Prefabricated Concrete Structures in the Netherlands [1])

Ouvrages en béton préfabriqués aux Pays-Bas

Vorfabrizierte Betonbauten in den Niederlanden

1 - Introduction

This contribution confines itself to a general survey, which does not claim to give a complete picture. In order to give a good idea of our prefabrication, especially when the general description may fail to do so, examples of some remarkable recently prefabricated structures are given.

The application of prefabrication may be considered for:

1 - Housing (various systems).

2 - Industrial buildings.

3 - Bridges.

4 - Hydraulic structures (caissons, subaqueous tunnels, quay-walls, dolphins, etc.).

5 - Miscellaneous (big pipes; road elements; sleepers; portal frames for electrical railway traction-lines; blocks for dike-protection, etc.).

In applying prefabrication special problems are met in regard to:

1 - Manufacturing of elements (factory or site; dimensions; tolerances).

2 - Transportation of elements (from factory to site; on the site; horizontal or vertical, etc.).

3 - Assembling the elements into structures (structural connections; filling joints; prestressing; welding, etc.).

4 - Finishing off the structure (plaster, tiles, touching up, etc.).

The development of prefabrication in the Netherlands will be shown in the following chapters, which are more or less chosen at random.

For lack of space it was necessary to reduce the number of chapters. An important and interesting chapter on the application of prefabrication in building of homes was omitted, as well as a chapter on caissons for dike-enclosure and one on bridge-piers. Several others could have been added.

First some information about the Stupre is given.

2 - The Stupre

The Stupre was founded in 1959 as a subsidiary organisation of the (Netherlands) Concrete Association (Betonvereniging). Its purpose is to study problems in the domain of Prefabrication in building-constructions, in order to come to a better understanding and later on to draw up rules. The membership of the organisation is mixed; it consists of representatives of different trades and branches such as architects, contractor firms, consulting engineers, factories, housing-systems, research laboratories, etc.

The Stupre organisation is divided into 4 sub-committees:

a) Principles of Prefabrication.
   Subjects: transportation problems; magnitude of series and cost; tolerances; permissible stresses; codes.

b) Structural Connections.
   Subjects: Joints, protruding reinforcement, etc.

c) Lightweight Concrete.
   Structural and other application of l.w. concrete.
   Designing.

d) Use of Prestressing in Prefabrication.
   Reference should be made to the report F.I.P. Congress, 1962, Rome: Some aspects of precast prestressed concrete in the Netherlands. Influence of shrinkage and creep when prefabricated beams are connected to continuous beams by cast-in-situ concrete; economy of statically determinate girders with regard to prefabricated beams, that are afterwards made statically indeterminate, etc.

Some publications already appeared in technical papers; others will follow soon. Some of the data given therein have been used in this issue (e.g. transportation).

3 - Prestressing

In building of houses prestressing is almost always limited to floor-elements, although many systems only apply mild steel reinforcement.

Prestressing is predominantly used in prefabrication of industrial buildings and bridges (see chapter on Bridges), while in hydraulic structures there is a tendency to an increasing application of prestress.

Pretensioned elements are almost always made in factories, but when it concerns large quantities, it may be done on or near the site (see chapter on Bridges). Dimensions and weights are limited by economic considerations and the possibilities of transportation (see there).

The elements are manufactured as floor elements (solid or with hollow cores), roof girders, floor beams, beams or slabs for small bridges, piles for foundations, etc.

To arrive at a more economical use, part of the wires can be bent up; the height or the thickness can be varied, if the structure lends itself to it (e.g. trapezoidal beams for roofs, etc.).

Floor elements are generally covered with a layer of cast-in-situ concrete, which serves as pressure element for the live load. The layer is provided with a mild-steel reinforcement for transverse load distribution and shrinkage. Sometimes transverse prestress is applied for that purpose.

The contacting surfaces are roughened and (or) provided with protruding bars for better shear connection.

Post-tensioned elements are made both on the site and in the factory, but in the latter case there are the same limitations as mentioned for pretensioned elements.

Girders or main beams for industrial building are often composed of several short elements that are connected by prestress in longitudinal direction. The joint (1-2 cm) is filled with dry mortar. Joints without mortar are seldom used, because it is very difficult to make them fitting sufficiently accurate. Synthetic glues outgrow the experimental stage. The elements are generally prestressed on a floor on the site and the completed beam is hoisted by cranes in its definite position. There is a tendency to apply as long elements as possible, to reduce the number of joints (weaker place; extra work; saving cable-ducts, etc.). In the case of long beams that cannot (or laboriously) be handled as a whole by the cranes, the elements are generally placed in their definite position on temporary or definite supports

and then connected by prestress. The same is done with separate beams over multiple spans, which are afterwards connected by prestress to a continuous beam.

It is also done with portal beams, which are later connected to the columns. In all these cases the elements must be sufficiently reinforced with regard to transportation and hoisting (mild steel reinforcement, pretensioning or part of the post-tensioning).

3 a - Joints

The Dutch « Recommendations for Prestressed Concrete 1962 » give the following directions for the execution of: Joints perpendicular to the beam axis between prefabricated elements, that are connected by prestress to a structure.

In relation to the width of the joint two cases are distinguished:

1 - with a joint width of 1.5 to 3 cm.
   The joint should be filled with a rather dry mortar of cement and sand (water-cement ratio max 0.35), which must be tamped in the joint.
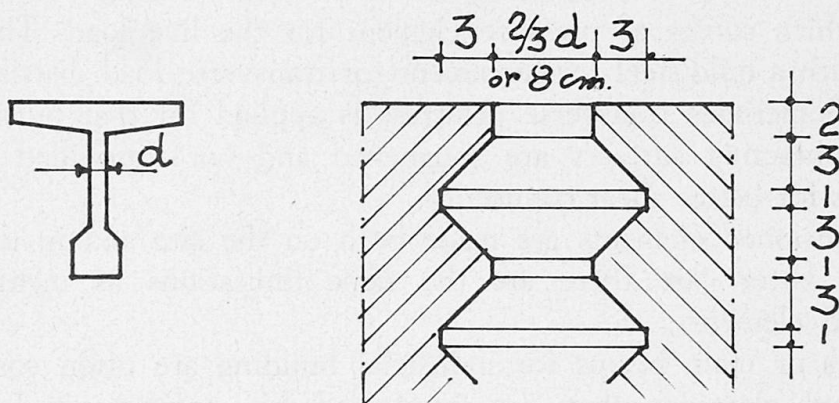

Fig. 3a.1

When the ratio of normal to shearing force in the joint in the stage of rupture is greater than 2 and smaller than 3, the end surfaces of the elements must be roughened. A smaller ratio than 2 is not allowed.

2 - with a minimum joint width of 8 cm and a maximum joint width of 2/3 of the thickness of the concerned element (fig. 3a.1).

The joint should be filled with vibrated concrete of at least the same strength as that of the elements. The end surfaces of the elements have to be roughened.

When the ratio of normal to shearing force in the joint in the stage of rupture is greater than 1 and smaller than 2, the end surfaces of the elements must be provided with a sharp-edged toothing as indicated in fig. 3a.1. A smaller ratio than 2 is not allowed.

4 - Transportation of the elements

Transportation of prefabricated elements from factory to site mainly occurs by motor-truck, sometimes specially designed for the transport of one kind of element, e.g., horizontally lying floor elements, vertically standing wall elements, piles, etc.

Transportation of large elements in their definite position is preferred, although not always possible (height limit may be greater than width limit).

The dimensions and weight of a transport are limited by prescription for road transport. For normal cases the width is limited to 2.50 m, the height to 3.80 m, but a relief from this rule is easily granted till a width of 2.80 m and a height of 4.00 m. For greater dimensions it is difficult or impossible to get relief, unless when the transport is escorted by police. The length depends on the kind of vehicle and varies from 10 m (two axles) till 18 m (truck with trailer). The load may project about 3.5 m before the vehicle and max. 5 m behind; the maximum transportation length is 22 m, but relief till 25 m is not unusual. The route for special transport can be fixed by the authorities, as well as the maximum speed and the hours of transport (e.g., at night).

The wheel load is limited till 4 t per wheel, which in the future will be 10 t per axle. For roads of minor importance the permissible dimensions and wheel loads are less; these roads are indicated with shields (B-roads).

Thus, the width of horizontally transported elements is limited to 2.50 till 2.80 m (exceptionally 3 m) and the height of vertically transported elements from about 2.50 m (normal truck) till about 3.20 m (truck with special low loading platform; e.g., fig. 4.2).

Special care must be given to the support of the elements resting on the truck floor, which generally has a minor stiffness than the elements, especially if transported vertically.

On the site the transport should be limited as much as possible. In some house-building systems the elements are hoisted by crane from the truck and immediately afterward placed in their definite position. This requires an
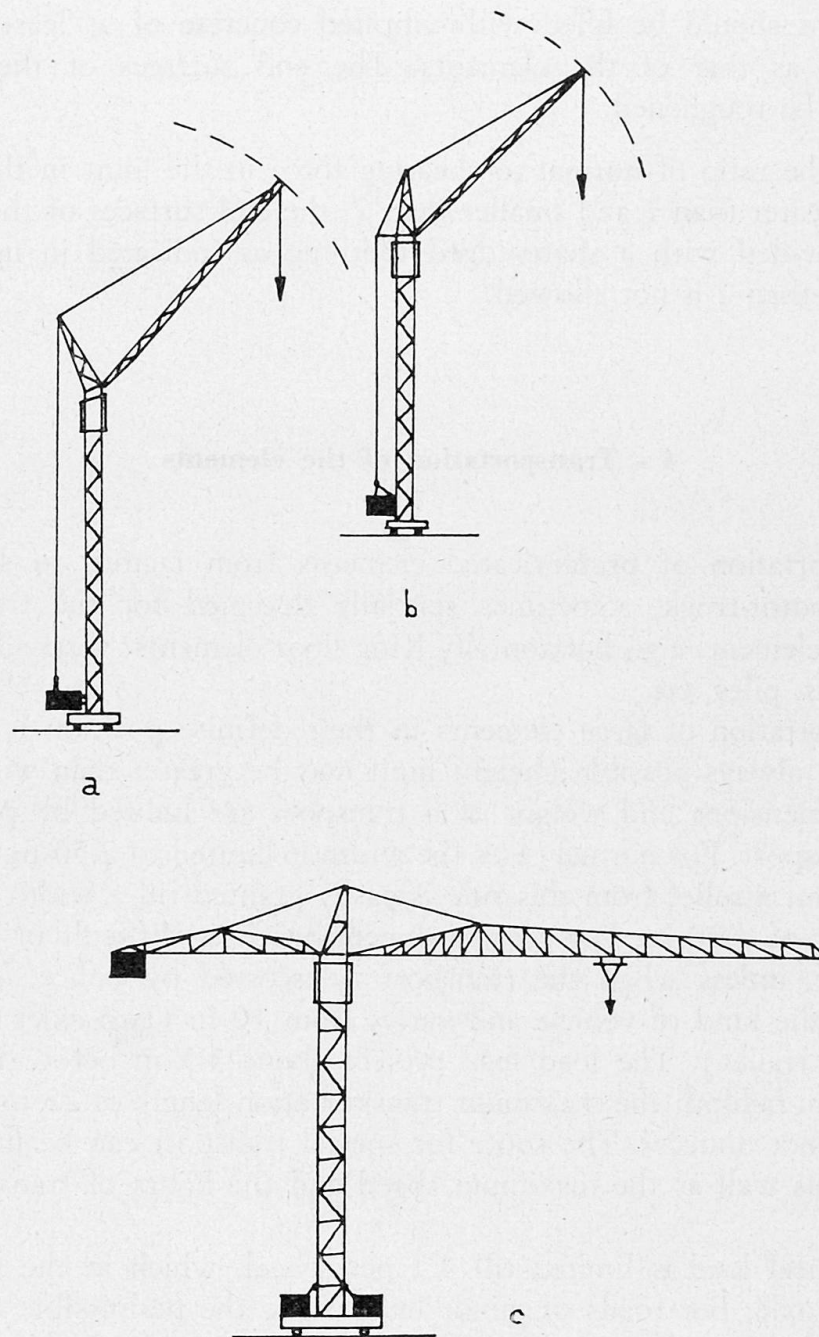
Fig. 4.1: a, b, c - Types of building cranes used the Netherlands (tower-cranes).

excellent transport and site organisation, which can be disturbed by delays caused by movable bridges, railway-crossings, rush hours, etc. For these inconvenients a certain stock may be inevitable.

Unloading a truck is usually done by the same crane that mounts the elements (similar weight).

Vertical transport of elements on the site is mainly done by cranes, movable on rails along or around the work and having a jib long enough to

reach every part of the structure; if that is not possible, a crane at each side is used. Heavy elements may also be handled by two cranes. Sometimes two different cranes are used, one for the heavy elements and one for the other elements.

The crane capacity has been increased during the past 15 years from about 20 to 40 m t up to 50-80 m t or more.

The maximum weight of the elements increased from 0.5-1 t some 15 years ago to 5 t; for portal-framed cranes this is still higher. An extreme example is the portal-framed crane for the construction of the Nabla girder (see description), which has a capacity of 250 t.

The aim will be to arrange the work in such a manner that the cranes are constantly working and to design the elements to such weight that the

Fig. 4.2 - The Rottinghuis-housing system. The lorries with the floor elements are unloaded from the trailer by a fixed crane. In the background the portal framed crane for mounting the elements.

cranes are loaded as much as possible to their maximum capacity. This requires a close collaboration between architect, structural engineer and contractor from the very beginning of the project. This ideal will hardly ever be reached. However, it is more and more admitted to be the only possible solution.

Mainly two types of cranes are used: see fig 4.1 a, b and 4.1. c; 4.6.

In most cases they can be made higher by insertion pieces, and only seldom they are telescopic. Most cranes can be disassembled and also easily transported over roads.

For low long buildings with moderate width sometimes portal cranes are preferred (house-building system Rottinghuis: fig. 4.2). These can more easily bear heavy loads independently of the distance (see description of the construction of the Nabla girder: loads of 250 t!).

If beams or other elements are prefabricated on the site, it is not always possible to make them at a place that can be economically reached by the building cranes. In that case large elements are transported by hanging them in one or two portal-shaped transporters that move on rails (in most cases) and are pulled by winches (bridge girders; reinforced concrete piles, etc.).

For industrial buildings one storey high, having beams of large spans, often movable cranes with rubber tires or caterpillars are used for weights till 25 tons or even more. Heavy elements are handled by two cranes (figs. 4.5 and 7.4).

DWARSTRANSPORT WAGEN
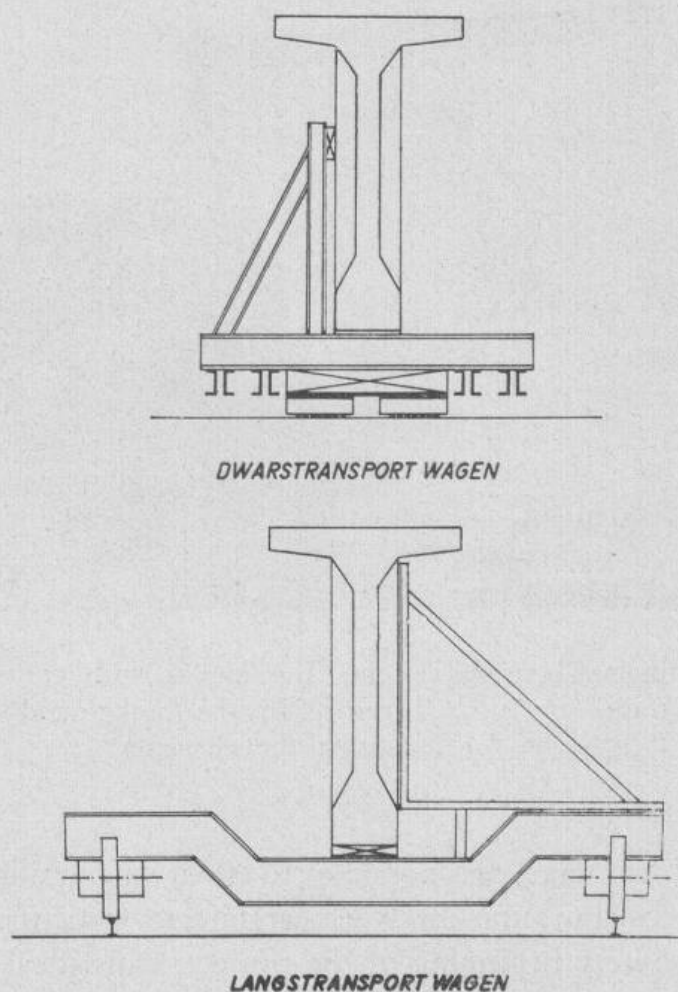
LANGSTRANSPORT WAGEN

Fig. 4.3 - Transverse and longitudinal transport of heavy beams on the site. Dwarstransport = transverse transport. Langstransport = longitudinal transport.
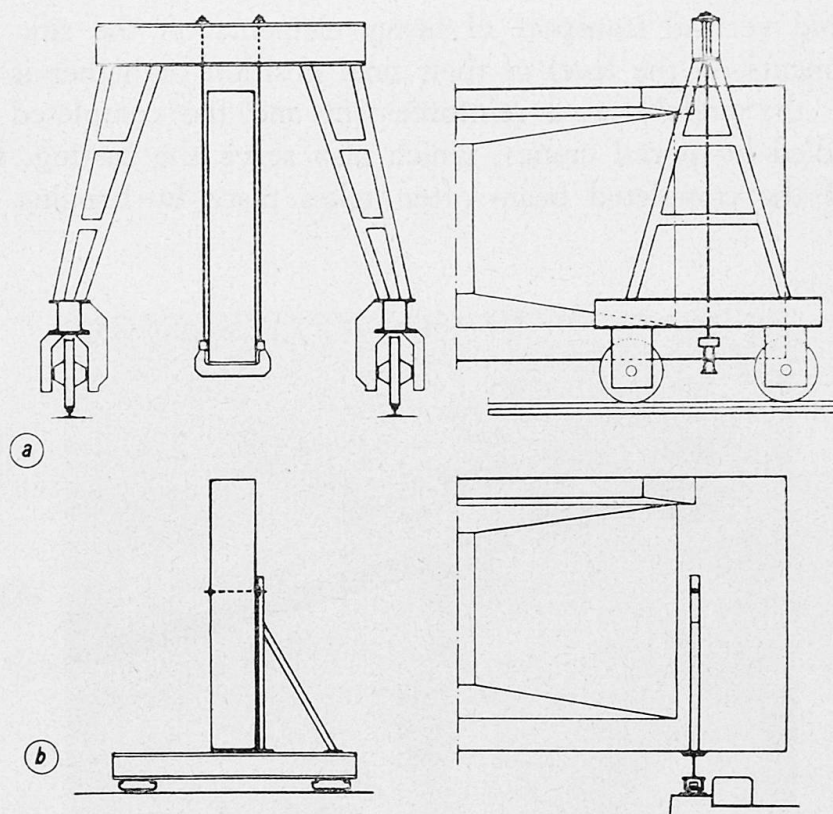
Fig. 4.4 - Longitudinal and transverse transport of bridge beams.

Fig. 4.5 - Handling a bridge element by two movable cranes.

To avoid vertical transport of heavy elements on the site, precasting of these elements on the level of their final position or higher is preferred. On the site the prefabricated reinforcement and the completed beam are usually handled by portal cranes, which also serve the casting. Horizontal transport of the completed beam often takes place by hanging it in two
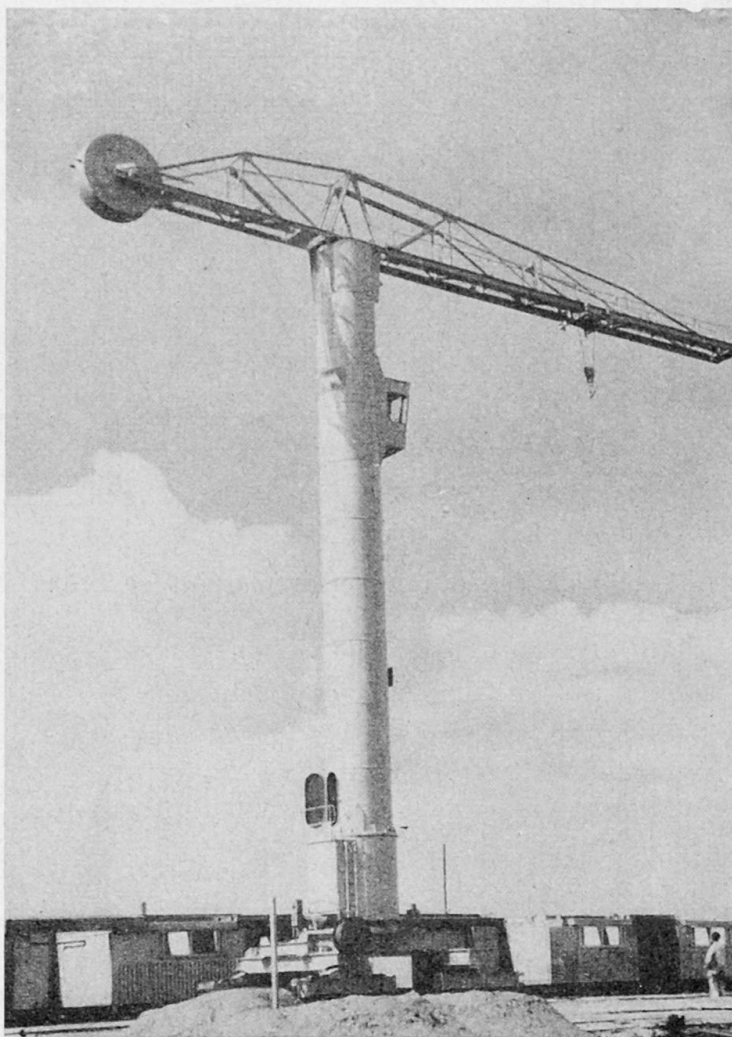

Fig. 4.6 - Horizontal transport on the site by portal - framed cranes.

portal-shaped wagons, one at each end (figs. 4.3 and 4.4). Further narrow-gauge railway track is used (figs. 8.8 and 8.9). Transportation on the pier perpendicular to the bridge axis often takes place by shallow roller-wagon-devices, which can bear some 25 t each (fig. 4.4).

Hydraulic jacks are used whenever a heavy element must be raised or lowered over small distances. By underpinning and repeating the action, raising

or lowering over greater heights is possible (raising or lowering of complete bridges, lowering beams from their temporary supports on their final bearings, etc.).

Ship and railway transport are practically used only when both the factory and the building site are located on a waterway, resp. a railway. In other cases the cost of transshipment is likely to become too high and the chance of damage is increased. Ship transport will also be considered for elements with dimensions or weights that cannot be transported by road. Ship transport is cheap on long distances and when great quantities are involved.

Transportation in water is the obvious and often only possible means of transport of heavy elements that can float or can be made floating, like caissons, tunnel elements, pipes, hollow piles, etc. This has been done in the Netherlands with the caissons for the dike-enclosures after the storm surge of February lst, 1953, with caissons for quay-building (Rotterdam, before and after the war), with the tunnel elements for the tunnel under the river Meuse (Rotterdam, 1940).

It will be done with a great part of the tunnel elements for the subway tunnel in Rotterdam and for the higway tunnel in Amsterdam, both under construction now. The magnitude of the elements is of the order of $60 \times 10 \times 6$ m (Rotterdam) to $60 \times 23 \times 7.5$ m (Amsterdam).

Transportation from factory to site on one or more pontoons is often done with steel bridges having weights of several thousands of tons; they are lowered on their bearings by letting water in the pontoons. There are as yet no examples of concrete bridges thus transported in our country but it will probably be done with the elements of the future bridging of the estuary Oosterschelde, length about 5 km.

For short distances floating cranes are often used, e.g., for transport of bridge beams from the building site on the river bank to the bridge structure (some hundreds of tons). This has been done with the beams of the Amstel bridge in Amsterdam in 1954 and recently with the beams of the prefabricated bridge in Roermond (see description: weight 120 and 130 t).

The caissons for the dike-enclosure in 1953 were prefabricated on a quay-platform and lowered in the water by floating cranes (weight 180 t).

5 - Bridges

For prefabricated bridges almost exclusively prestressed concrete is used. Pretensioned bridge elements are mainly used for the smaller spans up to about 20 m; post-tensioned elements for spans up to 50 m till now.

Pretensioned elements in the shape of a reversed T are exclusively used for slab-bridges (figs. 5.1 and 5.2). Between the elements cast-in-situ concrete is poured, provided with mild-steel cross-wire reinforcement in the top layer and near the underside mild steel bars through holes in the prefabricated elements in transverse direction. Sometimes transverse prestress
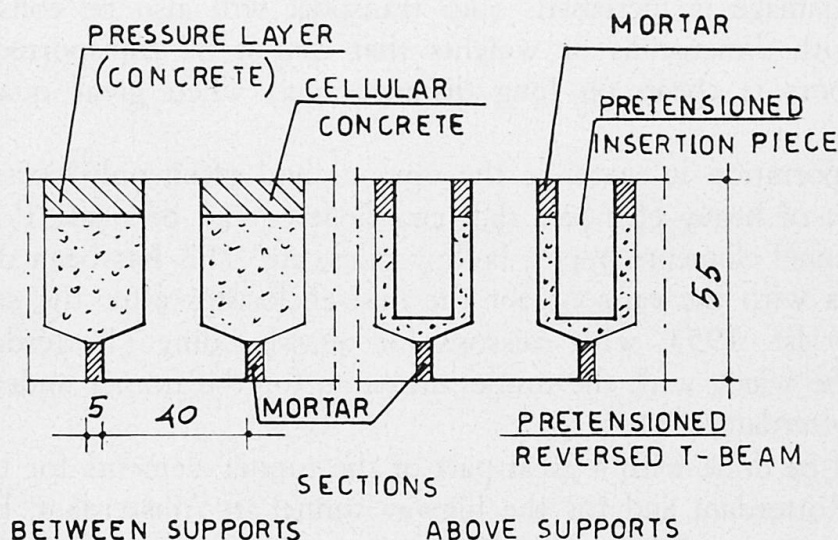

Fig. 5.1 - Composite viaduct in Highway 4A; continuity connection.
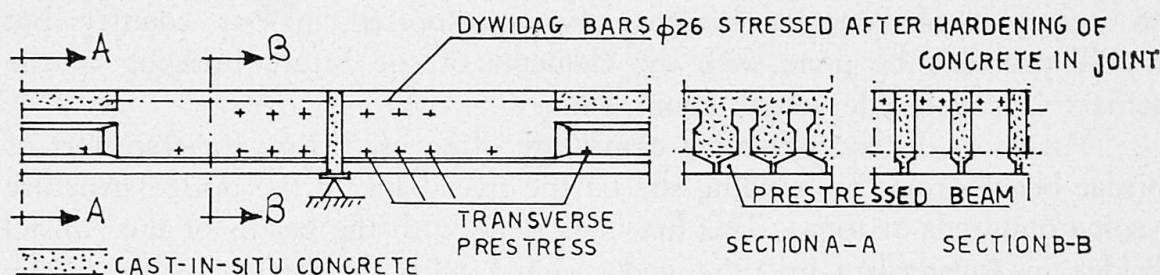

Fig. 5.2 - Continuity connection of a composite bridge.

is applied. To avoid shrinkage cracks a wire mesh net is generally laid in the top layer too.

Pretensioned slab elements, solid or with hollow cores, are also used for slab-bridges with minor spans (up to about 10 m). A layer of cast-in-situ concrete with normal reinforcement provides for the connection and transverse load distribution and serves as pressure « flange » for statically determinate structures on two supports. The transverse stiffness is badly influenced by the longitudinal joints, that have no reinforcement in transverse direction

over the thickness of the pretensioned slab, unless transverse prestress is applied. This disadvantage is of minor order at reversed T-sections with mild steel bars through openings in the pretensioned beams. The upper surface of the elements is roughened and provided with protruding bars or stirrups to give better adherence from the new concrete to the older.

SPAN   29,8 m
CENTRE DIST. 1,50 m.
AMSTERDAM 1956

CAST-IN-SITU CONCRETE

SPAN 45,10 m.
CENTRE DIST. 2,056 m.
GORINCHEM 1959.

SPAN 50,00 m.
CENTRE DIST. 2,56 m.
ROERMOND 1960.

SPAN 50,56 m.
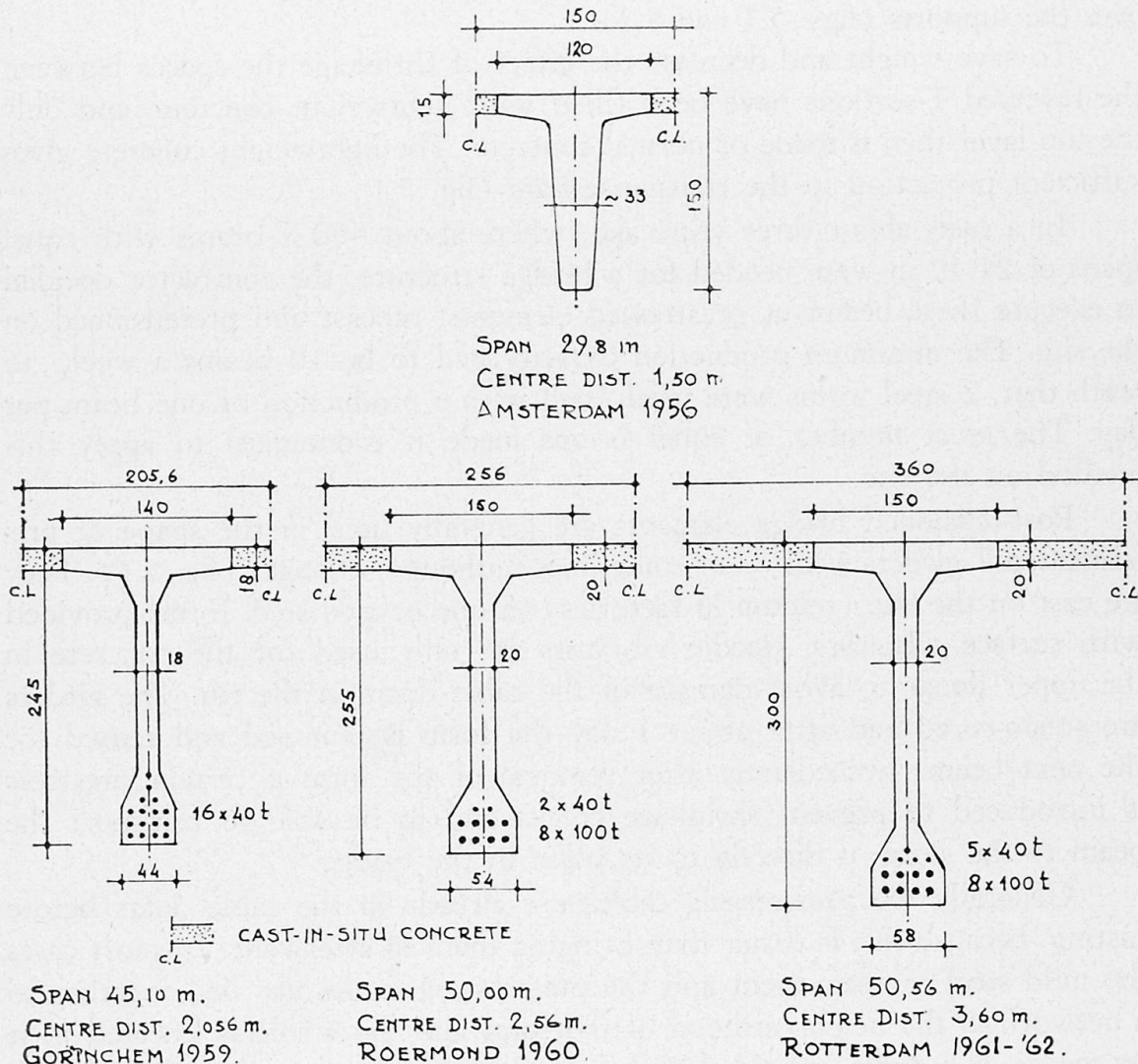CENTRE DIST. 3,60 m.
ROTTERDAM 1961-'62.

Fig. 5.3 - Sections of post-tensioned T-beams for bridges.

In both cases the pretensioned elements serve as formwork for the cast-in-situ concrete, so that they must be designed to be able to carry that weight. After hardening, the composite structure must be able to carry the live load too.

The statical behaviour of the composite section is influenced by shrinkage and creep in a manner that cannot be exactly calculated, as it highly depends on the almost unpredictable amount of shrinkage and creep of the cast-in-situ concrete with regard to that of the pretensioned elements. The effect of

prestress seems to be often neutralised to a large extent by the shrinkage stresses and particularly the bending moments caused by them. The ultimate strength, however, seems to be only little influenced by it, but tests are not yet available.

For bridges, continuous over more spans, it is possibile to insert pretensioned slab elements between the reversed T-sections in the top of the slab over the supports (figs. 5.1 and 5.2).

To save weight and decrease the effect of shrinkage the spaces between the reversed T-sections have been filled with lightweight concrete, and only the top layer then is made of normal concrete. The lightweight concrete gives sufficient protection to the transverse bars (fig. 5.1).

In a case, about three years ago, where about 400 T-beams with equal spans of 21.50 m were needed for a bridge structure, the contractor decided to execute these beams as prestressed elements, precast and pretensioned on the site. The minimum production capacity had to be 10 beams a week; to reach that, 2 steel forms were used, each with a production of one beam per day. The great number of equal beams made it economical to apply this method on the site.

Post-tensioned bridge elements are generally used in the shape of prefabricated T-girders with — or sometimes without — flanges (fig. 5.3). They are cast on the site (seldom in factories) in one or two steel forms provided with surface vibrators. Needle vibrators are only used for the concrete in the upper flange to avoid damage of the cable ducts in the rib. The girders are steam-cured and after about 1 day the form is removed and reused for the next beam. Immediately after removal of the form a certain prestress is introduced to prevent shrinkage cracks and to be able to transport the beam to the store or directly to its place in the bridge.

Generally the prestressing cables are already in the cable ducts before casting, because this is easier than bringing them in afterward. In most cases the mild steel reinforcement and the prestressing cables are tied together to a network in the neighbourhood of the form and the whole is lowered in it by means of a crane, provided with a steel grid beam over the whole length of the net. The side panels of the form can be moved or turned sideward as a whole, so that the reinforcement net can be easily placed and the finishing touches can be put to it. The removal of the form is an easy procedure, too.

Dimensions and weights of the beams increased in the course of the approximately 15 years of application (fig. 5.3). The spans increased to 50 m, the weight to more than 100 t; the distance center to center of the beams to 3-4 m; the space between the upper beam flanges from 20 or 30 cm to 1 m and more. The distance of 20-30 cm was very convenient, for it needed a minimum of formwork. The sides of the upper flanges are roughened by using a profiled form for them.

As far as we know, the deck is always prestressed transversely, by Dywidag bars or Freyssinet cables. The cross-beams are prestressed simultaneously with the same system. The tendons are but little bent or not.

Some 5 years ago almost only Freyssinet cables of 20 and 40 t were used as longitudinal tendons and Dywidag bars ⌀ 26 mm for transverse
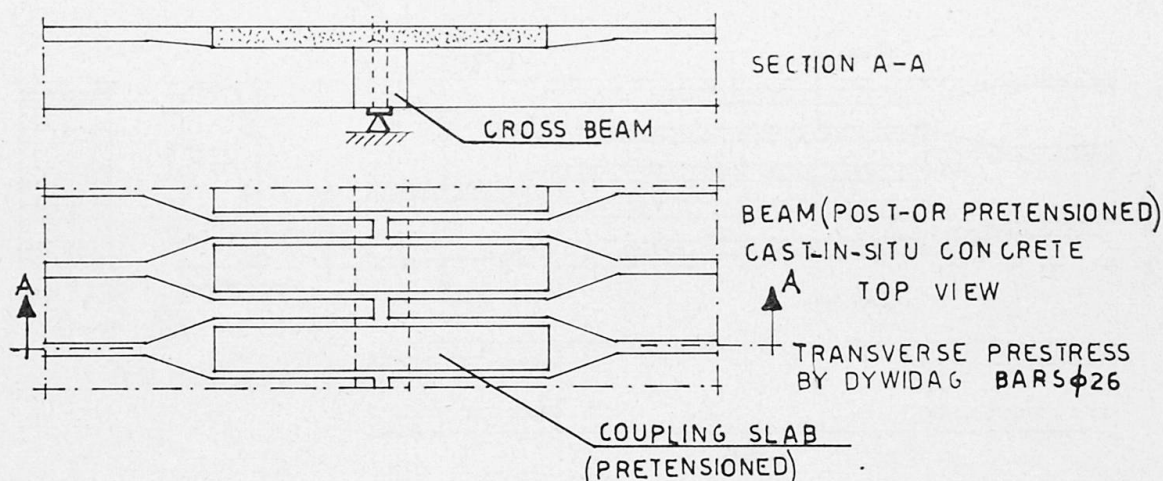

Fig. 5.4a - Connections for single span bridge beams to continuous structures.

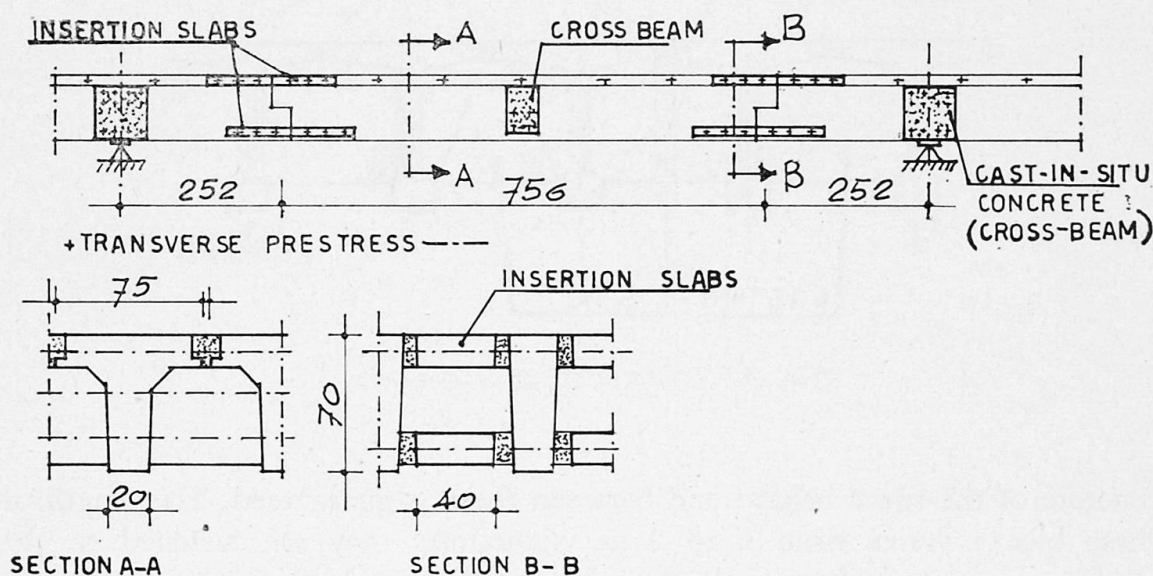Fig. 5.4b - Connection to continuous beam where Mpos = Mneg = Minimum (due to live load).

prestress. During the past 3 or 4 years Freyssinet cables of about 100 t are used, too, and also other systems with prestressing forces of 100 t or more (Polensky and Zollner, B.B.R.V.). Other systems are seldom used or not. Dywidag bars ⌀ 26 mm and ⌀ 32 mm are mainly used for transverse prestress, less for longitudinal. For large prestressing forces a moderate

number of heavy tendons is preferred to a greater number of, for instance, 40 t tendons (fig. 5.3). Generally the end sections of a beam with the anchorage elements in them are precast separately to be able to give utmost care to position and direction of the anchorages and to the quality of the concrete. They are cast with anchorages downward so that good filling with
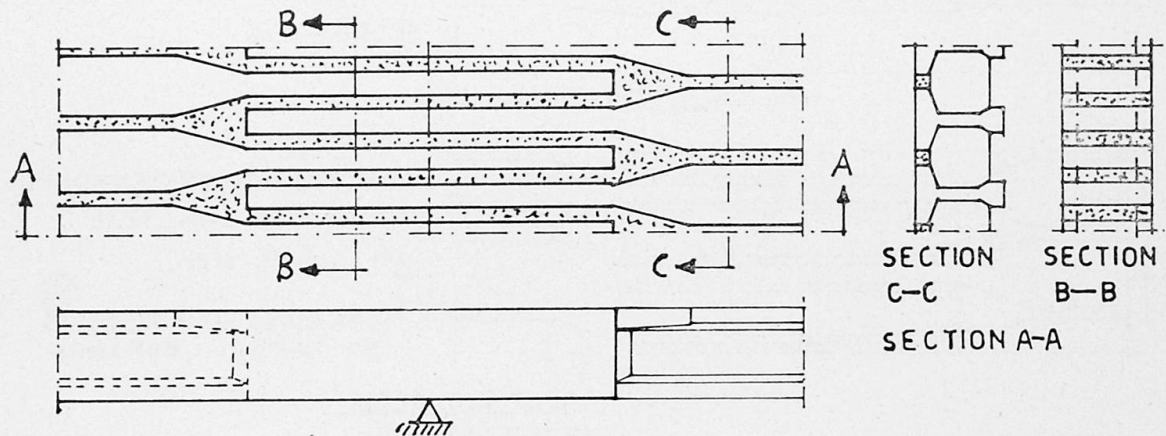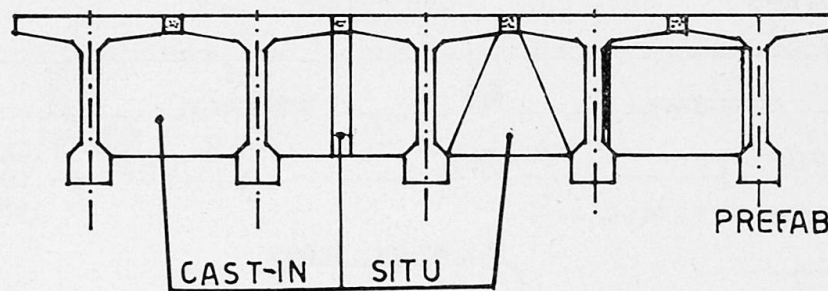

Fig. 5.4c

Fig. 5.5 - Execution of cross-beams.

concrete of the space behind and between them is guaranteed. The length of these blocks varies from 1 to 2 m. Sometimes they are fastened to the reinforcement network and placed together with it in the form (by the crane).

Fig. 5.4 gives some examples of the connection of single span bridge beams to continuous structures. They all have the principle of a prestressed (generally pretensioned) slab above the supports (or near them, fig. 5.4, b). The whole is prestressed in transverse direction and so enables the bridge to act as a continuous structure.

The number of cross-beams varies from 1 to 4 (seldom more), except those at the ends. The number generally increases with the length of the span. The cross-section is in most cases a rectangle, which is easiest to make.

The cross-beam can be cast separately between the main girders. In other cases the cross-beam is cast as part of it with the girder and only a joint equal to the clear distance between the flanges is filled with concrete (fig. 5.5). Further it is possible to use precast cross-beam sections which are hoisted between the main beams; the joint is filled with mortar or concrete. Precautions must be taken that the transverse cable holes are not filled with concrete (rubber ducts, pieces of metal ducts, sealed with sticky tape, a.s.o.). In all cases the cross-beams are prestressed.

Bridges consisting of elements that are connected in longitudinal direction by prestress (like the Marne bridges in France) have been applied in the Netherlands only incidentally. However, for the Nabla girder bridge, now under construction (see description page 122), this was the only possible way to make it (elements with weights of 250 t).

6 - The office of the municipal building and housing department in Amsterdam

This building must give accommodation to 1740 persons, who are now spread over 14 places in town.

It will consist of two wings, each with a length of about 60 m and a width of 16 m, which are shifted with regard to each other, and which are connected by a central part 30 × 36 m (figs. 6.1 and 6.2). The wings and the central part consist of 10 storeys with a height of 3.25 m (top floor till top floor). Under the total areas of the building a cellar is designed, partly two storeys high (fig. 6.3).

The total volume of the building is about 150.000 m³; the floor area
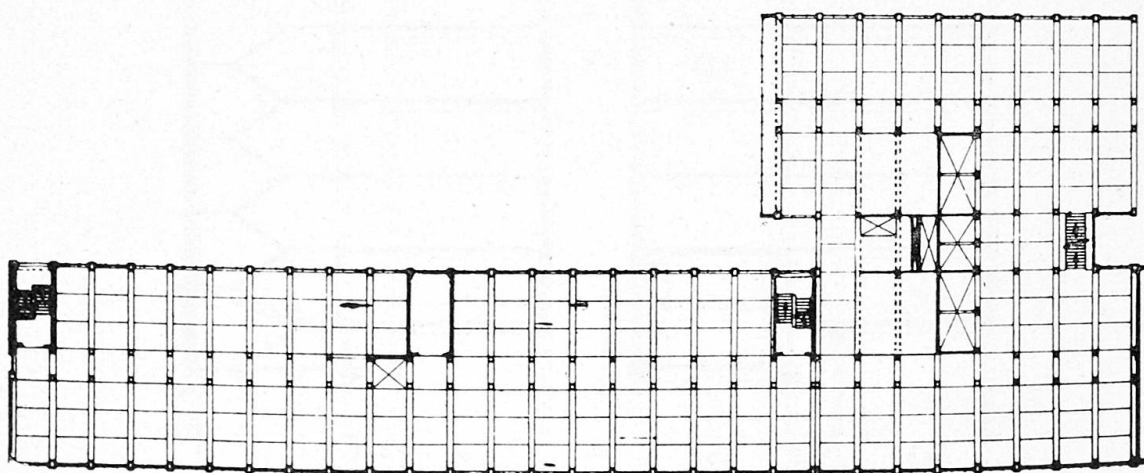

Fig. 6.1 - Horizontal section (right wing omitted).

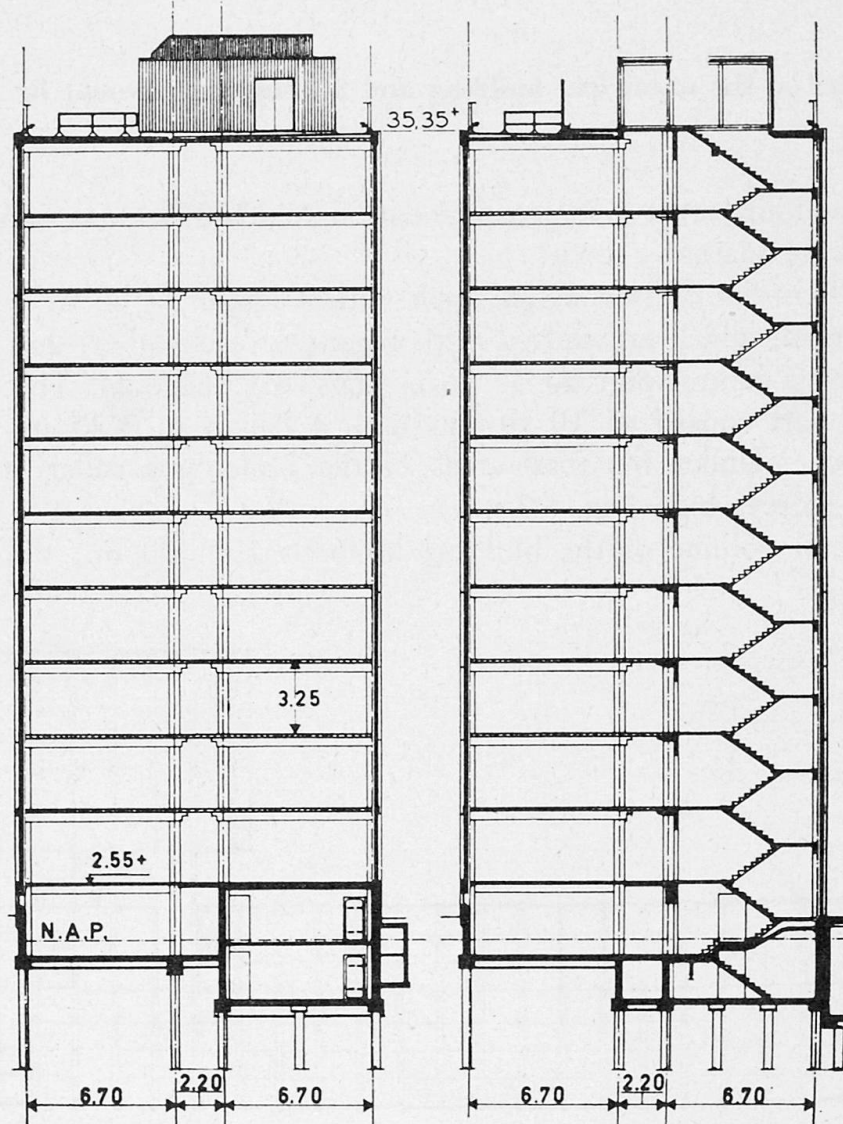Fig. 6.2 - The finished building (tric-foto).

Fig. 6.3 - Vertical cross-section. Left: normal cross-section. Right: cross-section over staircase.
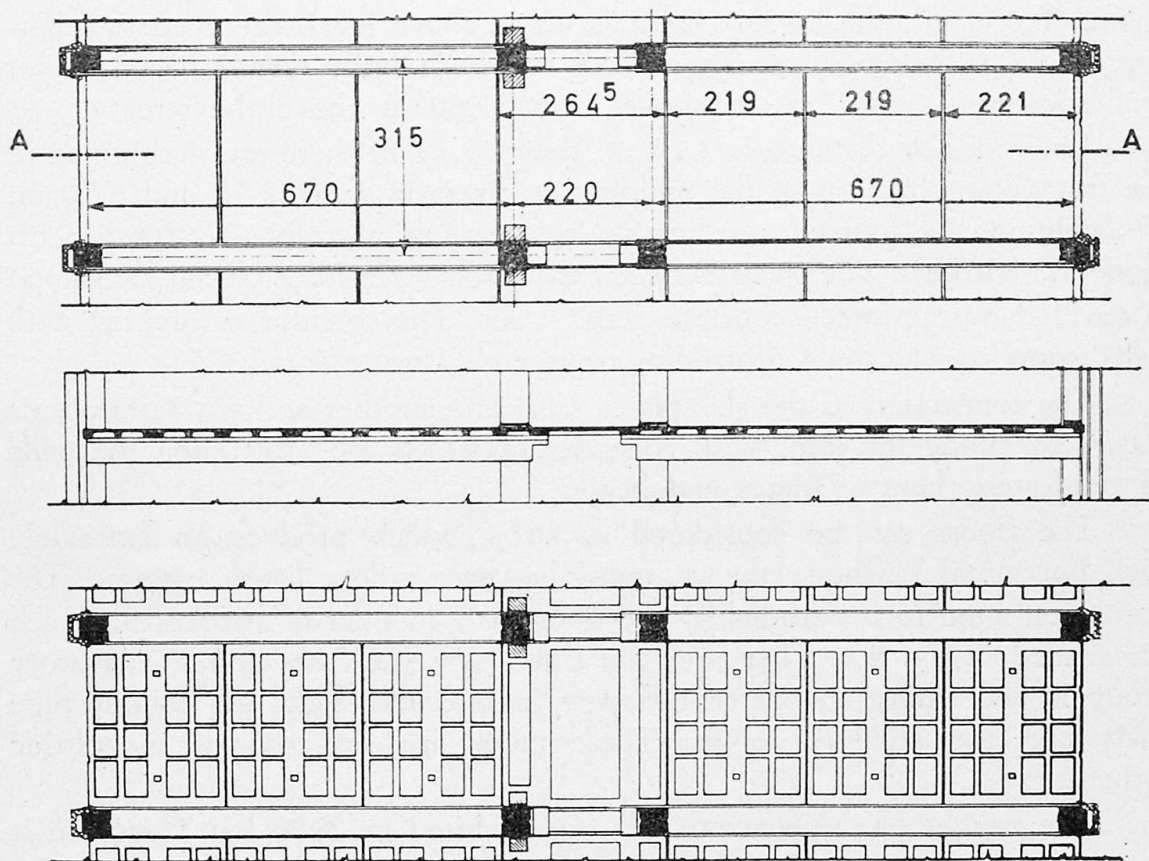
Fig. 6.4 - Floor with floor plates. Top view, cross-section, and underside view.
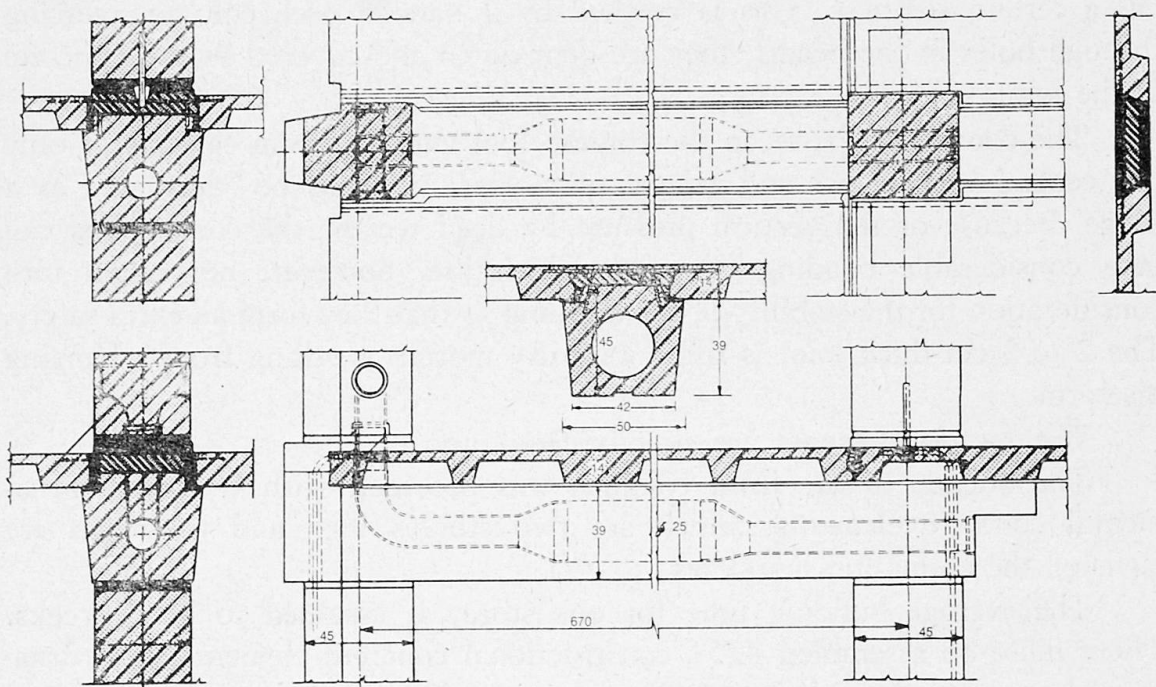

Fig. 6.5 - Connection of cross-beams, columns and floor beams.

about 40.000 m²; the highest point is 40 m above level, the deepest cellar-floor, 3.34 m below level. The edifice has been built monolithical — not prefabricated — till 2.60 m above level (1.60 m above the street).

The modular distance is 3.15 m. Every 3.15 m there are 4 columns in the transverse direction of the building at distances 6.70, 2.70 and 6.70 m. The columns are coupled two by two by means of a girder to a frame with moderate stiffness. The space between the girders (in longitudinal direction) is covered by reinforced concrete wafer slabs. The corridor is covered with slabs, supported by the 4 protruding beam ends (figs. 6.4 and 6.5).

The connection of the slab-plates with one another and with the beams occurs by filling the joint with concrete, in which are protruding the ends of reinforcing bars in plates and beams.

The floors can be considered as slabs, which produce an extremely high horizontal stiffness; the columns, however, allow little restraint. The horizontal wind forces are led by the floors to a number of stiff cores, which are shaded in fig. 6.1. They are: the emergency staircases and the lavatory group in the wings; in the central part the elevator-shaft, the conduit-pipe shaft and the archives rooms. These cores are executed as monolithic structures.

The weight of the elements has been limited to 2900 kg. Therefore it was necessary to use hollow beams. The cylindrical holes are partly used for heating and ventilation (fig. 6.5).

Fig. 6.5 shows the connection of beam and columns. Although the stiff cores can take the whole horizontal force, still the beam-column connection has a certain stiffness. This is reached by 2 bars in each column, piercing through holes in the beams; they are bent down and covered by the concrete in the joint.

The connection between the column foot and the beam consists of only one central vertical bar and a layer of mortar; it might be considered as a hinge. Because of the vertical pressure by dead weight the connections can take considerable bending moments which are, however, not taken into consideration for the stability of the building so that they form an extra safety. The 2 to 3 cm thick joint is filled with dry mortar, working from a hanging platform.

The façade elements are prefabricated, too.

The outside of the front columns was provided with U-shaped, orna-mental concrete elements, which are two storeys high and to which are fastened the aluminium windows.

The average building time for one storey is assumed to be 3 weeks. There must be assembled 4251 constructional concrete elements, 836 orna-mental concrete elements and 340 staircases and other elements.

Construction started in February 1962.

7 - The precast shell-roof structures for the office buildings of the Royal Netherlands Tourist Association A.N.W.B. at The Hague

There are two separate buildings: a tall multi-storey main building, with rectangular ground plan, in which the administration, accountancy and management offices are housed, and a lower building — the rotunda — with circular ground plan, for tourist information and shipping (figs. 7.1 and 7.2).

Of the main building, the roof of the canteen is covered with cylindrical shells; the rest of the roof is flat. On the contrary, the rotunda is entirely covered with shells: the central part with an elliptical dome, the surrounding office space with conical shells (fig. 7.2). For the shells of the main building and the rotunda prefabrication was the obvious means to overcome current building problems: shortage of labourers, limited building period, difficult concrete casting, intricate formwork, etc. Moreover, mass-production proved possible to a large extent.

All shells have been prefabricated on the ground in parts with such dimensions that they could be handled by the cranes and that a high degree of repetition was obtained. Therefore, each of the 10 cylindrical shells of the main building was divided into two halves in longitudinal direction. The same was done for the 24 conical shells of the rotunda. The elliptical dome shell was divided into 24 triangular double-curved elements; the cantilevering ring around it in 24 trapezoidal parts (fig. 7.3). Because it was the first time that prefabricated shell elements to such a large extent were used in Holland, it was decided to have the precasting and the erection of the cylindrical
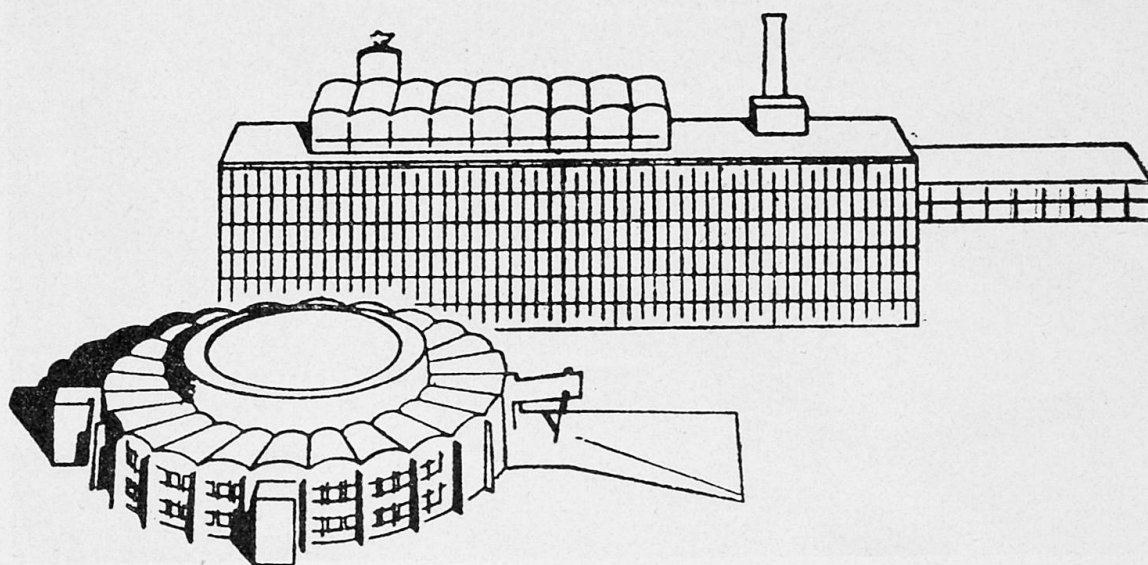

Fig. 7.1 - Perspective view of main building and rotunda.

shells on the canteen of the main building first and let them serve as an experimental execution, also for the contractor to gain experience.

The shell halves on the canteen were placed by two available cranes with different height and capacity (fig. 7.4) working together. Placing the first shell element lasted a few hours; for the last one only twenty minutes were needed.

The shells were cast on each other, so that they served as a mould for each other. They were separated by a sheet of sisalkraft-paper. In order to cast the first element a concrete mould was made. The curvature of the elements can only be kept constant if there is a small variation in thickness as to the width in each element.

The other shell elements, also the double-curved ones of the cupola, have been made in the same manner, but the double-curved elements could not be made in a vertical heap. Instead of sisalkraft-paper, which not entirely came up to the expectations, here plastic separating sheets were used, which met the requirements well.

The dimensions of the cylindrical shell elements were about 10.5 × 2.7 m; thickness 6.5 cm; weight 4.5 t. The conical shell elements had a length of 10.25 m, a thickness of 6.5 cm, too, and a weight of 4 t, while the cupola
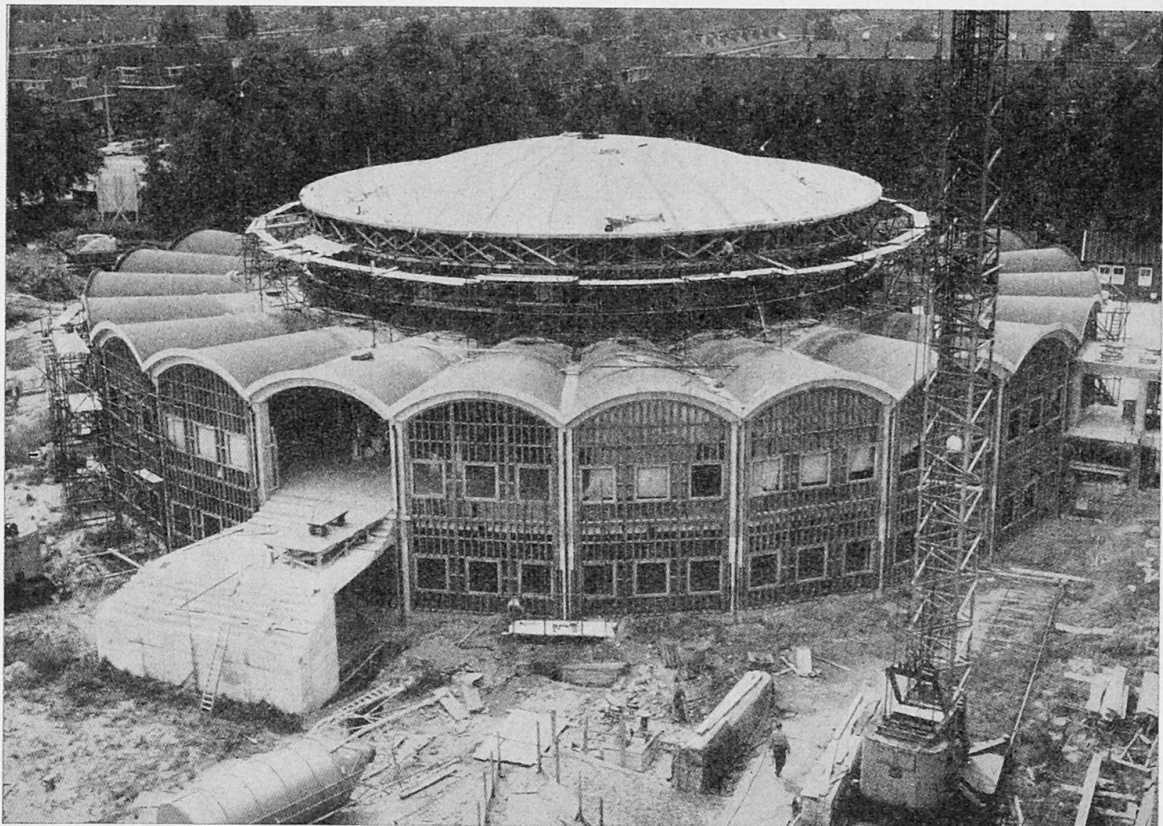

Fig. 7.2 - The rotunda with conical shells and dome.

elements had a length of 10.5 m, a thickness of 8 cm and a weight of 3.5 t (fig. 7.5). For hoisting the elements steel stiffenings were fastened on them at places established beforehand; the whole was hanging on a transverse beam on the crane (fig. 7.4).
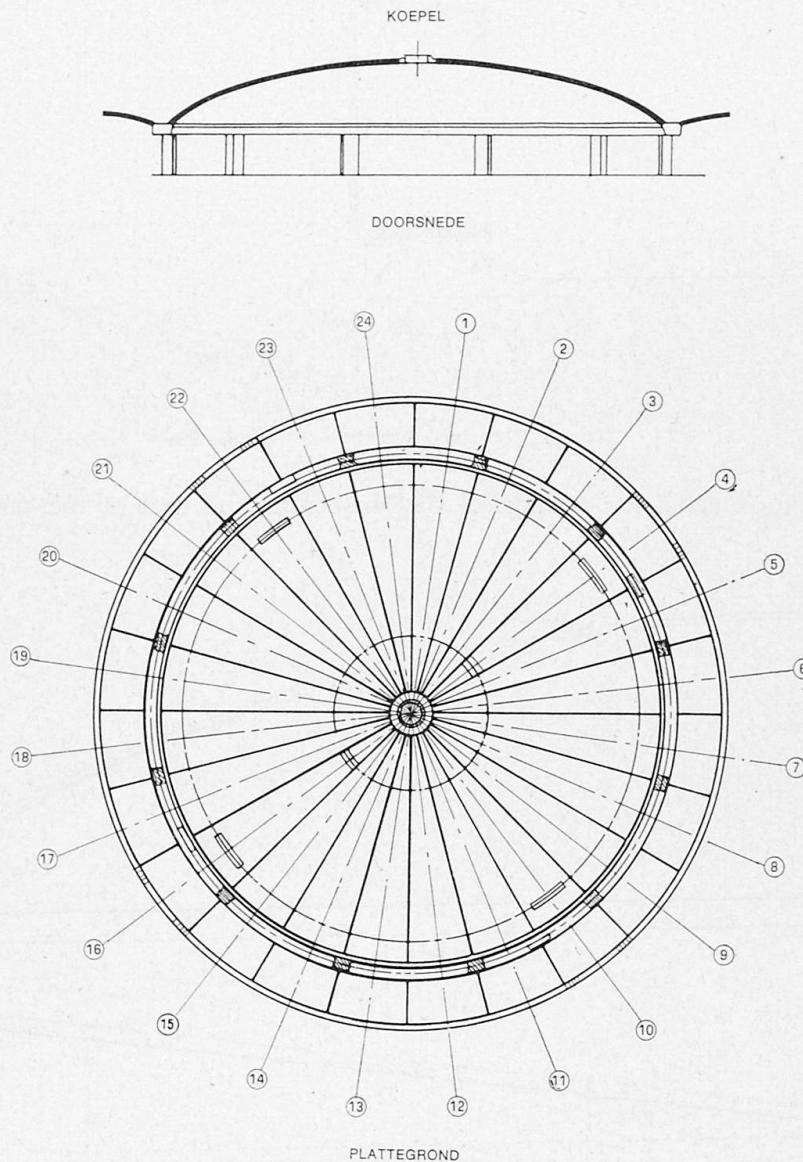
KOEPEL

DOORSNEDE

PLATTEGROND

Fig. 7.3 - The dome. Cross-section and plan. Koepel = dome. Doorsnede = cross-section. Plattegrond = plan.

The conical shell elements have been placed by a portal-framed crane that moved on two concentric rails (fig. 7.6); the elements of the cupola by means of a portal-framed crane, which turned around a fixed axis in the centre of the building (fig. 7.6). The second crane was almost entirely rebuilt from parts of the first.

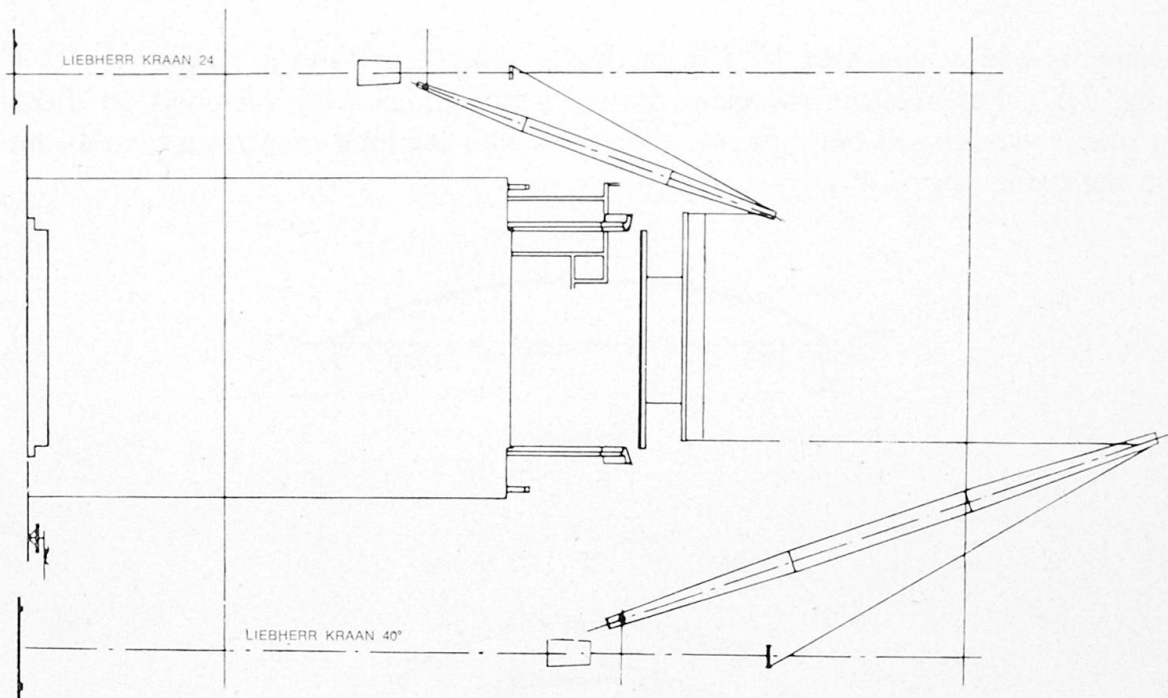The conical and cupola shell elements have been cast with 2 moulds each.

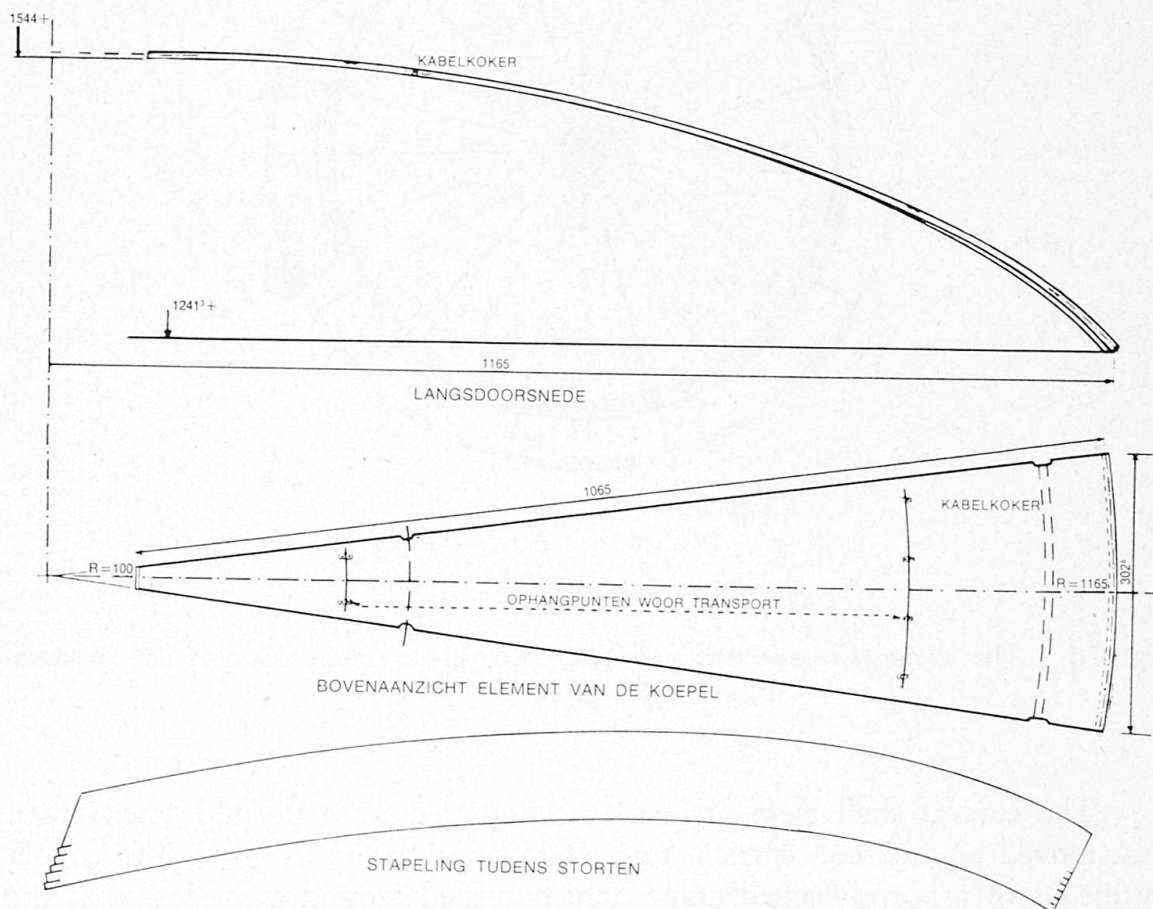Fig. 7.4 - Placing the cylindrical shell-halves on the roof of the canteen.

Fig. 7.5 - The cupola-elements. Langsdoorsnede = longitudinal section. Plattegrond element van de koepel = plan of an element of the cupola. Stapeling tijdens storten = stocking during casting.
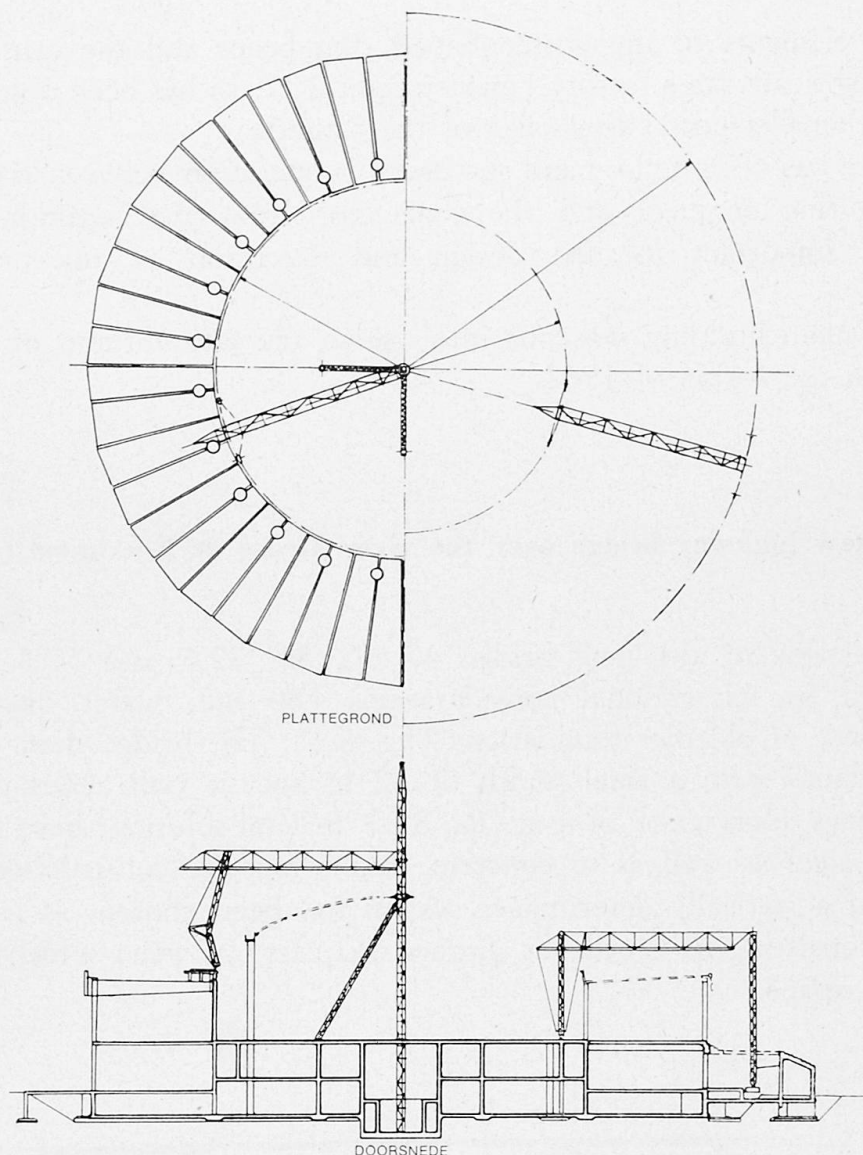
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Fig. 7.6 - Right: crane for placing the conical shell elements. Left: crane for placing the elements of the cupola.

The joints of the cylindrical and conical shells, along the top generatrices and in the valley between the shells — the gutter — were filled with cast-in-situ concrete (width at the top 20 cm; in the valley, varying from 30 to 50 cm.). The protruding bars in the joints were coupled with longitudinal bars to a net. The joints of the dome, the ring beam and the cantilever roof — width 1.5 cm — were filled with mortar and prestress was applied. The cupola was post-tensioned by 3 tendons 2 $\emptyset$ 7; one in the upper part and 2 in the lower part to neutralize the tensile stresses there. The ring beam is post-tensioned with 4 cables 12 $\emptyset$ 7 (Freyssinet) and the cantilever roof with 2 cables 4 $\emptyset$ 7 (fig. 7.5). The rather high prestress in the latter is to avoid temperature, shrinkage and bending deformations.

The elements of the gutter-shaped ring beam and the cantilever roof were prefabricated in a factory (max. weight 2 t); so has been done also with several other elements (no shells) of the rotunda.

There has been a close and successful cooperation between the architect, the consulting engineer and the contractor from the beginning. This is extremely important for the design and execution of any prefabricated structure.

The main building was put into use in the late autumn of 1960; the rotunda in the spring of 1962.

8 - The new highway bridge over the river Meuse at Roermond (1960-1962)

The spans of the new bridge — 60, 80, 72.5 and 57.5 m — are determined by navigational considerations (80 m), water discharge and the existence of old pier foundations (fig. 8.1). The bridge deck consists of 4 traffic lanes with a total width of 12 m and at both sides cycle-tracks and footways, each width of 4 m (fig. 8.2). Several solutions have been considered, in steel as well as in concrete, and composite construction too, but in the end a statically determinate system has been chosen, as indicated in fig. 8.3, consisting of cantilever girders on piers, between which are freely supported spans.
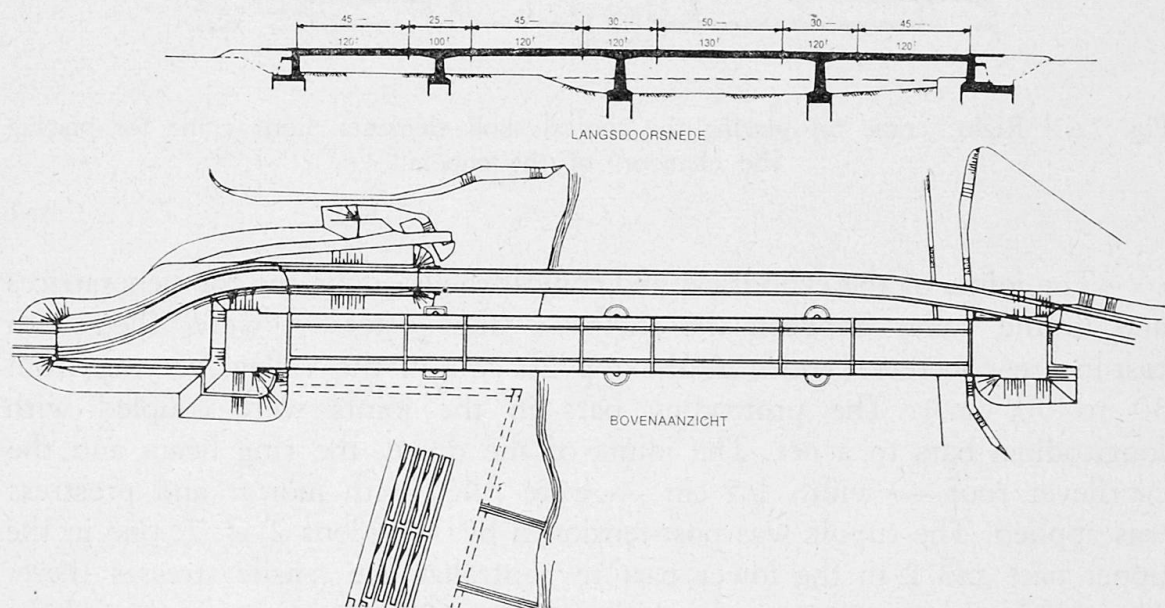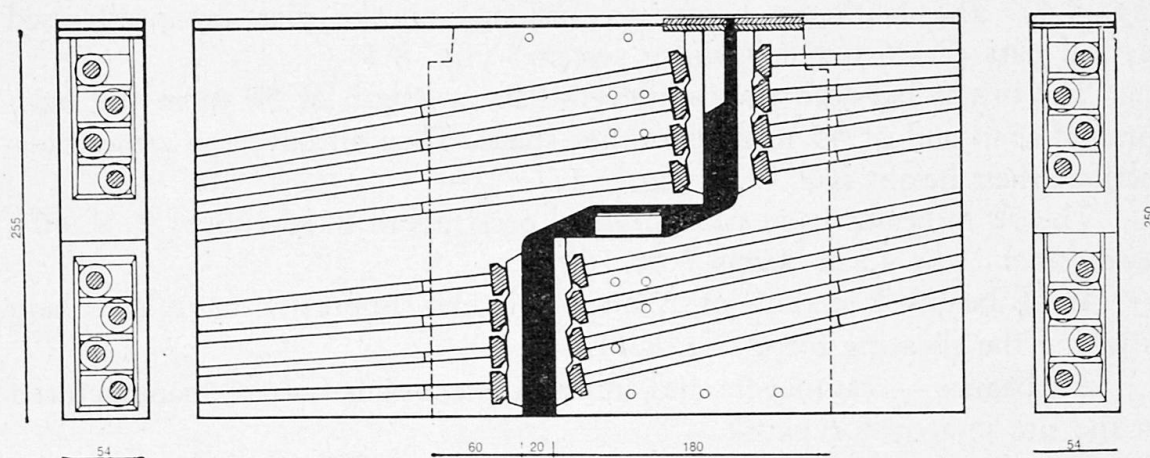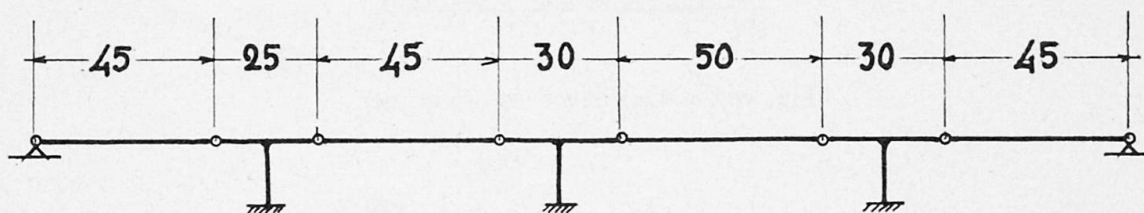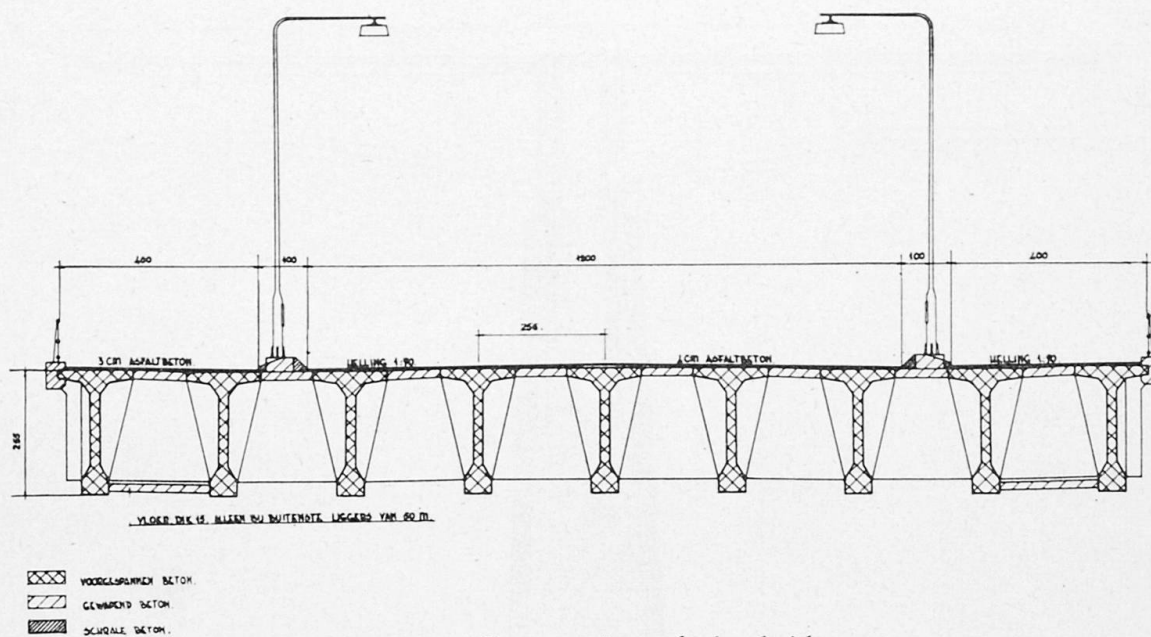

Fig. 8.1 - Longitudinal section and ground plan of the bridge over the river Meuse at Roermond.

Fig. 8.2 - Cross-section of the bridge.

Fig. 8.3 - Statical system of the bridge.

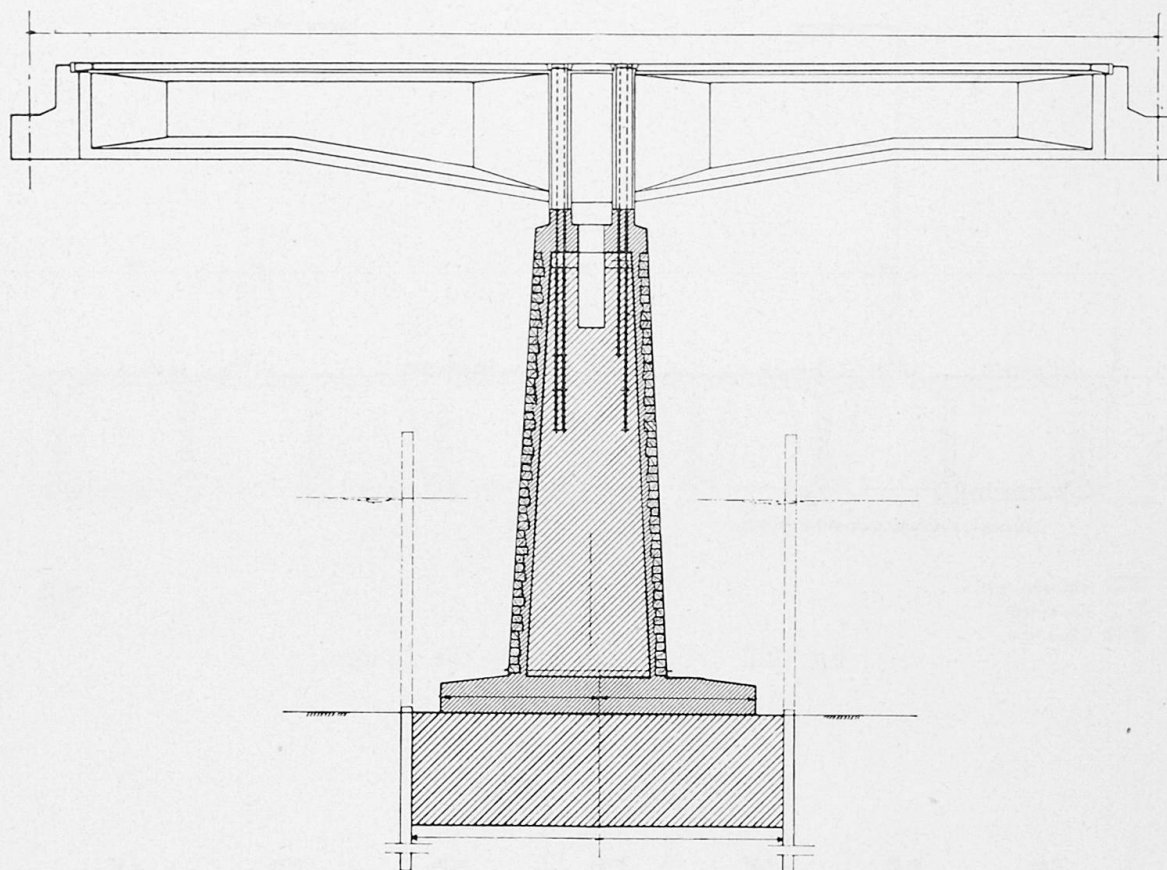Fig. 8.4 - Details of hinge and cable-anchorage.

Fig. 8.5 - Cantilever on river-pier.

The cross-section of the bridge shows 9 prefabricated prestressed concrete beams (fig. 8.2). The cantilevers on the river piers have a length of 30 m and a longitudinal prestress of 8 × 100 t - 8 × 40 t, Freyssinet system. The 100 t tendons are anchored in the ends of the beam, the 40 t tendons in the under flanges. The cantilevers on the land piers have a length of 25 m and a prestress of 7 × 100 t; all tendons are anchored in the beam ends (fig. 8.4). The cantilever beams are fastened on the piers by prestressed vertical bars $\oslash$ 26 mm (Dywidag system) (fig. 8.5).

The beams between the cantilevers have a length of 50 m in the navigational span and of 45 m in the other spans. They all have the same cross-section; their height is 2.55 m (fig. 8.2).

The 50 m beams have a longitudinal prestress of 8 × 100 t - 2 × 40 t (Freyssinet); the 45 m beams 7 × 100 t.

In all beams 4 tendons of 100 t end in the supporting console to help in taking the shearing force (fig. 8.4).

All beams — cantilevers and intermediate beams — are manufactured on the site in steel formwork.

The concrete was vibrated by vibrators fastened to the steel form, and has been steam-cured. The water-cement ratio was 0.40 and the cement content

375 kg portland cement A per m³; the cube strength after 28 days ought to be 500 kg/cm².

First the cantilever beams were mounted on the bridge piers, partly by floating cranes (fig. 8.6). In this stage only the cables for dead weight were stressed, i.e., 2 × 100 t for the 30 m beams, 1 × 100 t for the 25 m beams. Then the space between the upper flanges was filled with concrete, after which half of the transverse prestress (Freyssinet) was introduced, and finally the other longitudinal tendons were stressed. Only then the lower pressure flange between the girders was cast and all transverse prestress introduced. Then, too, were stressed the vertical bars ⌀ 26 mm (Dywidag), with which the beam is fixed to the pier.
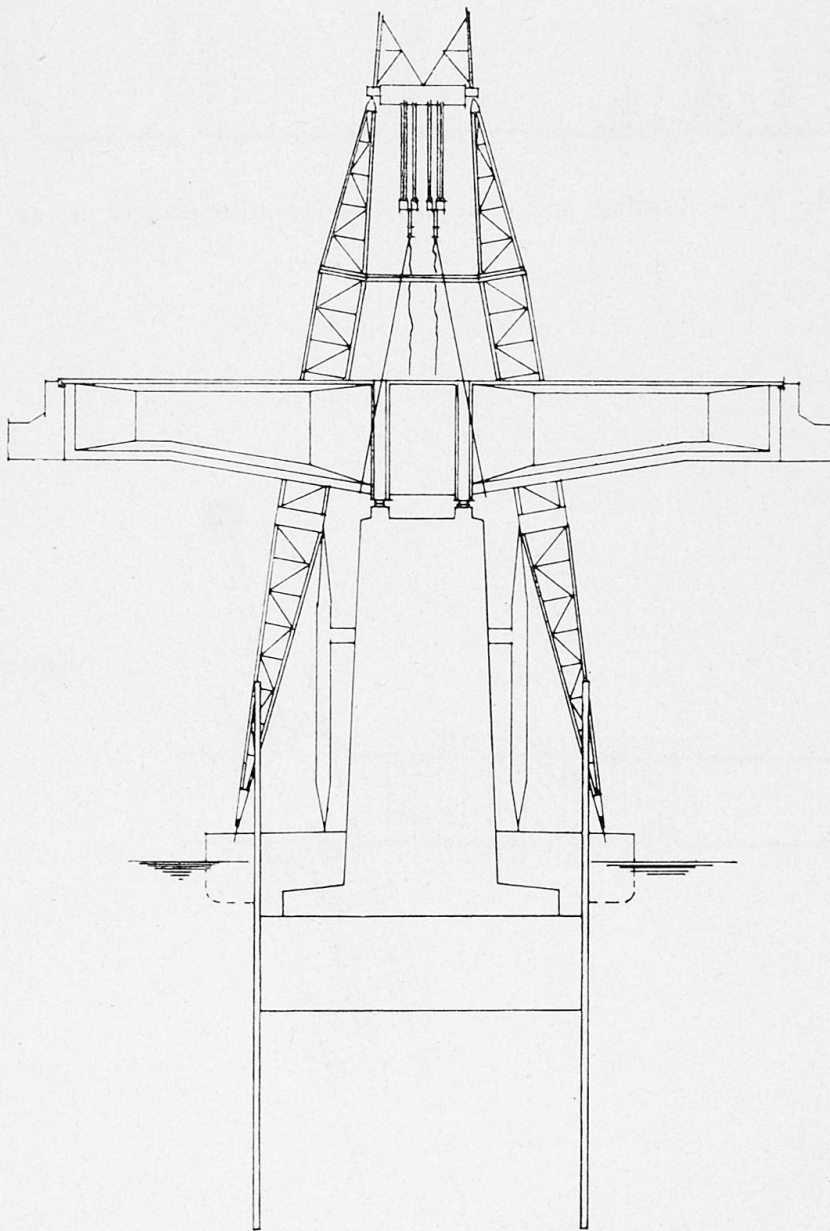
Fig. 8.6 - Mounting the cantilever-beams by means of a floating crane.

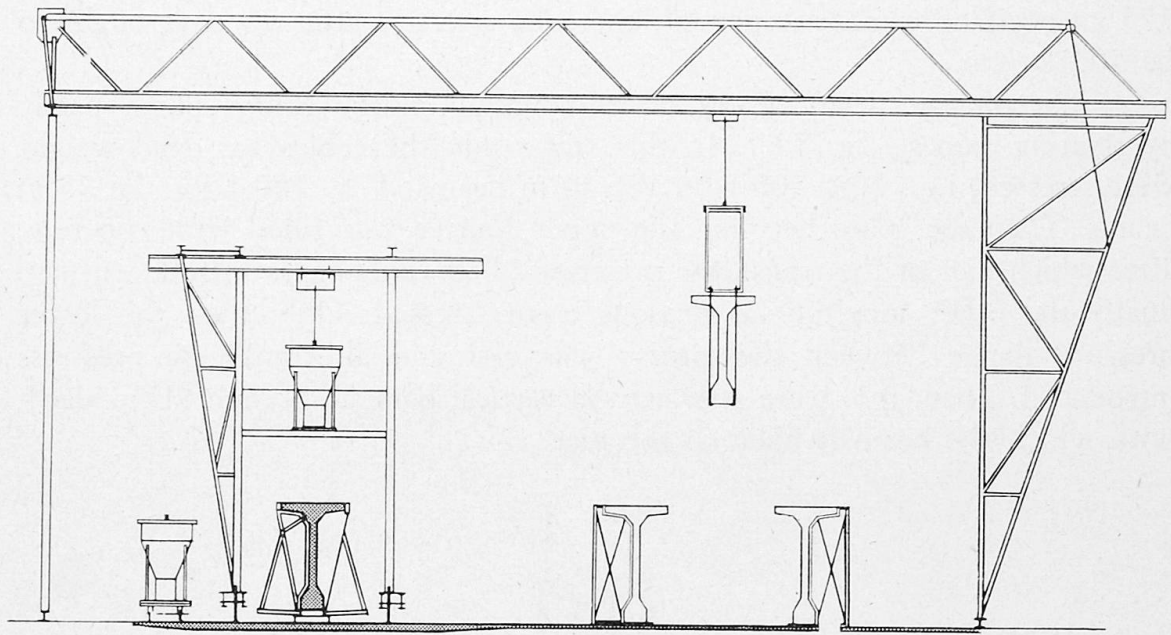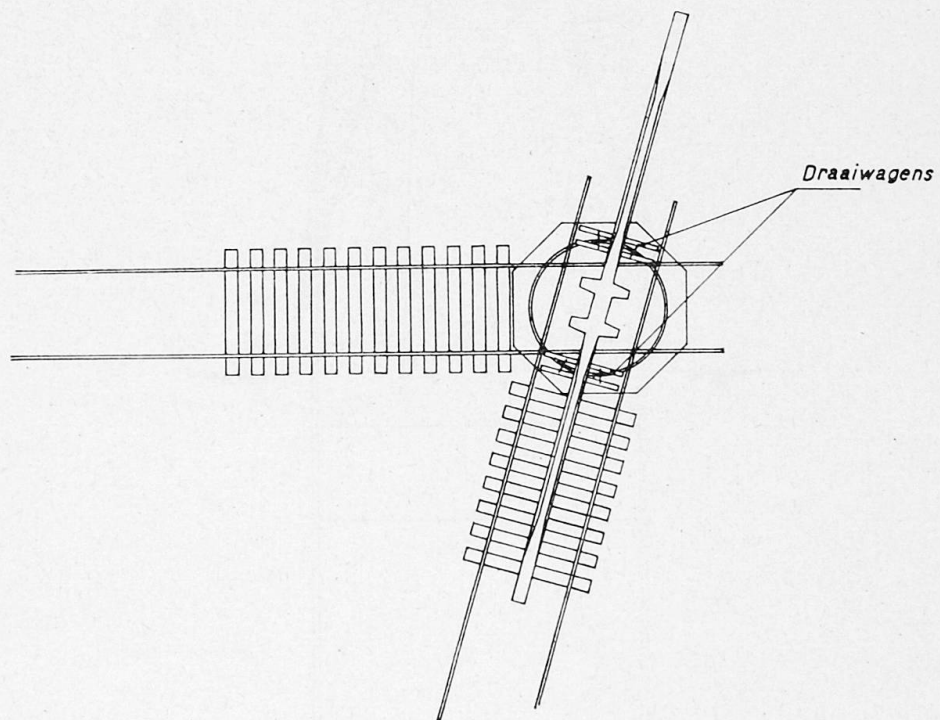Fig. 8.7 - Casting and transportation of intermediate beams.

Draaiwagens

Fig. 8.8 - Turning the cantilever beams.

Now the intermediate beams are placed, also partly by floating cranes. Il was important to keep on the right sequence to avoid too high stresses in the connection between cantilever and pier.

In the navigational opening a slab between the under flanges of the two extreme girders is introduced to have more resistance against impact from ships (fig. 8.2).
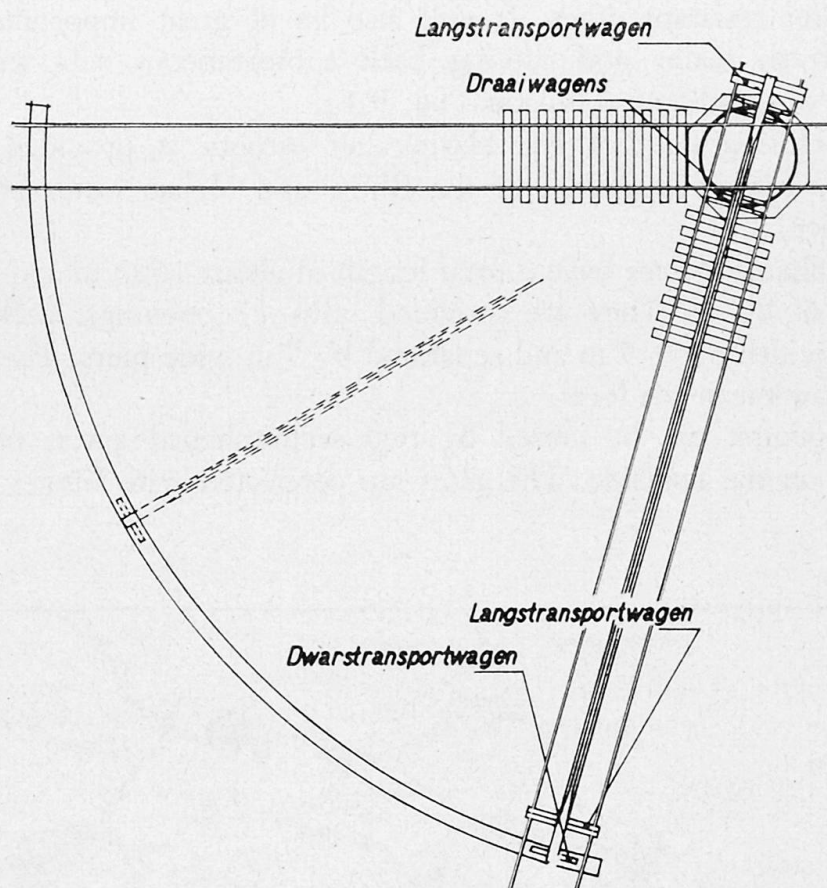
Fig. 8.9 - Turning the intermediate beams.

Fig. 8.6 shows the mounting of the cantilever beams; figs. 8.7, 8.8 and 8.9 show something of the casting, manufacture and transportation of the intermediate and cantilever beams.

The Gerber hinges consist of reinforced rubber blocks 40 × 50 cm for a maximum load of 146 t. Especially their low height is of great importance in Gerber structures.

The end blocks with the cable anchorages of the cantilevers and inter-mediate beams were prefabricated separately to be able to take extra good care of the concrete quality and place and direction of the anchorage elements, which are of great importance for such heavy anchorages (fig. 8.4).

The bridge has been opened to traffic in the summer of 1962.

9 - The Nabla girder bridge over the outlet sluices in the Haringvliet estuary

The enclosure of the Haringvliet estuary is one of the first and most important works of the so-called Delta plan, that has been conceived after the disastrous storm surge of February 1953 and that intends the enclosure of three of the four important estuaries in south-western Holland by storm- and high-water resistant dikes. It will also be of great importance for the storage of fresh water and driving back subterraneous salt water for a greater part of southwest Holland (fig. 9.1).

The enclosing dam of the Haringvliet estuary is provided with big outlet sluices for the discharge of the Rhine and Meuse water and for the removal of ice.

The discharge sluices have a total length of about 1000 m and a width at the bottom of 80 m. They are provided with 17 openings, each of them with a clear width of 56.5 m and separated by 5 m wide piers. The sill depth is 5.5 m below mean sea level.

Each opening can be closed by two sector-shaped gates, one on the seaside, one on the landside. The gates are connected with hinges to hollow

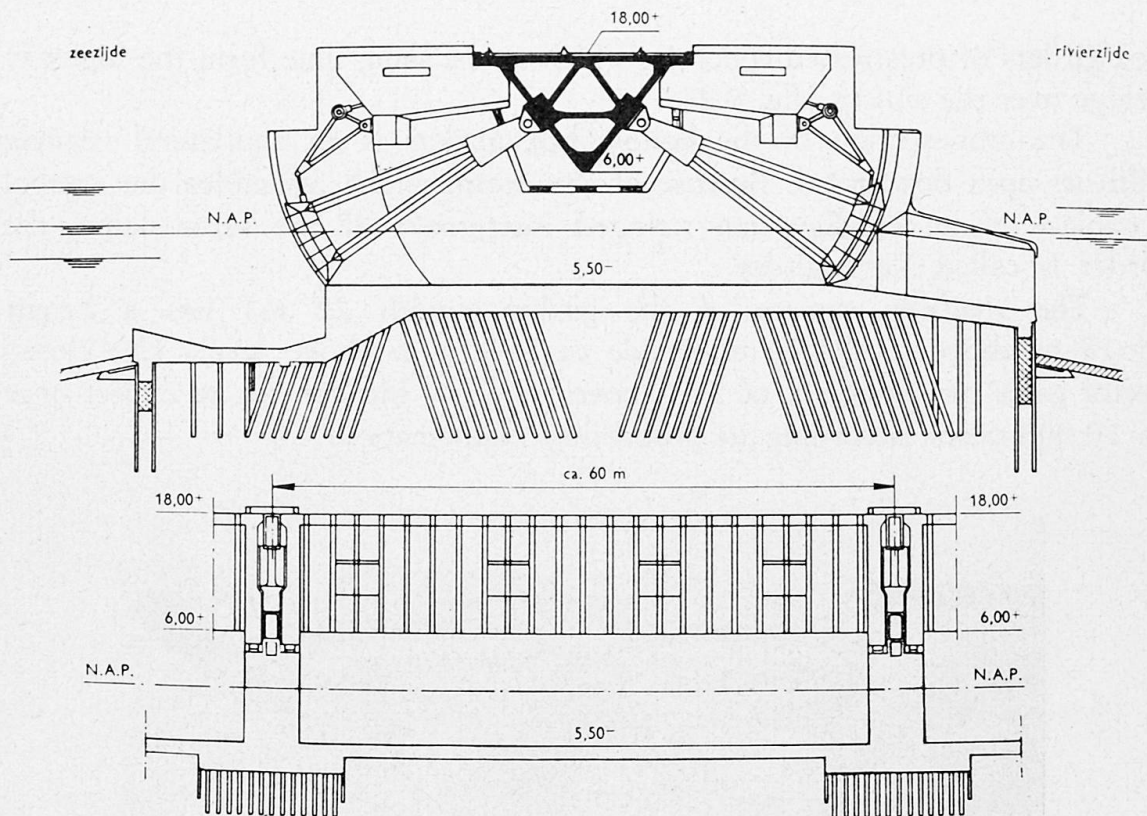Fig. 9.1 - The Delta-plan. Main enclosing dams (planned).

Fig. 9.2 - Transverse section of bridge, sluice gates and sill with pile-foundation; front view of bridge with piers.
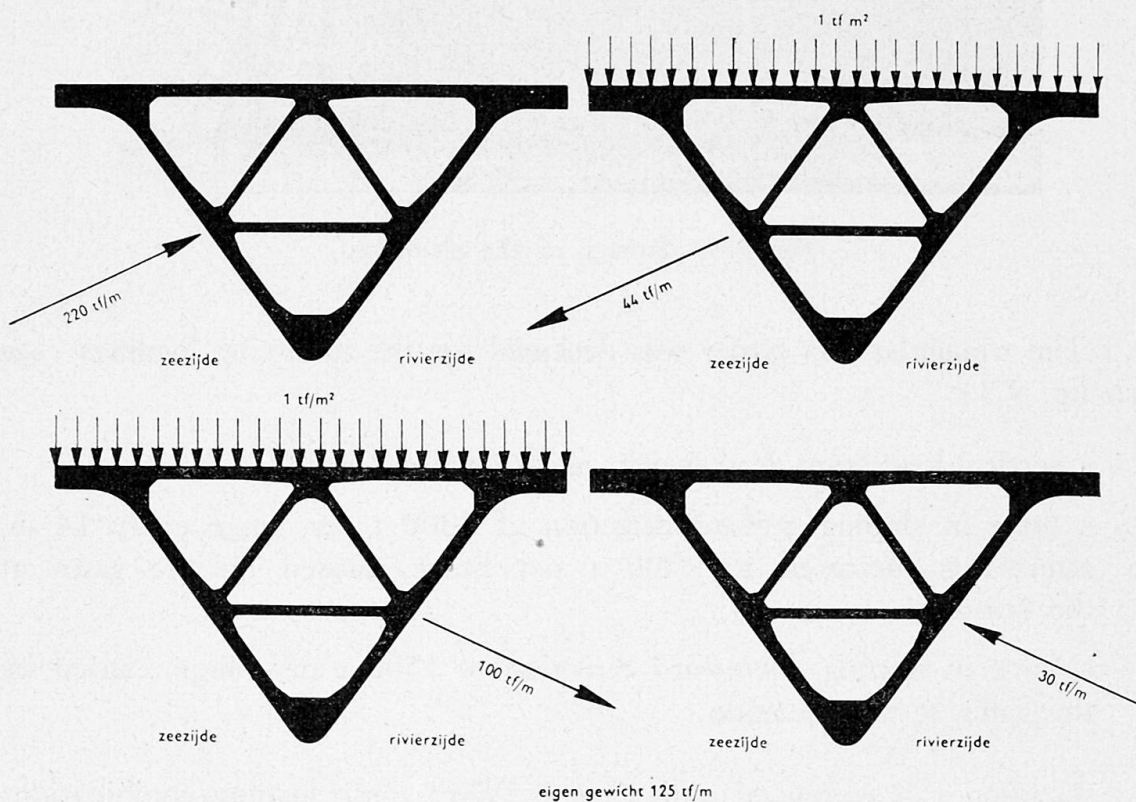

Fig. 9.3 - Bridge loadings.

box girders of prestressed concrete, which at the same time form the highway bridge over the sluices (fig. 9.2).

The cross-section of the hollow box girders is an equilateral triangle with its apex downward. Because of this form, which resembles the symbol « nabla » of an old-Egyptian stringed instrument of the same name, the girder is called Nabla-girder.

The roadway surface of the girder (width 22 m) has a height of 18 m above level; the underside of it is 6 m above level. The closed sector gates have a height of 5 m above level (= highest tide to expect once in 10,000 years, according to probability mathematics).
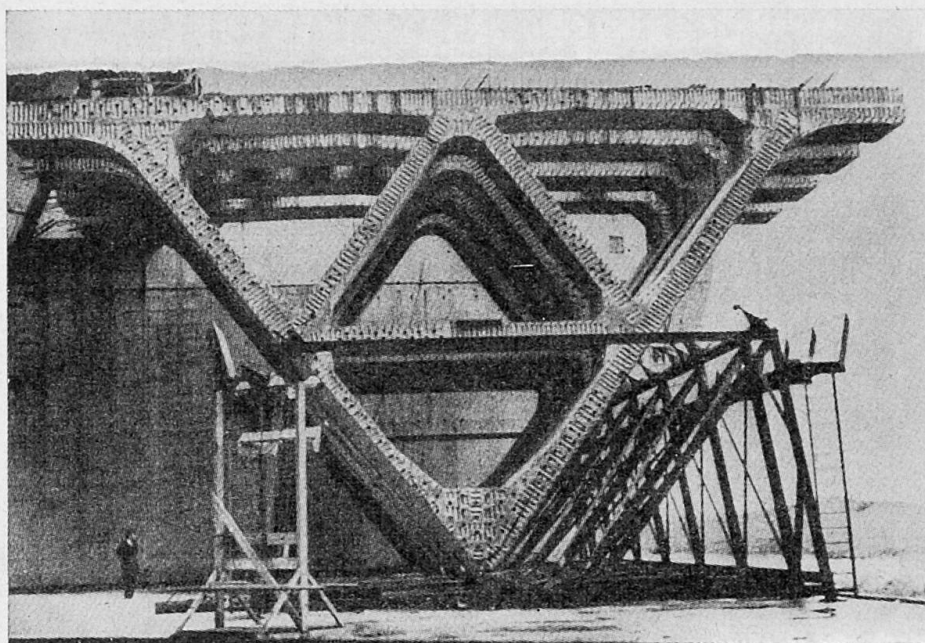

Fig. 9.4 - Storage of the elements.

The triangular box girder was designed for the following loadings (see also fig. 9.3):

1 - a vertical load from dead weight and traffic of 150 t/m;

2 - a force in sloping upward direction of 2000 t per hinge every 14 m, afterwards increased to 3200 t per hinge, caused by the gates at the seaside;

3 - a force in sloping downward direction of 1500 t per hinge, caused by the gates at the riverside.

Loading 1 is combined with 2 or 3. With these loading combinations there are no tensile stresses. The design safety of the structure against

cracking is at least 1.2, that against failure at least 2.2. Tests with a model in micro-concrete, also totally prestressed, scale 1 : 15, showed a safety against cracking of 1.4 and a safety against failure of more than 3.5.

Each girder contains 3500 m³ of concrete. It was almost impossible to cast this quantity in situ because of intricate and difficult formwork, casting in stages, many working joints, tight and intricate reinforcement, unequal shrinkage, unsurveyable stress distribution, etc.
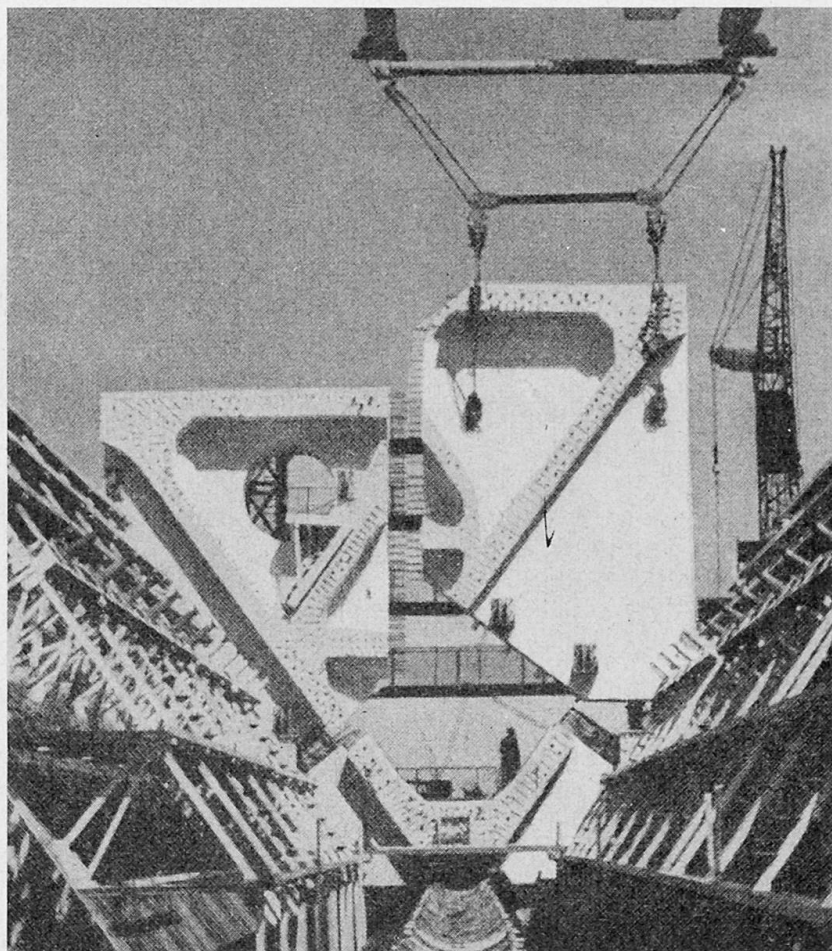

Fig. 9.5 - Placing the three parts of an end-section.

It was for these reasons that it was decided, after solid consideration, to precast the girders as triangular elements, each with a weight of 250 t.

Each girder consists of 22 prefabricated, 2 m high elements, and of 2 end sections, the latter each cast in 3 parts (fig. 9.4 and 9.5). The elements are cast in steel forms on the finished sluice sill (fig. 9.6).

For shrinkage and transportation the elements are partly prestressed by means of part of the 41.5 t Freyssinet prestressing cables, which will later constitute the transverse prestress. By means of a heavy portal-framed crane
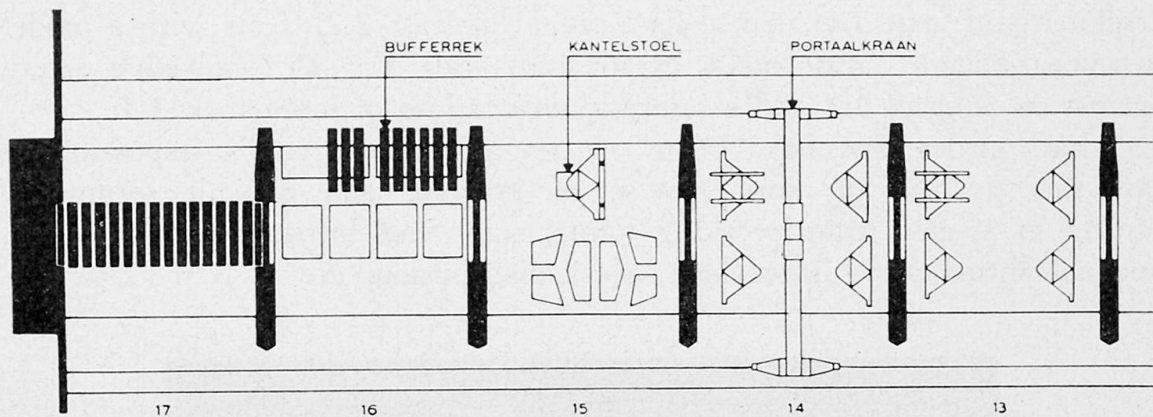
Fig. 9.6 - Prefabrication of the elements on the sluice-sill. Portaalkraan = Portal-framed crane. Kantelstoel = Tipping apparatus. Bufferrek = Store-plant.
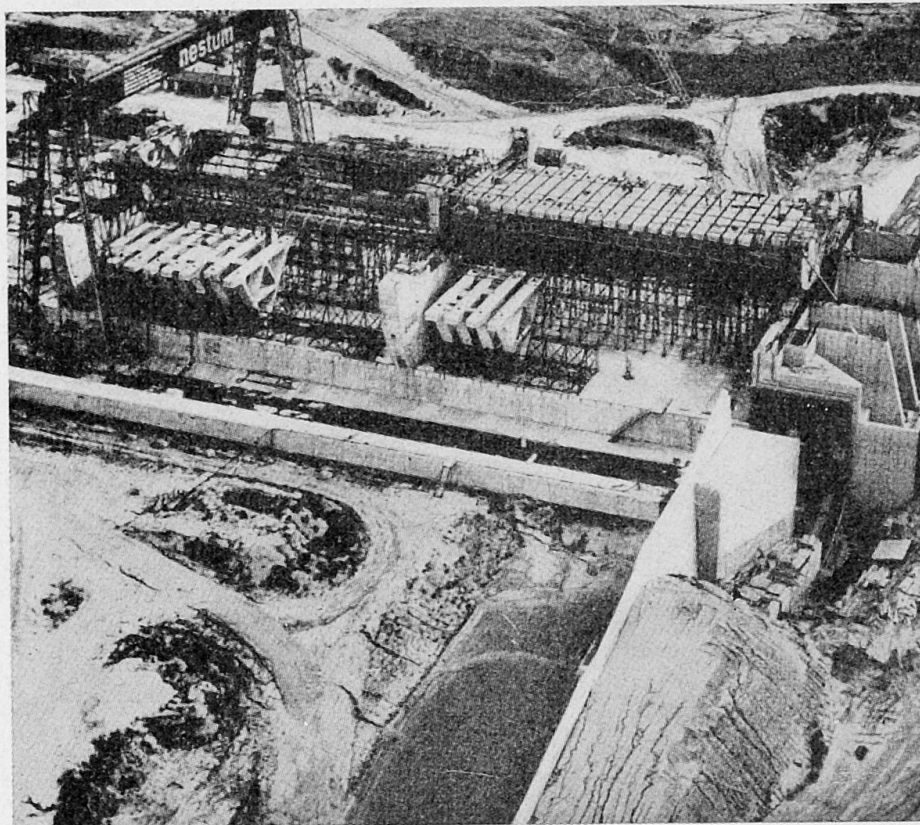

Fig. 9.7 - Placing the elements (see also fig. 9.6).

and a specially designed tipping apparatus the 250 t sections are turned in a vertical position and by the same crane they are stored in a row, till they shall be used (fig. 9.4). The sections are placed in their final position on a steel scaffolding, with an interspace of 0.50 m (fig. 9.7). The 0.50 m wide joints are filled with concrete; shortly after hardening of it the rest of the
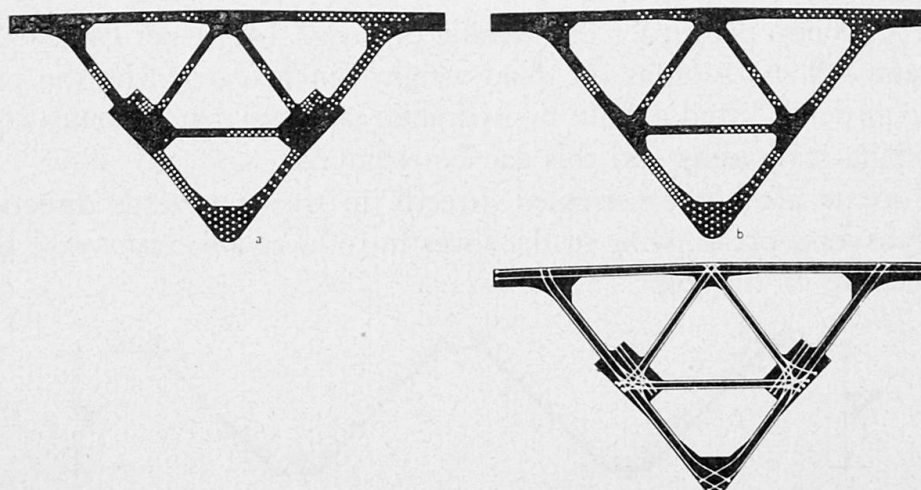
Fig. 9.8 - The prestressing cables (see also fig. 9.9). Longitudinal cables at place of hinge. Longitudinal cables between hinges. Transverse cables at place of hinge.
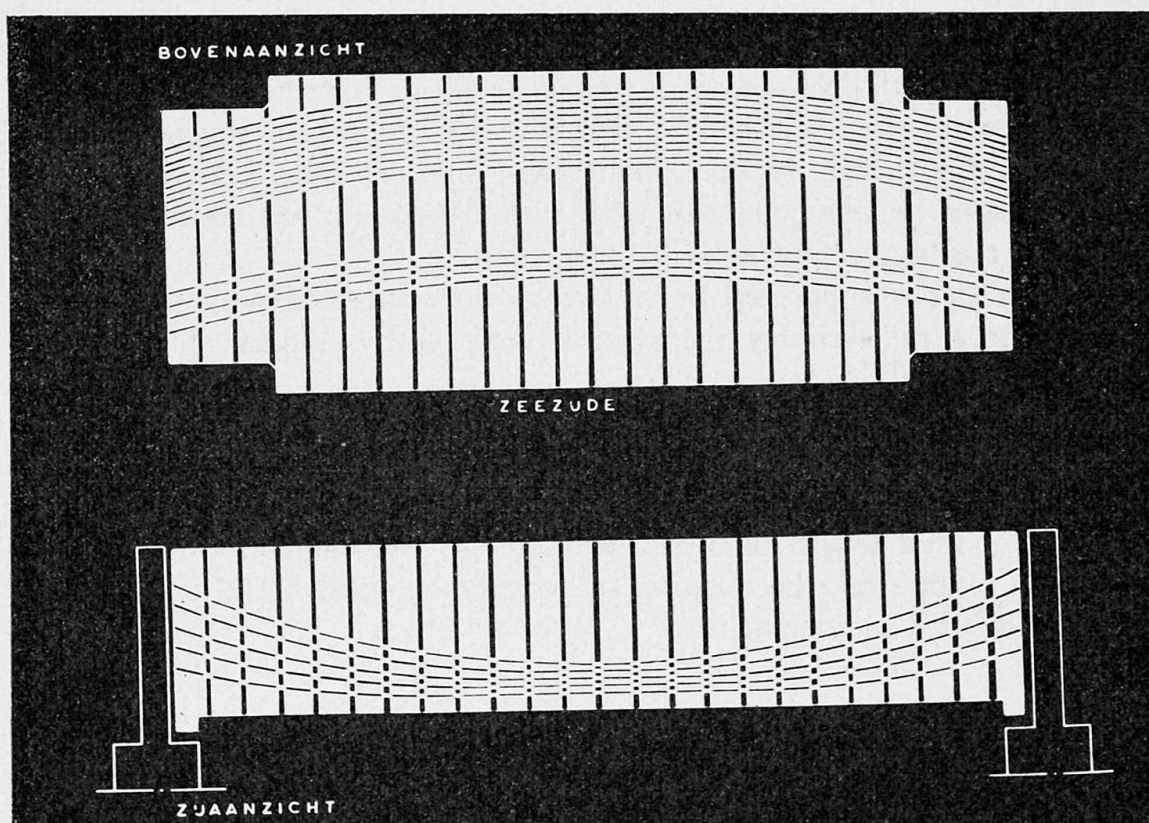

Fig. 9.9 - The prestressing cables in longitudinal direction. Bovenaanzicht = upper view. Zijaanzicht = side view. Zeezijde = seaside.

prestressing cables are brought in their tubes and the prestressing forces in longitudinal and transverse directions are gradually introduced.

The longitudinal prestressing force is introduced by means of 193 B.B.R.V. prestressing cables (54 $\varnothing$ 6 mm), each cable with a working force of 135 t. The transverse prestress is introduced by means of 1500 Freyssinet

cables 12 $\oslash$ 7 mm per girder (remaining prestress 14.5 t per cable). See also figs. 9.8 and 9.9. As soon as the dead weight can be carried by the prestress, the whole girder is lifted a little by hydraulic jacks so that it comes free from its supporting scaffolding and this can be removed.

The joints are not prestressed directly in the transverse direction, but further transverse prestressing of the slices introduces also transverse prestress in the concrete of the joint.
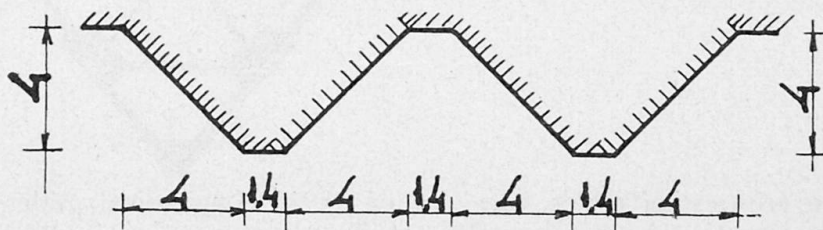

Fig. 9.10 - The joint surface.

Il was feared that the joints might form an important weakening of the structure, particularly where the new joint concrete touches the old concrete of the precast section. Many joint surfaces have been tested; the best proved to be triangular ribs with such dimensions that they were able to include the biggest gravel pellet (fig. 9.10).

The girder is supported by rubber blocks reinforced with steel plates: 6 blocks of 1 m² each for the vertical loads and 6 blocks of 1 m² each for the horizontal loads.

Finally some quantities are given:

For the whole work must be cast 450,000 m³ of concrete with 52,000 t of reinforcing steel. The foundation contains about 22,000 reinforced concrete piles with a total length of about 300,000 m. The amount of prestressed concrete is 60,000 m³, the quantity of prestressing steel 4,100 t. The sheet-piling is 24,000 t in weight.

10 - Tunnel sections

The sections of the highway tunnel under the river Nieuwe Maas in Rotterdam (building period 1938-1942) were prefabricated in a dry dock, floated to their destination and sunk in place. Descriptions of this tunnelling job appeared in many technical papers.

The sections of the subway tunnel in Rotterdam (fig. 10.1), now under construction, are also cast in dry docks or specially excavated building docks, and this time prefabrication was much more thoroughly applied than in 1940. The tunnel sections, varying in length between about 60 and 90 m,

are divided into uniform parts of 15 m, cast one after another and connected, if necessary for curvature, by wedge-shaped insertion pieces. So the same steel formwork is used several times (30 to 40), what makes it a very attractive prefab-job.

There are three building docks, one for the river section and two for the land sections. The dock for the river sections will afterwards be used for
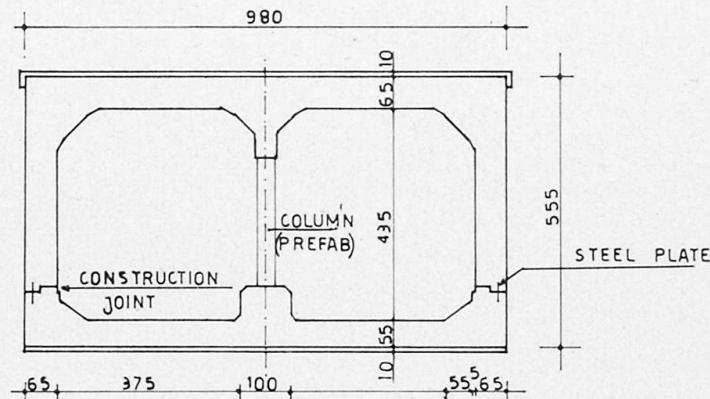

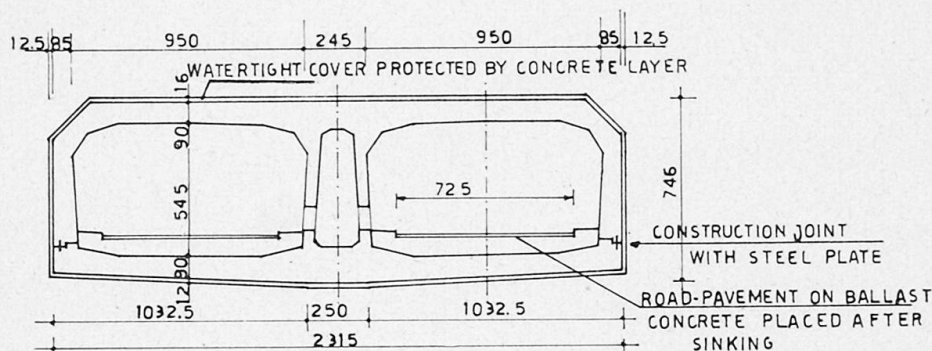Fig. 10.1 - Cross-section of subway tunnel element Rotterdam.

Fig. 10.2 - Cross-section of highway tunnel element Amsterdam.

the sections of the future highway tunnel, too. The sections are floated to their place and sunk on a pile foundation with adjustable pile caps. A description of this tunnel will soon appear in the technical papers.

Several other parts of the tunnel and subway stations are prefabricated description of this tunnel will soon appear in the technical press.

The under-water sections of the Amsterdam highway tunnel (fig. 10.2), also under construction now, are prefabricated in a similar manner, but here wooden formwork on steel shuttering is used (instead of the all-steel scaffolding in Rotterdam); the 6 tunnel sections have equal lengths of 90 m and are not curved in plan. They are built in an excavated dock, in which the sections of another tunnel in Amsterdam, also under construction now, will afterwards be built.

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