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The Precast Concrete and Lightweight Concrete Element Industry in Sweden ¹⁾

L'industrie du béton préfabriqué et du béton léger en Suède

Industrie für vorfabrizierten Beton und Leichtbeton in Schweden

Introduction

Since around 1950 the building industry in Sweden has developed a number of new mechanized production methods.

The rise in labour costs and the consequent increased use of machines are major reasons for this development.

Also the human factor, to avoid heavy manual labour, has played a rôle. The saving in construction time and the accompanying saving in interest costs are also important factors. Introduction of building cranes has e.g. increased the use of precast concrete elements. The yearly output of the Swedish precast concrete industry corresponds to about 125,000,000 Swedish Crowns, and the rate of increase per year is about 5%.

Structural concrete elements are manufactured in approximately 80 factories. Some of these factories are located at or near major building sites.

In most of the new buildings only some parts are made from precast concrete elements. The structural framework is usually cast in situ. For homes, apartment houses, industrial buildings, office-buildings, road-, street- and railway bridges and pipe-lines, concrete elements are used extensively. In the following a brief description is given of characteristic element systems used within the different categories in Sweden.

Some of the technical problems of current interest for our builders are presented.

In addition to this precast concrete industry there is a big lightweight concrete industry in Sweden. The yearly production of steam-cured lightweight concrete in the country runs about 1,400,000 cu. m and represents

¹⁾ The present Report was prepared for the Swedish National Committee of IABSE under the chairmanship of Prof. Georg Wästlund by civ. ing. Bertil Neyman, what concerns the concrete element industry, and by civ. ing. Anders Nylund, what concerns the lightweight concrete industry.

a value of more than 150 million Swedish Crowns. 40 percent of the total output goes into the production of reinforced lightweight concrete elements, representing a value of approximately 80 million Crowns a year. These elements include roof and floor panels as well as different types of wall elements. Roof and floor panels represent the bulk of the yearly production, or 330,000 cu. m. The lightweight concrete industry will be mentioned in the last section of this report.

Structures

Homes

Few homes in Sweden are built entirely from precast concrete elements. However, it is common to use precast panels over basements. Fig. 1 shows the panels which are in more general use. These elements are manufactured in permanent factories and are made of regular reinforced concrete. The concrete quality is usually K 400 (compressive cube strength at 28 days equal to 400 kg per sq. cm) and the reinforcement Ks 40 (deformed bars with a yield point of 40 kg per sq. mm) or Ks 60 (deformed bars with a yield point of 60 kg per sq. mm). The elements are mounted by means of truck-cranes, trolleys and lever-arms. An 11-ton precast unit containing bath-room, toilet and the sanitary installations for a kitchen, as well as a boiler-room, is manufactured in large series.

This unit is prefabricated at the factory. It includes all installations, and walls and floors are finished. A manufacturing program of other room units is in the stage of preparation.

Apartment houses

The development within the area of housing projects in Sweden at the end of the fifties showed a considerable increase in the production of houses built with concrete elements. This development has not further continued.

Presently less than 5% of the total production of the 70,000 apartments per year has the whole structural framework in concrete elements. However, elements are commonly used for certain parts, such as staircases, balconies, chute-tubes, etc. The units which would be most time-consuming to cast in place, are usually prefabricated.

There are several reasons why « true » element construction business has shown a temporary retardation for apartment houses. Generally it was not realized that element construction calls for a large effort as well in

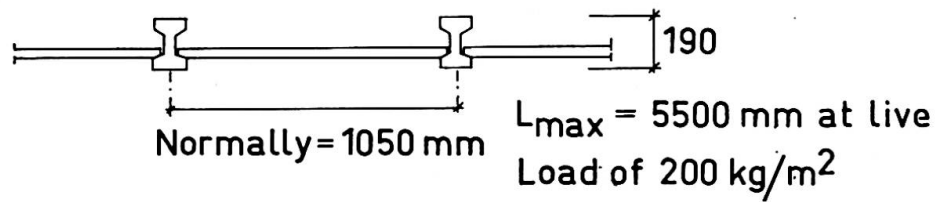
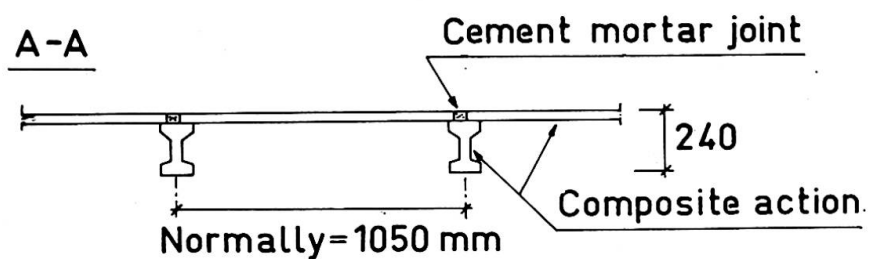
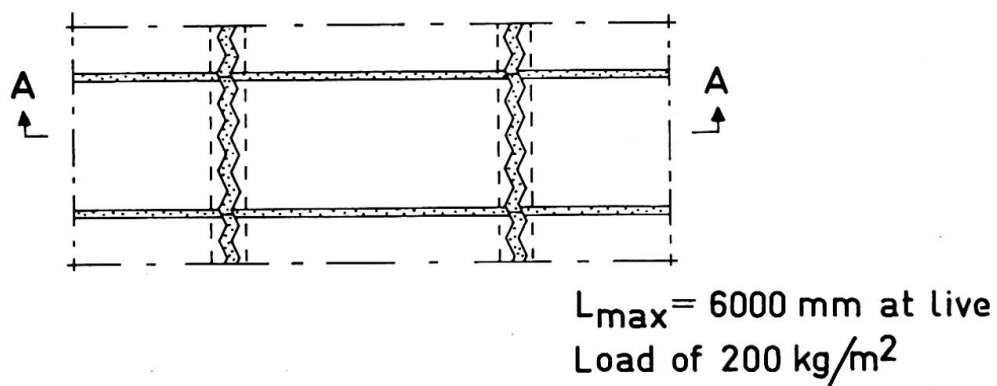
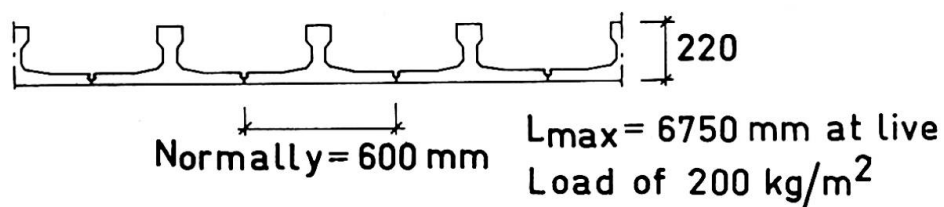
Floor, type ERGE AFloor, type ERGE BFloor, type AH

Fig. 1

research as in capital over a number of years in order to render economical advantages. Second, the traditional building methods have been rationalized at the same time. Third, it has not been possible to take advantage of the slender dimensions of elements made of high-class concrete because the

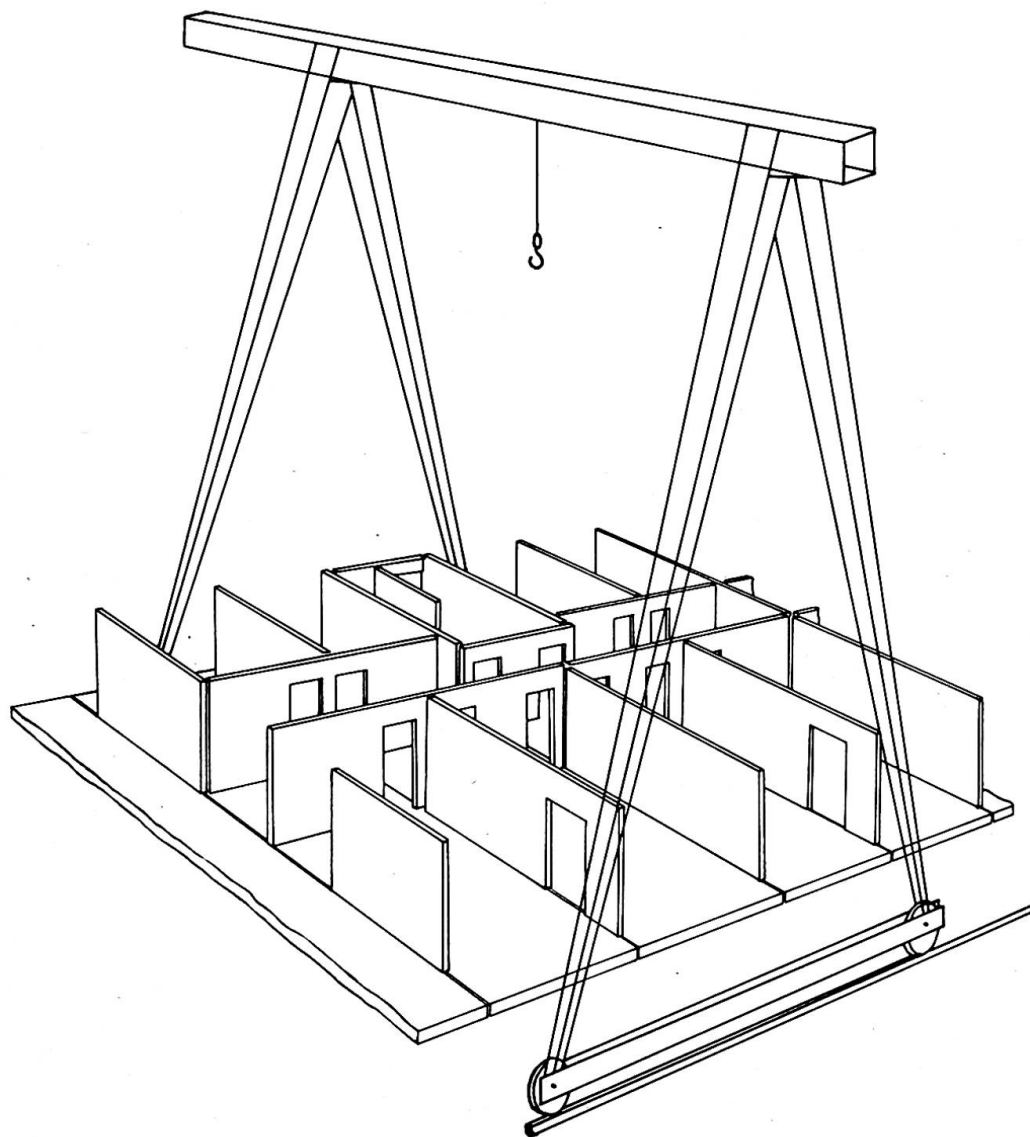


Fig. 2

thickness of the elements usually is determined by the requirement of sound insulation. However, some systems of precast structural framework have proven to be economically advantageous, and it is reasonable to believe that future development within the element industry will follow the general ideas of these systems. Two systems are described in the following.

One system is known under the name of « Skarnes heavy system ».

The structural idea can be seen from fig. 2. According to this system the whole building, including foundation-walls and floors, is precast. Only

the interior walls are load-carrying. These walls have been made up to 8 meters in length, and they are placed on the top of other walls or on the floor slabs. Floor slab elements, which can be up to 25 sq. m, are supported on very carefully levelled steel supports on the walls. By means of the steel supports it is possible to correct differences in dimensions in each storey. As the tolerance of the elements is small, it is thus possible to obtain very small deviations in the over-all dimensions.

Walls and floors are made with a careful surface finish in such a way that wall paper and wearing surface can be placed directly and walls

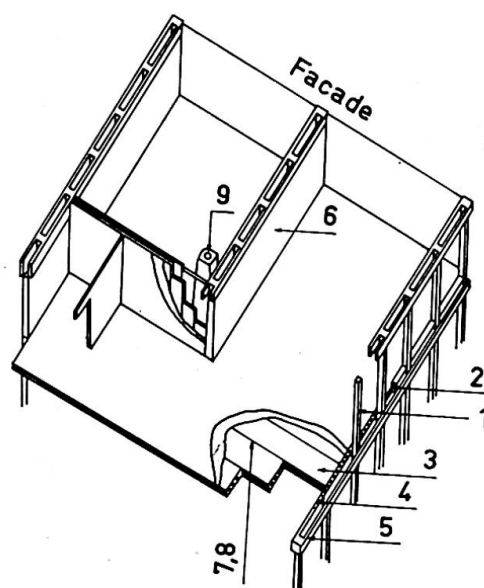


Fig. 3 - 1, Concrete column - 2, Rock wool filling - 3, Floor slab unit - 4, Cork bearing pad - 5, Floor beam - 6, Division cavity wall of 2 10 cm foam Light-weight concrete and filled with 3 cm rock wool - 7, Skim coat over joints - 8, Cement mortar - 9, Prefabricated refuse chute.

can be painted without any additional treatment. The floor slabs are joined together by means of cement mortar and welding. Sanitary installations are placed in special units. Even room-units for lift machinery, and ventilation equipment are precast.

Floor slabs are cast and transported horizontally. Walls are cast vertically in package-forms and transported vertically. Concrete quality K 250 and steel quality Ks 40 is used. The elements for buildings up to 4 or 5 storeys are mounted by means of door-cranes. For buildings with a larger number of storeys, turret-cranes on rails are used.

The second system for precast concrete element construction is called « The Gothenburg system ». See fig. 3. This system is used when structures are narrow and approximately four storeys high. This method also involves foundation walls and floor structure over basements made from precast elements.

The structural framework consists of one-storey high concrete columns on which slotted concrete beams are placed transversely. Sanitary installations are placed in the slots.

Simply supported floor slabs provided with longitudinal channels span between the beams. All elements are made to close tolerances in order that linoleum can be placed directly on the slabs after joints have been sealed in transversal direction. Wind forces in transversal direction are carried by plate-walls and in longitudinal direction by diagonal steel plate girders. The concrete elements are manufactured in a permanent factory. The tolerances obtained are ± 1 mm for the length of the columns; ± 2 mm for the width of the beams; ± 1 mm for the height of the beams; and ± 2 mm for the thickness of the slabs. The height of beams is checked very carefully, and possible irregularities are adjusted by grinding. In order that beams should not warp under curing, elements are stored on special steel beams. All elements are mounted by mobile cranes.

Industrial buildings

A large bulk of the total element production in Sweden is used for industrial buildings and warehouses. Fig. 4 shows some common systems for one-storey high industrial buildings. Columns are placed in foundations cast on the site. The main beams which are supported by the columns can be obtained up to 24 meters in span in regular reinforced concrete, and up to 35 meters in span in prestressed concrete. Fig. 4 shows profiles currently used. The concrete quality used for such elements is usually K 600. Different qualities and dimensions of steel are used.

The more common are presented in the following table.

| Dimensions in mm | Type | Yield point or 0.2 limit Kg per sq cm | Application |
|---------------------|--------|--|----------------------|
| Ø 2 | St 220 | Cold-drawn wires | Prestressed concrete |
| Ø 5 | St 165 | | Prestressed concrete |
| Ø 6 - Ø 16 | Ks 60 | Deformed bars | Reinforced concrete |
| Ø 12 - Ø 25 | Ss 70A | Cold-drawn with special devices for anchorage | Reinforced concrete |
| Ø 26 | HJS 80 | | Prestressed concrete |

Mounting is usually done by means of mobile cranes.

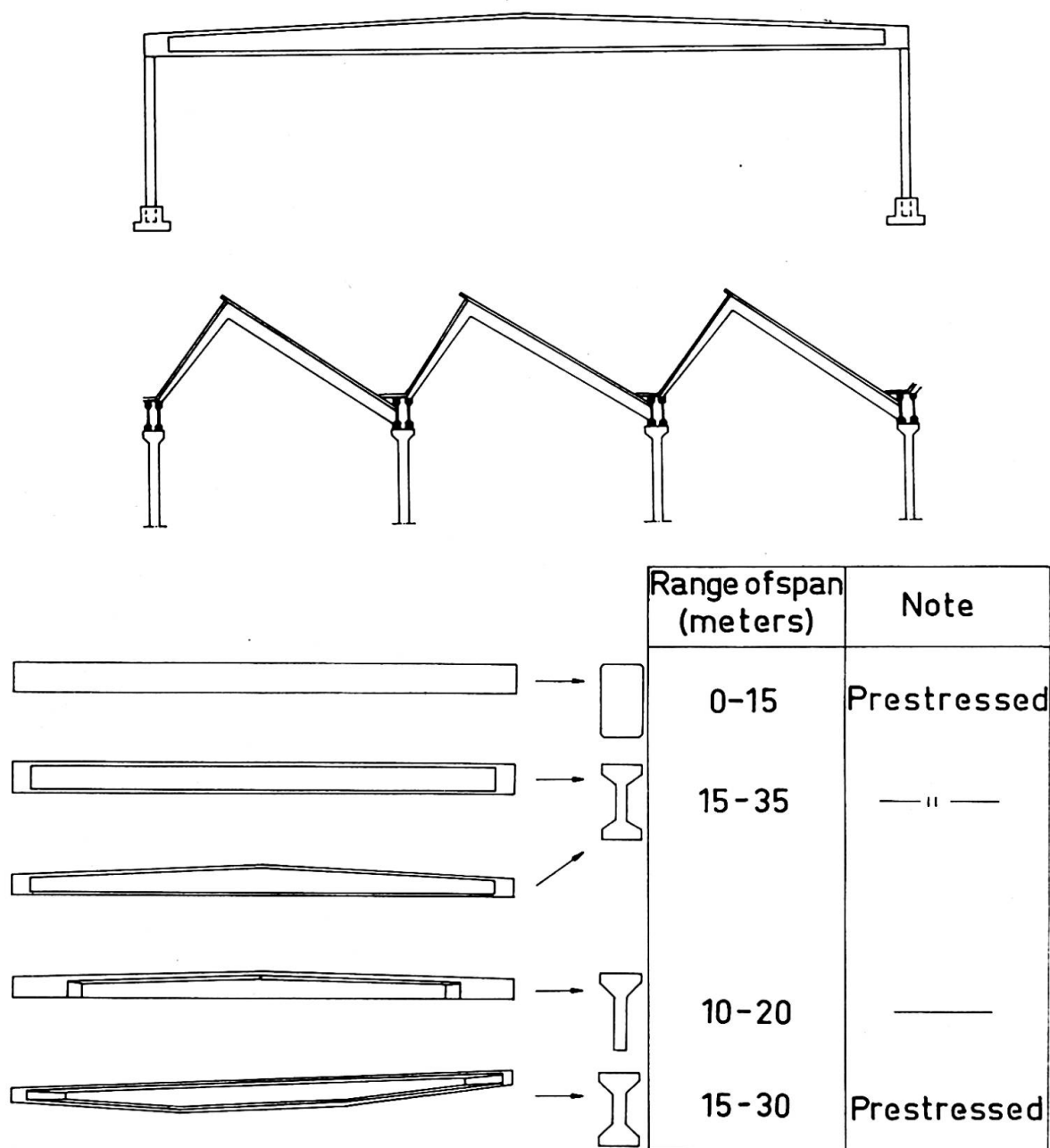


Fig. 4

Commercial and Office Type Buildings

Some commonly used structural arrangements for office buildings are shown in fig. 5. The double T-beam is a structural element which has been dominating this development. This rather simple element is shown in fig. 5. With such elements spans up to 17.5 m for roof structures and 15 m for floor structures designed for a load of 400 kg per sq.m have been used.

A limited number of tall office buildings have recently been built in

Stockholm with an exclusive use of prefabricated elements in a combined system of both steel and concrete.

The skeleton consists of steel members which are ready made in the workshop and then assembled on the site, e.g. comprising four storeys each time. The slabs can consist of prefabricated concrete elements like those in fig. 5. The walls are of different prefabricated types. This combined system has proven to be a most time saving system, and it is only due to the accompanying interest saving that the system can be economical at the present time.

Bridges

Construction of precast culverts and bridges is common in Sweden since a long time ago. Precast elements are generally used for small spans, but they have in some cases been used for re-construction of old bridges where the deck is replaced and where the structural framework must be ready in a very limited time.

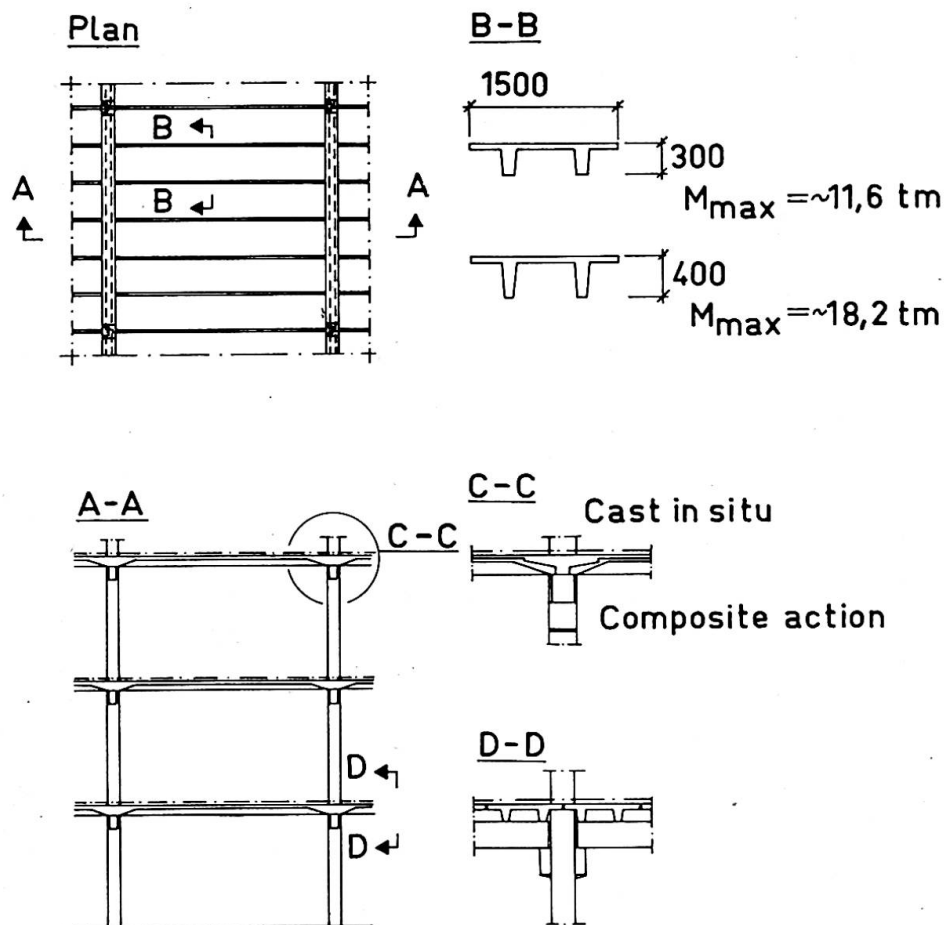


Fig. 5

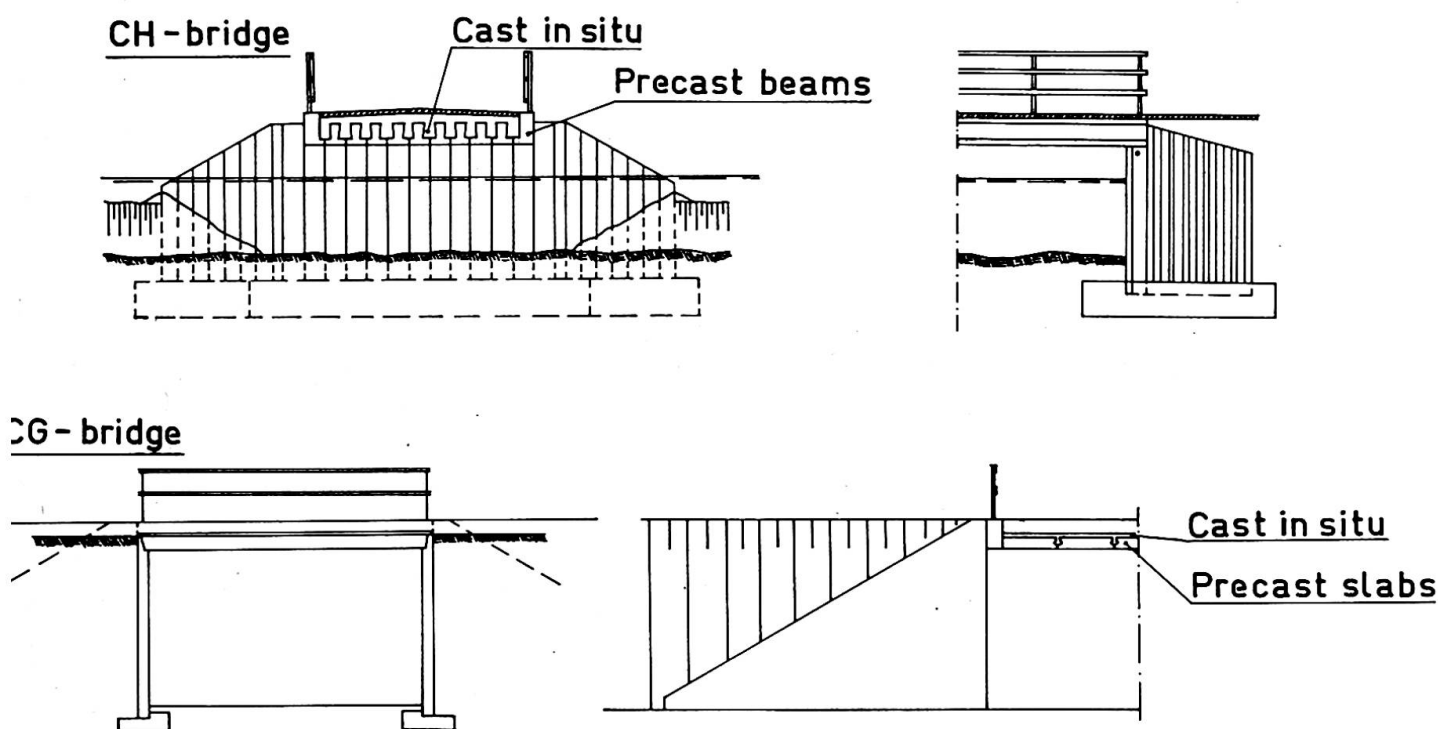


Fig. 6

Elements in common use for culverts and bridges are shown in fig. 6. A description of these elements will be given in the following.

The CH-bridge consists of a precast concrete form in which the necessary reinforcement is placed. The concrete bridge deck is cast directly in the form. The CH-bridge is manufactured in spans from 4.2 m to 9.2 m. Height of abutments may vary from 2.3 to 4.3 m.

The SCG traffic-tunnel consists of bottom slabs with interjacent stay beams, wall elements, roof elements and wing elements. The tunnel is manufactured in spans from 2.5 to 8.0 m in regular reinforced concrete and up to 10 m in prestressed concrete.

Recently bridges with larger spans have been built. However, in these cases only the structural beams have been precast.

Formwork for the concrete deck has been built on these beams, see fig. 7. Spans up to 25 m have been used; the bridges have been around 300 m long. These beams are generally prestressed. Continuity over the joints has been obtained by prestressing the concrete deck, cast in-situ. In certain cases prestressing steel was placed under the upper flange of the beams.

Lately a number of quay structures have been built from precast elements. Economical advantages were obtained due to the reduced cost of formwork.

Pipe-lines

Concrete tubes is the main production item for a number of factories in Sweden. Tubes for sewers are manufactured in dimensions from 100 to 2000 mm in diameter, pressure tubes are made for sewers for pressures up to 2.5 kg per sq.cm and with dimensions from 300 up to 1250 mm in diameter and up to 5000 mm in length. High-pressure tubes are also manufactured for pressures up to 15 kg per sq.cm with dimensions from 300

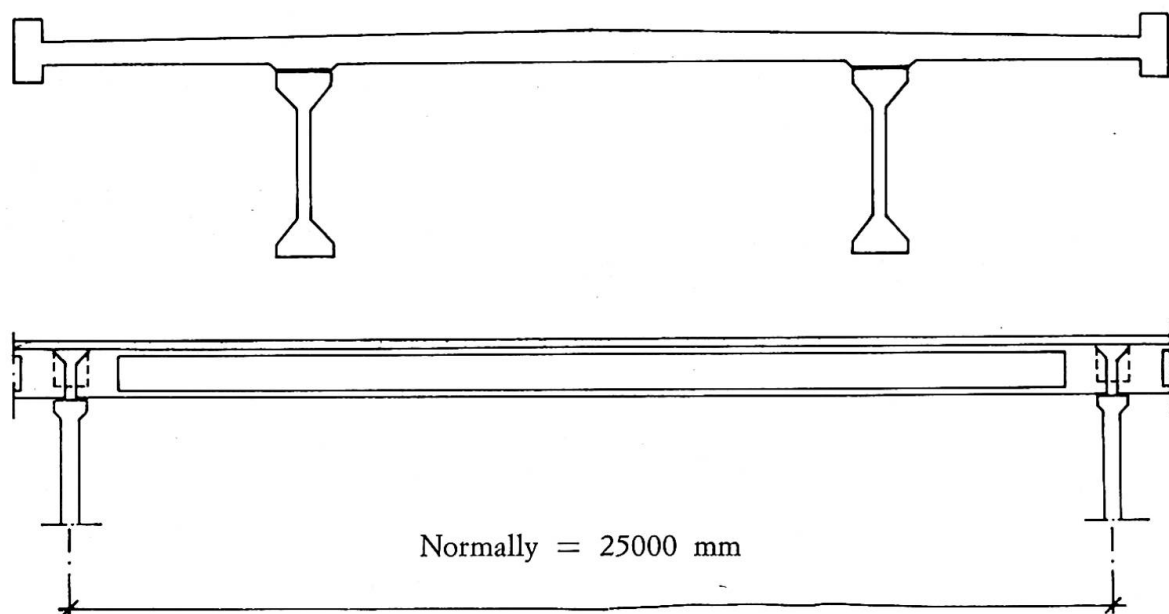


Fig. 7

to 1250 mm in diameter and up to 5000 mm in length. These tubes may be prestressed in both directions or they may be provided with a steel core. Sleeve-joints are generally sealed by rubber rolls.

The Swedish state specifications of 1949 and 1951 for concrete pipe-lines are rather unique ¹⁾. They comprise, among others, reinforced sewage pipes with diameters from 500 mm up to 2000 mm. The interesting point are the safety factors for design and the test requirements. The following three criteria are prescribed for the design and calculation of such pipes.

- 1 - In place the pipes shall carry the earth pressure with a safety factor of 1.0 against cracking.
- 2 - A crack width of 0.5 mm for single reinforced pipes and about 0.2 mm for double reinforced pipes is acceptable under earth pressure

¹⁾ « Normalbestämmelser för rör och rördelar av betong till avloppsledningar, trummor och brunnar ». Stockholm 1952.

and exceptional traffic load. Earth pressure is calculated according to Marston's theory.

- 3 - In place the pipes shall have a minimum safety factor against rupture of 1.5 at normal load and 1.3 at exceptional load.

For the pipes corresponding test requirements are as follows:

- 1 - A certain minimum crack load.
- 2 - Certain minimum loads at the above-mentioned crack widths.

The two requirements 1 and 2 are alternative, so that only one of them has to be met.

- 3 - A certain minimum rupture load.

These criteria were based on a number of tests¹⁾. The experience from these specifications is on the whole good.

They are, however, at present under revision.

Standard Specifications

Design for concrete elements follows the Swedish « State Specifications for Precast Concrete Elements, B2 1960 » issued by the State Concrete Committee. These specifications form a complement to the official concrete specifications and they cover special problems for precast concrete elements. The specifications are limited to structures in regular reinforced concrete²⁾.

The chapter on control and supervision of the manufacture is of interest. For structures cast in situ design drawings must be checked and the construction supervised by regular authorities (this does not apply to government-owned structures). It was not regarded as appropriate to let these rules apply also to precast concrete elements which often are manufactured in permanent factories far from the building site. For such elements the drawings should be checked by the local authorities or by state authorities for what concerns standard elements. The manufacture must be supervised by the « Swedish Council for Manufacture of Precast Concrete Elements ». This supervision is exercised on random samples taken several times a year. In order that the supervision may be limited to random samples it is required that factory equipment applied in the production is

¹⁾ G. Wästlund and S. Eggwertz: Dimensionering av betongrör. Betong, No. 4, 1948.

²⁾ The concrete element specifications have been translated into English and can be requested from the Swedish Cement and Concrete Institute, Stockholm 70.

of recognized quality in order that uniform and good quality of the elements can be obtained. Moreover, it is required that the plant supervision is good.

Tack-welding, tolerances for slender structures, marking of the elements, and many other problems are treated in the specifications. Some particular problems mentioned in the following are treated in the state specifications for regular concrete structures.

For the time being these specifications apply in addition to the « Provisional Specifications for Highway Bridge Structures in Prestressed Concrete » issued by the National Swedish Road Board, June 15, 1961.

Technical Problems of Current Interest

Joints

Joints are a constant source of trouble in structures built with precast elements. Development towards larger elements reduces the number of joints in a structure, but the problems do not become less serious.

Weld-joining is increasing in popularity.

One manufacturer has developed an interesting solution of the problem of concrete shrinkage. Through special methods for casting and placing, this manufacturer has succeeded in making a concrete where the coarse aggregate concentration corresponds to a concentration usually obtained only in Colcrete or similar special concretes. In this way it has been possible for the manufacturer to reduce the total shrinkage to approximately half the shrinkage of regular concrete.

Supports

Costs connected with centering of supports were earlier avoided whenever possible. However, it has been found that this often resulted in splitting failure at sides and ends of beams. The tendency towards splitting due to load was aggravated because of creep, shrinkage, and temperature movements of the elements. It is very important, that those movements are taken into account, also for a proper and safe design of the supports themselves. In fact, many damages due to improper design of the supports have appeared in prefabricated structures. There is now a clear tendency among builders to center the supports. This is done by embedding small steel plates in the concrete, or by providing the supports for smaller beams with elastic inserts (see fig. 8).

Lateral Buckling

The use of high class material for concrete elements has initiated a development towards more slender structures. Recent laboratory tests of very slender concrete beams showed failure due to lateral buckling at relatively low loads. As a consequence the problem has been studied and rules for the design have been developed. (See O. Petterson, Nordisk Betong nr. 3, 1960).

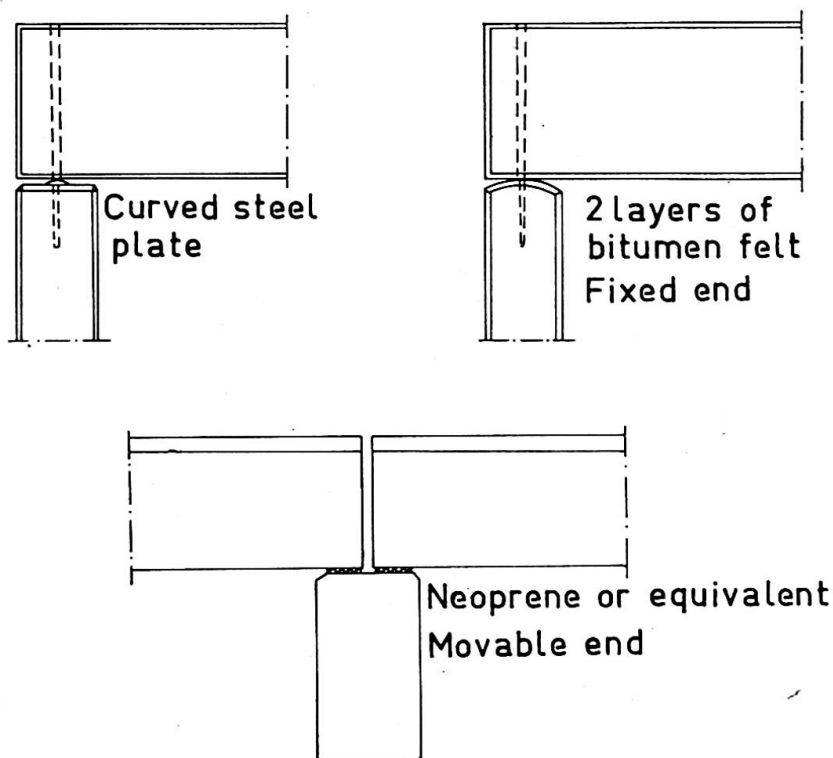


Fig. 8

Cast-in Devices for Hoisting of Elements

After failure of some devices earlier in common use, cast-in devices for hoisting concrete elements have been subjected to a thorough investigation. Some of these devices were pulled out when elements were handled at a very early age. In some cases the very devices failed. The reason for these failures was that the steel loop had been cold-deformed and the steel had aged and become brittle. Because of such failures it has now been decided that each new type of device for hoisting must be tested before it can be accepted. Moreover, it has been decided that devices which are to be cold-deformed must be made of killed steel.

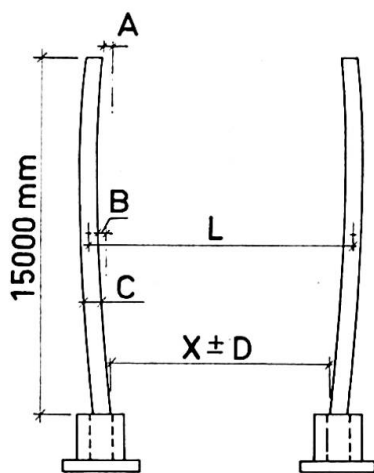
Tolerances

The problem of tolerances in connection with element construction is serious when elements are used for completing a building after the structural framework is cast. But it is also of extreme importance when considering arrangement of support. It is not known for sure which tolerances are common in the manufacture of elements in Sweden. Therefore a systematic investigation in order to measure the tolerances at some typical Swedish element factories has been initiated. In the meanwhile it has been necessary to provide recommendations for tolerances, even if they could be based only on a comparatively small number of observations. The required tolerances can be found in « Bygg-AMA 1960 ». Bygg-AMA means « General Description of Materials and Work for House Building Work ». Bygg-AMA generally forms an appendix to the contract between builder and owner. Some of the requirements to tolerances are mentioned in the following:

Elements for floor structures

Allowable deviations:

$\pm 1/500$ of the length, when the element is under 5 m, ± 10 mm. Dimensions in cross-section, ± 10 mm. However, the negative deviation for exterior cross-sectional dimensions must not exceed 10 % of this dimension. Warping, max. $1/800$ of the length and not more than 7 mm.



$$A_{\max} = 20 \text{ mm}$$

$$B_{\max} = \frac{15000}{500} = 30 \text{ mm}$$

$$C_{\max} = 10 \text{ mm}$$

$$D_{\max} = 15 \text{ mm}$$

$$\begin{aligned} L_{\text{actual}} &= L_{\text{theor.}} \pm 2 \left(\frac{A}{2} + B + \frac{C}{2} \right) \pm D = \\ &= L_{\text{theor.}} \pm 2 \left(\frac{20}{2} + 30 + \frac{10}{2} \right) \pm 15 = \\ &= L_{\text{theor.}} \pm 105 \end{aligned}$$

Fig. 9

Columns, beams, struts, etc.

Allowable deviations:

In length, $\pm 1/500$ of the length or max. 25 mm. Dimensions in cross-section ± 10 mm, or max neg. deviations for exterior dimension

10 % of this dimension. Lateral warping for mounted element shorter than 5.0 m, max ± 10 mm. When an element is more than 5.0 m long, the lateral warping must not exceed $1/500$ of the length of the element, or max. 50 mm. The position of a column must not in error deviate more than $1/200$ of the free length of the column from the position of the bottom of the column, or max. 20 mm. The position of the bottom of a column must not in error deviate more than ± 15 mm from the correct position of the nearest columns. An example of the application of these rules is given in fig. 9.

Tendencies for future development

The use of concrete elements within the building industry in Sweden is on the whole increasing. Research and development move towards elements made from high-strength materials.

A few manufacturers of precast concrete elements have obtained special permission from the authorities to use and to take advantage of high class concrete with a compressive strength of 400-600 kg per sq.cm. The manufacture at these factories is under special official control.

There is a certain tendency in Sweden towards standardization of profiles. Moreover, an increasing understanding of the importance of planning well ahead of time is felt.

Precast elements made of steam-cured lightweight concrete

Roof panels

The main part of the Swedish production of reinforced lightweight concrete elements are roof-panels of industrial buildings. Two thirds of all new industrial buildings in Sweden are covered with such elements. The panels are reinforced in the bottom for snow-loads, and in the top in order to allow for transportation and erection.

The panels are 7.5 - 25 cm thick up to 6 m long, and always 50 cm wide. In exceptional cases still longer roof panels may be obtained. The thin elements and panels designed to take maximum snow-load are shorter. See fig. 10.

Usually the panels are mounted directly on the structural beams or frames which may be made of concrete, steel or wood. The panels are

attached to the structure by steel strapping in order to be able to withstand wind loads. The strapping passes through the joints and is nailed to the top of the panels. The elements are joined by cement mortar, cast in a slit along the edges. The transversal joints are reinforced each by means of



Fig. 10 - Roof panels.

one bar which is approximately one third of the length of the panel. This continuous reinforcement reduces deflection of the elements and prevents that the transversal joint open up and damage the roofing-felt.

When lightweight concrete panels are used over humid workshops or storage areas, two layers of roofing-felt are glued to the elements by means of hot asphalt. It would seem that this method is undesirable, considering the risk of vapor condensation under the roofing-felt. Nevertheless experiences

have been good, probably because the water through the capillary pores of the material returns to and evaporates from the bottom of the panels. However, experimental investigations have shown that the elements do become moist in the winter, but that the moisture evaporates during the summer when the roof panels are warmed up by the sun.

Over extremely humid areas, or areas with aggressive atmosphere, ventilation of the top surfaces of the element is required. In such cases a roof of wooden ribs and panels or thin lightweight concrete panels covered with roofing-felt is placed over the ordinary lightweight concrete roof. It is essential that the ceiling in such cases should be covered with a vapor-tight membrane or paint.

Floor panels

Lightweight concrete floor panels are primarily used in one-family homes. Their inferior sound insulating properties are not adequate for use in apartment buildings.

Floor panels are made in the same dimensions and lengths as the roof elements, but designed for 200, 300 or 400 kg per sq.m.

The floor panels are joined in the same way as the roof panels. Elements designed for 200 kg per sq.m are joined by groove and tongue. (See fig. 11). The top surface is finished by cement mortar or a wooden floor is placed. The lightweight concrete is not hard enough to support a linoleum floor.

Wall panels

Lightweight concrete wall panels can be used as exterior walls in all types of buildings. Wall elements which carry the load vertically, in the following called « standing » elements, are manufactured storey-high, 12.5 - 30 cm thick, and usually 50 cm wide. Wall elements which carry the load horizontally, in the following called « lying » elements, are manufactured in the same dimensions but up to 6 m long.

« Standing » elements may be used as load-carrying exterior or interior walls. Maximum allowable load is 5 kg per sq.cm for the thickest elements. « Lying » wall panels are mainly used in industrial buildings, and they are reinforced for a wind load of 80 kg per sq.m. They are mounted against and bolted to the structural columns (see fig. 12). The « standing » elements are placed in cement mortar on the structural beams, and the joints between them are filled with cement mortar. The joints are formed by two half-circular grooves in the edges of each element, which form the tube through

which the mortar is poured. « Lying » wall elements can have either plane joints or tongue- and- groove joints. Strips of foam plastic provide a seal of the joint.

A 25 cm thick exterior wall made with lightweight concrete panels



Fig. 11 - Floor panels with groove and tongue.

having a specific gravity of 0.5 kg per cu.dm obtains a coefficient of thermal conductivity of approximately 0.5 kcal per sq.m per hour per deg. C.

A special type of wall with better insulating properties is manufactured. A 7 cm thick lightweight concrete plate is glued on each side of an insulating core of polystyrene foam plastic. A 22.5 cm thick element has a coefficient of thermal conductivity of 0.27 kcal per sq.m per hour per deg. C. Allowable load for storey-high insulating wall elements is 1.0 ton per m of wall.

Special panels are used for partition walls. They are 7 or 10 cm thick, 50 cm wide and storey-high. These planks are glued together, placed in stiff cement mortar and mounted in a groove in the ceiling.

A limited number of elements, larger than what was mentioned above, is also manufactured in Sweden. However, dimensions presently do not exceed 1.50 by 8 m.

Surface finish

The inside surfaces of walls made with lightweight concrete panels are finished by puttying before paper-hanging. Thin plastering is used in some cases.

If a façade has a protected place against the climate, exterior lightweight concrete surfaces may be left without any finish at all. This is often the case for industrial buildings. The wall panels are generally so smooth that no plastering is necessary. The joints are emphasized by a groove. Usually special hydrophobic plasters are applied in thin layers. It is very important that such plasters allow diffusion of vapor to such an extent that the wall may dry up even if the finish on the inside surface is vapor-tight.

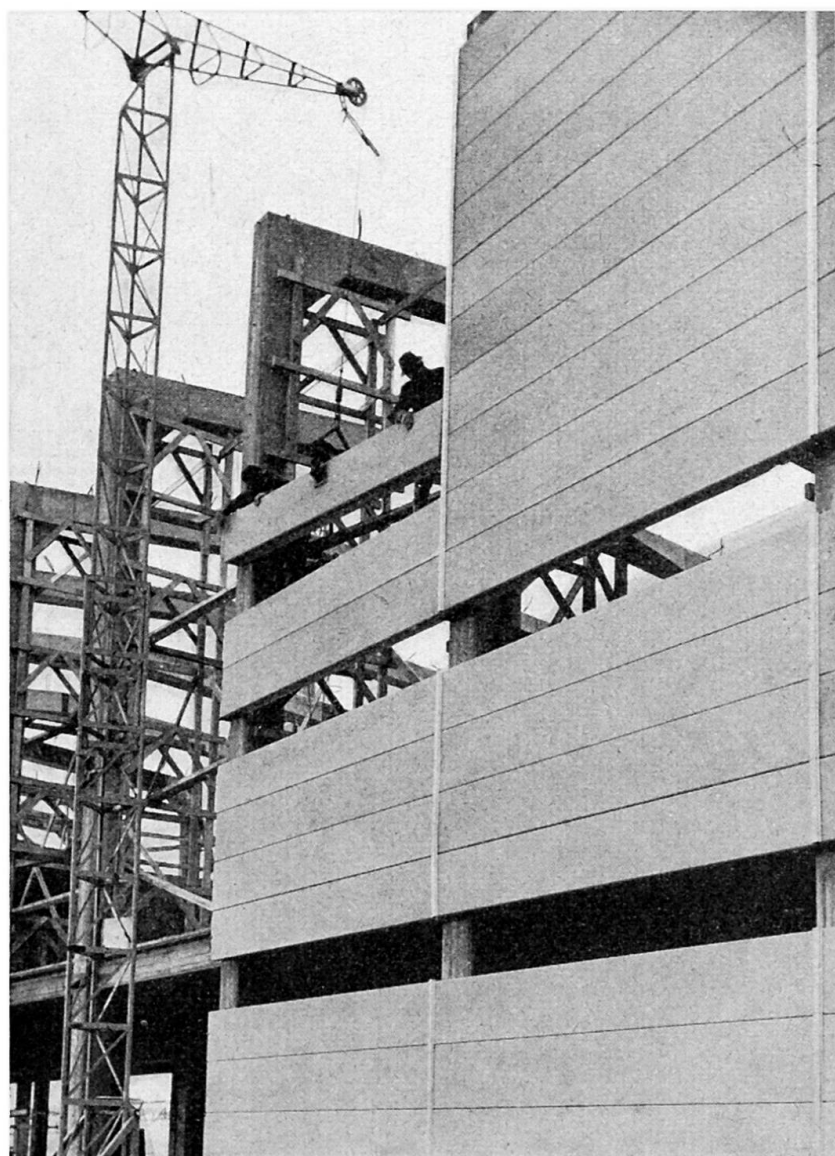


Fig. 12 - « Lying » elements.

Precast lightweight concrete elements are also manufactured with a factory-applied finish. This is done by treating the elements with a dispersion of acrylic plastic and pigment. In quality and presentation such factory-applied finishes are of a very high class. However, extreme caution is required when handling and erecting pre-finished elements.

Erection

Erection of precast lightweight concrete elements may be done by means of cranes or special equipment which can be rented from the concrete manufacturer. A large selection of hand tools is also available for the site.