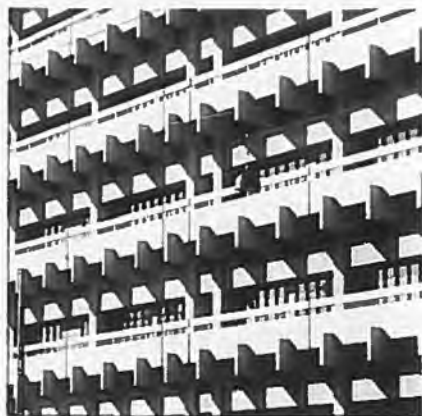
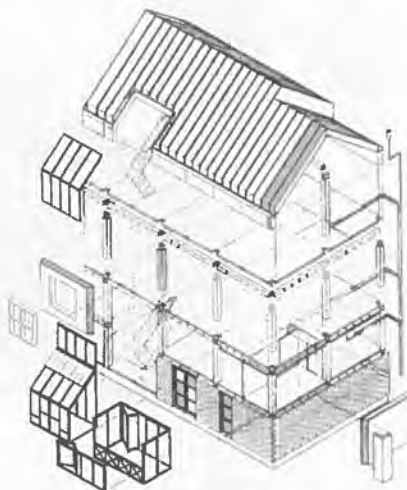
Columns and beams

Columns, beams and slab

Stair flights and landing

Gable





PC-Structural Systems

Structural precast systems could be either column-slab systems, column-beam-slab systems or wall-slab systems depending on the architectural and structural considerations and the functional requirements as well.

Common for PC-systems are the structural regularity and a certain degree of repetition of dimensions. It should be a challenge to the architect to avoid such building systems to look boring.

1.2.3 Structural considerations in Precast Design

In the earliest stages of the building design process it has to be considered whether to design and construct conventionally or to bring in prefabrication building technique. By the conventional way means mainly on-site operations, and by prefab methods means using as many prefabricated building parts as possible and reasonable in the building project in question.

In most cases it is not an either-or solution, but a mixture between the two methods. For instance, a project with the main structural system executed fully on-site in combination with a prefab cladding, or a project with the bracing core only as a cast-on-site part combined with a fully precast structural and cladding system.

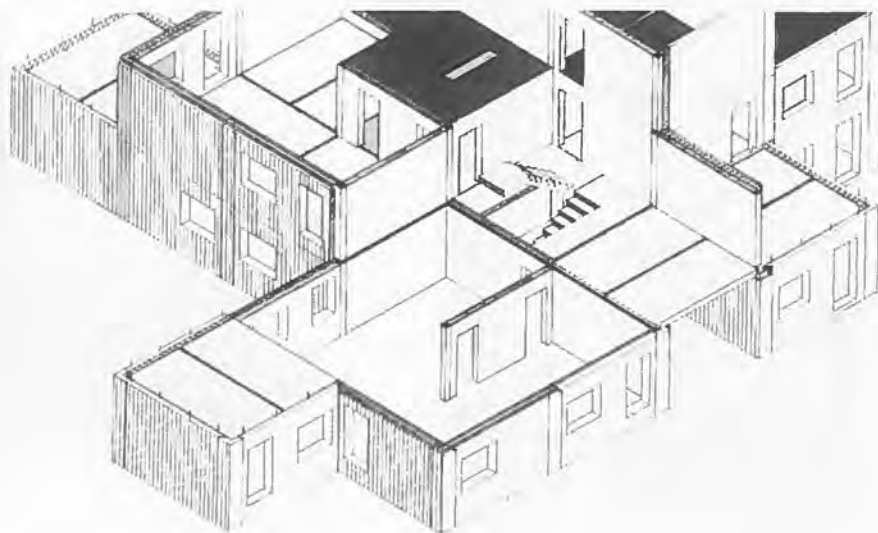
The final decision whether to choose fully or partly prefabricated techniques will normally rely on an economical estimation. It is therefore important to collect necessary information about the present stage of prefabricated buildings parts in the market: which components are available, how is the quality and the costs.

It is also important to realise if the necessary prefab knowledge is present among the designers and producers involved in the project or if specialized prefab consultants have to participate in the design and built period.

A prefab structure normally calls for a high degree of repetition of dimensions. This is in many cases already done for instance, storey heights are the same and distances between columns in a particular project are equal. If not, some few adjustments of dimensions which do not have to differ are necessary. This is known as the modular or the dimensional coordination.

Advantages and constraints

Changing from conventional to prefabrication methods means advantages as well as constraints, structurally and architecturally.



Among the prefab advantages are higher construction speed with increasing productivity and at the same time a better quality. Normally a prefabricated external wall or cladding also gives the architect a possibility for new shapes and different surfaces and colours.

Constraints could be less variety in a project as a high repetition factor means better economy. Also cantilevered features and curved facades could be more difficult to make precast.

A precast structure has less continuity than a cast on-site construction. Normally all PC-components are simply supported and therefore the designers have to put emphasis on the structural joints and the bracing system. However, the normal structural design due to vertical forces will be easier as design charts may be available from precasters catalogues.

Architectural constraints could be the positioning of load bearing walls or columns affected by the choice of floor slab which means an influence on an optimal architectural lay-out.

Integrated design concept

It is of great importance that the PC-design team have sufficient knowledge about prefab techniques and are aware of the advantages as well as the constraints in prefab design, production and execution. Furthermore it is essential to know which components are available and if the precaster can participate in the design of components and joints, and also if the contractor has the necessary knowledge about how to handle prefabricated components.

It is also important to judge the market in the sense of possibilities for buying standardized modular components from a so-called open system or if only components belonging to a fixed and closed system are available which means less design flexibility.

Producing to an open building system means to produce standardised modular components by which it is possible to create buildings.



Industry Buildings

The above photo shows the structural system for a industry project based on a column-beam-roof system with a high degree of dimensional repetition.

PC-Systems for Housing

Even using modular PC-components housing project can have a different look from the outside.

It could be concentrated blocks created by a panel system, f.inst. a system as shown on the opposite page; or it could be row houses with slabs spanning across from facade to facade.





Variety in PC-Facade

Even with a high degree of repetition of PC-facade components and of the placing of windows the facade could be nice to look at, f.inst. by the architectural use of different colours and textures.

Connections

In a PC-project connections too are an important part of the structural consideration and concern.

These connections will usually be solved in a cooperation between the structural engineer and the precaster; maybe the contractor will be involved as well.

The open system concept normally offers standardised joints as well. A closed building system consists of special components which together form buildings more and less fixed in their design. Normally such components cannot interact with components from the open system.

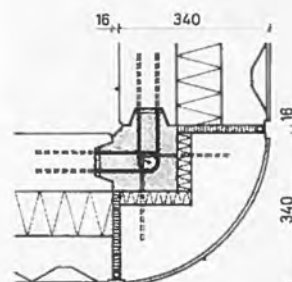
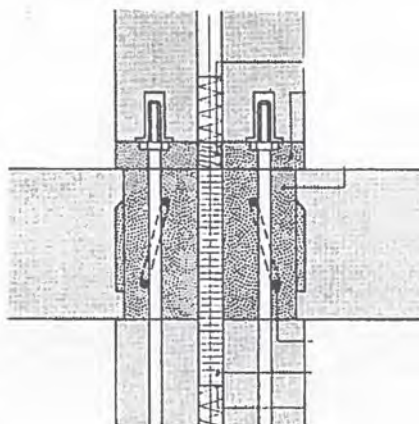
Typical for a conventional project three designs are often carried out, namely one by the architect, hereafter the structural engineer will do the structural design and probably make changes in the architectural design, and after that the producer or the contractor maybe will make some final adjustments based on there experiences.

CONVENTIONAL BUILDING PROJECTS

Professionals →	Architect	Structural Engineer	Contractor
Design Phases			
1. Architectural Design	X		
2. Structural Design		X	
3. Drawings	X	X	(X)

← Separated Design Concept →

To avoid this design situation for a prefab project it is necessary and wise to use the integrated design process. Hereby means that all participants in the design team as soon as possible shall work together in order to optimize the design parameters and to avoid the time consuming re-designs.



PRECAST BUILDING PROJECTS

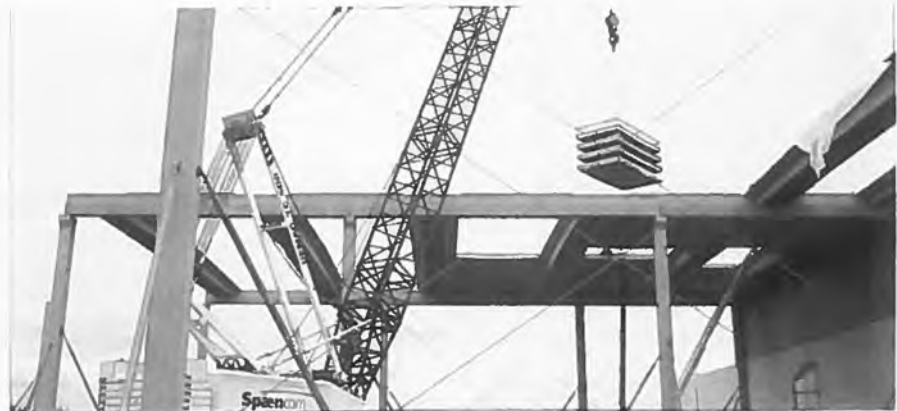
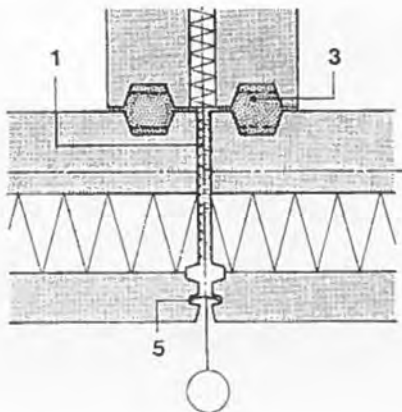
Professionals →	Architect	Structural Engineer	Precaster	Contractor
Design Phases				
1. Architectural Design	X	(X)	(X)	
2. Structural Design	(X)	X	(X)	(X)
3. Precast Design				
3.1 Structural	(X)	X	X	X
3.2 Architectural	X	(X)	X	(X)
4. Joint Design				
4.1 Structural	(X)	X	(X)	X
4.2 Architectural	X	(X)	(X)	(X)
5. Drawings				
5.1 Structural	(X)	X	X	
5.2 Architectural	X	(X)	X	
5.3 On-site Operations		X		X

← Integrated Design Concept →

Integrated Design Concept

If a PC-project should really be a success regarding all important aspects, such as high construction speed, low waste rate, high quality, precise positioning of com-

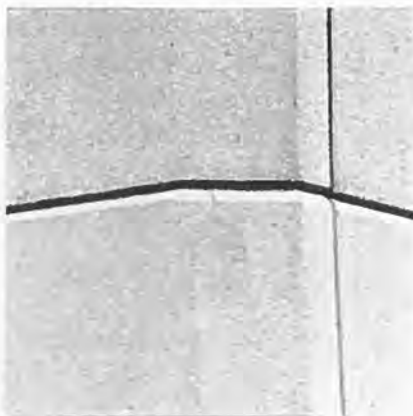
ponents, good architecture and high productivity, all parties involved shall co-operate from the very beginning of the design phases by using the Integrated Design Concept.





Design Responsibility

When many professional PC-technicians are involved in the structural design it is important to define who is responsible, or if the responsibility is shared it is necessary to define exactly who is responsible for the different design phases. Important is also to ensure that no gap is left in the total design responsibility set-up. The architect is maybe responsible for the positioning of windows and together with the precaster for the appearance of the facade joints, while the structural engineer together maybe with the contractor are responsible for the assembling of the main structural system.



Distribution of PC-design responsibility

The PC-design process has to take place in close cooperation between the architect, the engineers, the prefabricator and also the contractor, using the so-called integrated design concept.

However, this method calls for a strong management concerning the entire design process.

It will be necessary and important from the very beginning carefully to define who is responsible for the different design phases.

A precast project will consist of many different components such as walls, columns, beams, slabs, stairs and balconies. Some of these elements will naturally be designed by the precaster or are already a part of a standardized production described in catalogues including design charts for vertical loads.

Contrary, more special components will be designed by the structural engineer and maybe together with the precaster.

In both cases it is necessary to establish who is responsible for the design of a specific component.

Also important is to define clearly the responsibility for the correct load assessment, load distribution and load accumulation as well as the responsibility for the overall stability of the structural main system and for the foundation project.

In a conventional design process the structural engineer will normally be responsible for the entire structural design including all calculations and all drawings.

Introducing the use of prefabricated components the responsibility for the structural design should be shared between the consulting engineer and an experienced precaster. Dividing lines could be drawn at different stages in the design process, for instance, the following designs could be given to the precaster:

- only shopdrawings,
- plus detailing of the components,
- plus joint detailing,
- plus the overall stability of the precast structure.



DESIGN DISTRIBUTION/RESPONSIBILITY

Models of Distribution					Structural Design Phases
1	2	3	4	5	
↑ Structural Engineer ↓	↑ Structural Engineer Precaster ↓	↑ Structural Engineer Precaster ↓	↑ Structural Engineer Precaster ↓	↑ Structural Engineer Precaster ↓	Load Assessments Structural Design Overall Stability Foundations Main Drawings Precast Structural Stability Precast Joint Design Precast Component Design Precast Shop Drawings

However, it would be obvious and natural if the structural consulting engineer at least should be responsible for the load specifications, the overall stability including the structural joints and the foundation. And it would be as natural if the precaster at least was responsible for designing the precast components. The final decision regarding the distribution of the PC-design responsibility has to be stated in the tender documents.

**PC-Design Distribution**

Bringing together many precast and prefabricated buildings parts do not only call for strong managements, efficient logistics and just-in-time principle, but also distribution of design and production.

As shown in the table the structural design phases could be divided into a conventional part and a PC part. It has then to be decided, as early as possible, if the structural engineer or the precaster does the PC-design. The decision agreed upon should be written in the final contract.





The in-situ casting construction method generates a large amount of waste, prevents access and is labour intensive both in construction, cleaning up and finishing. The PC method is clean and effective with minimum waste.



1.2.4 Economical and Ecological Considerations

When calculating budgets and estimates for PC loadbearing construction, the following have to be taken into consideration:

A. Increase in costs:

The amount of concrete in the construction will normally be larger than a similar construction cast in-situ. This is due to the relatively weaker horizontal mortar joints where the weight has to be distributed over a larger area compared to the solid in-situ cast columns. Also the need for standardisation of sizes will lead to over-dimensioning of some concrete elements. An average of 0.35 m³ of concrete per square metre floor area have been experienced for a PC loadbearing construction for normal multi-storey housing projects.

Consultants and contractors must be prepared to spend more time in the design and construction planning phase to gain the benefits during the construction.

B. Reduction in costs:

The waste in the construction process is reduced considerably. The controlled castings in re-usable moulds will reduce the waste in the PC construction to approximately 3%. In conventional construction, it is not uncommon to have a waste of 8-15%.

Scaffolding is normally not necessary in a fully PC panel construction. Facade joints, painting and inspection can be done from gondolas.

Cost of moulds for the elements will vary depending on the design but it is the experience that the cost of a steel mould for PC is equivalent to the cost of the timber shuttering for 5-8 conventional castings.

Labour cost is reduced on a PC construction. In the element production the experience is that every ton of cast concrete element is equivalent to 3-4 man hours of labour. On site, every component resembles approximately 3 man hours of labour for erection.

The team needed for the erection consists of : 1 crane operator, 1 element storage worker, 3 workers on the building receiving and locating the elements. Compared to conventional construction method the reduction in the labour force on the main construction by more than 50% have been experienced using the PC method.

C. Rules of Thumb:

The experience for a fully PC loadbearing construction is that one square metre of finished construction floor area is equivalent to a total of 4-5 man hours of labour.

Construction time schedule depends on the nature of the project as mentioned above but the experience is that 1000 m² PC construction can be carried out in 9-12 days as follows:

- Erection of vertical elements: 2-3 days
- Positioning of slab elements: 1 day
- Slab and joints' reinforcements: 4-5 days
- Casting of topping and joints: 2 days

Human resources : The rough figures for a fully PC construction as indicated above is based on a situation where all involved personnel have a basic knowledge of the PC method and some experience from similar jobs.

The final calculation will vary from project to project depending on the local conditions, experience of the management and work force and of the sizes and complexity of the elements and the building.

TOTAL EXPENDITURE	Factory	On site	Total
TRADITIONAL FLATS, 1950 (Bricks, in situ concrete)	300	1400	1700
INDUSTRIALIZED FLATS, 1970	450	400	850

ON-SITE OPERATIONS (Average from many schemes)	Skilled (Trade)	Unskilled and Semi-skilled	Total
TRADITIONAL FLATS, 1950 (Bricks, in situ concrete)	1000	400	1400
COMPOSITE STRUCTURES (Bricks, floor elements)	600	300	900
INDUSTRIALIZED FLATS, 1965	250	250	500
INDUSTRIALIZED FLATS, 1970 (4 flats per day)	180	190	x) 370

x) MAN-HOURS PER FLAT ON SITE MAY BE SUBDIVIDED AS FOLLOWS:

Erection, jointing	120
Sanitation, plumbing, etc.	25
Electricity	35
Paint, joinery	135
Total above basement	315
Foundation, basements air-raid shelters, etc.	40-70
Total approx.	370

The figures include idle time, but exclude laundries, boiler house, public sewers, and landscaping.



The major reduction in the number of workers needed for the main construction of columns, walls, facades and slabs results in significant reduction of labour costs.

Man-hours per flat - Comparative schedule from Denmark



D. Ecology:

Due to environmental concern it has become natural and obvious to evaluate the total energy consumption for different buildings, for materials and production methods used in the building process itself. Not the energy loss from the building but the amount of energy used for producing and handling materials and components in relation to the execution of a building project.

In many countries companies have to prepare for the environmental authorities so-called "green accounts". Such accounts have to prove that the whole building project is executed with respect to the environment as far as the energy consumption is concerned, and that no unnecessary energy loss has taken place.

So to speak, a new decisive design parameter has occurred: the proper environmental design. This new phase regarding the total energy consumption has to be carried out besides the classical architectural and engineering design.

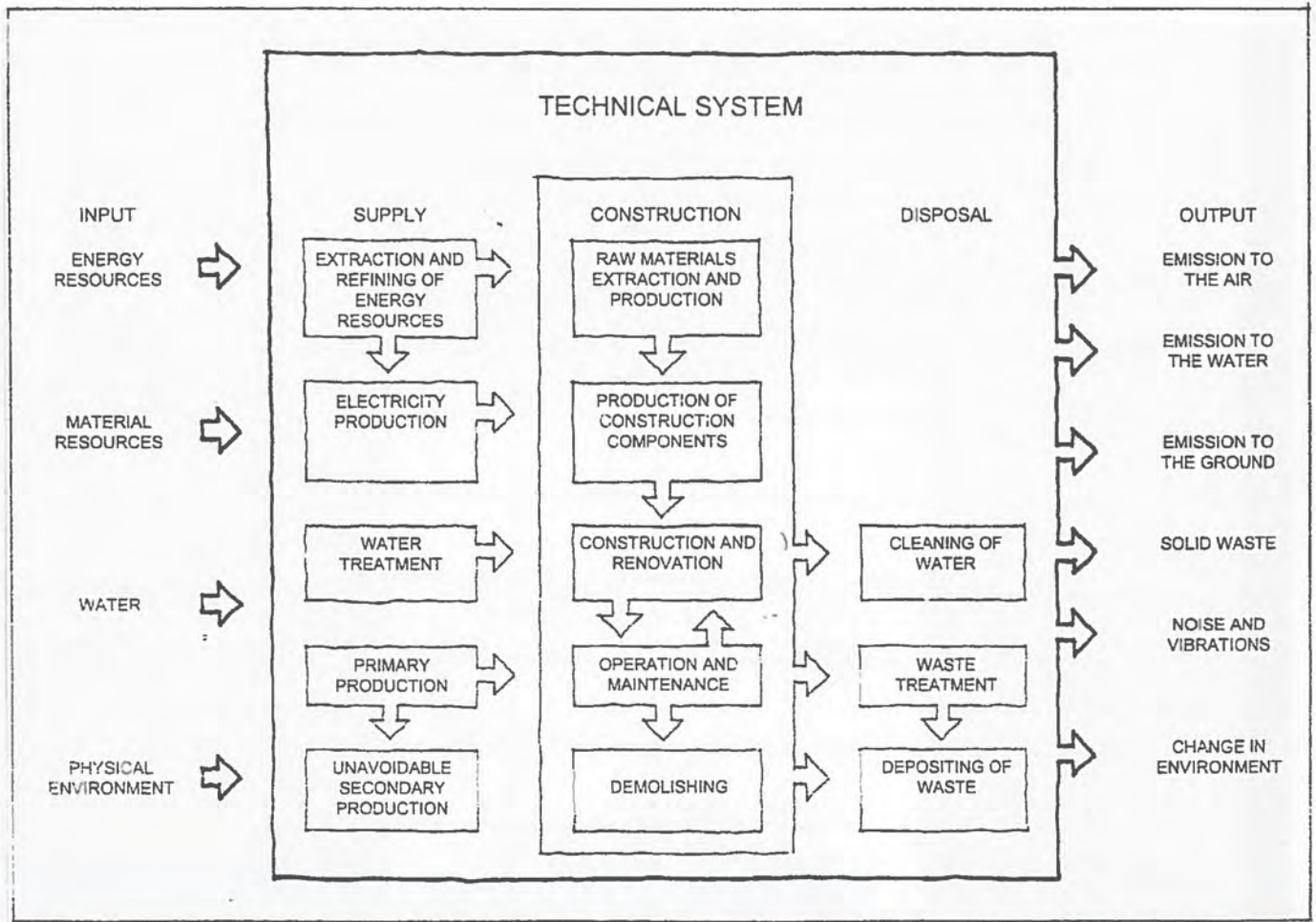
For this purpose, handbooks with energy datas for the construction sector are now available, which enable the designers to judge the consequences of using other materials regarding the energy consumption.

Also the producers are now forced to prove and inform the customers about the total energy content in their products.

Furthermore, the designers have to judge the impact on the environment when removing raw materials from the nature, and also the energy consumption for demolishing the building and for the disposal of the materials back into the nature.

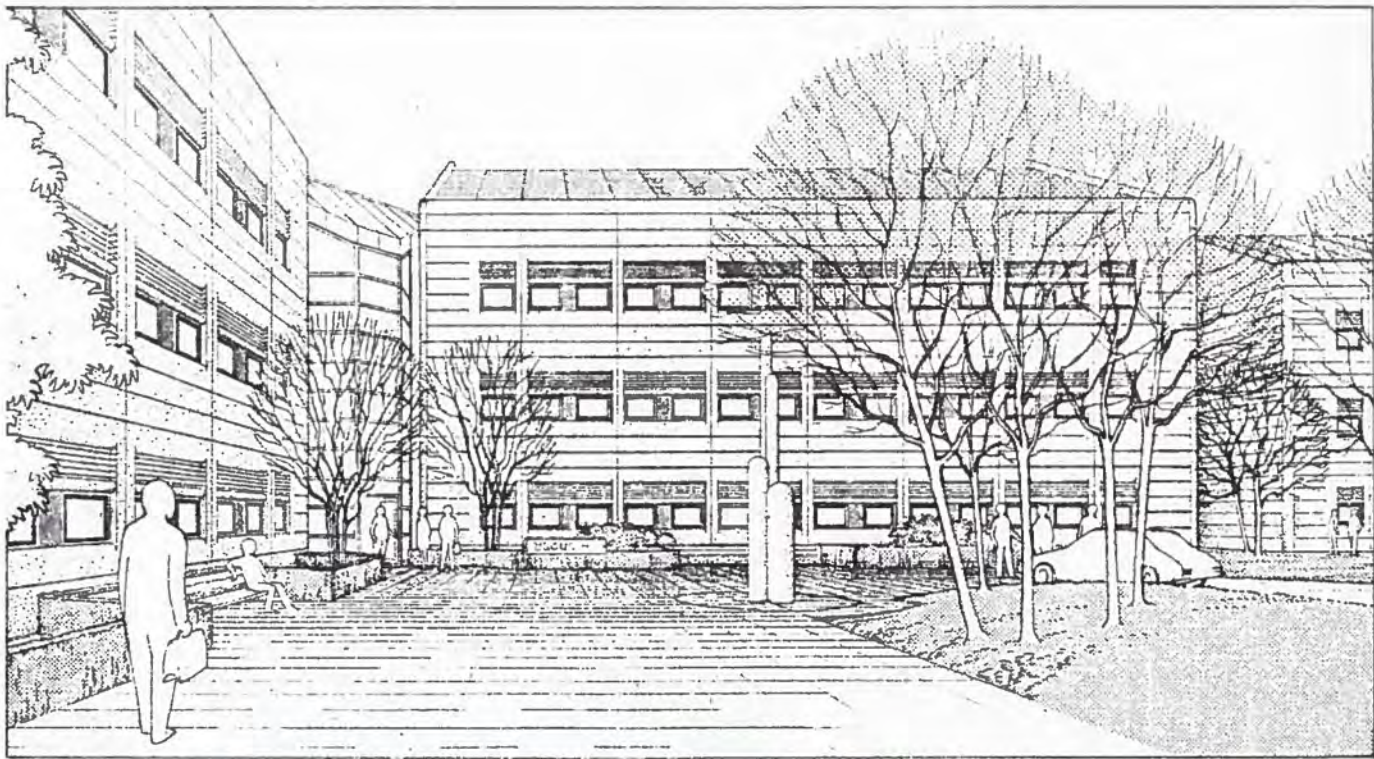
This means a total energy evaluation and energy account for all materials and processes in building design and construction from cradle to grave.







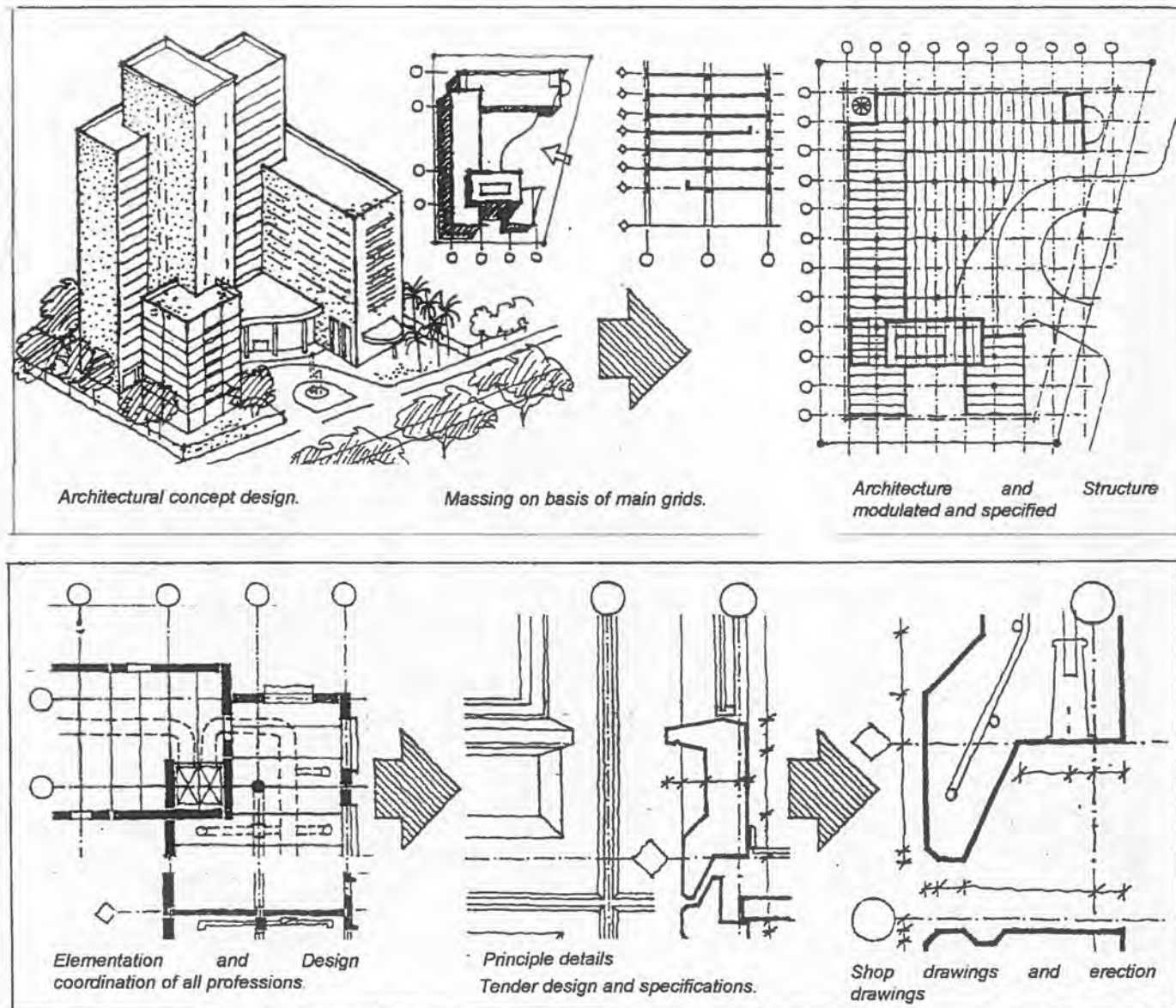
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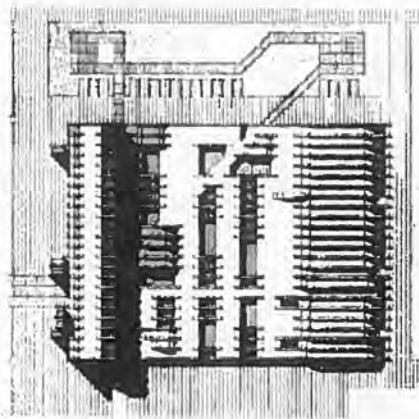


1.3 PC Design Process

For a fully precast construction the design process for the involved consultants are slightly different from the conventional cast in-situ project.

The following describes the sequences and the types of design to be performed in each sequence with special emphasis on the PC components:

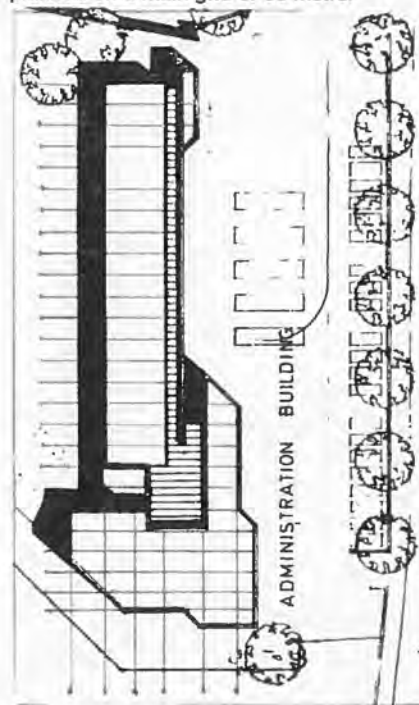




Top:
Complex for a National Athletic Federation planned on a strict 3 metre module.

Bottom:
Administration building planned on 3 metre and 2.4 metre grid systems

Right:
Headquarters for an international body planned on a main grid of 36 metre.

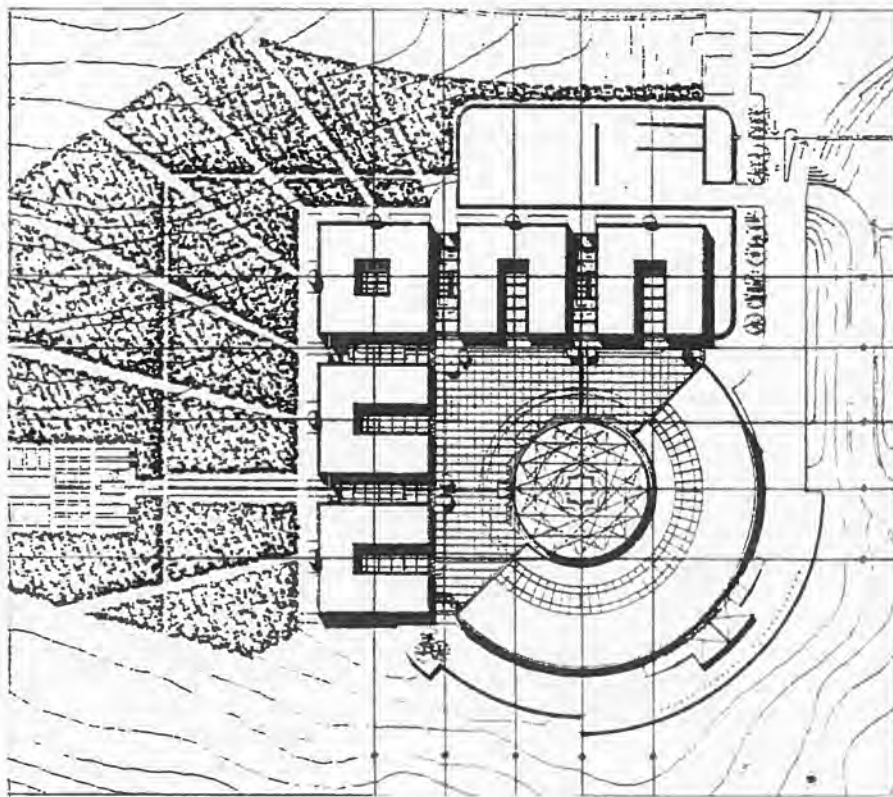


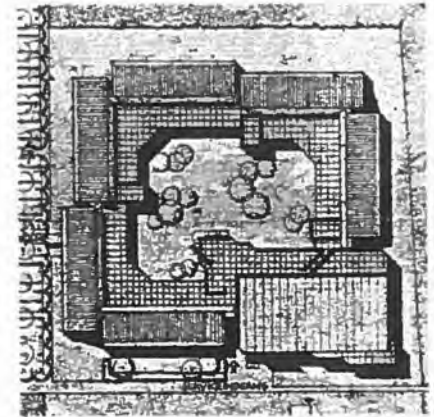
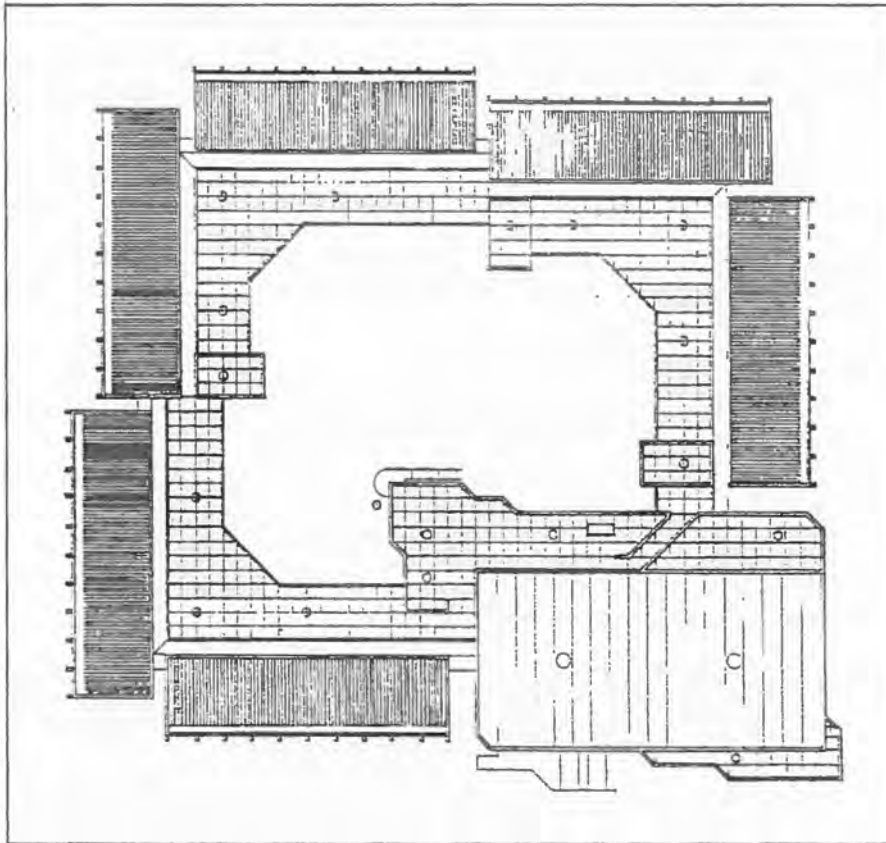
A. Architectural Concept Design

Concept planning, layout plans, sections and elevations based on a modular grid system. The design shall include proposals for location of loadbearing elements and basic structural considerations.

Do's and Don'ts for Planning

- Fix a modular grid system suitable for the job as the basis for all site and plan layout dimensions.
- Define the location of the grid system within the site so that there is space for later detailing of the construction within the set-back and building lines. Normally 300 - 400 mm distance from a design gridline to a restrictive line is sufficient.
- Insist that all consultants use this modular grid system as the basic dimensioning: civil works, structural, mechanical and electrical as well as landscaping. This will facilitate internal coordination and ensure integrated design.

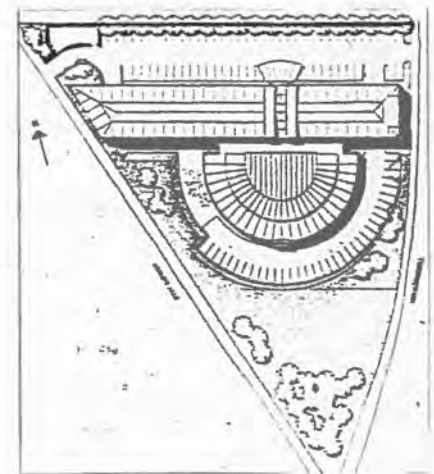
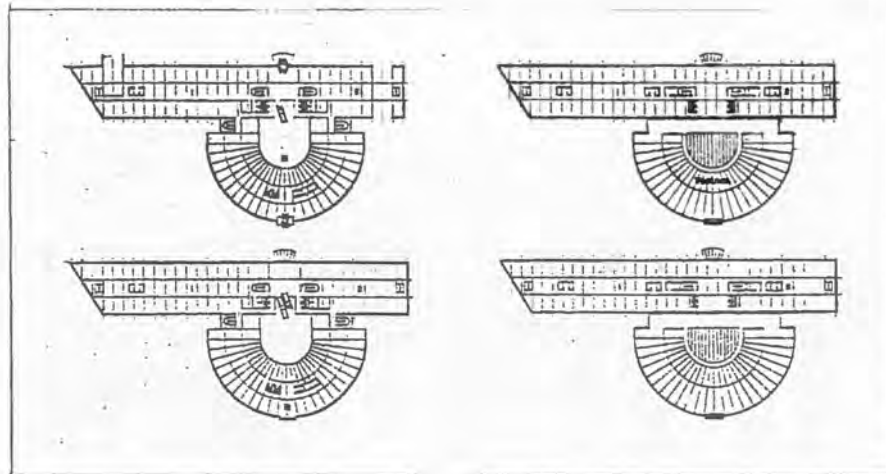




High school planned on 1.2 metre modules and 3.6 metre grids

The examples show the versatility and flexibility in planning that is possible within a strict module or planning grid. All the concept designs are suitable for design development into PC projects with extensive use of standard modular components.

Administration building planned on 3 metre grids



B. Integrated preliminary Architectural and Structural Design

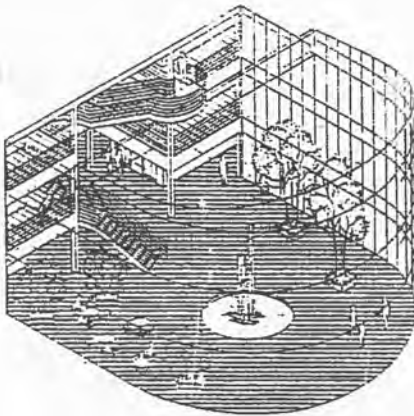
Based on the architectural concept design, the structural engineer calculates the basic structural characteristics of the building, main dimensions and highlight weak and difficult areas in the structural system.

With these information, the architect and the structural engineer together will amend the concept design to the best possible solution within the programme.

During this process the architect and structural engineer will work together to break down the overall design into elements of a size and form that can be precast.

Do's and Don'ts for Building layout design

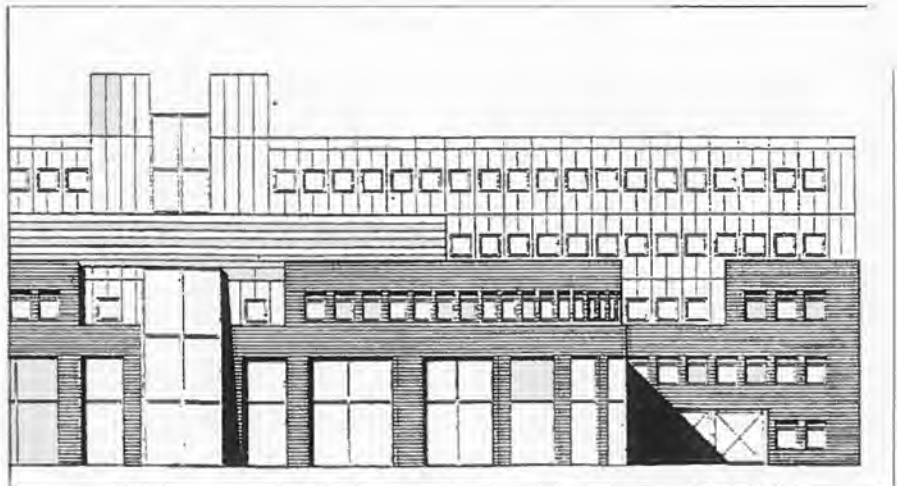
- Develop the building layout plan on the basis of the standard PC slab widths, normally a 900 or 1200 mm sub-modules.
- Simplify the main structure with maximum spans and locate the internal loadbearing walls, columns or beams so that there can be maximum flexibility for interior non-loadbearing walls' layout.
- Break down a complicated layout into simple geometrical forms to be connected with a few non-standard elements and details.
- Special complex layouts can be forced upon the architect due to the shape, location or other special requirements for a specific site. But with the help of a few non-standard components and details, it will nearly always be possible to fit in regular building components.
- Special one-off features such as canopies, connecting buildings' entrances and lobby balconies, etc., will normally not be feasible to do in precast.

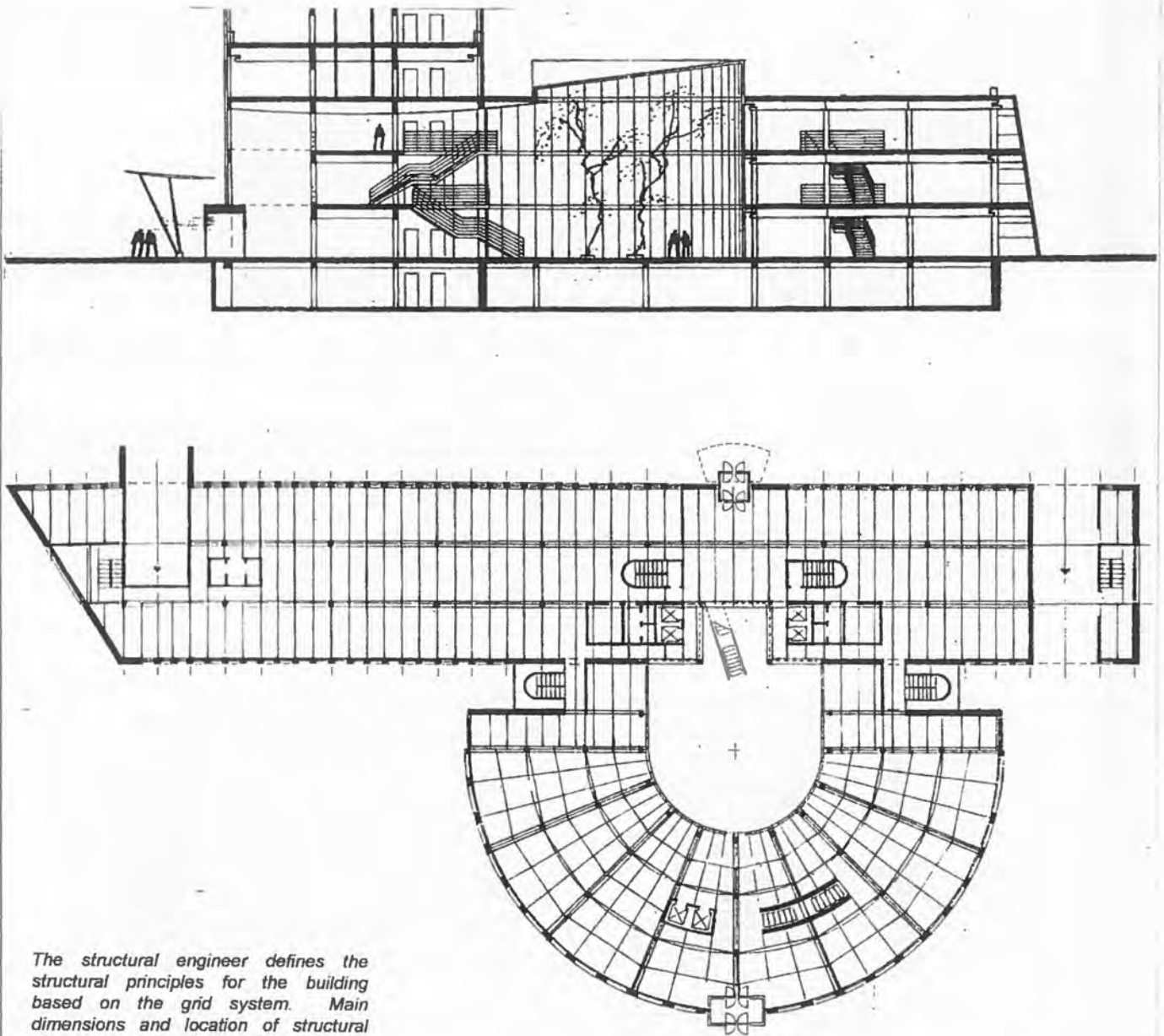


Atrium

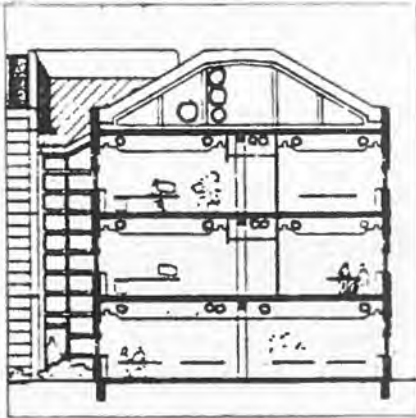
The architect develops the building design on basis of the planning grid and the modules and highlight special features where the standard modular system cannot be applied.

Part elevation with indication of possible elementation.





The structural engineer defines the structural principles for the building based on the grid system. Main dimensions and location of structural elements is defined.



Principal section of incorporating the ventilation.

The architect is the coordinator in bringing together structural, mechanical and electrical components into the overall building design.

Design and elementation of the facade

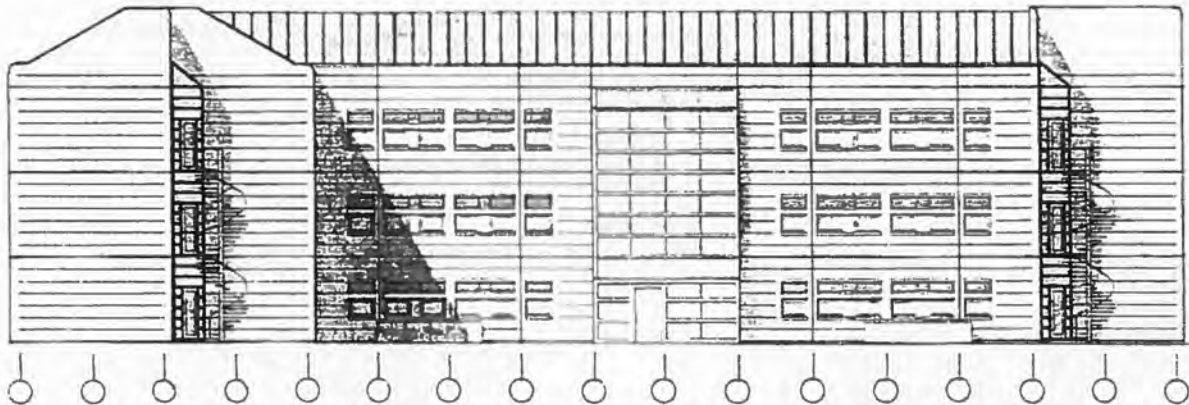
C. Integrated preliminary design for all works

For the preliminary design, all the principal works have to be incorporated in the drawings : architectural, structural, mechanical and electrical. Mechanical and electrical engineers must define the main lines of trunkings and cables and specify preliminary dimension and location of their needs for holes and recesses in the construction.

Preliminary design includes principle examples of detailed drawings of PC components and connection details.

Do's and Don'ts for Design

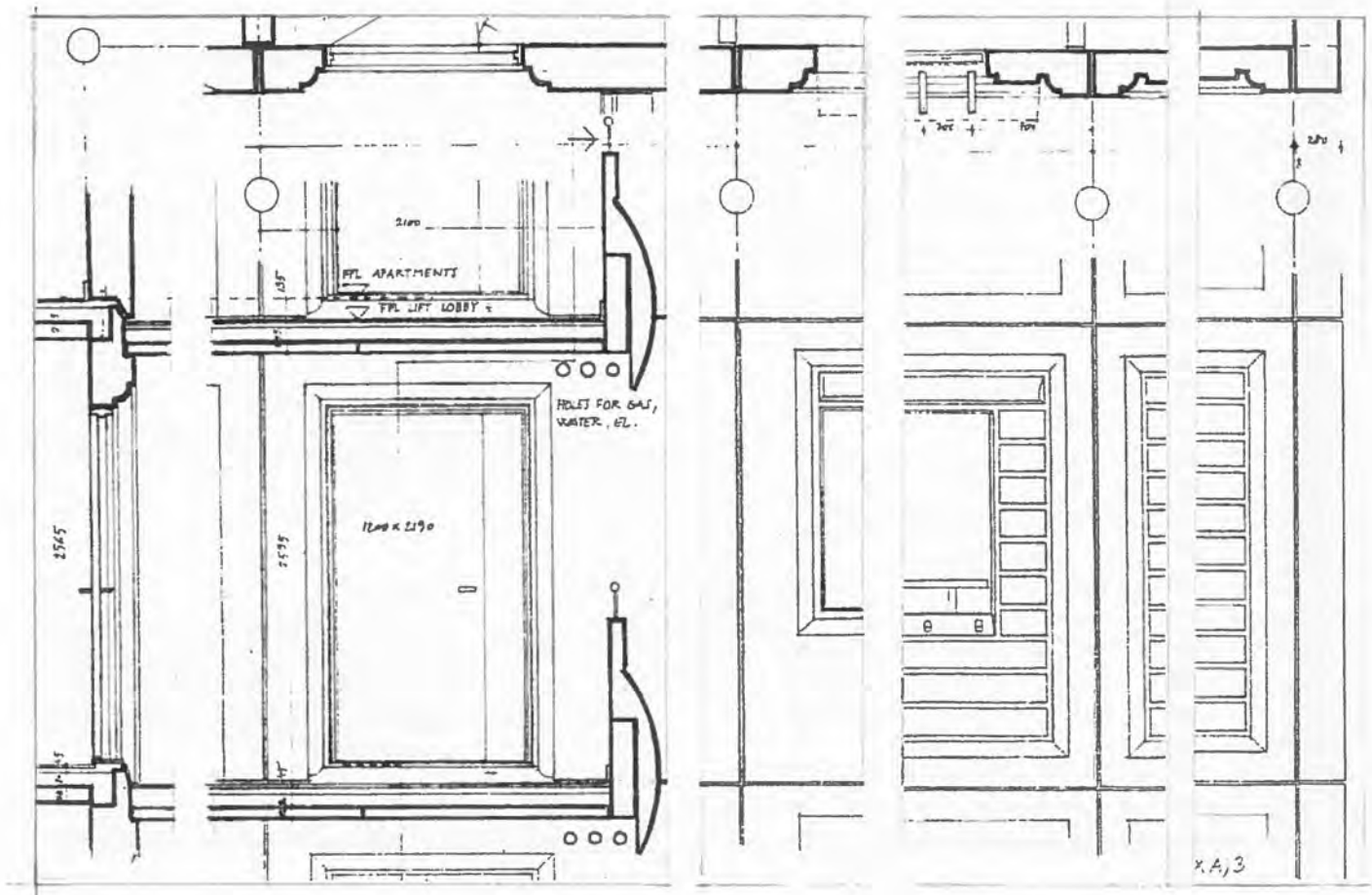
- Accept and take advantage of the precast element concept: size of elements, joints and the actual construction process of adding element to element will inevitably be visible in the finished building and the architectural design can emphasise this more or less but not ignore this fact.
- Avoid designs and finishes that try to hide joints. Joints can be disguised as part of a facade pattern or can be emphasised with deep recesses but a filling or covering with tiles or similar will not last.
- Insist that the gridlines or modular system lines are included in all drawings from all consultants and that all dimensions are related to these lines. This will ensure an easy orientation in the project and provide the basis for the check of the location of elements and services throughout the building.

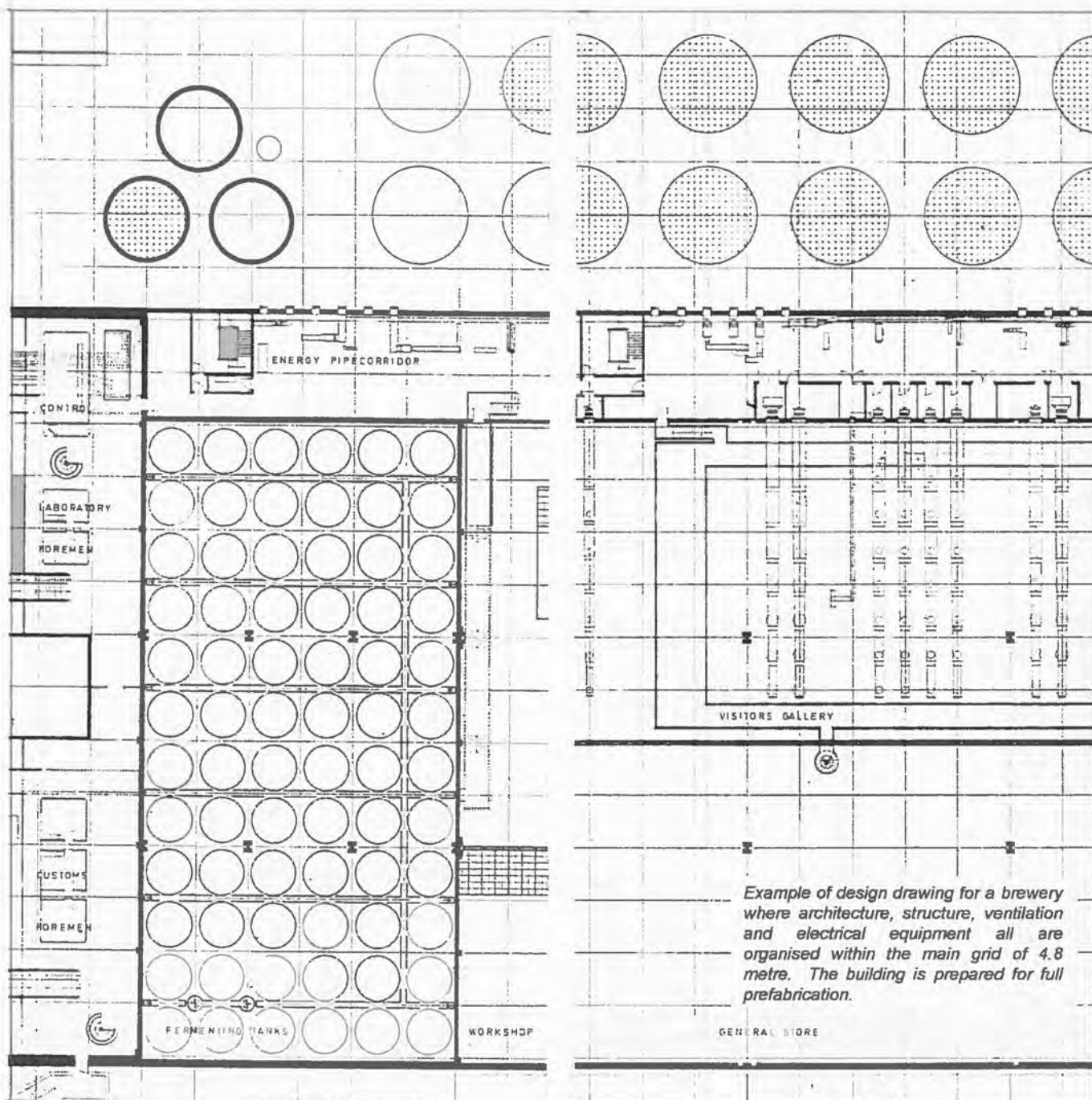


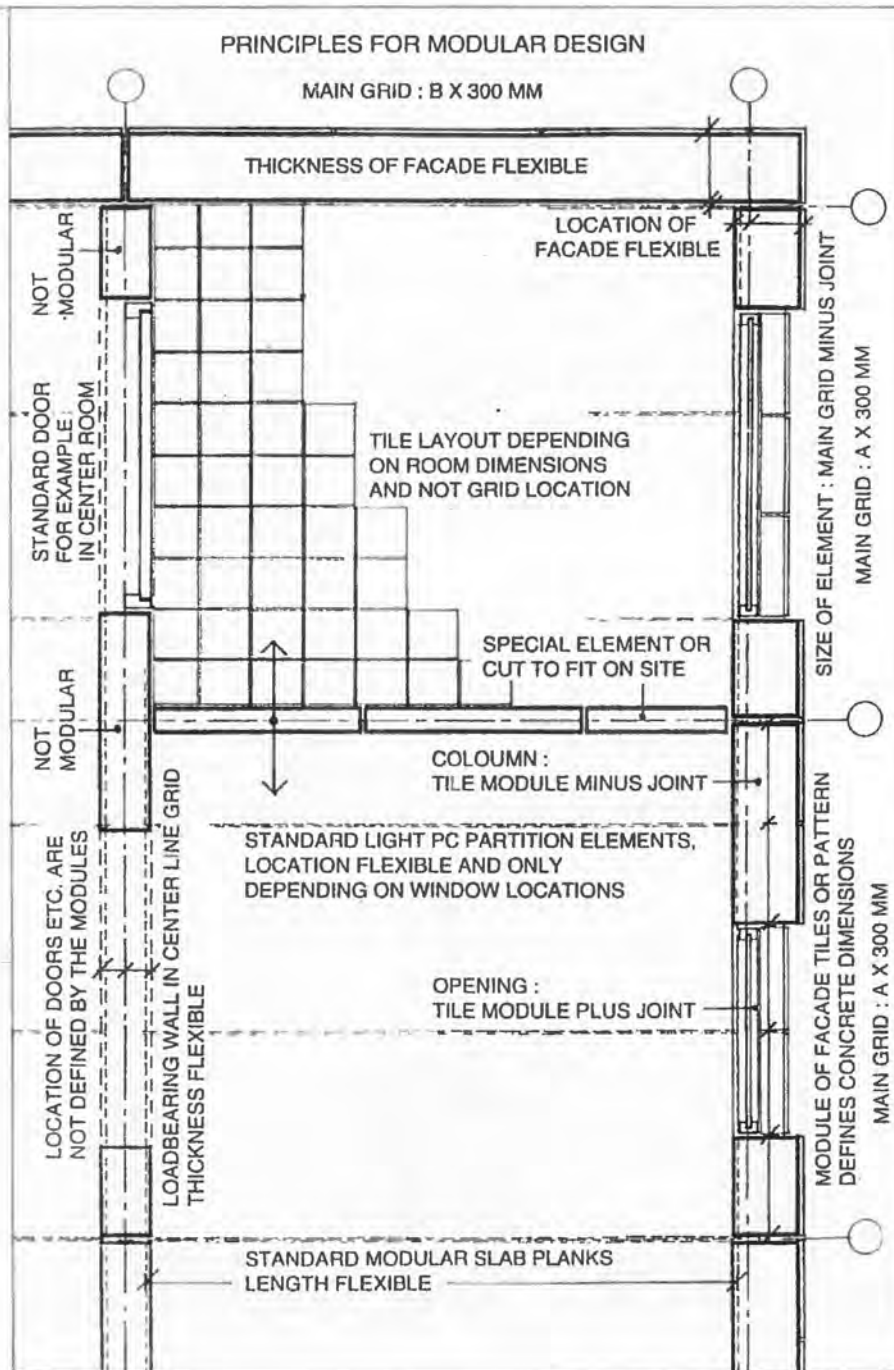
- Be prepared in the design for the tolerances. Elements, even if precast in steel moulds of high quality and accuracy will vary in size.
- Be prepared to accept the structural realities of a precast element construction. The design must be developed in a collaboration between architects and structural engineers and adapted to the possibilities of the standard joints and elements. Special one-off design should be very limited.
- Incorporate the main supply lines for mechanical and electrical works in the design in the initial sketches so that cut-outs in elements can be planned at an early stage and taken into consideration during structural calculations.

The architect produces coordinated drawings of the principal construction components in collaboration with the structural, mechanical and electrical engineers.

Coordinated architectural drawing showing all works.







Plan:

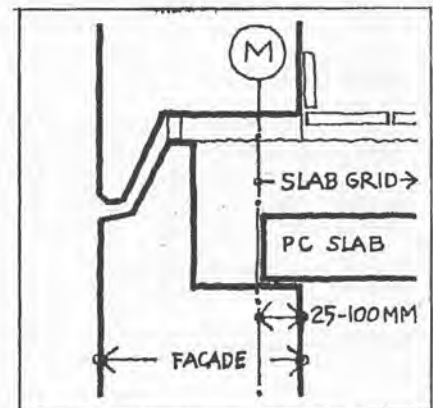
Design principles for a construction with loadbearing internal wall and facade.

Modular Design is basically guided by the slab components. The design will normally start with laying out the modular net of 300 mm into which standard slab components always will fit.

Internal loadbearing components are located within the main grid of the building as agreed with the structural engineer.

The facades are positioned around the standard size slabs according to the geometry of the connection detail with the facade.

Vertical section in facade



D. Tender Drawings

A typical sample of tender drawings for a fully loadbearing PC project should comprise the following :

1. Site plan (Architect)

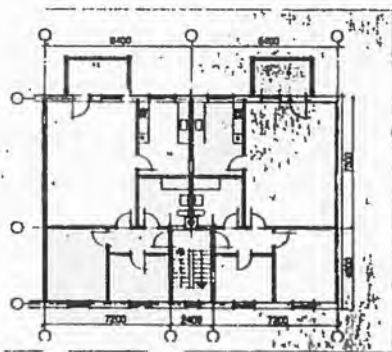
- With gridlines, location of buildings as defined by dimensions of the gridlines from the site boundaries

2. Site plan / Utilities (Engineer)

- Location of major lines and items dimensioned from gridlines

3. Plans & Sections (Structural Engineer)

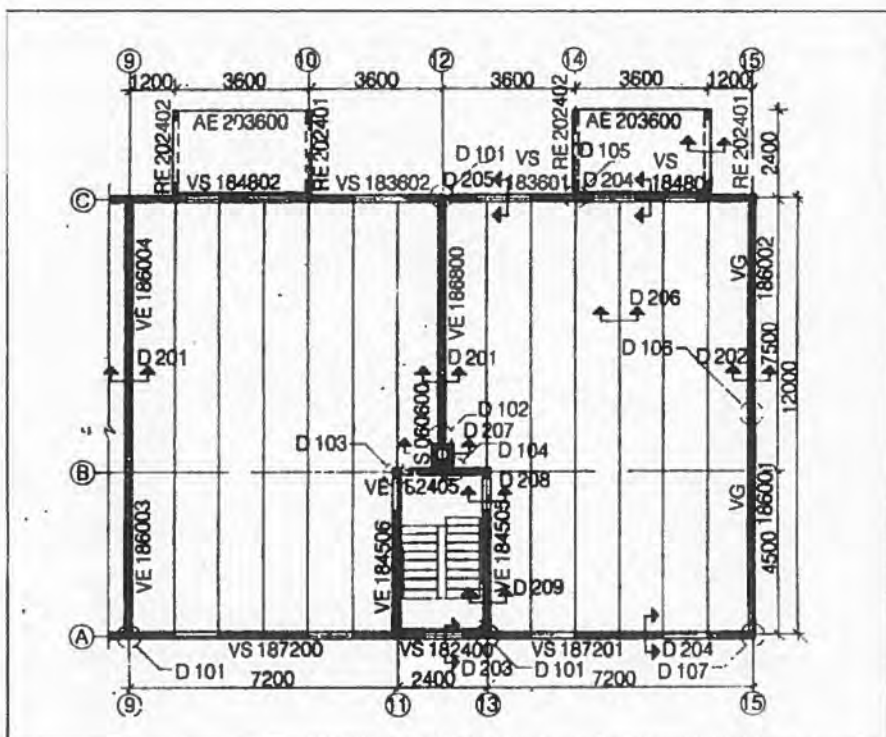
- Main drawings, normally scale 1:100, from which the building is constructed.
- All dimensions connected to the gridlines, modular net, and all PC elements numbered and located within the modular grid.
- The drawings should only give modular dimensions for elements in relation to the gridlines and not basic dimensions of the elements and joints since these are specified on the element drawings and joints' details.



Architect's layout plan

Based on the architect's layout plan, the modular system and the elementation, the main drawings from the structural engineer defines the components and joint's details references.

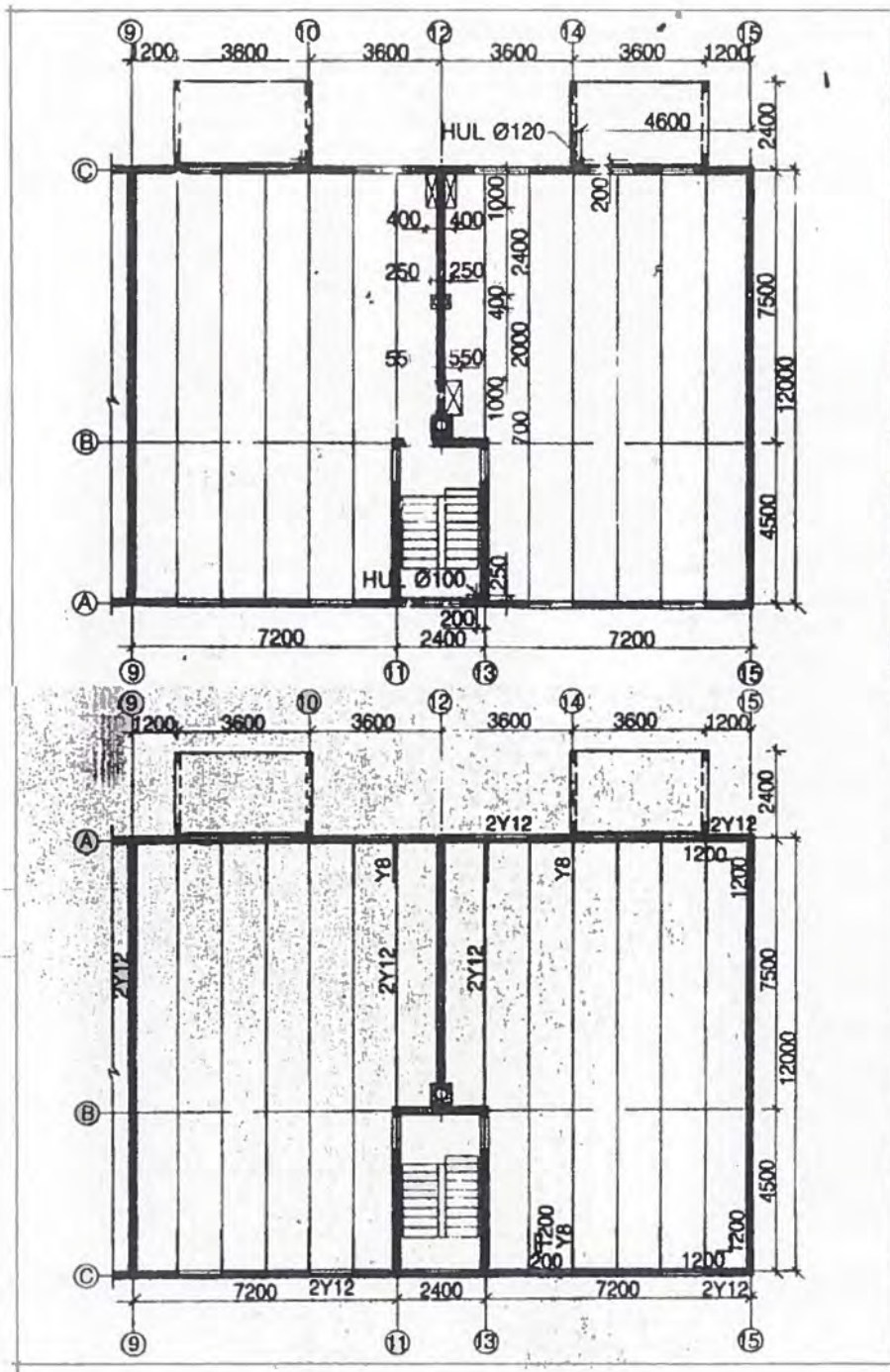
Structural engineer's main plan.





Top:
Special "Hole plans" are normally prepared for M & E works.

Bottom:
Main reinforcement plan for joints and horizontal ties.
Beams, walls and slabs are prepared for the installation.
Only minor holes will be drilled on site and patching up and making good on site will be minimised.

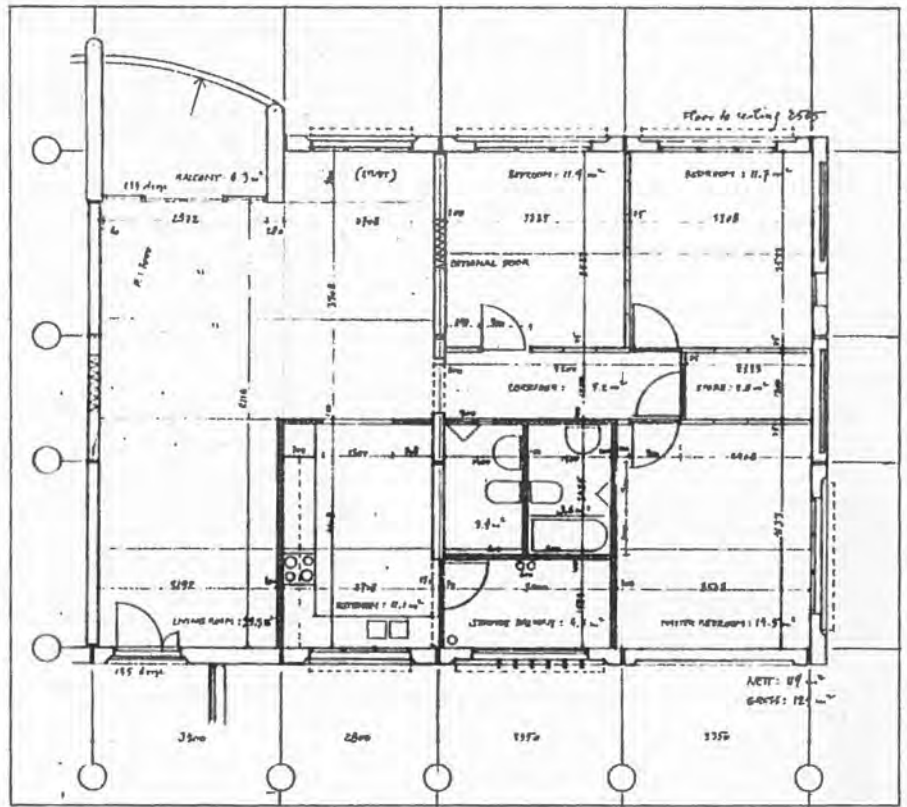
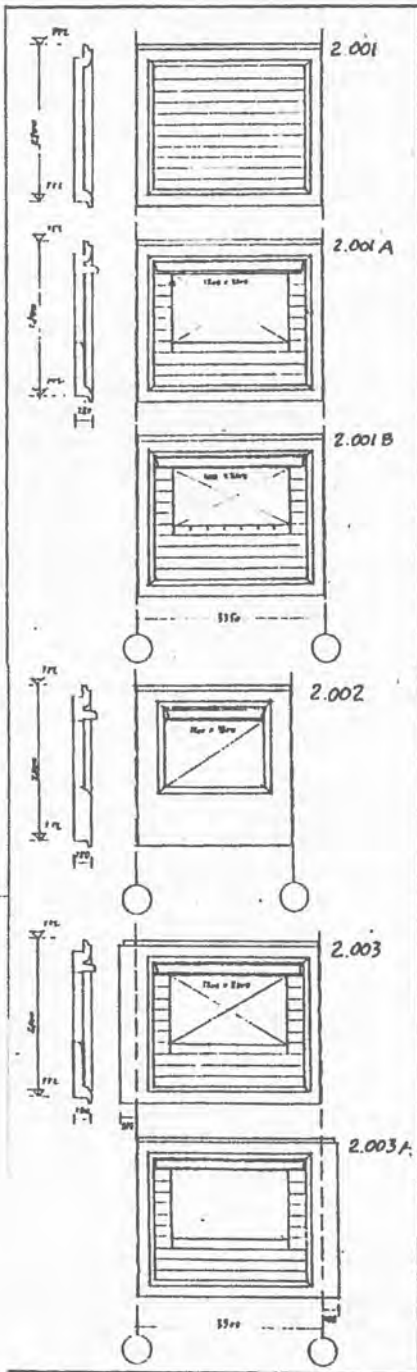


4. Plans, sections & elevations (Architect)

- The architect's main drawings, normally scale 1:100, for the architectural works : non-structural such as brickwalls, doors and windows
- The drawings should only give dimensions from PC elements and gridlines and not dimensions on PC elements - since these are specified on the element drawings.

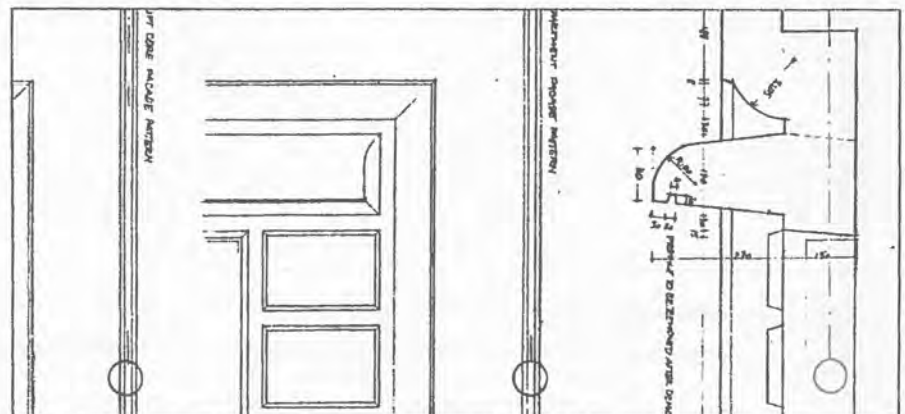
Architect's facade elevation and section / elevation.





Left:
Architectural treatment of facade
elements.
Bottom:
Architectural details of elements.

Above:
Traditional architectural drawings of room layouts with light partition walls, doors, sanitary fittings, etc, dimensioned from elements and reference to gridlines.



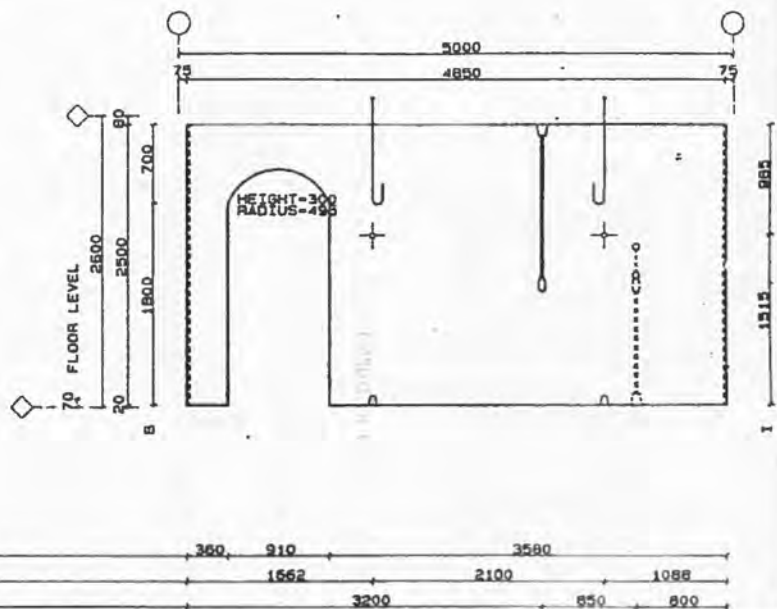
5. PC Elements' drawings (Architect, Structural, Mechanical & Electrical Engineers)

- Each and every element drawn out and numbered. Preferably on its own sheet and normally scale 1:20. The following information should be included:
 - location in relation to gridlines
 - basic dimensions
 - reference to detailed drawings of edges, corners, etc.
 - possible architectural treatment on surface
 - cut-outs and recesses for mechanical & electrical works
 - cast in items
 - principal amount and location of reinforcement
- Other useful information would be weight and number of elements of each type in total.
- Since the PC elements are the main structure these drawings are the responsibility of the structural engineer. It is, however, the responsibility of the architect to locate and dimension doors, windows, etc., and to detail and specify any architectural finish treatments. Likewise, it is the responsibility of the mechanical and electrical engineers to specify cut-outs and recesses necessary for their works.
- The element drawings are the most important result of the integrated design process and the better the coordination during this process, the better the construction process and the economic feasibility of the system.

Example of PC wall element - Structural engineer's drawing with all the necessary tender information: dimensions, weight, number of similar elements, surfaces, cast-in items and lifting hooks.

This example is generated from a special PC CAD programme.

WALL		
150MM		W01A
WEIGHT: 3700 KG.		NUMBER: 14 PCS
JOINT DETAILS		
FACE 3: J017		FACE 4: J017
FACE 2: J029		FACE 5: J029
FACE 1:		FACE 6:
	CAST IN PIECES	DETAIL
1	2 M16. 1 ELEC.1.	
2	2 LBA20.	WD10.3
3		WD34.5
4		WD34.5
5	2 TOPHAT20.	WD22.2
6	1 ELEC.2.	
NOTES		
DIMENSIONS AND LOCATIONS		
B	BL. OUT 1	
L	LIFT.	
E	ELEC.	



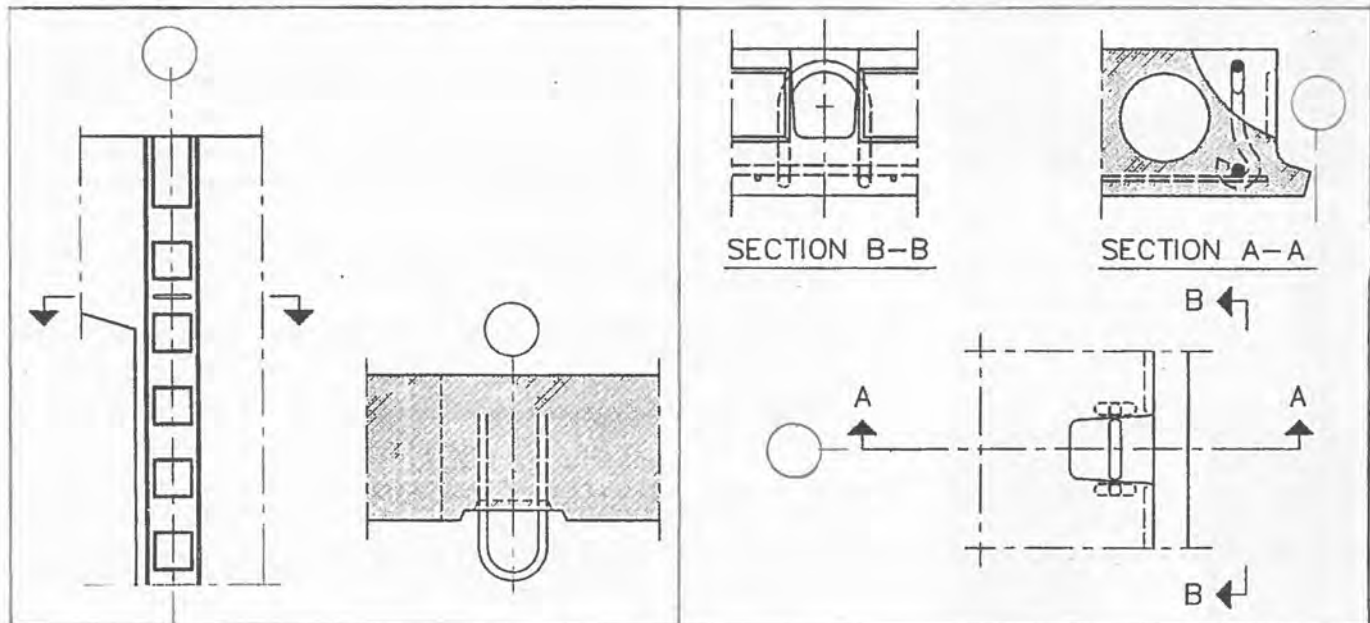
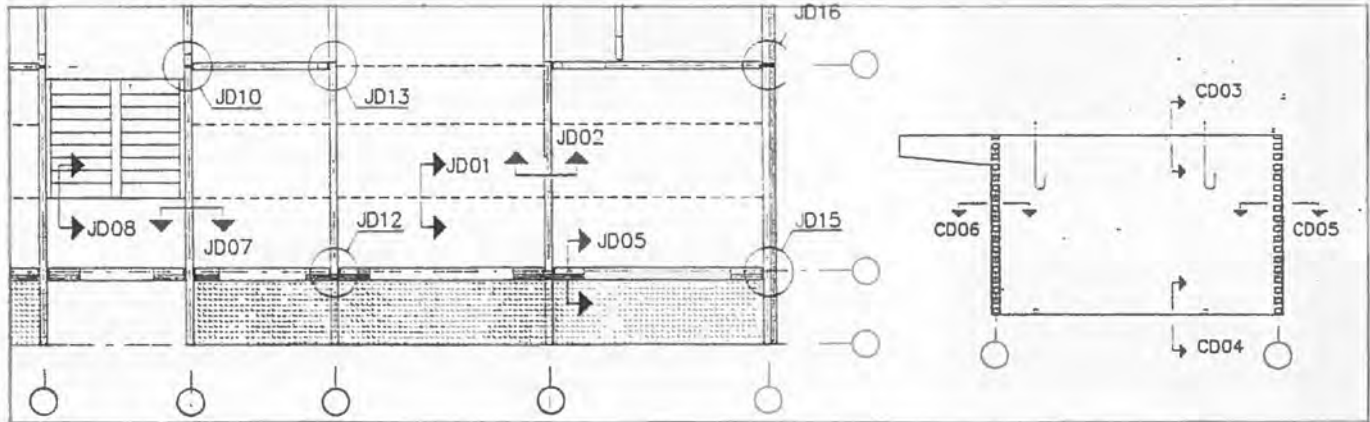
6. *PC elements principle details (Structural Engineer & Architect)*

- Elements' design details of corners, edges, architectural patterns and principle connection details, joints, etc. Scale 1:5.
- Basically the responsibility of the structural engineer, but with the necessary contributions from the architect.
- Also, for the details it is important to relate dimensions to the modular grid so that there is coherence in the documents right from the site plan and down to the details.

Principle joint references and the corresponding PC element details.

Principle element details

The examples shown are all generated from a PC CAD programme of which several are available.





Do's and Don'ts for Design Details and Elements

- Minimise the number of different moulds for elements. This can be done in several ways without compromising on the architecture:
 - In one mould with standard dimensions and edges different-sized windows can be easily interchanged between castings.
 - Complicated elements cannot be handed without a new mould in the way symmetrical elements can.
 - It is far easier to add to a basic mould than to remove eg., profiles, windows, holes, etc.
- Be aware that prestressed elements, slabs and beams do curve and that the curve will vary from element to element.
- Keep all elements at practical sizes. For handling and transport, a maximum weight of 6-8 tonnes and a height of 2-5 metres.
- If larger elements are necessary remember to check the Highway Codes for the size of the element loaded on the transport vehicle.
- The architect must discuss with the structural engineer all the necessary structural dimensions on elements and connection details and determine details for water-proofing while adding architectural features such as profiling, cladding, over-hangs, dripnoses, etc.
- Design elements to be cast flat down in a tray mould with the desired pattern, windows and holes fixed to the bottom. Sides of the mould will normally be removable.
- Remember that the up-side will be flat and finished by hand. Up-stands on this side will have to be cast in a second operation and should be avoided if possible.
- Design the edges with a chamfer of minimum 15 mm. If not chips of edges will occur during demoulding and result in time-consuming and difficult patching-up.
- Profiles, recesses, etc. in the mould must have a "slip angle" of at least 10° for deep recesses and 5° for small profiles.
- When locating windows and holes, avoid connecting dimensions of concrete less than 200 mm.
- Include the gridlines on all drawings so the element is accurately located in the construction.
- The modules are normally from centre joint to centre joint. The facade joint itself is normally designed to be 16 mm, 8 mm on each side of the gridline.
- Consider the finishes on the joints' castings which will be done in situ and not be comparable with the element finishes.



Design Details

Left:

Wall element where the reinforcement is prepared for a possible later door hole between two apartments.

Below Left:

Holes in PC beams and walls for installation.

Below:

Simple design details of columns and beams



7. Drawings and tender documents for the remaining works in the construction as per tradition and local practice (Architect, Structural Engineer, Mechanical and Electrical Engineers)

- It should be noted that since the gridlines, modular net, are such an important part of the PC project, they should be incorporated in all drawings and dimensions should always be related to the gridlines.

E. PC Specifications

Introduction	Specifications for PC works will vary from project to project depending on the nature and amount of this type of construction. The following list of items can be used by the consultants as a checklist in working out the tender documents for possible PC components in a project and the relevant information included in the particular specifications.
General	The particular specifications for PC elements shall be read in conjunction with the conditions of the contract, general specifications and the PC drawings. A professional engineer, experienced supervisors and foremen and trained workers shall be employed. The contractor will be responsible for the detailed design and suitability of the PC components.
Standards and Code of Practice	All relevant standards and code of practice shall be specified as well as possible additional requirements or derivations.
Detailed design/ Shop drawings	The PC contractor's design details and shop drawings shall incorporate all architectural and structural aspects of the PC components, including manufacturing, storing, transport and erection.
Submissions	The PC contractor / main contractor shall submit all PC related drawings for approval by the consultants.
Method statement / Time schedule	The contractor shall submit information on his method of the PC construction and the proposed detailed time schedule related to the overall construction time schedule.
Derivations and Amendments	Derivations and amendments to the tender drawings shall be possible, subject to the approval of the consultants.
Test Reports	The procedure for submissions of test reports shall be specified.
Quality Assurance	Methods and forms for quality assurance and inspection shall be defined. Training and experience level of the personnel involved in the PC operation shall be established.
Materials	All materials used to produce and erect the PC components shall be specified such as specifications of concrete and mix, reinforcement, inserts, exposed material, bearing pads, etc.
Manufacture	The total process of manufacturing of the PC components, as well as the design of moulds, method of demoulding, handling, and transport, shall be subject to approval by the consultants.
Damages, Making Good	Clear instructions on when PC components can be rejected due to damages either in the architectural or structural aspects, shall be specified.

Storage	The principle method of storage and the storage equipment shall be specified and subject to approval.
Delivery and Handling	This item shall include specifications for all the lifting hooks and inserts and the ways of handling and transport.
Erection	Inspection procedures for the components and joints shall be established.
Erection procedure	The entire erection procedure shall be specified from cleaning of the setting location, preparation of joints' backing, location of shims, setting and adjusting, and especially the grouting procedure specification shall be elaborate since the grouted joints forms major part of the overall structural stability system.
Complementary Works	Other PC related works such as welding, concrete pumping, etc, shall be included in the specifications.
Connections	The method and workmanship of the works on the connections and /or joints shall be described in detail.
Control of Dimensions	Distribution of responsibility for correct dimensions on the PC elements and the finished construction works shall be established. The tolerances for all measures on PC components and finished works shall be specified with regards to the specific project and local conditions.
Individual PC Components' specifications	If necessary, additional detailed specifications can be issued for particular or critical elements.

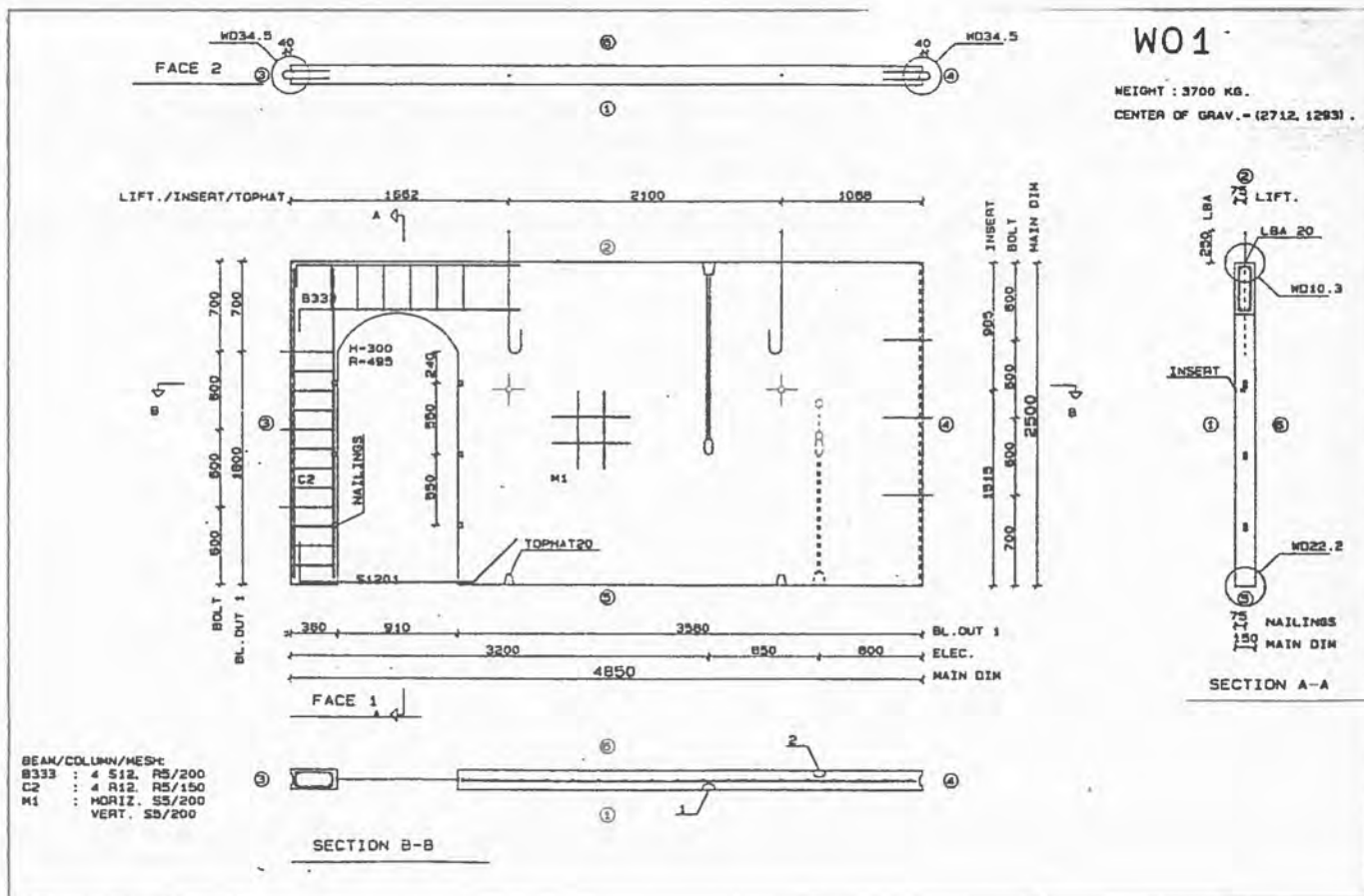
F. Shop Drawings

For the production of elements shop drawings are necessary. Detailed drawings of every element, reinforcement details and bending schedules, lifting and connection insert details, etc., and a complete numbering system of all elements. The precaster will normally prefer to be responsible for the shop drawings.

The precaster will also normally prefer to be responsible for the mould drawings to be able to incorporate his experience in production and handling in the detailed design.

If the precaster do not have "in-house" experience, special consultants (structural engineer) should be commissioned. The consultant architect and engineer for the project will then check and approve all elements' shop drawings before the production can start.

Wall element shop drawing, CAD-generated

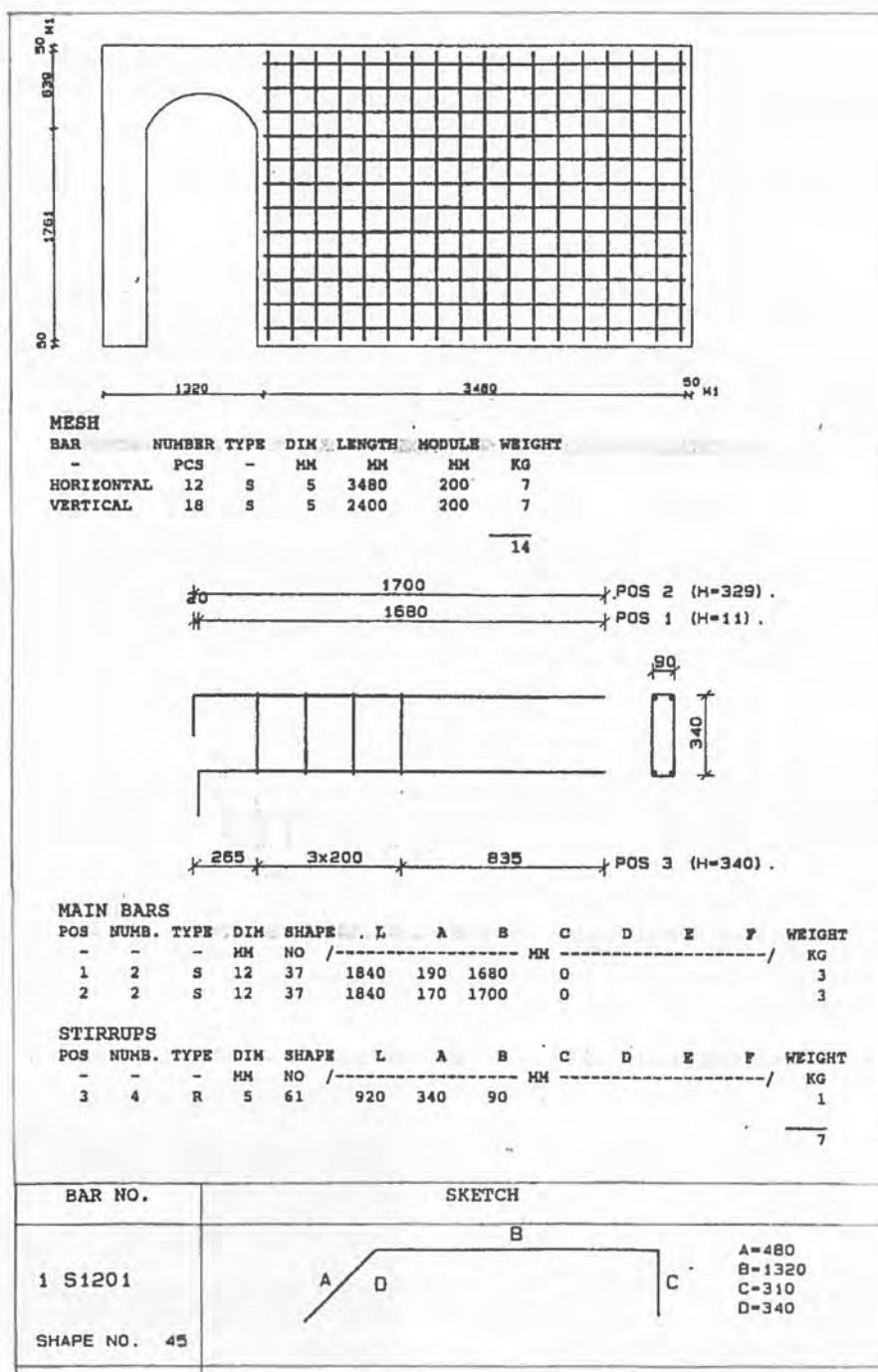




Details of mould edge, lifting hook, stirrups and cast edge with waterproofing profile.

Detailed reinforcement drawings and bending schedules.

The drawing is CAD-generated and organised so that the different reinforcement components can also be prefabricated and pre-welded and tedious work on steel binding in the mould can be minimised.



Each and every element must be permanently marked with type number and other information needed for the erection.



G. Samples

When the first mould incorporating a number of the standard features for the project is ready, at least one sample casting must be carried out to determine if the anticipated character and quality can be achieved.

When approved by client and consultants, the sample is kept as reference through the entire production and construction process.

H. Production of elements

It should be noted that in the erection of one level of a fully PC loadbearing construction, nearly all types of elements will be needed. Hence all the moulds must be ready before construction starts. Production of all types of elements should start simultaneously and the production frequency following the erection time schedule to avoid unnecessary storing of elements.

Do's and Don'ts for Production and Construction

- Include provisions for sample castings in the tender documents.
- Ensure that the resident architect has experience in precast method and is thoroughly familiar with the project and the reasons for particular designs.
- Be aware that changes in the project are practically impossible when production of elements have started.

I. Casting and Construction - Quality Control

It is the responsibility of the resident consultants to check the quality of the elements against the approved samples before using them in the construction. For PC handling, see Chapter 1.7

J. Making good / repairs

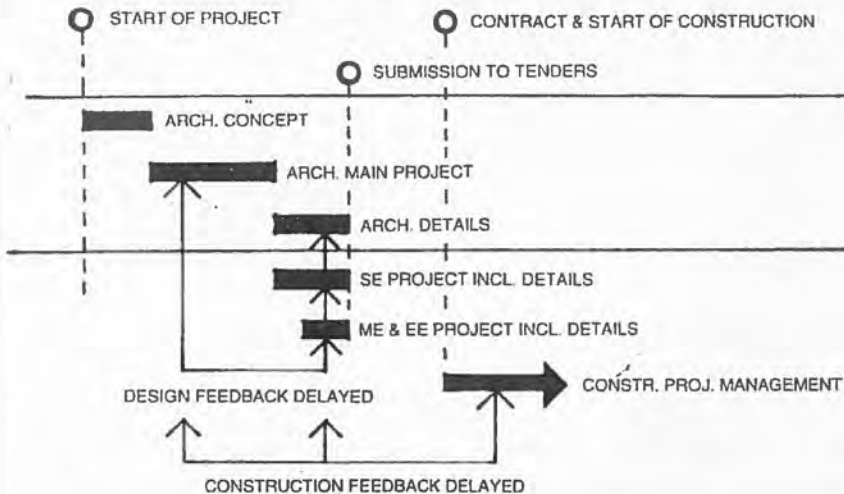
On basis of initial castings, the consultant architect must establish guidelines and rules for the resident architect to be able to reject elements and define the quality of repairs.

Some elements will inevitably be damaged. Special care must be taken to ensure that all repair is done before hoisting.



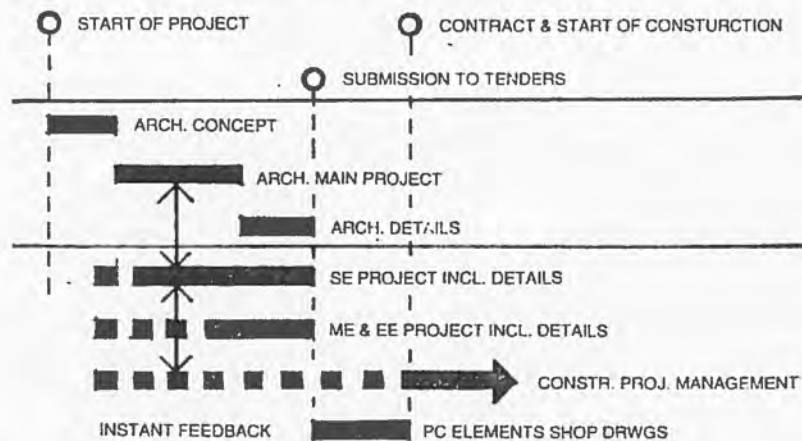
SEQUENTIAL DESIGN & PROJECT MANAGEMENT SYSTEM

FEASIBLE WHEN LAYOUT, CONSTRUCTION METHOD AND DETAILS ARE WELL KNOWN BY ARCHITECTS, ENGINEERS AND PROJECT MANAGEMENT



INTEGRATED DESIGN & PROJECT MANAGEMENT SYSTEM

IMPERATIVE IF NEW DESIGN IDEAS AND CONSTRUCTION METHODS ARE TO BE INTRODUCED WITH MINIMUM INCREASE IN DESIGN TIME



EXTRA DESIGN TIME NEEDED IN THE INITIAL PHASES OF INTRODUCTION OF A FULL PC CONSTRUCTION METHOD IS ESTIMATED TO BE 0.1 MANHOUR PER SQM.

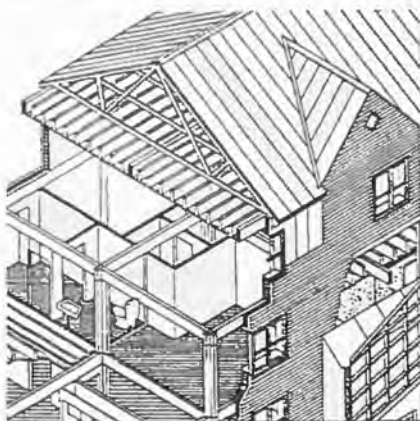
Integrated Design:

The process for the design of the PC components in a project must be an integrated design: Decisions on dimensions, details and connections have to be taken during the design process and the mechanical and electrical works have to be incorporated so that the design of the elements can be finalised in the tender stage.

The future construction project management should be involved during the design stage to enhance the understanding of principles and details in the project and advice on access possibilities and specific site conditions that may influence the design.



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1.4 PC-REQUIREMENTS IN CODES

1.4.1 Structural requirements

In general

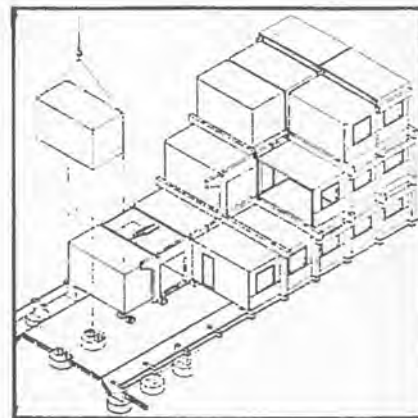
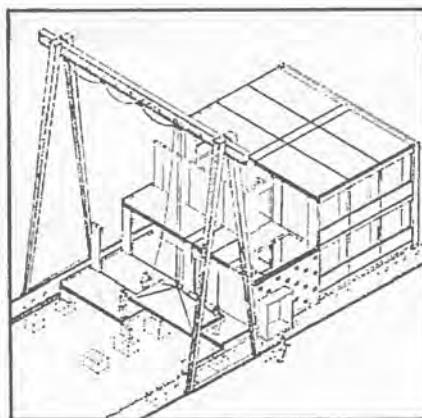
Prefabricated structures, f.inst. precast buildings, are normally composed by using simply supported components, such as walls, columns, beams and slabs. These components are not complicated to design for vertical loads. The structural consultant can use well-known design theories, or even often choose right dimensions from catalogues issued by the producers of precast members.

However, a complete statical calculation of a prefabricated building must include the following:

A: Load assessments. B: Formulation of a model of the main structural system. C: Description of load paths. D: Design of structural members. E: Design of connections.

PROCEDURES	ACTIONS
1. LOAD ASSESSMENTS	Loading Tables Load Estimate
2. CALCULATION MODEL	Structural system Load Path Stiffness of Components and Joints Bearing on Methods Load Combinations Calculations: Internal Forces Reactions
3. STRUCTURAL ANALYSIS (CODES OF PRACTICE)	Design: Stresses Deformations Deflections
4. DOCUMENTATION	Specifications Calculations Sketches Drawings

PROCEDURE FOR STRUCTURAL DESIGN
STATICAL REQUIREMENT ONLY



Procedure for Structural Design

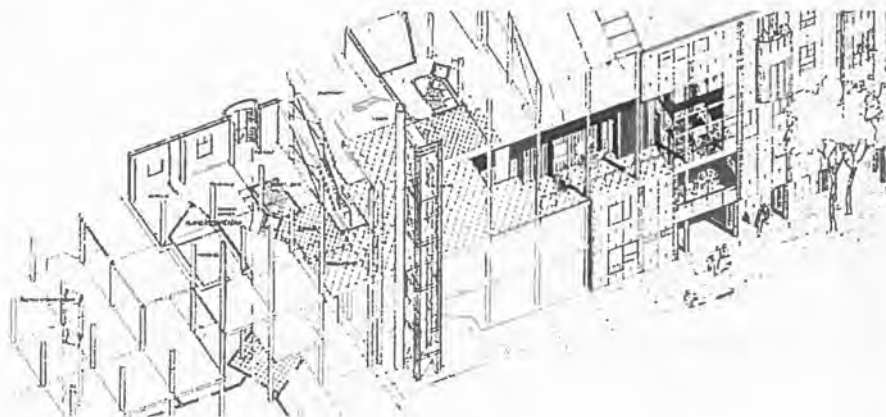
A logical procedure for the structural design is shown in the table above.

For precast structures it is very important to put emphasis on the bracing system and on the design of connections.

Isometric Drawings

Prefabricated building systems for housing purposes have been developed by using many different components, such as walls, columns, beams and frames in combination with slabs. Also systems composed by 3-dimensional members like boxes are used.

They have all in common that the components are simply supported.

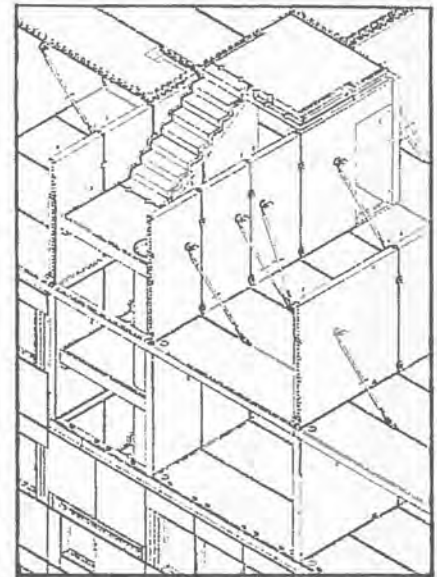


Houses constructed by simply supported components are of the so-called "house of cards"-type of buildings. Only seldom it is possible to achieve restraints in the connections; therefor such structures call for special precautions to ensure the over-all structural stability, the robustness, under horizontal loadings.

The connections between the structural members therefor become a very important issue in the design process of precast buildings. However, such connections are normally difficult to design using normal calculation methods.

In many cases the nature of forces, deformations and failure mechanisms cannot be foreseen with sufficient accuracy without supplementary analyses based on tests. So often consultants have to carry out such structural tests in laboratories in order to come up with reliable bearing capacities.

By the application of such tests, precast technology has obtained the basic and essential knowledge of the nature of precast structures and connections in use today.

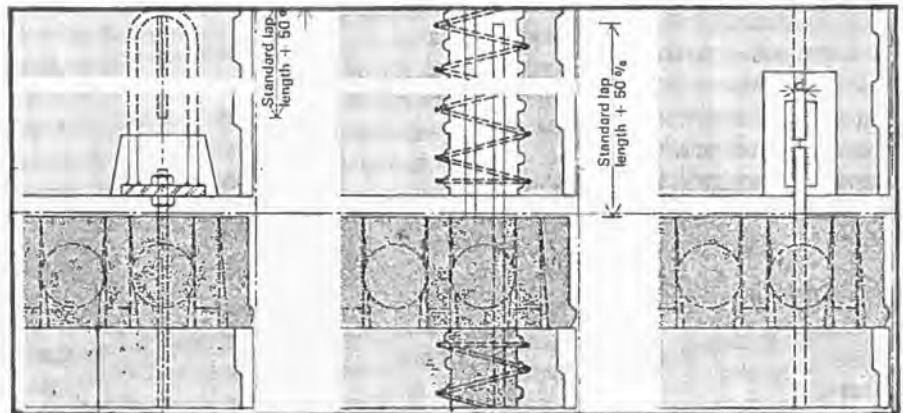
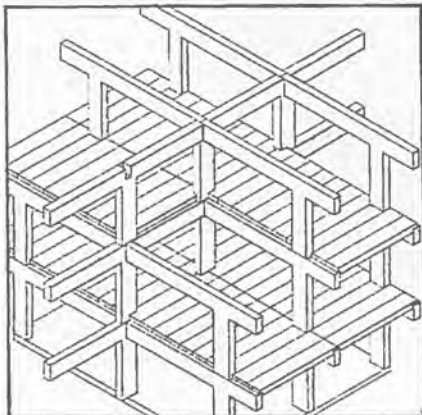
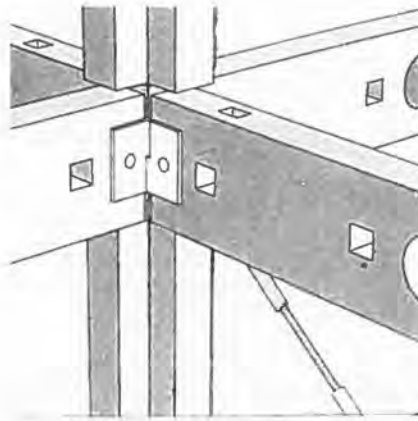
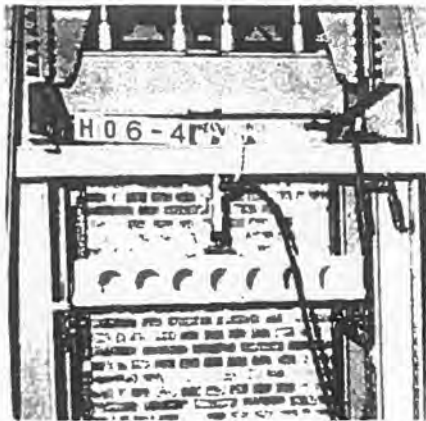


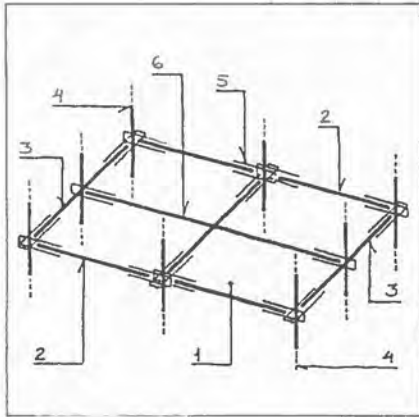
BUILDING-SYSTEM-KEY
-AN EXAMPLE OF SYSTEMATIC PRESENTATION OF DESIGN DETAILS IN BUILDING SYSTEMS

Testing of Connections

Prefabricated structures with simply supported members are basically "house of cards"-types. Bracing and structural coherence are decisive.

Often laboratory tests have to be carried out in order to determine the actual bearing capacity, first, for tensile connecting details as shown.



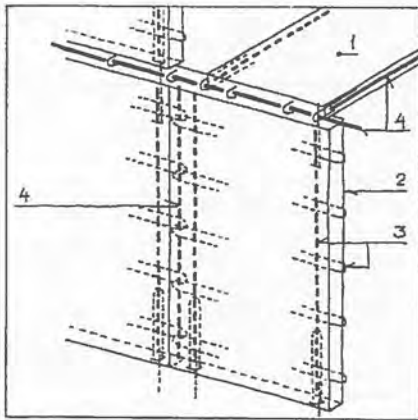


In practice

In time many of the testing results and structural experiences have found their way into Codes of Practice, especially items such as the use of structural ties, precautions against progressive collapses, structural robustness and joints, lap length for reinforcements etc are now parts of many National Codes or Standards.

Furthermore, many of the often used structural connections between standardized precast components have been developed and tested to such an extend that they are now considered as standardized joints. Such joints and their bearing capacity could be found in catalogues from the precasters together with technical information on the main product, the PC-members.

Design charts with bearing capacities for standardized PC-components and some designs for PC-joints are shown in Volume 2, together with a great number of shop drawings for structural joints.



Structural Ties

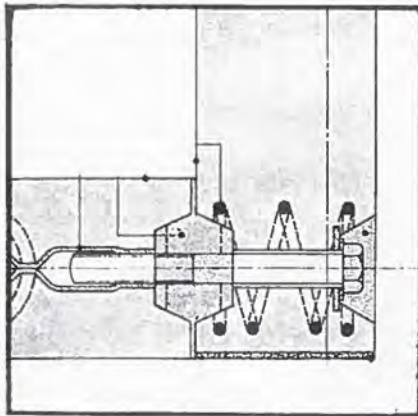
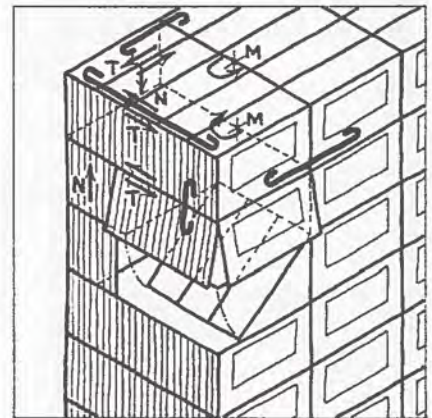
On top left is shown a principle for structural ties in the slab structure.

1 Slab structure. 2 + 3 Horizontal ties. 4 Vertical ties. 5 Connecting stirrups. 6 Joint reinforcement.

To the left vertical coherence is shown.

1 Slabs. 2 Walls. 3 Vertical tie cast-in. 4 Vertical tie in wall-wall joint.

To the right the principle for structural integrity is shown, especially for precautions against progressive collapses.



1.4.2 Other performance requirements

Modular coordination in general

Modular coordination is to be considered mainly as a tool for coordinating dimensions.

Such coordination will also lead to adjustments of dimensions which do not necessarily have to differ. This means that a high degree of repetition of dimensions can be achieved and therefore also a possibility of using many identical or almost identical prefabricated components.

Modular coordination starts in the architectural design. By choosing the main dimensions for rooms there will be a platform for dividing the structure into prefabricated components with modular sizes. Normally it will be possible to use modular facades and balcony slabs as well.

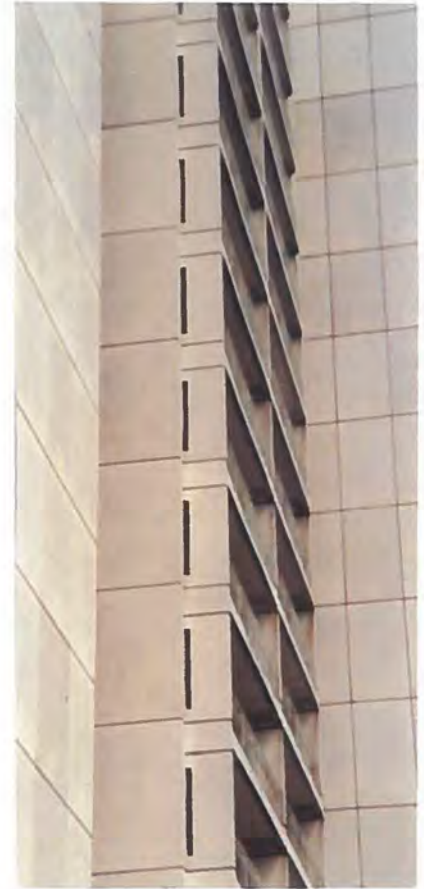


Dimensional Coordination

Coordination of important dimensions is essential for prefabricated structures.

Very often the coordinating module chosen by the architect and the structural engineer is visible from the outside.

It could be cantilevered structural members, it could be balcony structures or just simple the placing of windows in the facade module.



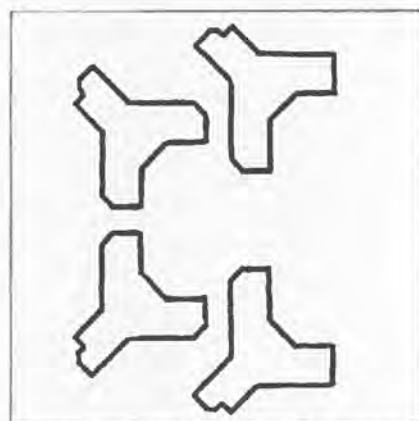


The architect could also choose to consider the whole building or a part of it as a super-module to be repeated, turned or mirrored to form the desired architectural expression.

So in fact it is possible to begin the modular design in different ways: using super-modules, using the floor slabs as decisive modules, or just using a suitable planning module for the whole building.

This dimensional coordination should be used if the market has already components which follow the modular rules from Modular Standards.

If the market has only non-modular components available the modular design will turn into a simple dimensional control but still following the basic modular rules such as grid lines and placing the main components in a coordinated way.



Nauticon

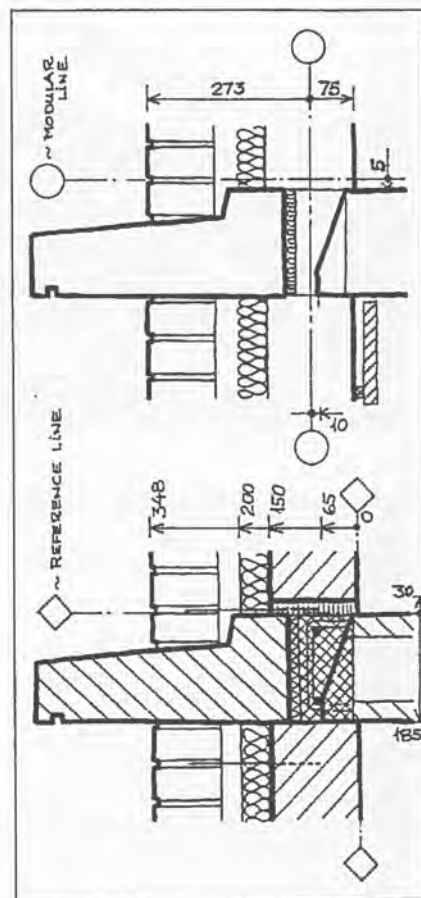
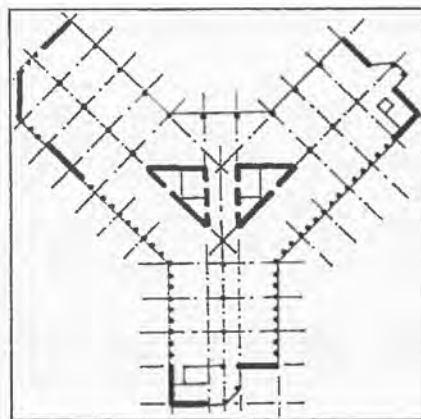
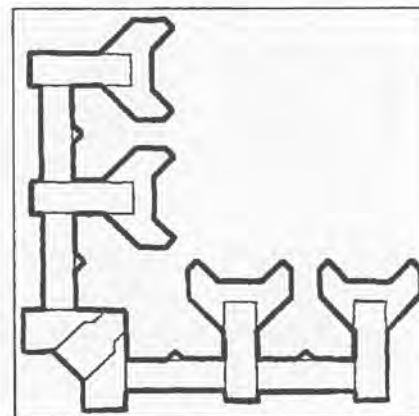
The Danish office PC-system: Nauticon uses the whole building as planning module.

The Y-shaped blocks can act separately or can be linked together to form many different building complexes.

Modular Design

To the right is shown the difference between a modular detail and an assembly drawing.

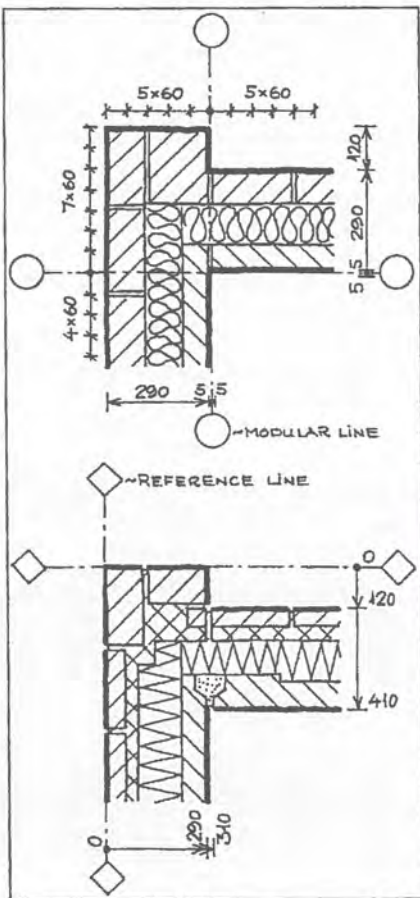
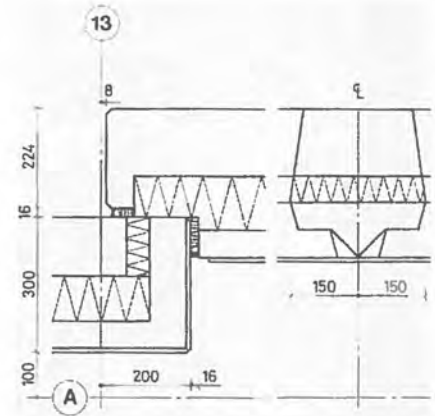
The modular detail clears up the placing of components in relation to the modular grid. The assembly detail is a working drawing on which all necessary information in connection with the execution are given;



The first thing to be done is to draw the grid and to decide whether to use the axial or the facing principle for placing the main components such as columns, walls, beams and floor slabs.

Thereafter it must be decided how to connect the components. Quite often it should be possible to use standardised connections. In some cases it could be necessary to adjust such details due to special circumstances in the project or due to unusual loadings or structural requirements.

When judging the joints it is also important to take into consideration the production and the placing tolerances, so that the joints can be executed on-site in a simple and safe way, still able to meet and fulfil all relevant functional requirements.



Precast Details

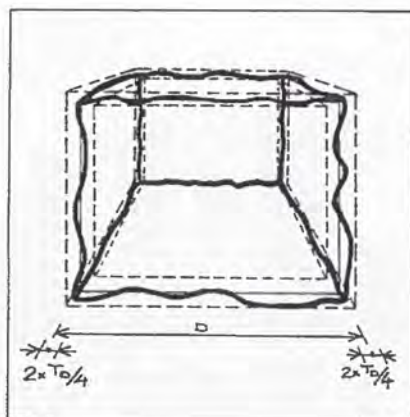
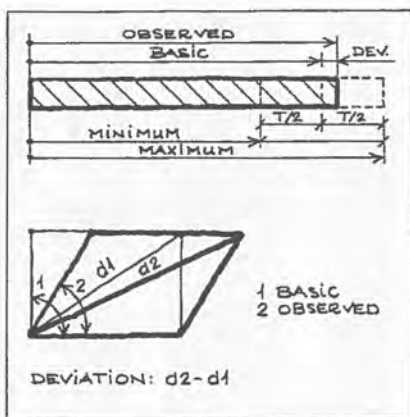
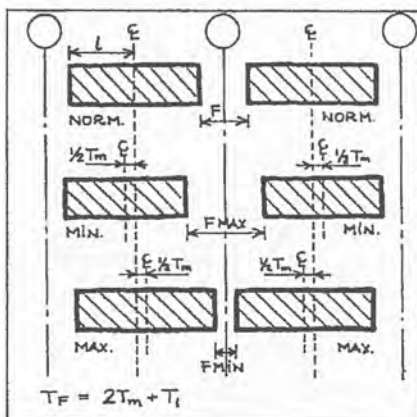
After having drawn the gridlines all components can be positioned with regard to joints. Hereafter the structural calculation of the components and joints can begin.

PC-Facades

Precast modular buildings have of course a high degree of repetition of dimension. However, nice looking buildings with great variations in shape and colour can easily be designed.

The photos show an apartment block with the balcony as planning module and an example with row-houses using the width of a house as planning dimension.





Modular coordination, definitions

The modular grid should be chosen in accordance with the basic rules in the Code of Practice for Modular Coordination. Also suitable planning modules have to be decided and at the same time preferred sizes for main components should also be considered.

First the lay-out plans from the architect have to be adjusted in such a way that main dimensions follow reasonable planning modules. Normally these are a multiply of 3M horizontally and 2M vertically, where $M = 100 \text{ mm}$.

This step makes it possible to use preferred sizes for structural main components, f.inst. floor spans and wall lengths.

Then the modular grid can be decided and drawn.

A modular dimension is simply the distance from one grid line to the next one.

The basic dimension of a modular component is determined in accordance with the design of the adjacent joints. The width of these joints are designed due to the fulfilment of all relevant functional requirements. It could be structural, it could be related to waterproofing, acoustics or to fire precautions. In this design process it is important also to consider the practical execution of the joint on-site.

In connection with prefabricated components and joints the designers have also to consider tolerances connected to production of components and to the placing on-site.

Production tolerances are normally available from the precaster while placing tolerances are to be discussed with the contractor carrying out the erection.

Production tolerances are often given as a figure T, which is equally and symmetrically distributed from one edge of the component.

Sometimes it is necessary to consider tolerances as a 2- or 3-dimensional matter depending on the shape of the component in question.



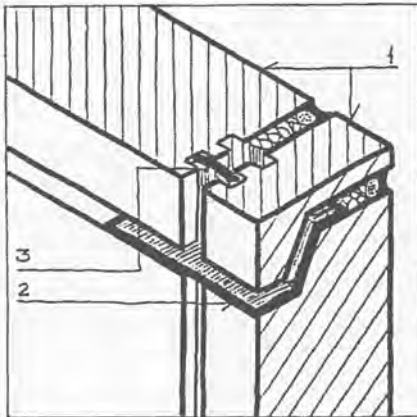
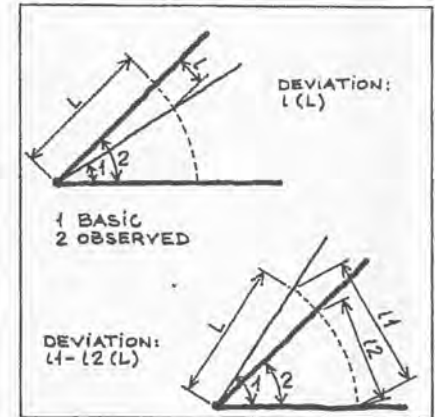
Supplementary to linear deviations it could be relevant also to evaluate angle deviations or deviations from a basic plane.

The general building physics

Supplementary to static requirements housing projects have to be evaluated due to other functional requirements, such as acoustics, thermal insulation, water and vapour barriers and fire precautions.

In Europe and in other parts of the world it has been normal practice now for many years to make so-called overall house building designs for all relevant functional requirements.

By-Laws and Building Regulations in many countries have nowadays included paragraphs which cover the general building physic aspects, giving limits for f.inst. noise levels, heat losses, amounts of condensation, values of cold bridges, precautions against water penetration, and fire resistance.

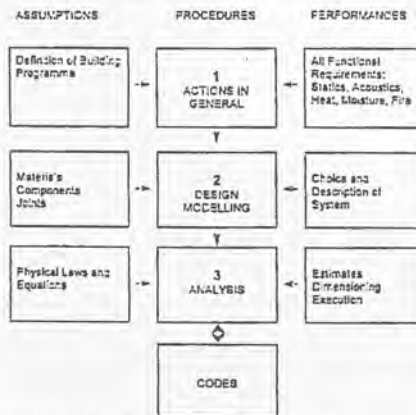
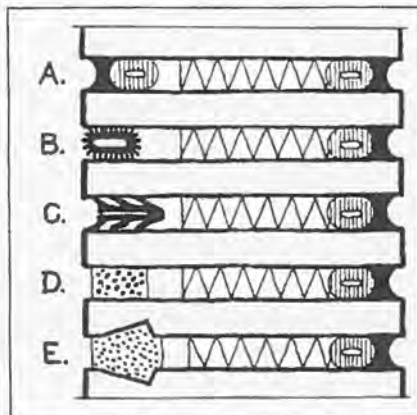


Water Proofing

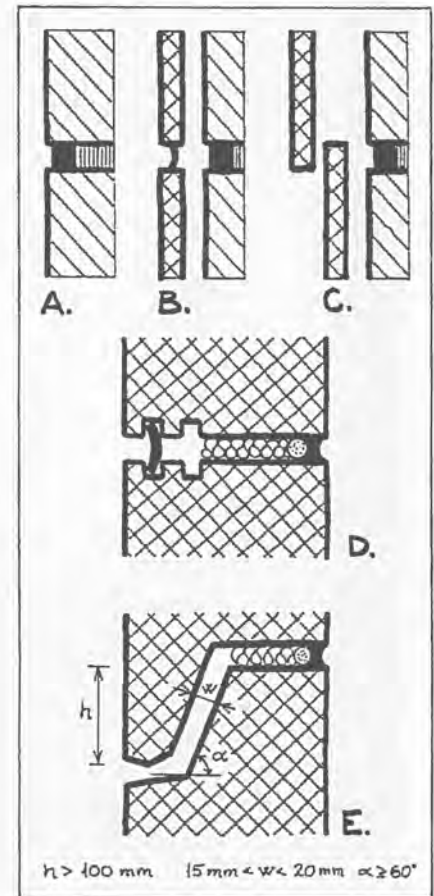
Joints are the most important part of a precast design. Especially the facade joints can be difficult because of the strong exposure to water in combination with wind.

To the right the principle for 1- and 2-step joints are shown on A, B and C. D is a horizontal section, and E is a vertical section in a common used 2-step facade joint.

Bottom left show 5 different fillings in the outer side of a facade joint: mastic, neoprene, cellular profile and mortar.

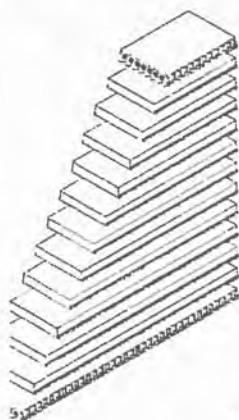


PROCEDURE FOR A GENERAL DESIGN PROCESS REGARDING ALL RELEVANT FUNCTIONAL REQUIREMENTS





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Floor Slabs	
Walls	101
Columns and Beams	102
Double T-slabs	104
1.5.2 Other Components	104



Type mark	Length mm	Weight kg/m²
PC 1000	10	1700
PC 1400	21	2000
PC 2000	30	2500
PC 2700	37	3000
PC 3000	38	3000
PC 3200	38	3200
PC 3500	38	3500
PC 3800	42	4100
PC 4200	42	4400
PC 4500	42	4700
PC 5100	51	5000
PC 5400	51	5300

FLOOR SLABS TABLE OF TYPES

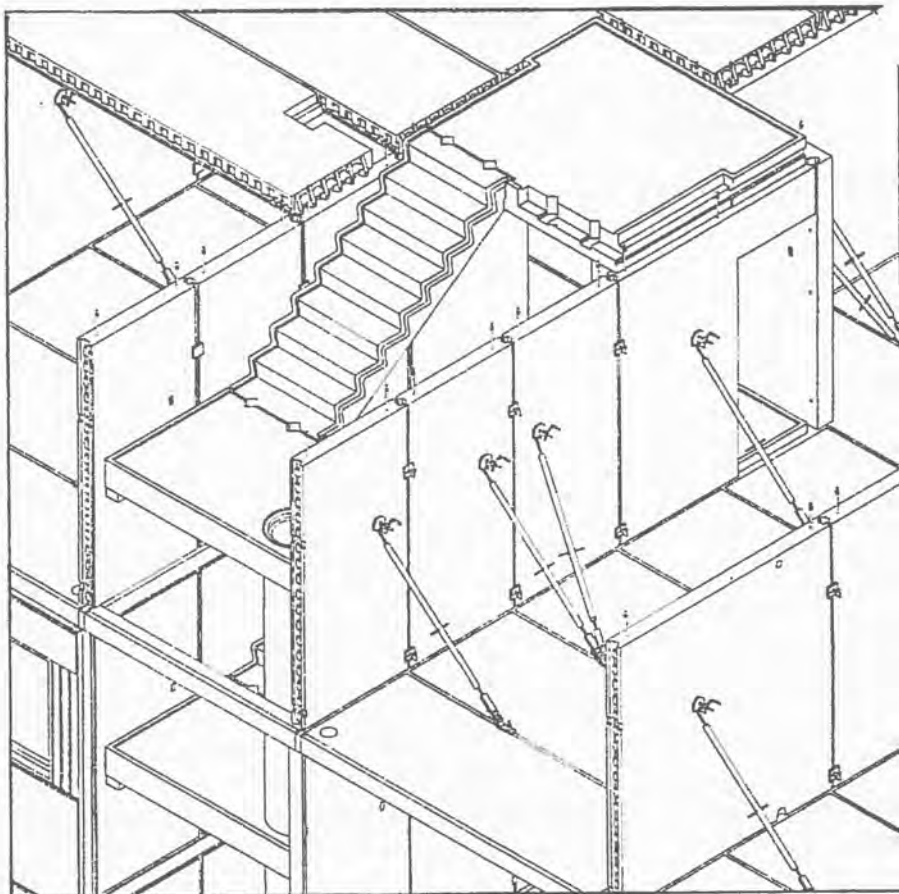
1.5 PC-COMPONENTS AVAILABLE

1.5.1 Standardized components and joints

Floor slabs

The most common standardized PC-component is the floor slab. This element is produced either as a hollowcore type or as a plank, a thin solid concrete plate. Both types are available as normal reinforced or as prestressed members, and they are designed as one-way spanning components. Both floor types have a very smooth bottom surface cast in steel moulds. The main dimensions, length and width, depend on national agreements on planning modules, basic modules and preferred sizes.

A modular floor slab plays an important role in the planning phase of the project, because it naturally acts as planning module for horizontal dimensions.



Floor Slab Structures

Normally the floor slab components act as planning module for horizontal dimensions. Mainly two types of slab structures are used: hollowcore components if joints are acceptable, or precast planks with a structural screed on top.

Panel PC-Systems

Many apartment blocks are structurally composed as panel systems, f.inst. as shown on the isometric drawing. Wall components and slabs with moderate spans, flights, landings and bracing cores form the main load bearing system.



Hollowcore slabs are built together via reinforcement bars placed in the castellated horizontal joints. Such connections are able to transmit shear forces vertically as well as horizontal.

In some cases a thin structural screed is cast on top.

Planks are the lower part of a composite slab construction. Containing the main reinforcement the plank element acts as permanent scaffolding for a reinforced structural screed. A rough top surface and reinforcement along the edges ensure shear transmission between plank and screed.

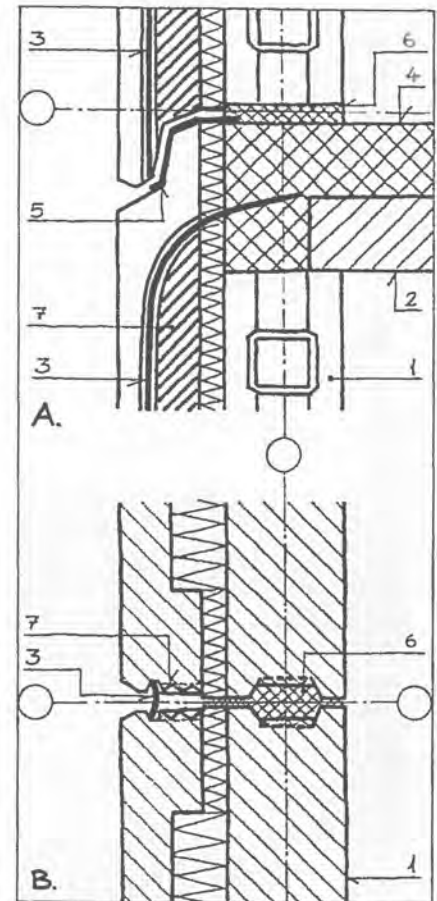
Walls

As panel systems are very often used for residential buildings, PC-walls are also a common structural component.

Normally the wall element is cast vertically with smooth surfaces and unreinforced or reinforced with one or two nets in accordance with the local Codes, depending on the loadings and the wall thickness.

In a panel system the load bearing walls will act as bracing members as well, which means that vertical and horizontal wall joints have to be structural. These connections have standardized reinforced and castellated profiles. Besides the load bearing capacities a wall component often has to meet other functional requirements such as sound and fire protection, especially if the component acts as partition wall.

Wall heights will depend on f.inst. modular dimension for the total storey height and the thickness of the floor slab.



Modular Drawing and Joint Principle

Standardized walls and slabs leads to standardized connecting details, here shown vertically on A and horizontally on B.

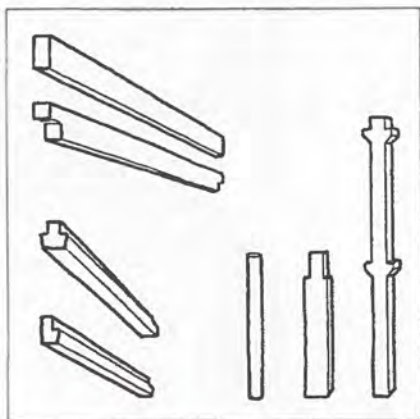
1 Wall. 2 Plank. 3 Neoprene strip. 4 Structural screed. 5 Water proofing. 6 Mortar grout.

Standardized Walls

To the left:

Similar wall panels are shown on stock ready for transportation and erection, and painted PC-panels used as facade in a car parking project.





Columns and beams

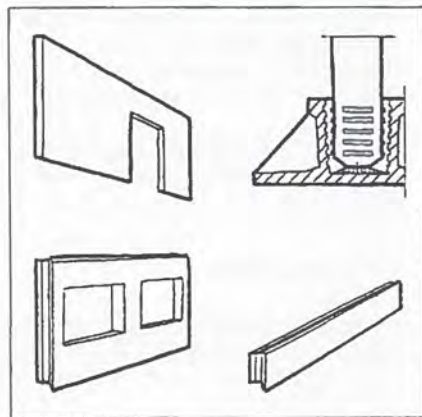
PC-building systems of today are often based on a more open structure, especially buildings for office purposes should have more flexible floor plans than possible in a panel system.

The structural system for such buildings consists of columns, beams, slabs and bracing walls in connection with f.inst. gable walls or stair and lift cores.

Columns are either square, rectangular or circular, while beams almost always are rectangular.

The beams could be normal reinforced or prestressed, and beams could be structurally prepared to be built together with floor construction, acting as T-beams.

Column height depends on the modular storey height and height of beam and floor slab; beam length is decided due to span and loadings.



Columns and Beams

For office buildings skeleton systems are often used. Such systems are based on columns and beams or frames plus bracing structures.

Beams are almost always simply supported with a rectangular cross section. Structurally it is a great advantage to have beams and slabs interact as a T-beam.

Column heights could be of one or more storeys; cross sections could be square, rectangular or circular.

Columns can be restrained in PC-sockets, if the building is limited to one or two storeys.

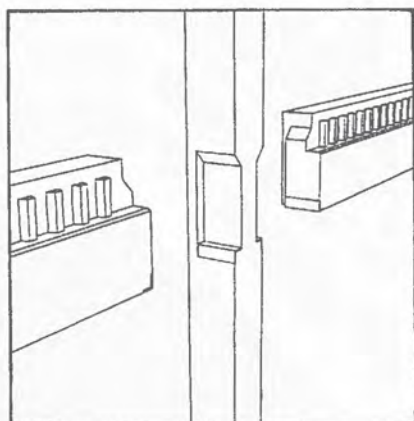


Prefabricated Components

In many countries prefabrication of building parts includes much more than only precast members.

The definition of a modular design is: A design dimensionally prepared for the use of as many prefabricated, modular building parts as possible.

The photo to the left shows a timberbased modular roof element with a modular width, a reasonable span due to the structural design, and curved due to the architect's wishes.

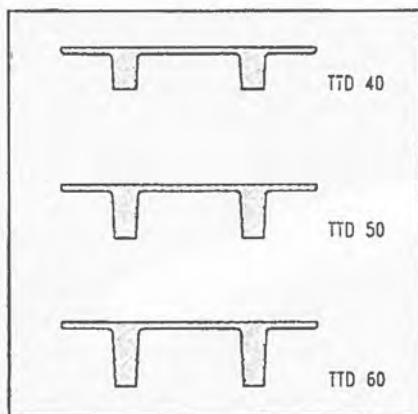


Columns, Beams and TT-slabs

The drawing above shows in principle a standardized connection detail between a 2-storey high column and two beams. Recesses have been made in the column to form the supporting area for the beams. Some locking devices or continuous bars have to be installed.

The photos to the right show circular columns ready on-site to be restrained in foundations boxes. The column head serves as support for the inverted T-beams which form the support area for TT-beams.





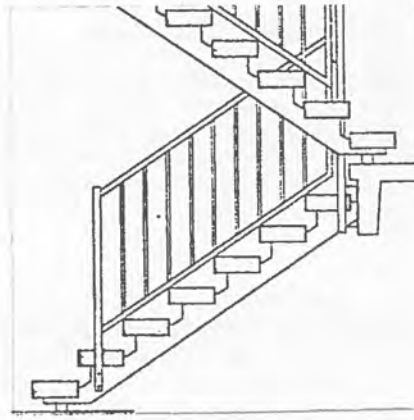
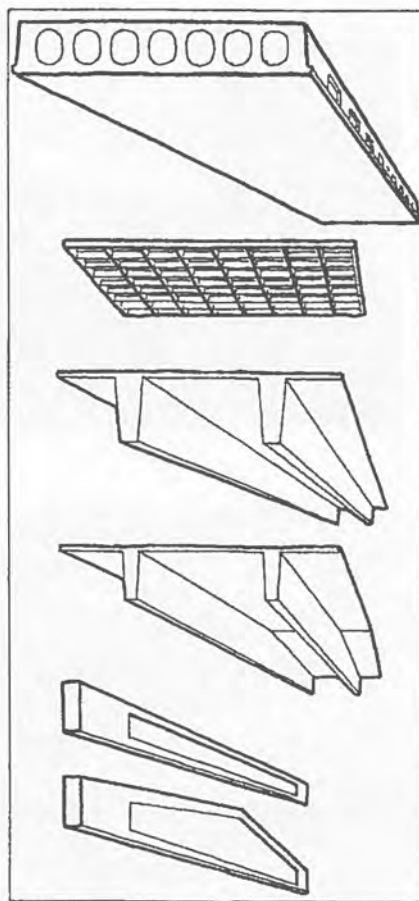
Double-T slabs

A combination of beams and floor slabs is the double-T precast component. This element is normally available on PC-experienced markets and is useful and economical for industry buildings. The element can also be used as roof slab in connection with other building types.

The great advantage is long spans with relatively low self weight; the double-T component is normally prestressed. Shear joints along the edges are based on welded connections.

1.5.2 Other components

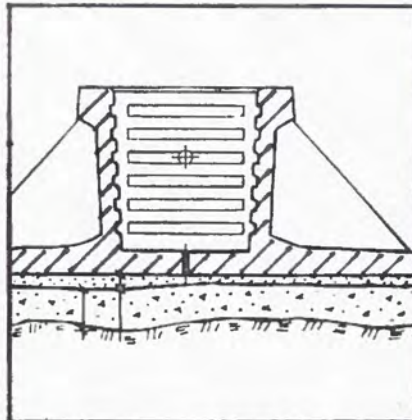
Besides the main structural, standardized PC-components many other PC-elements have been developed due to structural needs and advantages in combination with possibilities for better and more economical design, structural as well as architectural. It could be more freedom in shapes and colours, higher accuracy, better durability, lower maintenance costs etc.



The most important of other PC-components are the following:

- A. Staircase systems, flight and landings
- B. External walls, facades and gables
- C. Balcony structures, slabs and parapets
- D. Frames, T- and L-shaped as well
- E. Foundations boxes
- F. Refuse chutes
- G. Foundation piles.

The above mentioned PC-components will be presented and also structural designed in Volume 2. This Volume will deal with structural ideas and calculations of main connections as well.





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1.6 PC Moulds and Finishes



1.6 PC Moulds and Finishes

Precasting means in principle that concrete parts of a construction, the elements, are cast and cured in one location and thereafter positioned in the special location in the construction determined for this element. The advantages are that the shuttering for the casting, the mould, can be located on ground level in a protected production area with convenient access and working space around. It can also be positioned in the most practical way (normally horizontal) for casting.

Types of Moulds

A. One-off castings:

For special elements, e.g., corners, spherical complicated components, renovation/renewal of sculptural works, letters or signs.

The mould can be made of any suitable material such as timber, plywood, GRC, standard steel components, rubber, GRP or combinations of materials, and can be designed to be lost in the de-moulding process.

Care should be taken in the design to ensure that the pouring concrete will be able to float into all corners and recesses, and that the mould is completely water-tight to avoid water and thereby cement sieving away and leaving fragile edges and corners of honey-combing.



Top:
Casting in a mould and finish of the topside.

Left:
In renovation works, casts of a deteriorated panel can be rebuilt and new renovated panels cast.

Bottom:
Flexible edging for one-off castings.





B. Limited-number castings' moulds:

Occasionally, it will be feasible to cast a limited number of special elements (2-15) such as entrance arches or decorative elements, parapets, double height columns, non-standard stair flights, etc.

Moulds for a limited number of castings can be made from materials as mentioned under one-off castings above but designed for demoulding and re-assembling. Repeated castings in timber, plywood or rubber will wear down the edges and surfaces in the mould and reduce the quality of the surface and the accuracy of the elements. It will also be increasingly difficult to make the mould water-tight in the joints and keep the dimensions within the tolerances.

For casting a limited number of elements it must be carefully evaluated if it is feasible to make the necessary number of one-off moulds or to invest in one durable mould.

The majority of buildings constructed by the PC method will have a few special PC components on corners, parapets and entrances.

The moulds for these components can be made of materials that only can sustain a limited number of castings such as wood or GRC.



C. Standard production moulds:

Where multiple castings, 15 and upwards, are planned, moulds must be made of durable materials and carefully designed to withstand repeated assembly, dis-assembly and cleaning. Normally, steel, GRP, concrete or combinations of these materials are used.

In the basic design of the mould the rough conditions on the casting site and the possible lack of experienced labour must be considered. Connections and number of mould elements must be simplified and minimised, and mould components must be rigid and strong enough to withstand the wear and tear of assembling, dis-assembling and cleaning.

A well-designed and well-maintained steel mould can be used for a large number of castings while the life of a mould with GRP or concrete surface is more limited and heavily dependent on the care in the handling process.



Left:

All-steel mould for extensive production

Left Bottom:

GRP architectural facade finish mould and steel edges

Top:

Steel mould, tilted for easy removal of PC element.



D. Flexible Production Moulds:

A careful determination of the dimensional design and the elementation will result in a large number of elements with similar size. Complementary features such as windows, recesses and cut-outs for services can then be individually added into the standard mould for the variations required.

Moulds for slabs, beams and columns can also be designed to be flexible. This can be done by having the basic cross-section remaining constant but with the length changeable by moving the closing bulkheads.



*Top and Right:
Continuous slab moulds where any
length of slab components can be
produced by flexible bulkheads.*

*Bottom:
Flexible parapet steel mould*



E. Battery Moulds

Walls, columns and panels can also be cast in a vertical position, pouring the concrete in from one of the edges. The method is feasible when the elements are simple and with a limited number of not too deep grooves and patterns so that de-moulding is easy.

The advantages are that both sides of the element will be of high quality surface finish and that the casting operation takes up little space.

The method is very feasible for casting flat, thin panels, internal walls, columns, etc.



Internal walls by battery casting have high quality surfaces on both sides - no plastering is needed.

Vertical casting in battery mould on site. Normally used for internal walls.



All reinforcement for battery mould castings is prefabricated and hoisted into the mould as one unit.

Mould Designs

When well proportioned, specified and mixed concrete is poured into a mould and left to harden, the shrinkage is very limited.

Two measures are to be taken to be able to demould : application of "slip oil" to the mould and design of the mould with "slip angles". Ideally the mould should be a simple trough, where concrete is poured in and lifted out when hardened.

The most simple form of precasting: lintels cast between timber profiles.

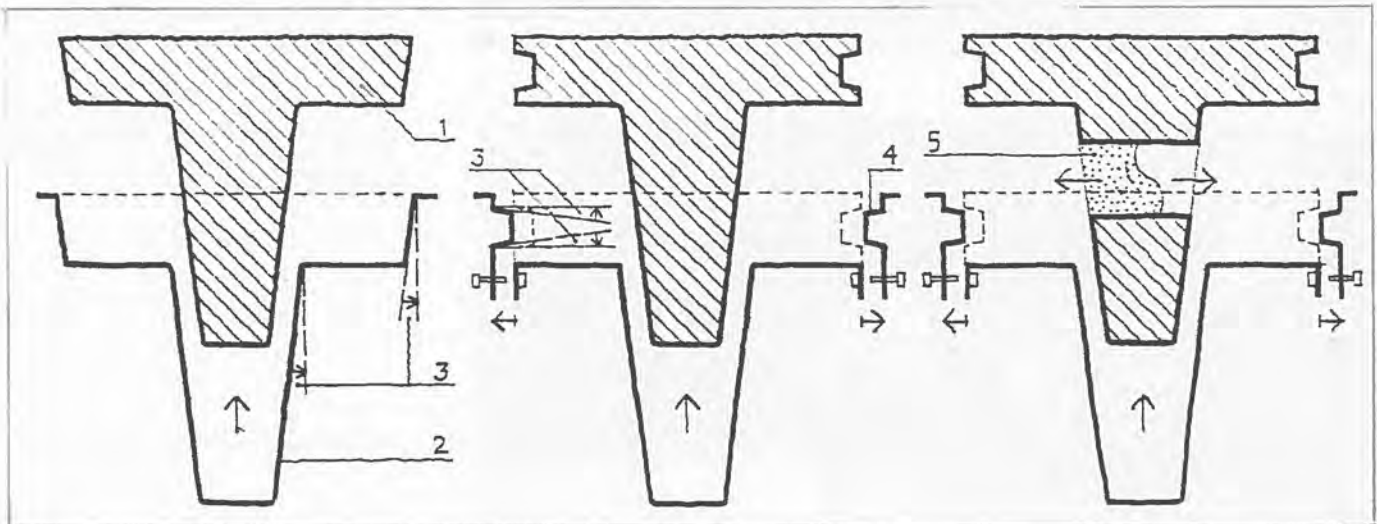


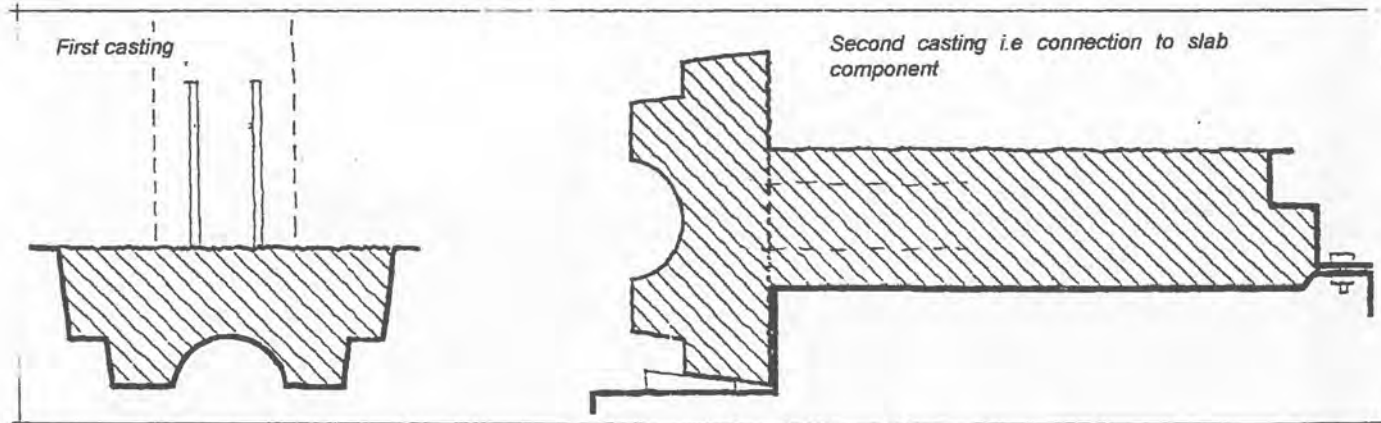
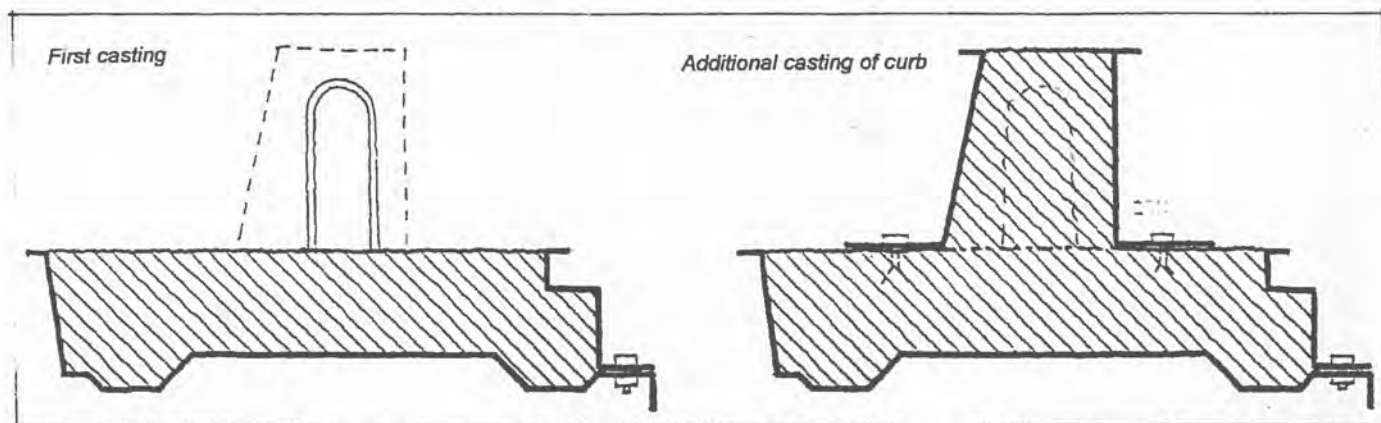
One, two and three operations in demoulding

1. PC component
2. Mould
3. Slip angles
4. Removable mould edges
5. Secondary mould parts or foam to be removed after demoulding from main mould.

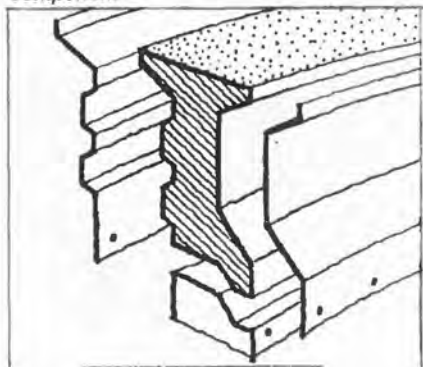
The majority of elements will, however, have special designs for edges, connection reinforcement and protruding stirrups. This makes it necessary to design moulds that can be dis-assembled in various parts. Normally the edges of the mould are made to be removable.

Care should be taken to minimise and simplify the number of mould elements and dimensions on steel plates, etc., should be sufficient to withstand the repeated rough handling and cleaning.





Vertical casting of complicated component



Profiles, patterns and edges of Moulds

All profiles, recesses or upstands in the mould must be designed so that the hardened concrete element can be removed. The easier it is to remove the fewer chips will occur.

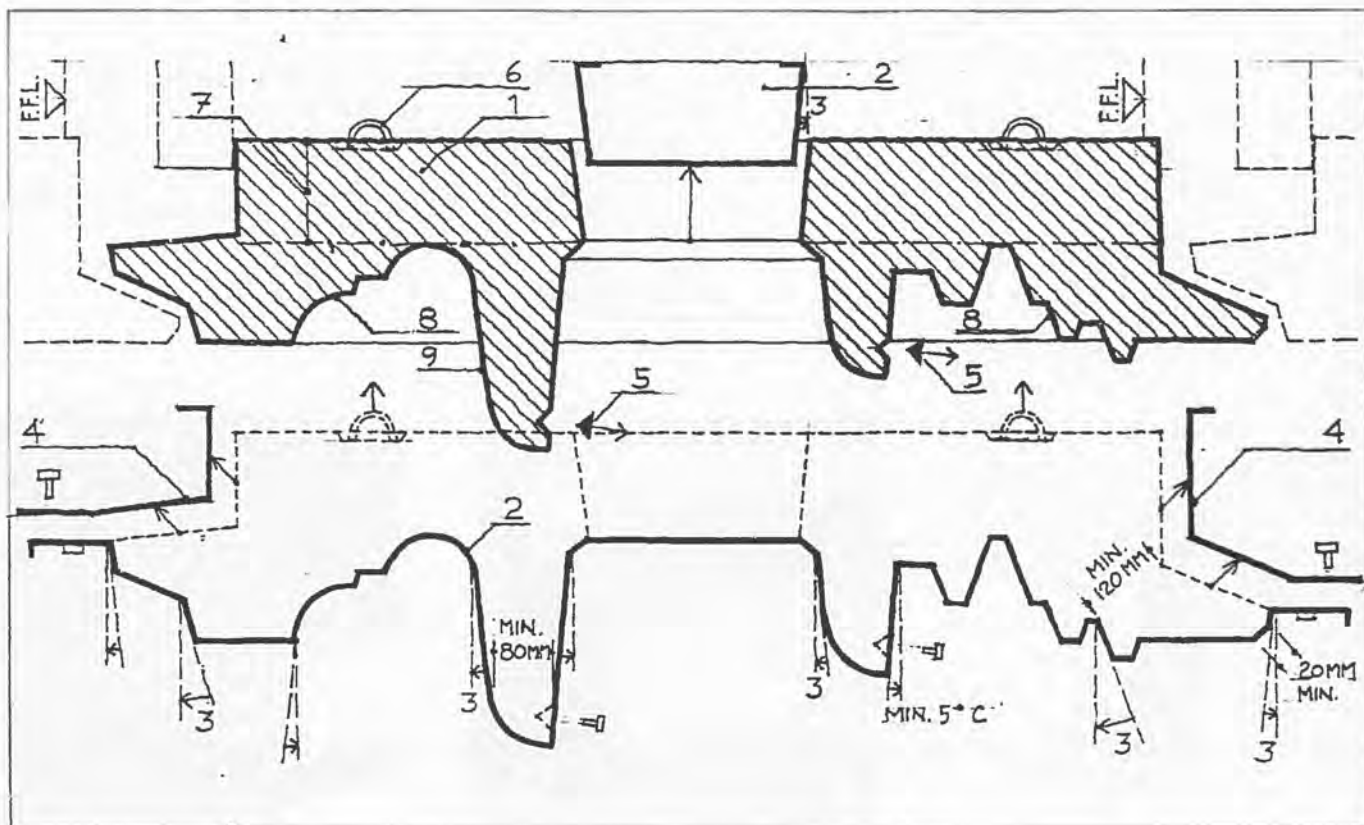
Slip angles should not be less than $5-10^\circ$ and all corners tight and smooth. All 90° edges should be chamfered at least 15-20 mm.

Principal components and design recommendations:

1. PC component
2. Mould component
3. Slip angle, minimum 5°
4. Mould edges
5. Profile for drip nose
6. Lifting hooks for demoulding
7. Structural zone in the component
8. Architectural profiling
9. Canopy

When patterns, profiles and details are being designed for the concrete elements it should be remembered that the moulds have to be made out of materials such as wood, GRP or steel. Each of these materials for moulds have limitations in workability, e.g., spherical forms are very difficult to manufacture in steel but possible in wood or GRP. On the other hand, steel is well-suited for profiles.

Occasionally, items manufactured for entirely different purposes can be incorporated in the mould design, e.g., steel balls cut into half or brass castings.





Dripnoses and additional grooves

For some facade panels, dripnoses have to be included in the design. This extra profiles normally will complicate the de-moulding they are parts of the main mould since they prevent the easy "slip".

Dripnoses and similar profiles can be loose items of neoprene rubber or similar that is fixed in the mould before casting but removed from the element after demoulding of the main mould.



Moulds, examples



Examples of PC components where the design principles for the moulds are clearly visible, such as slip angles and secondary mould parts.

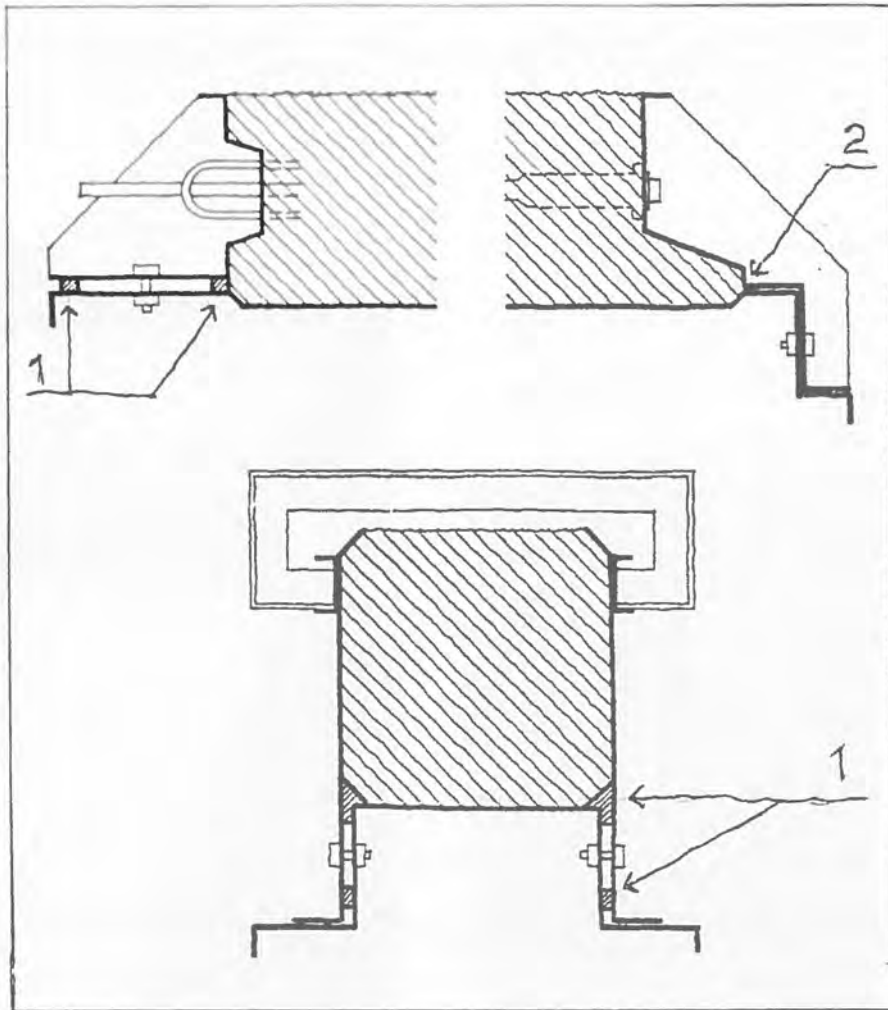


Water-tightness of Moulds

When designing break-down moulds, special care must be taken to ensure water-tightness between all parts when assembled and ready for casting.

Water sieving away will carry cement along the leaking joint in the mould and leave the sand and gravel in the vicinity without binding. The concrete will be weak and porous (honey-combing), and chip easily and not provide corrosion protection for the reinforcement inside.

Where reinforcement or tension bars protrude the mould special sleeves must be installed in the mould to ensure water-tightness.



In water tight moulds, edges of elements can be cast in very high quality.

1. Neoprene rubber profiles

2. Silicone joint

Top:

Wall element casting

Bottom:

Column or beam casting where the water tightening profiles form chamfer.



Cast-in surface finishes

Tiles, natural stone plates or other items such as stainless steel or bronze brackets can be cast into the element during the production.

The items must be fixed firmly during the casting and a sufficient and lasting bond to the concrete must be ensured.

Tiles must be the extruded dovetailed type and laid down in the mould and fixed in a casting mesh which is usually available from the tile manufacturer.

Natural stone plates must be supplied with corrosion-proof anchors in dimensions specified by the structural engineer. Other items such as anchors and inserts must be firmly fixed to the reinforcement according to structural specifications.

When the design of the elements include cladding with tiles or natural stones it must be remembered that the joint between elements is approximately 16 mm and varying with the tolerances and this joint is different from the joints between the cladding items.

The design of the pattern must incorporate the special element joints.



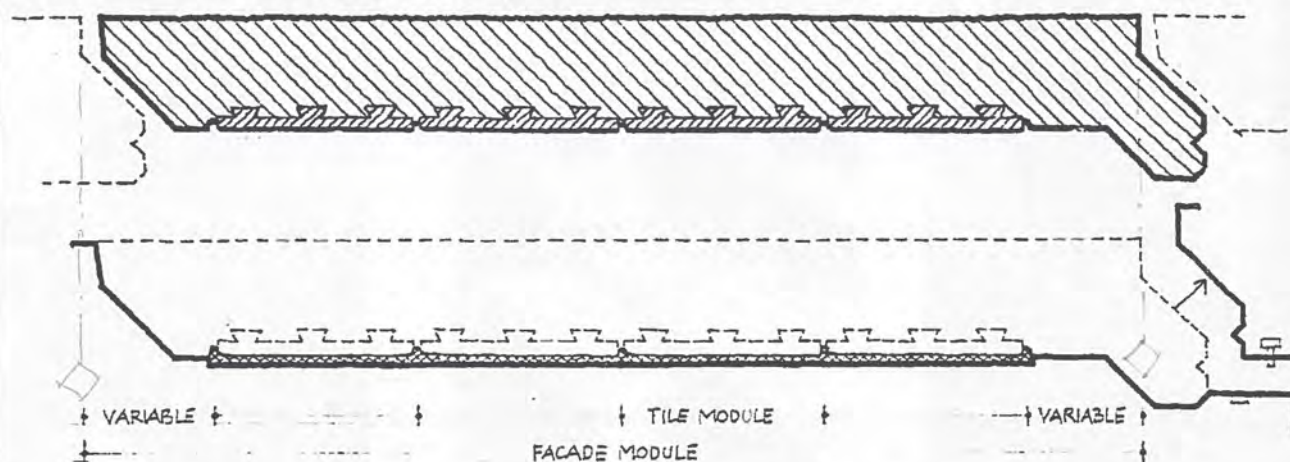
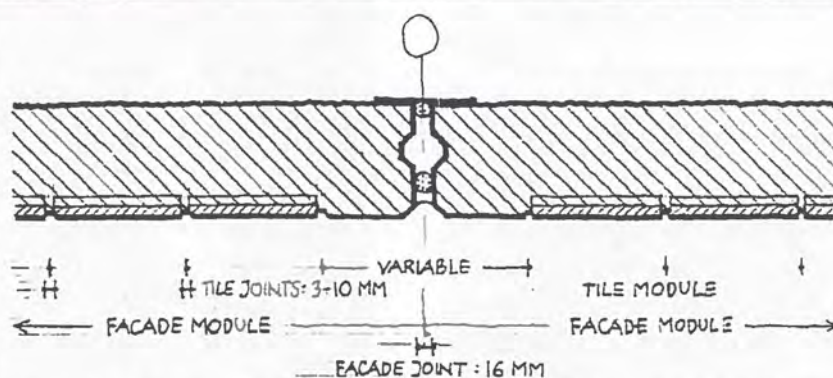
Top:
Tiles in the moulds before casting
Left:
Tiles and concrete
Bottom:
Granite with corrosion proof anchors
Right:
Full cover tiles





Top Left:
Special bricks with reduced depth
Top Middle:
Tile pattern in concrete
Top Right:
Full cover homogeneous tiles

Architectural design coordination of the horizontal and vertical facade modules with the tile module





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Bracing of Components	
Demoulding	125
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Bracings in large openings, dimensions and location coordinated with the lifting hooks.

1.7 PC Handling

Introduction

One of the major advantages in precasting is that accurate, complicated and detailed shaped components can be produced under optimal conditions in factories or protected site-casting yards.

If the components are built into the construction without damages, the finishing works on the buildings will be reduced to an absolute minimum. The advantages of construction speed, minimum waste of material, reduction of labour and good, durable finishing quality depend heavily on the methods and care with which the components are handled. A calculated good economy of a PC project can be spoiled by extensive making good works due to handling damages.

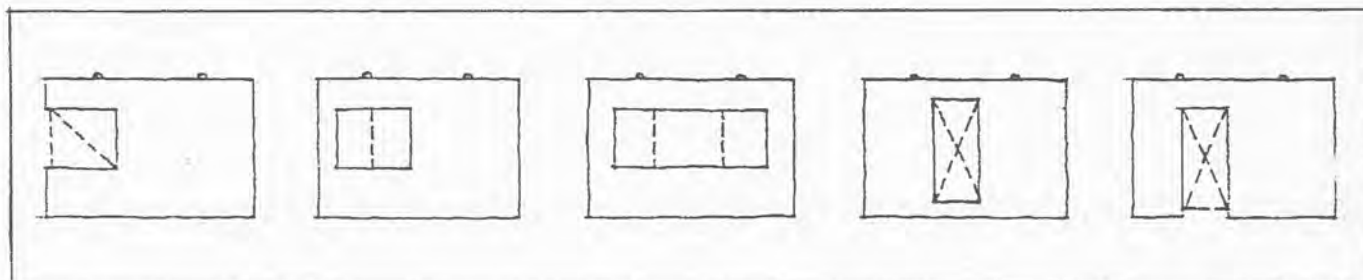
Precast components are subjected to different phases of stress during the production, transportation and erection stages. As such it is important to understand the stresses they are subjected to at each stage and to design the element that can withstand such stresses. In addition, the concrete strength is also different in each of the stages. The safety when handling the normally heavy components have to be considered both for human and economic reasons.

Shapes of Precast Components

Precast components come in different shapes and sizes. As these components are cast normally in reusable mould, it is important to shape the panel in such a way as to ease the demoulding process. This will invariably prevent damage to the components as well as the moulds. (See Chapter 1.6)

Bracing of Elements

The main reinforcement and strength of elements is designed for the structural forces when the element is in position in the construction. Temporary bracings should be installed in elements with large openings during demoulding and handling to prevent damages. The bracings can either be removable steel frames or cast-in bars which are cut off after the component is installed in the construction.



Demoulding

During demoulding the concrete strength of the precast components is less than the actual strength. It is common to assume a concrete strength of 10N/mm^2 during demoulding for normal precast concrete. In addition, the forces due to the form suction and impact must also be taken into account in the design. To allow for these forces a factor is normally added to the member weight.

Demoulding can be done in the following ways:

- Lifting from two points along one edge, with the opposite side resting on the mould.
- Lifting from four points
- Lifting from two points along one edge with the mould tilted at an angle.

a. Lifting from two points.

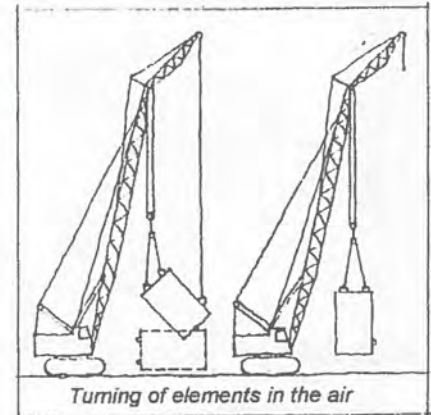
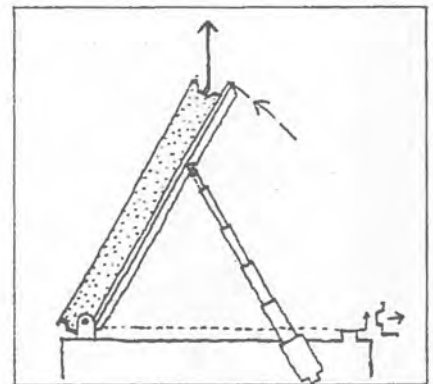
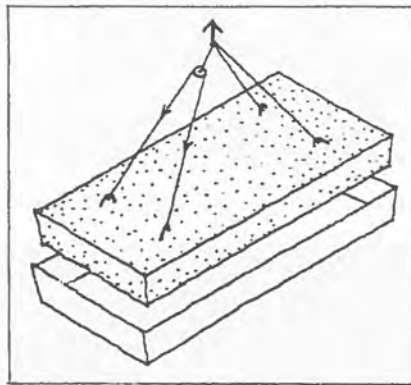
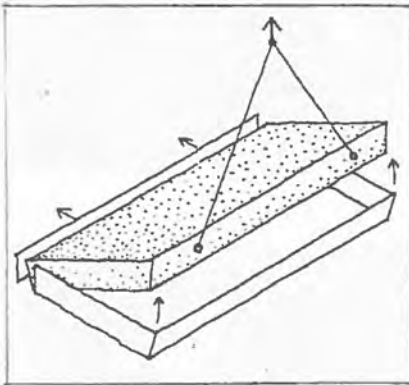
The edge on which the element is resting will easily be damaged and the lifting inserts at the other edge is under severe strain.

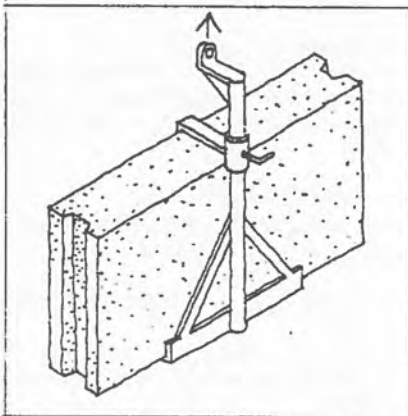
b. Lifting from four points.

Two of the points must be connected to ensure even distribution of the weight.

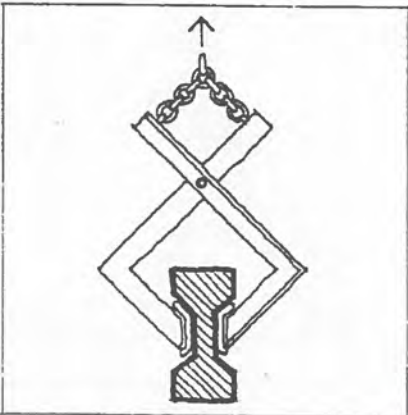
c. Lifting from two points from tilted mould.

Details of profiles and edges in the mould must be suitable for the slip in this direction.



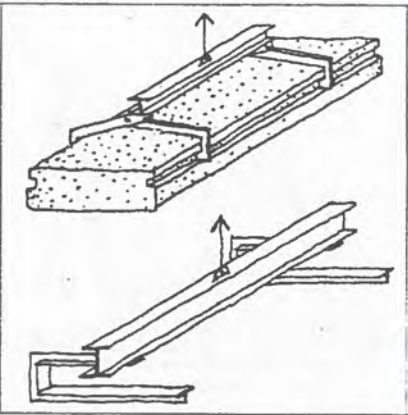


Lifting bracket for small components



Scissors for beams

Scissors and slice for slabs



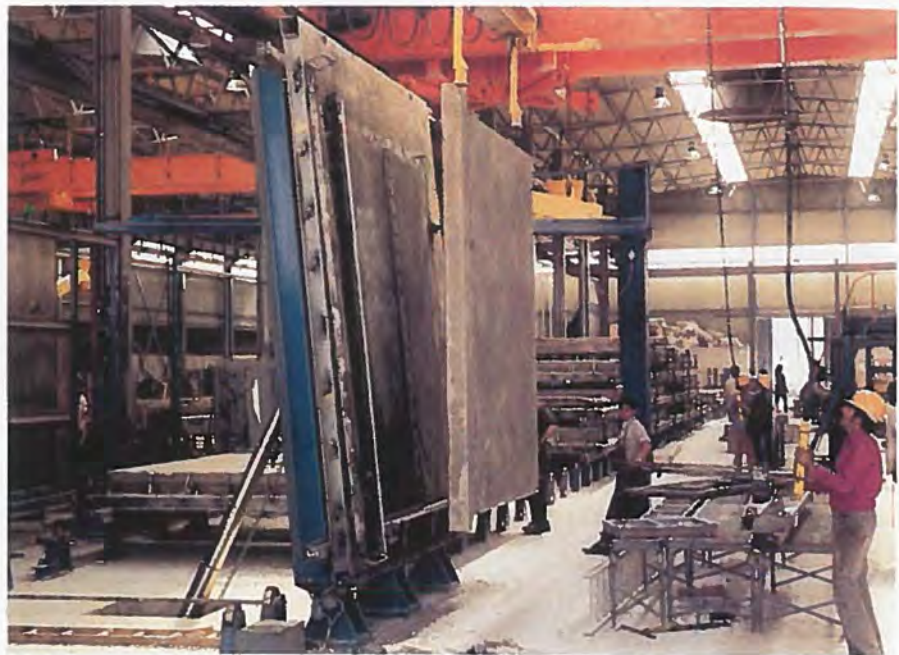
Lifting Devices

Lifting devices is used to spread the load and to lift up the precast components from the mould. It is also used for erection purposes.

There are different designs and the shape and sizes depends on the weight and the configurations of the precast components. In certain type of precast component, such as precast floor slab, small panels, it may not be practical to install lifting hooks. For such cases, some clamping devices would have to be used.



Special lifting devices in factory handling



Lifting Hooks and Inserts

The most common lifting devices are the prestressing strand projecting from the concrete, threaded inserts or proprietary devices.

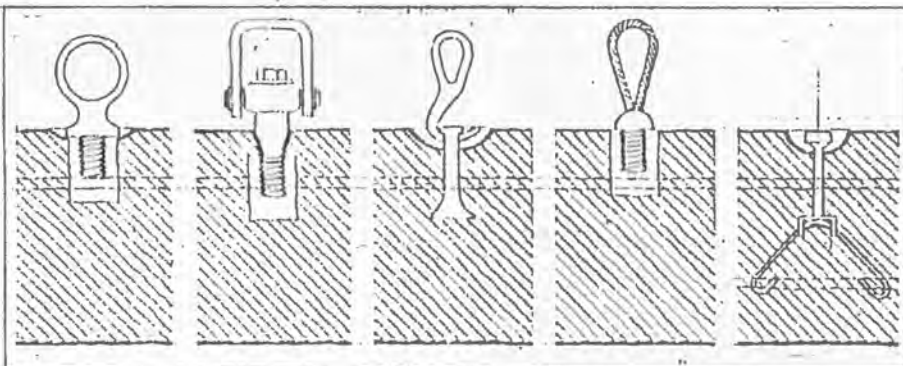
Since lifting devices are subjected to dynamic loads, ductility of the material is part of the design requirement. Deformed bars should not be used for lifting. Mild steel bars may be used subject to adequate embedment length and strength of the bar.

Prestressing strand may be used as lifting hooks. The capacity of the lifting hooks depends on the length of the embedment, diameter of the strand and the strength of the concrete. A safety factor of 4 is recommended against tension or slippage.

Lifting inserts can also be used. However, its use must be carefully assessed in relation to its capacities and the concrete capability.

In any case, connection hardware should not be used for lifting purposes. Suggested factors of safety for the lifting hooks and bracing inserts due to various construction loads are:

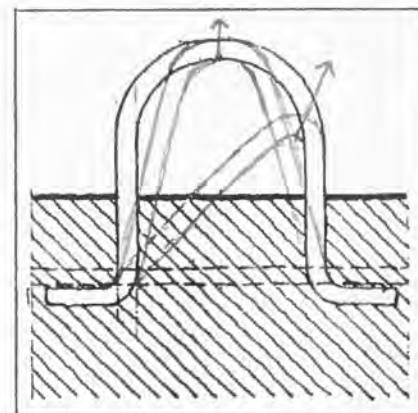
a.	Bracing for wind loads	2
b.	Bracing inserts cast into precast members	3
c.	Reusable hardware	5
d.	Lifting inserts	4



Safety

All safety measures should apply from the first lift out of the mould until the component is permanently installed in the construction.

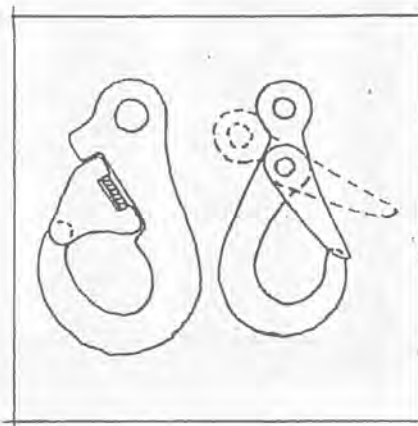
If local statutory safety regulations do not exist, a safety manual have to be agreed upon to clarify the justifications of claims from possible human or material damages due to defaults or accidents.



Top:
Prestressing Strand

Left:
Examples of Lifting devices :
Either screwed into inserts or cast into the component.
Location and details of the lifting points must be coordinated with the reinforcement.

Bottom:
Crane hooks with safety provisions.





Storage

Elements should be stored in the position similar to the elements final position in the construction.

The method of storing immediately after demoulding is especially important since uneven stresses and different temperatures and humidity on two sides of the element can cause permanent warpage during the curing time.

Wherever possible elements should be stored on hard, level ground and on two points of support - normally of hard wood.



*Top Left:
Element factory storage directly outside
the casting yards.*

*Far Left:
Timber wedges in steel storage frame
Above:*

*Vertical storage with high capacity and
easy accessibility.*

*Left:
Horizontal storage on site of wall panels
can be necessary but is inconvenient for
the crane handling since elements have
to be turned, either in the air or by lifting
from one edge which will cause damage.*

Transportation

The method used for transporting precast concrete products can affect the structural design because of the size and weight limitations and the dynamic effects imposed by the road conditions.

The height and weight limit on the vehicle must be made known before commencement of design work. In certain areas, access can determine the final design of the precast components.

As precast concrete components are transported by trailers, it is important to consider the deformation of the trailers during transportation. Special platforms may have to be used for long span components.

Considerations must also be given to the height, width, length and weight limitations when designing precast components. Permit may be required if the dimensions and weight of the components exceed the allowable limit.

Where possible, precast components should be transported in the same orientation as when they are installed in the building.

A good example is the use of A-frame to support the precast panels in the upright position when they are on the trailer. The A-frame provide good lateral support. Longer units are transported on their sides to take advantage of the increased stiffness compared with flat shipment.



Turning the element in the air

Transportation on A-frame trailers of wall components and flat trailers with slab components.



1.8 PC Implementation



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1.8 PC Implementation

When a contractor for a PC project is appointed, the following checklist can be used to ensure a feasible implementation.

The number of items that need to be checked will depend on the project. However, all items listed should at least be carefully evaluated in relation to the actual project before a decision is taken as to which items and checks should apply to this project.

The items below are listed in sequence following the implementation process and are specifically related to the PC method.

The additional conventional works to finish the building are not incorporated but can follow the local traditional code of practice.

1.8.1 Standards and Code of Practice

All provisions, requirements, reference code and standards regarding design, materials, methods, manufacturing, erection, workmanship and tests for the PC project shall be reviewed and agreed upon by all parties.

Consultants
Precaster
Contractor

1.8.2 Shop Drawings

The Precaster and his consultant normally produce shop drawings of each and every element including: All elevations and sections, quantity and location of reinforcing steel, anchors, stirrups and inserts for lifting and erection.

Overall dimensions on the shop drawings of elements shall be related to the modular grid system in the project.

The element drawings shall also include architectural finishes, claddings, concrete strength, weight of the elements and total number of similar elements. Preferably one drawing per element, where all the information are incorporated.

Structural performance requirements shall be proved for every element.

Precaster

Shop drawings shall be approved by the consultants.

Consultants

1.8.3 Mould Drawings

The Precaster shall produce drawings for moulds, including methods for assembling and dis-assembling, water tightening, draft, method of compacting and vibration and the method of keeping within the tolerances shall be ensured in the design.

All parts of moulds shall be of materials and dimensions that can withstand repeated rough handling.

Precaster

1.8.4 Assembly Drawings

Contractor Precaster Consultants	<p>During an integrated design process, the contractor together with the precaster and the consultants shall produce detailed assembly drawings of each and every type of joints and sections that occur in the PC project.</p> <p>The assembly drawings shall include: Reinforcement and ties, grouting, shims or adjustment bolts, joint casting, chalking, sealing and water proofing as well as finish treatment of the joints.</p> <p>The modular grid in the project shall be included in the assembly drawings for easy reference.</p> <p>Structural performance requirement shall be proved for every assembly detail.</p>
Consultants	<p>Assembly drawings shall be approved by the consultants.</p>

1.8.5 Site Planning

Contractor	<p>The Contractor shall produce a comprehensive drawing of the construction site planning. The drawing shall at least include the following: Location and size of all equipment such as tower cranes, batching plant, casting yards, and element storage areas - all coordinated with the underground services and access roads, etc.</p> <p>The storage and curing area for the elements shall have a clean, hard level and well-drained surface to prevent warp, bowing, chipping, cracking, discolorations, staining or soiling of the PC elements and shall include detailed organizing of the storage coordinated with the erection sequences.</p>
Consultants	<p>The drawings shall be issued to all the consultants for comments.</p>

1.8.6 Production and Construction Planning

Contractor Precaster	<p>The contractor shall produce a detailed, coordinated time schedule for production and erection of all types of elements. The planning can be based on a thorough evaluation of the production and erection of a few typical elements.</p> <p>The works to be performed and the time needed for the following processes shall be included: Assembly of mould, application of slip oil, reinforcement and binding, inspection, pouring of concrete, vibration, settling and hardening, dis-assembling of mould, lift and transport to curing and storing, lift to building, location in the construction, frequency of use of that particular element with casting of joints and topping taken into consideration.</p> <p>Time for sample castings shall be included in the overall time schedule.</p>
Consultants	<p>The production and construction planning schedule shall be issued to the consultants for comments.</p>

1.8.7 Sample Mould and Casting

At least one typical mould has to be manufactured and a sample element cast. This operation is a test of the anticipations referred to in item 1.8.6 and concrete specifications, reinforcement and method of works on the sample shall be similar to that of the actual elements to be casted.

Precaster

Only after the sample element is approved by client and consultants can the remaining moulds be manufactured.

Client
Consultants

Sample mould and element casting may prove that the PC elements detailed design must be amended and extra time needed. The sample element is to be kept on site as a quality reference.

1.8.8 Site Set-up and Mould Manufacturing

The site is set-up according to the detailed plan and all moulds are manufactured.

Contractor
Precaster

1.8.9 Training and Information

The quality and feasibility of the PC method depends heavily on the level of knowledge and experience of all the persons involved in the particular project.

Before and during the initial production of elements, joint courses, lectures or information-dissemination sessions must be organised by the site office and conducted by professionals with the necessary experience in the PC method and knowledge of this particular project.

Precaster
Contractor
Consultants
Site Staff

The sessions shall be attended by the entire site office staff, all supervisors and foremen and a selection of skilled as well as unskilled workers.

An integrated knowledge of the entire PC method by all the involved persons will facilitate the supervision of the work processes because of the common understanding of the importance of particular works.

1.8.10 Production of Elements

Since all types of elements will normally be used in the building of every single storey in a PC construction method, the production of all types of elements must start simultaneously.

Before pouring of the concrete into the mould, inspection of the following items must be done: Dimensions and angles of the mould; the amount, size and location of the reinforcement, location, fixing and tightening of all stirrups and ties; tightness of mould edges and comers, cast-in items such as inserts, lifting hooks and architectural finishes.

Structural
supervisor
Precaster
Architectural
Supervisor

Precaster
Structural
supervisor

The method and equipment used and the duration of vibration shall be agreed upon during the sample casting and initial castings.

Minimum hardening time before de-moulding shall also be agreed upon - normally overnight 6-12 hours.

The method and tools for de-moulding shall be tested and agreed upon during the initial castings with respect to chipping of concrete and wear and tear on the moulds. Handling and storage of the newly cast elements is covered in Chapter 1.7

1.8.11 Repair of Elements

Precaster
Architectural &
Structural
supervisors

During the initial castings, guidelines for the acceptable finish of the elements must be agreed upon.

The maximum size of chips and the repair method must be specified.

It must be possible to reject elements for architectural as well as structural reasons.

1.8.12 Safety

Contractor
Supervisors

All safety measures must be specified and approved by the relevant authorities. Especially in a full PC construction where no scaffold is erected, the installation of flexible safety balustrades on the top floor must be considered.

Contractor
Structural
supervisor
Consultants

Also temporary bracings of elements and crane handling procedures must be evaluated and specified with regards to the safety of the construction and the workers.

1.8.13 Measurements and Tolerances

Supervisors
Contractor

All measurement tools such as meter tapes, spirit levels and straight edges must be approved. In a repetitive PC construction it is an advantage to manufacture fixed-length straight edges and templets specifically for the project.

1.8.14 Erection Process

The erection of each and every element follows a schedule described below, where the corresponding checks and inspections are included.

- a. On the erection frequency plan, the actual element number is identified.
- b. In the storage yard, the element is inspected for damage during storage. If damaged, approval from structural and architectural supervisors is needed before hoisting.
- c. The element is hooked up in the position as it will be installed. If walls are stored horizontally, the element has to be turned by an additional crane operation or by a "gym".

Architectural &
Structural
supervisors

Contractor's
erection foreman



The element is hooked on directly from the A-frame trailer or from the element storage on site and hoisted in the position that it will be installed.



Erection, Setting Preparations

Structural
supervisor

d. On the building, the location space of the element is thoroughly cleaned and all joints' backings and waterproofings are fixed according to the joint's details.

e. The estimated level and horizontal location of the element is established by shims and bolts.

f. Grouting is mixed. Specifications for the grouting must be strictly followed and supervised as it is loadbearing and part of the main structural system.

Right:

Joint preparation with backing strip

Far Right:

Steel dowel resting on shims and shims ready for the wall element

Right:

Grouting mortar mixed centrally for quality control

Far Right:

Grouting mortar mixed on the construction floor



g. The element is hoisted and settled in its place and checked for vertical and horizontal positioning, hooked up and balanced by the crane.

h. Eventual adjustments - horizontal and vertical - are done while the element is hooked up and only when the location is within the tolerances can adjustable bracings be fixed.

The necessary number and method of fixing the bracings are to be approved.

i. When all bracings are installed the element is hooked off and the vertical alignment for wall and column elements finally adjusted by the bracings.

Structural
supervisor



*Far Left:
Setting of the element
Left:
Horizontal adjustment
Far Left:
Bracing
Left:
Hooks off*



Structural
supervisor

j. The grouting under walls can be laid out on the loadbearing surface before the element is positioned or it can be pressed into the joint after settling of the element.

In both methods it is very important that the grout is sufficiently dry and is densely packed in the joint so that the anticipated loadbearing capacity can be obtained. A thorough supervision is necessary.



Right:
Setting on mortar bed

Far Right:
Compacting and finishing

Right:
Dry setting and compacting with mortar afterwards

Far Right:
Tools for compacting of mortar grouting



k. When all the loadbearing vertical elements are braced and grouted, the horizontal beams and slabs can be positioned. Again special care must be taken to clean the loadbearing surfaces before resting of the beam and slab components.



Slab component installation



Architectural
supervisor

1. Vertical joints can be rebarred and cast before or after positioning of slab elements, but will normally have to be structurally finished before construction of the next storey can start.

Special care shall be taken to ensure that the shuttering for the vertical joints is flushed or evenly recessed from the wall surface and tight and firmly fixed.

The open side of the vertical joints are normally on the inside and the flushed or recessed casting is easy to finish with plaster, shimming and paint.



Right:
Vertical internal and external open joints

Far Right:
Slab - facade wall joint

Right:
Vertical closed joint

Far Right:
Internal backing of facade joint



m. The vertical ties for structural bracing shall now be connected either by casting out special connection fittings or by welding. This operation is crucial for the structural soundness of the building and must be thoroughly supervised.

Structural
supervisor

n. The reinforcement and the horizontal ties are now installed on the slab elements and in the joints and cast - preferably in one operation to ensure a continuous cohesion.

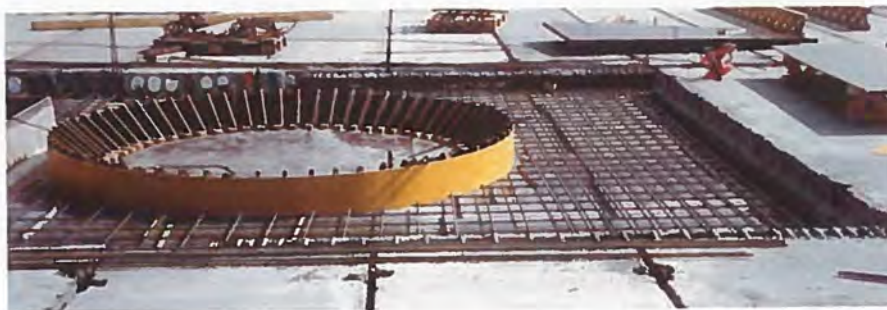
The cutting, bending, welding, laying and binding of this reinforcement in the topping and the horizontal joints, together with the casting, is the most labour - intensive work in the PC method and have to be carefully supervised and approved at various stages.

A careful and detailed design of this reinforcement and extensive use of prewelded cages and connections can minimise the time and labour force needed on the building for this operation and reduce the overall time consumption.

Structural
supervisor



Reinforcement of topping - labour intensive process.



Special slab part cast in-situ in between the standard slab elements.

Structural
supervisor

o. After the approved curing time of topping and joints' casting, element erection on the next storey can start.

p. Bracing on the storeys below can be removed after an approved schedule.

q. Internal finishes and services' works can follow the element erection process 3-5 floors below as soon as bracings and props for the slabs are removed. The amount of work on the internal finishes on PC components are normally reduced considerably due to the high quality of the PC surface compared to an in-situ cast surface.

Architectural
supervisor

r. The external finishing works on a full PC construction are normally confined to: Backing and sealing of joints - mainly vertical, patching up of a few erection damages, cleaning of the facade and coating with paint. These comparable light works as well as the supervision and inspection can be done from the top of the finished construction and down the facades using gondolas or flexible work platforms.

*"Raw" element facade and painted
profiled elements*



1.8.15 Construction Management and Quality Control Form

During the implementation of a project where the PC method is incorporated, a number of checks and approvals have to be performed to ensure the quality and the distribution of responsibility between the involved parties.

It is practical to use one standard form for each and every element where all the necessary checks, approvals and distribution of responsibility are listed right from the start of setting up the mould until the component is finally located in the construction.

A number of the items on the form are detailed and specified in Standards and Code and in the Particular Specifications for the PC - Works on the job, while some other items are subjective where quality must be decided upon with the local conditions taken into consideration.

Type of Element: _____
 Weight: _____
 Total No. of this type of Element: _____
 This Element Number: _____

Consultant Drawing No: _____
 Shop Drawing No: _____

Type No: _____

Operation, Check Approval, Receipt	Consultants, Supervisors		Precaster		Contractor		Comments
	Structural Engineer	Architect	Structural Engineer	Supervisor Foreman	Structural Engineer	Supervisor Foreman	
MOULD							
Tolerances							
Assembly / Tightness							
Holes for installation							
Cleaning							
Slip-oil application							
REINFORCEMENT							
Main reinforcement							
Ties							
Stirrups & Loops							
Cast-in Items							
PRODUCTION							
Pouring date & time							
Concrete test-cube							
Vibration							
Demoulding date & time							
Tolerances & Quality							
Making good							
Receipt & Approval							
Storage date							
Earliest date for use							
ERECTION							
Approval for Erection							
Erection date							
Ties Connection approval							
Reinforcement approval							
Joints' rebar approval							
Grouting							
Joints' casting date							
Topping's casting date							
Concrete Test-cube							

Project Drawing Label



Seminar On
"Precast Buildings - Design and Implementation of the Precast Method", October 2003

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