VSL

CONCRETE STORAGE STRUCTURES

USE OF THE VSL SPECIAL CONSTRUCTION METHODS

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CONCRETE STORAGE STRUCTURES - USE OF THE VSL SPECIAL CONSTRUCTION METHODS

Foreword

Tanks fulfil an important role in supplying mankind with essential products. They are used for storing liquids or solids which may be either intermittently produced but consumed at a fairly uniform rate, or continuously produced at a fairly uniform rate but consumed in an irregular manner. A further important aspect is that the locations of origin and consumption are frequently appreciable distances apart. These circumstances necessitate the provision of appropriate storage capacities.

The building of tanks in concrete offers several advantages:

- Concrete tanks are economical to construct and maintain (they require virtually no mainte nance). Construction is relatively inexpensive because the basic materials for making concrete are usually locally available and sui table special building methods make rapid construction possible.
- Concrete tanks are relatively insensitive to mechanical influences, whereas steel tanks, for example, when used for storing environ mentally polluting or dangerous substances have to be surrounded by protective concrete walls to assure the required degree of safety.
- Concrete tanks are eminently suitable for the storing of a very wide variety of substances; for example, if provided with a suitable liner, they may even be used for low temperature liquefied gases.

The present report, which comprises descriptions of more than forty completed tank structures, has been prepared with the objective of illustrating the advantages of concrete tanks, of providing a summary of the numerous possible applications, and of explaining what VSL special construction methods can be employed in the building of concrete tanks and when, where and how these methods may be used. Since the type of substance to be stored has a profound influence upon the form and construction of a tank, the descriptions have been placed in appropriate chapters and usually arranged in chronological order. This will facilitate a certain degree of comparison within each group, though it must be remembered that the design conditions can vary appreciably on account of the differences in national codes and standards.

The VSL organizations will be pleased to assist and advise you on questions relating to tank construction and hope that the present report will be helpful to you by stimulating new ideas, providing some pointers and offering possible solutions. The VSL Representative in your country or VSL INTERNATIONAL LTD., Berne, Switzerland will be glad to provide you with further information on the subject of «Concrete tanks» or on the VSL special construction methods.

1. Applicable VSL

1.1 Introduction

In tank construction three VSL special systems are of particular importance:

- VSL Slipforming,
- VSL Post-tensioning,
- VSL Heavy Rigging.

These systems ar1.e generally used in the above sequence, a tank being first built with the assistance of slipforming and then prestressed, after which, in certain circumstances, the tank itself of some other component, such as the roof, is brought into an elevated position.

In principle, the systems are used separately, but it is especially advantageous if VSL is chosen for all the systems. By making use of the various VSL systems in combination and taking account of this possibility at an early stage in planning, the Client will obtain substantial advantages. These may include, for example:

- The placing of the cable fixings and ducts during the slipforming operation is carried out simultaneously with the fixing of reinforcement and can be continually monitored by the VSL slipforming personnel.
- The formwork panels, to which the VSL anchorages are fixed at the buttresses, are reused during slipforming.
- Lifting cables can be converted into suspension cables and the latter can then be post-tensioned.
- The preparatory work, progress and also the use of personnel and materials are all under one control, which considerably simplifies coordination.

1.2. VSL Slipforming

Tanks at or near ground level and the shafts of water towers are especially well suited to the use of slipforming during building, since the preconditions for economic use of this construction method exist to a particularly high degree in these structures:

- The proportion of walls to the total structure is high.
- The shape and dimensions of the structure usually remain unchanged throughout the height.
- The number of openings, built-in items, reces ses etc. is small.
- Large structures can be built by steps or segments.
- Insulation can be installed during building of the walls.

The advantage of slipforming include the short construction time resulting from continuous working, monolithic construction without construction joints and of high dimensional accuracy and cost savings even where the height is moderate.

The slipforms of the VSL Slipforming consist of 1.25 m high elements of steel. They are standardized components, from which any desired plan form can be made up. Steel was chosen as the formwork material because it guarantees the highest dimensional accuracy in construction. The inner and outer forms are connected together by transverse yokes. At the upper edge of the forms, working platforms are located and scaffolds for finishing the concrete surface are suspended beneath them.

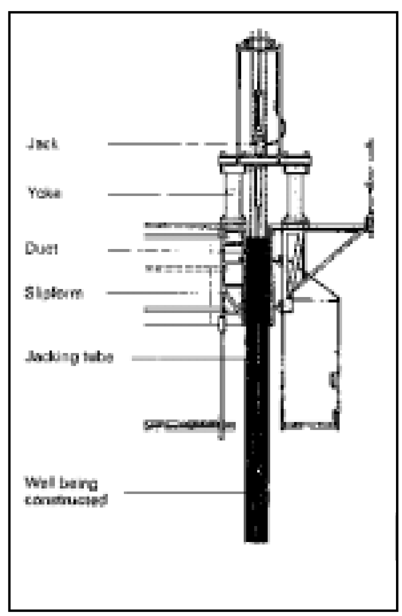


Figure 1: Basic construction of VSL Slipforming

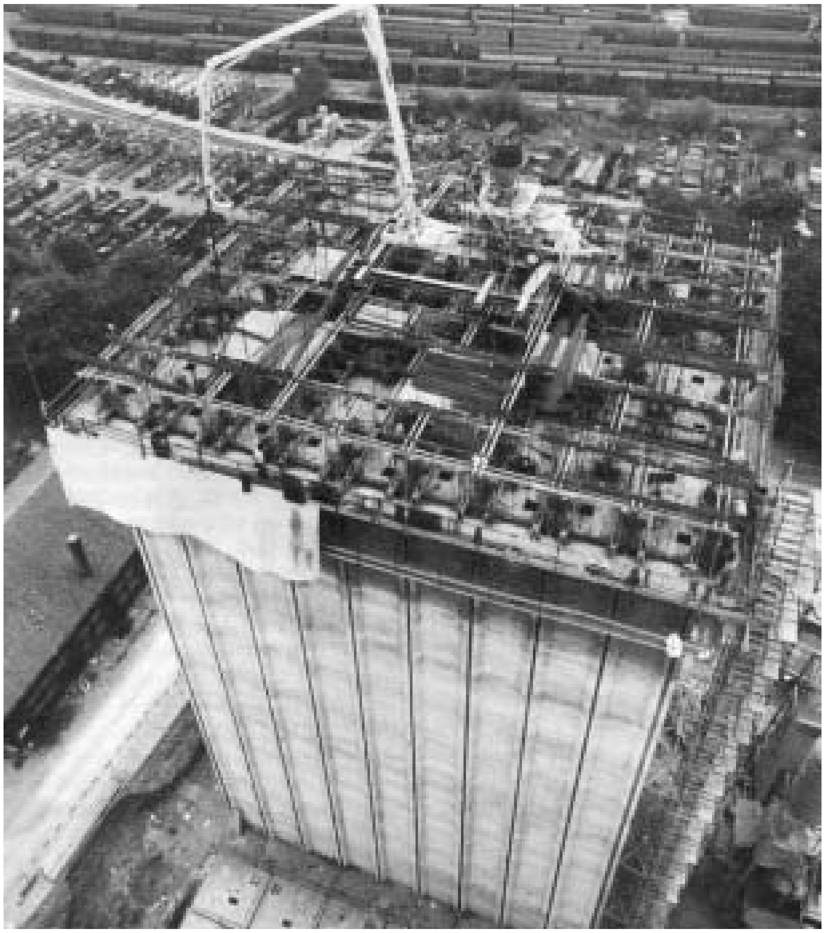


Figure 2 The use of VSL Slipforming in thank construction

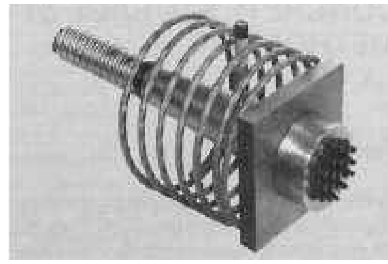


Figure 3: Stressing anchorage VSLtype E

Figure 4: Stressing anchorage VSL type EC

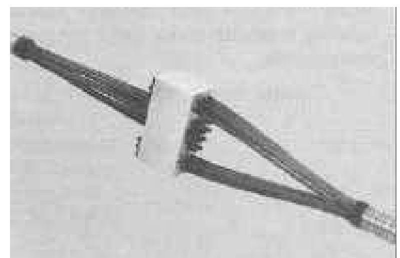


Figure 5: Centre stressing anchorage VSL type Z

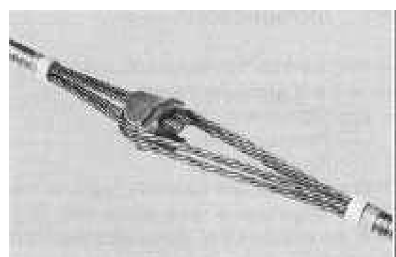


Figure 6: Centre stressing anchorage VSL type ZU

The forms are raised by hydraulic jacks of 30 or 60 kN lifting force moving on jacking tubes. The jacking tubes are positioned inside the wall under construction and transfer the load from the formwork equipment to the foundation. In the wet concrete zone the jacking tubes are encased in ducts which are connected to the slipform. These ducts provide antibuckling guidance to the tubes and prevent them from being concreted in, so that they can be recovered and used again (Fig. 1).

VSL Slipforming can also be used with special forms, by which conical walls and walls of variable thickness or special shapes can be produced. The speed of progress depends upon many factors, such as size of structure, dimensions, reinforcement, concrete quality, temperature etc. The rate varies from 2 to 6 m per 24 hours. Slipforming is a largely mechanized construction procedure. A trouble-free and therefore economic sequence of work requires certain preconditions in respect of design, organization and construction. Cooperation should therefore be established as early as possible between the project designer, main contractor and slipforming contractor. This will then guarantee rational and coordinated construction.

Information about the use of VSL Slipforming in the building of tanks and water towers (Fig. 2) will be found in the following chapters. Attention is also drawn to the publication «VSL Slipforming», which contains further details and examples of use.

1.3. VSL Post-tensioning

Post-tensioning is used in tank construction for the following reasons:

- It provides the required resistance to the acting forces.
- It makes possible solutions more economic than those achievable with reinforced concrete or steel.
- It renders the concrete virtually free of cracks.

The VSL Post-tensioning System (see publication «VSL Post-tensioning» with its wide variety of types of anchorage and cable units, is ideally suited for use in tank construction. The methods adopted for assembling the tendons are also of particular advantage in tank construction, since they can be adapted to the particular circumstances encountered.

The VSL Post-tensioning System uses, as tension elements, only 7-wire strands of 13 mm (0.5"), 15 mm (0.6") or 18 mm (0.7") nominal diameter, with ultimate tensile strengths of 1670 to 1860 N/mm^2. In addition to the high strength and low relaxation, the great ease with which the strands may be grouted (due to the screw action) should be emphasized. The strands of the VSL cables are stressed simultaneously, but individually locked in the anchorage. Stressing can be carried out in as many steps as desired.

In tank construction, the VSL Post-tensioning can provide the stressing anchorages types E and EC (Figures 3 and 4), which are installed in buttresses, are installed in buttresses, and also the special centre stressing anchorages types Z and ZU (Figures 5 and 6), which make the provision of buttresses unnecessary as these anchorages can be stressed in a block-out in the wall. Of the dead-end anchorages, apart from types H and U (Figures 7 and 8), special mention should be made of type L, in which the tendon can be retur-ned through 180° in a small space. This type is especially suitable for vertical post-tensioning, since it enables the posttensioning steel to be installed later, which has constructional advantage (Fig. 9).

The horizontal tendons also are usually installed after concreting. The VSL pushthrough method is most commonly used here; this consists of pulling the strand from the dispenser and pushing it by means of a special device directly into the duct. When the strand has reached the necessary length it is cut off and the procedure is repeated

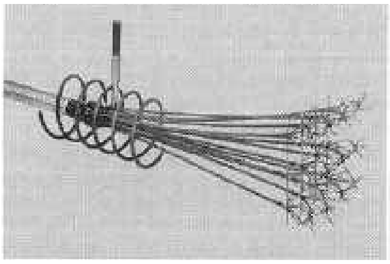


Figure 7: Dead-end anchorage VSL type H

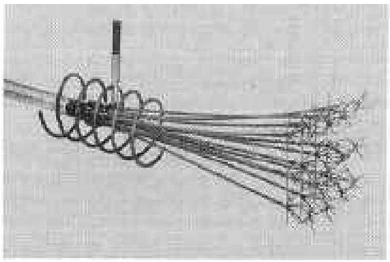


Figure 8: Dead-end anchorage VSL type U

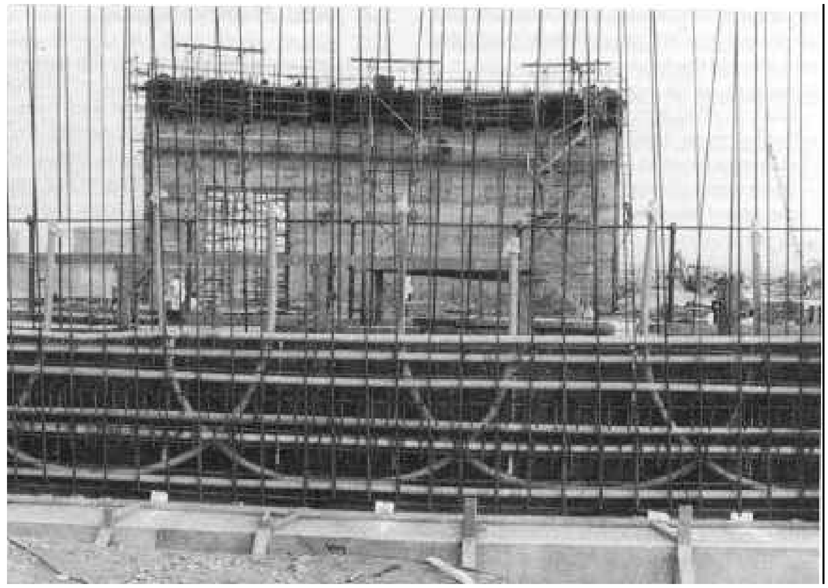


Figure 8: Dead-end anchorage VSL type U

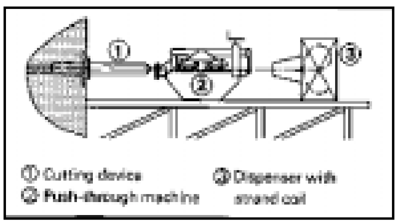


Figure 10: Diagrammatic representation of the VSL push-through equipment

until all the strands of the cable have been placed in the duct (Fig. 10). In tank construction, the following possible applications of post-tensioning may be considered:

- Post-tensioning of foundation slabs,
- Longitudinal post-tensioning of straight walls,
- Circumferential post-tensioning of walls,
- Vertical post-tensioning of walls,
- Post-tensioning of flat tank roofs,
- Post-tensioning of tank shells,
- Suspension of tank shells.

In foundation slabs, the crack-free nature of the structure obtained and economic savings are decisive advantages favouring the use of post-tensioning. Especially in the case of tanks of large horizontal dimensions, post-tensioned foundation slabs are cheaper than ordinarily reinforced slabs, since less material is required. The tendons are usually arranged orthogonally, even for circular foundation slabs.

For straight walls, post-tensioning serves particularly for making the concrete crackfree.

The circumferential post-tensioning of walls is provided by means of individual tendons where the VSL system is used. It would also be possible to use a winding method. This does, however, have certain disadvantages: before winding can commence a complete wall must have been erected. After winding, the prestressing wires must be covered with a sprayed concrete layer to protect them against corrosion. Since this layer is not prestressed, its freedom from cracking is not assured and thus also the corrosion protection of the post-tensioning steel is not fully assured, as some cases of failure have demonstrated.

The cables of the circumferential wall prestressing are, where anchorages type E and EC are used, anchored in buttresses and, when anchorages types Z and ZU are used, anchored in block-outs. In the last named case each cable forms a complete circle; otherwise, the number of the buttresses is the determining factor for the cable angle. In practice this number is 2, 3, 4 or in certain circumstances even 6 or 8; the cables accordingly extend around 120°, 180°, 240°, or 360°. The value to be chosen will depend upon the diameter of the tank, its height, the size of tendon used, the friction coefficient and the labour and material costs. For practical reasons the buttresses should not be further than 35 m apart in the case of low tanks built by segments (length of slipform). The cable length should not exceed 120 m. In general it may be stated that the economic range lies between 180° and 360°. With decreasing tank diameter, the most favourable angle shifts towards the complete circle. Cables of fairly high ultimate strength are more economical than smaller cables, but it is not always possible to use them, since the spacing between cables should usually not exceed three times the wall thickness. In order to achieve a uniform distribution of prestressing force, the anchorages of successive cables are staggered from one another. The width of the buttresses depends upon the diameter of the tank, the wall thickness and the cable unit employed, and upon the straight length of cable necessary behind the anchorages. It is therefore not possible to make a general statement, but various specific indications will be found in the examples in the following chapters.

For anchorages types Z and ZU, a special curved chair is inserted between the anchor body and the jack, thus enabling the strands to be bent out from the block-out (Fig. 11). After stressing, the block-outs are filled with concrete. Depending upon the access facilities, block-outs may be located either either on the inside or on the outside. The block-outs of successive cables are likewise staggered from one another.

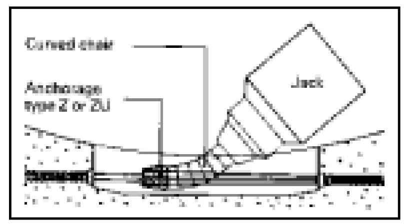


Figure 11: Anchorage VSL type Z or ZU with stressing jack and curved chair

The use of cables comprising Z- or ZU-anchorages also has the following advantages:

- No buttresses are required,
- Only one anchorage per cable (except for very long cables, where a number of anchorages may be necessary),
- Thus as a rule only one stressing operation per cable,
- An economical solution, especially for small and medium tank diameters.

For the vertical post-tensioning of walls, two types of cables may be considered: (1) cable type EH (possibly EU), i.e. a cable with a stressing anchorage type E at the top edge of the wall and a dead-end anchorage type H (possibly type U) at the foot of the wall. Cables of these types must be installed completely before concreting. (2) cables of type ELE, i.e. a cable possessing two stressing anchorages type E at the top edge of the wall and a dead-end anchorage type L at the foot of the wall. With this arrangement the cable can be installed after concreting. The anchorages of type L are arranged overlapping one another. Instead of type E the type EC may of course be used alternatively.

Flat tank roofs, such as are used particularly for low tanks of fairly large horizontal dimensions, and which are supported on a regular grid of columns, are more economical to construct if they are post-tensioned, as in the case of slabs for buildings. The advantages of the post-tensioned tank roof as compared with an ordinarily reinforced roof include the following:

-For a given thickness of slab a larger column spacing is possible,

-For a given column spacing a thinner slab may be used,

-More rapid construction is possible with the use of post-tensioning,

-Expansion joints can be reduced in number or entirely eliminated,

-Post-tensioning makes the slab largely watertight.

The detailed design may be carried out according to the technical VSL report «Posttensioned Concrete in Building Construction -Post-tensioned Slabs» which discusses design and construction in considerable detail.

For the post-tensioning of slabs, two special VSL post-tensioning systems are available (Figures 12 and 13):

-Slab Post-tensioning System with unbonded tendons (Monostrand Post-tensioning System),

-Slab Post-tensioning System with bonded tendons.

In the first named system, individual strands coated with grease and subsequently sheathed with a polyethylene tube extruded over them, known as monostrand, are used. In the second system four strands lie in a flat duct, which is grouted after stressing. Details and examples of use (other than in tank construction) will be found in the brochure «VSL Slab Post-tensioning».

Tank shells are usually circumferentially prestressed. To avoid the need for buttresses, cables with anchorages of VSL type Z or type ZU can be used. Other forms of construction for tank shells and the corresponding post-tensioning are given in Chapter 2.

The suspending of tank shells by means of prestressing tendons is usually adopted when the shells are lifted into position (by converting the lifting cables into suspension cables).

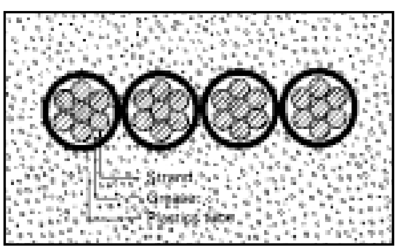


Figure 12: The basic layout of the VSL Slab Post-tensioning System with unbonded tendons

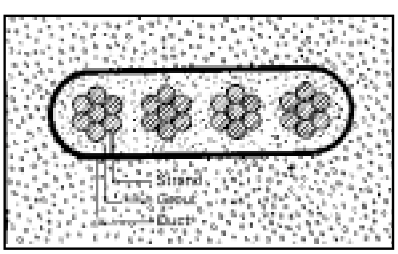


Figure 13: The basic layout of the VSL Slab Post-tensioning System with bonded tendons

1.4. VSL Heavy Rigging

The tanks of water towers and the roofs of relatively high tanks may with advantage be constructed on the ground and subsequently lifted into their final position. This enables the use of expensive formwork, which is sensitive to deformation, and high risk working at a great height to be eliminated. Initial erection on the ground facilitates working sequences and the quality of construction is improved, because supervision is more thorough.

The components are preferably raised by pulling rather than by pushing, since the pulling method is simple, economical in materials and comparatively rapid. The VSL Strand Rigging System (see also brochure «VSL Heavy Rigging») has been developed from the VSL Post-tensioning System. Its essential components are the motive unit, the strand bundle and the anchorage at the lifted structure (Fig. 14).

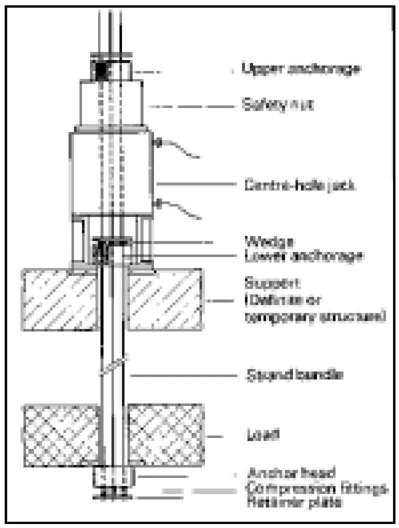


Figure 14: Basic construction of the VSL Strand Rigging System

Figure 15: Use of VSL Heavy Rigging in tank construction

The motive unit consists of a VSL centrehole jack and an upper and a lower strand anchorage. The upper anchorage is situated on the jack piston and moves up and down with it. The lower anchorage is fixed to the support of the jack.

For the load-bearing element, 7-wire prestressing steel strands Ø 15 mm (0.6") are normally used. Strands have the advantage over other load-bearing elements that their specific carrying capacity is particularly high and they can be cut to any required length. The number of strands per cable is adapted to the load to be moved, so that within the scope of the six existing VSL basic motive units any force between 104 and 5738 kN is possible. The simultaneous use of a number of sets of motive units enables even very heavy loads to be raised (see, for example, Fig. 48).

The anchoring of the strands to the structure lifted is effected with components of the VSL Post-tensioning System. The fact that the VSL Strand Rigging System makes use of the same elements as the VSL Post-tensioning System is a particular advantage, in that it is possible to convert the lifting cables into suspension cables and thus, for example, to attach a tank shell to a shaft of a tower (see, for example, chapter 2.2.4.).

1.5. Reference to other VSL systems

In connection with the construction of tanks, there may be occasion also to use other VSL systems, such as

-VSL Soil and Rock Anchors,

- VSL Measuring Technique,

-VSL Fabric Formwork,

-VSLFlatJacks.

VSL Soil and Rock Anchors may be used, for example, for counteracting the uplift on tanks located in groundwater. Such tanks or basins are to be found, for instance, in sewage treatment plants. The technical VSL report «Soil and Rock Anchors Examples from Practice» contains a description of the prevention of uplift by means of VSL anchors.

The other VSL systems referred to may be used in particular cases. The appropriate brochures give information about these Systems.

Services offered by VSL

it will be apparent from the preceding chapter that the VSL organizations can offer a very comprehensive range of services in tank construction, namely:

- Consultancy service to owners, architects, engineers and contractors,
- The carrying out of preliminary design studies,
- Assistance with the preliminary design of tanks,
- The development of complete projects,

- The design and manufacture of slipforms,
- The execution of slipforming work,
- Detailed design of post-tensioning,
- Carrying out of post-tensioning work,
- Design of rigging operations,
- Carrying out of rigging operations,
- The use of other VSL systems.

The VSL organizations I are in a position to provide these services on advantageous terms; for each case the possibilities and extent of the services will usually need to be clarified in discussions between the owner, the engineer, the contractor and the VSL organization.

*) The addresses of VSL Representatives will be found on the back cover of this report.

In many cases the use of several VSL systems is possible on a single project. This enables the use of labour and materials to be rationalized with consequent savings in costs.

At this point reference may again be made to those VSL publications which are of importance in tank construction:

- Brochure «VSL Slipforming»
- Brochure « VSL Post-tensioning»
- Brochure «VSL Slab Post-tensioning»
- Technical report «Post-tensioned Concrete in Building Construction - Posttensioned Slabs»
- Brochure «VSL Heavy Rigging»

In addition, the following VSL publications are available:

- Brochure «VSL Soil and Rock Anchors»
- Brochure «VSL Measuring Technique»
- Brochure «VSL Fabric Formwork»
- Brochure «VSL Flat Jacks»
- Technical report «Soil and Rock Anchors - Examples from Practice»
- Brochure «Who are VSL International»
- Brochure «VSL in Hydroelectric Power Schemes»
- Various Job Reports
- Technical Report «The Incremental Launching Method in Prestressed Concrete Bridge Construction»
- Technical Report «The Free Cantilevering Method in Prestressed Concrete Bridge Construction»
- Technical Report «Prestressed Concrete Pressure Tunnels»
- VSL News Letters.

2. Storage tanks for liquid:

2.1. Water tanks

2.1.1. Introduction

Water storage tanks are certainly the commonest of all tanks, because water is a necessity of life. Since the medium water can adapt to any form without difficulty (even in the operating sense) and tanks require no lining, water tanks can have the most varied shapes.

Water tanks on or in the ground are usually cylindrical, rarely rectangular. The roof is either flat, supported by columns, or is domed and therefore spans the vessel without supports. Since the pressure on the walls of the vessel is proportional to the water head, relatively low walls are preferred for water tanks on or in the ground.

2.1.2. Water tank, Willows, USA

Owner Willows Water District, Englewood, Col.
Engineer Meurer & Associates, Denver, Col.
Contractor Western Empire Constructors, Denver, Col.
Post-tensioning VSL Corporation, Dallas, Tx.
Year of construction 1978

Introduction

This water tank was built between May and November 1978 in the southern urban district of Denver. The structure was designed and built on the basis of ACI Standard 318 «Building Code Requirements forReinforced Concrete», the report of ACI Committee 344 «Design and Construction of Circular Prestressed Concrete Structures», the report of ACI-ASCE Committee 423 «Tentative Recommendations for Pre-stressed Concrete Flat Plates», and ACI Standard 301-72 «Specifications for Structural Concrete for Buildings».

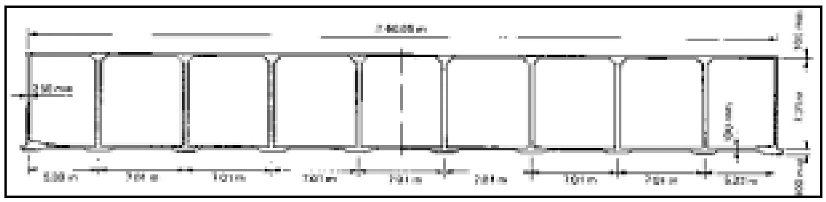


Figure 16: Section through the tank

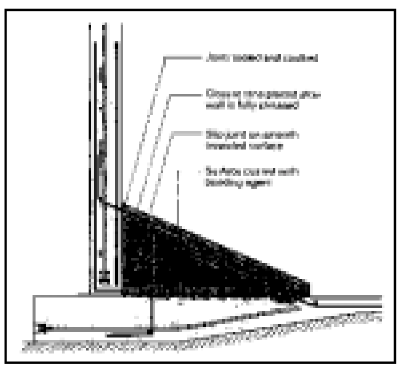


Figure 17: Detail of connection between wall and bottom slab

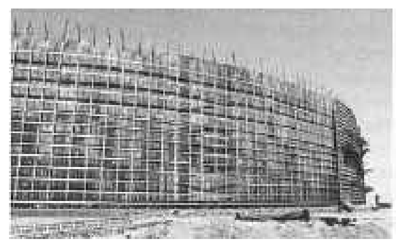


Figure 18: Tank wall during construction

Details of the structure

The tank (Fig. 16) has an external diameter of 60.65 m, a wall height of 7.31 m and wall thickness of 250 mm. The bottom slab is generally 130 mm thick, with an increase at the edge and beneath columns to 300 mm. The roof is flat and has a thickness of 165 mm. It is supported by circular section columnsØ 410 mm on a grid of 7.01 m. When finally constructed, the wall is rigidly connected to the bottom slab (Fig. 17).

Construction procedure

The bottom slab was constructed in two sections, after which the wall was concreted in eight segments using conventional formwork (Fig. 18). After all the wall tendons had been stressed, the roof was built; this again was carried out in two halves.

Finally, the triangular in-fill between wall and bottom slab was concreted.

Post-tensioning

The tank is entirely in post-tensioned concrete, i.e. the wall, the bottom slab and the roof are all post-tensioned.

The bottom slab post-tensioning consists of orthogonal monostrands Ø 13 mm, at uniform spacings. The strands were stressed after the second section of the slab had been concreted.

For the wall, cables in ducts were used. In the horizontal direction, tendons of type VSL EE 5-7 (ultimate strength 1286 kN) were used. They each extend around one quarter of the circumference and the spacing between tendons ranges from 460 to 760 mm. Eight buttresses of 2.70 m width and 300 mm additional thickness serve for anchoring the tendons. For the vertical post-tensioning, 4-strand cables in flat ducts were used. The centre-to-centre spacing is 660 mm. At the lower end, the vertical tendons have dead-end anchorages of the monostrand system. The vertical cables are at a distance of 114 mm from the outer face, the horizontal cables being outside the vertical ones.

The roof is also post-tensioned with monostrands. In contrast to the bottom slab, however, the strands in one direction are concentrated over the columns and in the other direction are distributed (Fig. 19).

The tendons could be stressed after a concrete cylinder strength of 17 N/mm² had been reached.

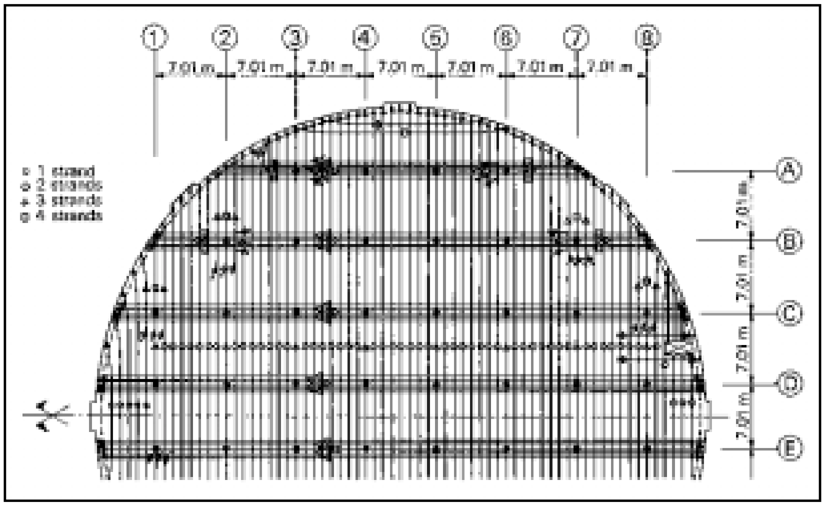


Figure 19: Layout of tendons in tank roof

2.1.3. Water tank, Paarl, South Africa

Owner	Municipality of Paarl, Cape Province
Engineer	Ninham Shand and Partners Inc., Cape Town
Contractor	LTA Construction (Cape) Ltd., Cape Town
Post-tensioning	Steeledale Systems (Pty.) Ltd., Johannesburg
Year of construction	1978

Introduction

The Municipality of Paarl, a town approximately 40 km to the east of Cape Town, has had a water reservoir of 36 000 m³ capacity built in its vicinity. The structure is circular with an external diameter of 78.80 m and a free height at the centre of 8.90 m. It is covered by a 230 mm thick flat roof with a slight fall from the centre to the perimeter, on which there is a 100 mm thick layer of gravel. The roof is supported on square columns (dimensions 400 x 400 mm), arranged on a grid of 9.20 x 9.20 m. The external wall of the tank is 6.30 m high and 400 mm thick. It is structurally separated both from its foundation and from the roof. The joints are equipped with rubber bearing plates and the usual water stops. A fill embankment is placed around the tank (Fig. 20).

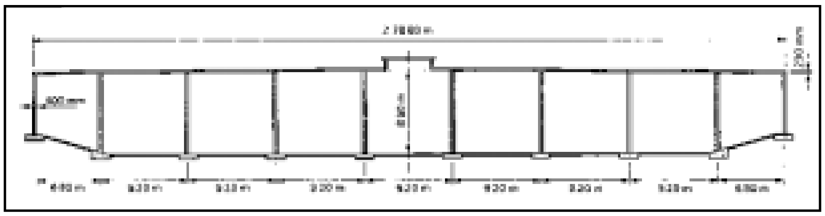


Figure 20: Section through the structure

In this tank both the outer wall and also the roof are post-tensioned. The post-tension-ing of the roof was based upon a special proposal from Steeledale Systems (Pty.)

Ltd., which indicated considerable cost advantages for the prestressed solution over an ordinarily reinforced structure.

Construction procedure

The structure was built of in-situ concrete throughout. After the excavation had been completed, the foundations, which are situated approximately 3 to 5 m below the natural ground surface, and also the bottom slab were constructed, followed by the columns and the outer wall. The wall was constructed in a total of 12 segments, which in turn were subdivided into three sections of 1.20, 2.10 and 3.00 m height. For each of these three sections, a separate form was used. The roof was built in three steps, approximately 375 m3 of concrete being required for each step.

Post-tensioning

The post-tensioning of the wall required a total of 42 VSL cables, each of which extend around tends around one-third of the circumference. The length of each cable is therefore approximately 85 m. The 24 tendons of the lowest eight rings each consist of 12 strands Ø 13 mm (cable type therefore 5-12, ultimate strength per cable 2189 kN). The next 4 x 3 cables each contain 7 strands, while at the top there are 3 cables of 5 strands and 3 of 4 strands of the same quality. The spacing between the tendons varies from bottom to top between 355 and 550 mm. To obtain the most uniform post-tensioning possible, the cables of two successive rings have their anchorages offset by 60° from one another.

The wall therefore has 6 external buttresses; these are each 3.00 m wide and 400 mm thick, additionally to the wall thickness. The tendons are 130 mm from the outer face of the wall and are all fitted with stressing anchorages type E at both ends.

The empty ducts only were placed during construction of the wall and the strands were pushed through after concreting using the VSL push-through method. The cables of one complete ring were simultaneously stressed to 70% of the ultimate force by means of 6 jacks ZPE-12. During a first stage, the tendons of each alternate ring were stressed, and after this the remainder were stressed.

The roof was post-tensioned with VSL cables of type 5-4 (ultimate force each 730 kN, working force after all losses 474 kN), for which flat ducts were used. For each span, 11 tendons were required in each direction, of which 7 run in the column strip (axial spacing of the cables 0.66 m) and 4 run in the span strip with an axial spacing of 1.05 m (Fig. 21). To suit the construction procedure, all the cables are continuous in one


Figure 21: Cables laid for the roof

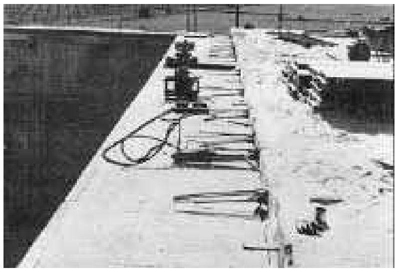


Figure 22: Stressing of tendons at the couplers in the construction joint

direction, whereas in the other direction just sufficient tendons were coupled and stressed at each construction joint to support the self-weight and construction loads (Fig. 22). The remaining cables in this direction are also continuous and were installed after concreting by the pushthrough method. For all the other tendons, the strands were placed before concreting, the ducts being first laid and the strands then pushed through them. Depending upon the length, the cables either have stressing anchorages at both ends, or a compression fitting anchorage, that is a dead-end anchorage, at the one end. A concrete strength of 25 N/mm^2 was required before the prestressing forces was applied. The cables were stressed to 80% of ultimate force and locked off at 70% of ultimate force. The stressing steel requirement for the roof, which is fully prestressed (that is no tensile stresses are permitted) was 7.6 kg/M^2. All cables were grouted with cement mortar. In addition to the post-tensioning cables, orthogonal ordinary reinforcement comprising 4 bars Ø 20 mm in each direction was placed over each column.

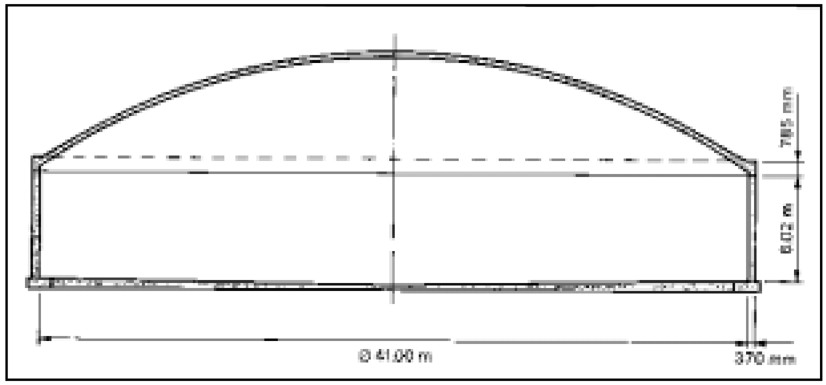


Figure 23: Section through the water tank at Buraydah

Figure 24: The tank just before completion

2.1.4.	**Water tank, Buraydah, Saudi Arabia**
Owner	Kingdom of Saudi Arabia, Ministry of Agriculture and Water, Riyadh
Engineer	Vattenbyggnadsbyran, Stockholm, Sweden
Contractor	Saudi Swiss Construction Co., Riyadh
Post-tensioning	VSL INTERNATIONAL LTD., Berne, Switzerland
Year of construction	1978

Introduction

This water tank has a capacity of 8000 m^3 and is situated at the edge of the town of Buraydah, adjacent to a water tower, to which it is connected by piping.

Details of the structure

The internal diameter of the tank is 41.00 m. Its 370 mm thick wall stands on a 500 mm deep, post-tensioned foundation ring, and is separated from the ring by a joint. The wall is 6.02 m high and carries at the top a 785 mm deep tension ring, also separated by a joint, which forms the boundary of the domed roof (Fig. 23). of the domed roof (Fig. 23). The wall and tension ring are also post-tensioned. The tendon anchorages are situated in four buttresses, which are 3.40 m wide in the finished state (Fig. 24).

Construction procedure

After the foundation ring had been built, the wall was constructed by sections (Fig. 25). The external formwork and the stopends were first ereted, then the ordinary reinforcement, the empty horizontal ducts and the complete vertical cables were installed. The inner formwork was then fixed and the section was concreted. The number of sections was eight, four with and four without a buttress.

Post-tensioning

As mentioned above, the wall is horizontally and vertically post-tensioned. The horizontal cables are of type VSL EE 5-7 and 5-12 (ultimate forces 1292 and 2216 kN) and the vertical cables of type EH 5-7. The horizontal tendons in the foundation ring are also of type EE 5-7, and those in the tension ring of the domed roof of type EE 5-10. All horizontal cables extend through 180°. Their axes are 120 mm from the outer face (or 130 mm in the foundation ring). The vertical spacing varies from 410 to 850 mm. The vertical cables are located at the centre of the wall at a uniform spacing of 1.31 m (Fig. 26). In total, 99 vertical tendons and 14 x 2 horizontal tendons were required.

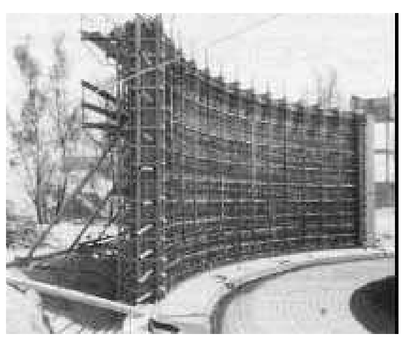


Figure 25: First section of wall during construction

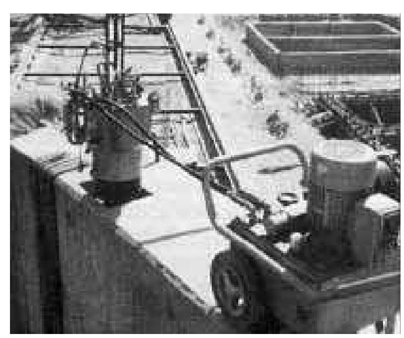


Figure 26: Stressing of a vertical tendon

2.1.5. Water tank, Barnarp, Sweden

Owner - Municipality of Jonkoping
Engineer Allmanna Ingenjorsbyran AB, Stockholm
Contractor Nya Asfalt AB, Malmo
Post-tensioning Internordisk Spannarmering AB, Danderyd
Years of construction 1978-1979

Introduction

At Barnarp, near Jonkoping in Southern Sweden, a water tank of approximately 3300 m3 capacity was built between November 1978 and May 1979. Its cylindrical wall was to have been equipped with eight buttresses for anchoring the post-tensioning cables, but on the basis of a proposal from Internordisk Spannarmering AB the number was reduced to two and the cable layout accordingly modified. This resulted in a saving in costs.

Details of the structure

The internal diameter of the tank is 18.00 m and its height 13.00 m above the foundation. The foundation slab is 400 mm thick and rests on rock. The thickness of the tank wall is 250 mm. The roof consists of three prefabricated, post-tensioned beams, with prefabricated slabs resting on them. These slabs are faced with insulation. The tank wall was constructed by slipforming. Between the wall and the foundation there is a joint which is sealed by a water stop (Fig. 27).

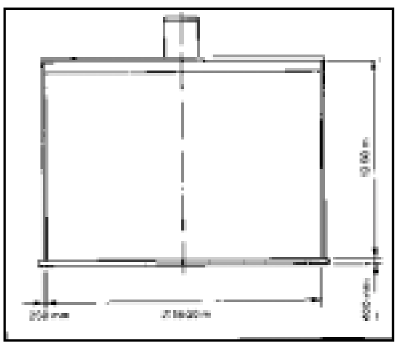


Figure 27: Cross-section

Post-tensioning

The tank wall, as mentioned above, was to have had eight buttresses and cables each extending through 180°. This arrangement was modified to only two buttresses, with cables extending through 360° (Fig. 28), thus providing cost savings. The quantities of prestressing steel and ducting for the asbuilt solution were indeed greater, but the number of anchorages, the work and in particular the quantity of concrete and ordinary reinforcement were reduced, since six buttresses had been eliminated. In total, 22 cables were required, namely two each of VSL type EE 5-5 Dyform (ultimate force 1045 kN) at the top and bottom and 18 cables of VSL type EE 5-7 Dyform (ultimate force 1463 kN) between them. The cables, which are located on the axis of the wall, are at spacings of 420 to 750 mm. For the coefficients of friction, μ = 0.18 and k = 0.0022 were used in the calculations. The tendons, 58.30 m in length, were assembled by pushing through

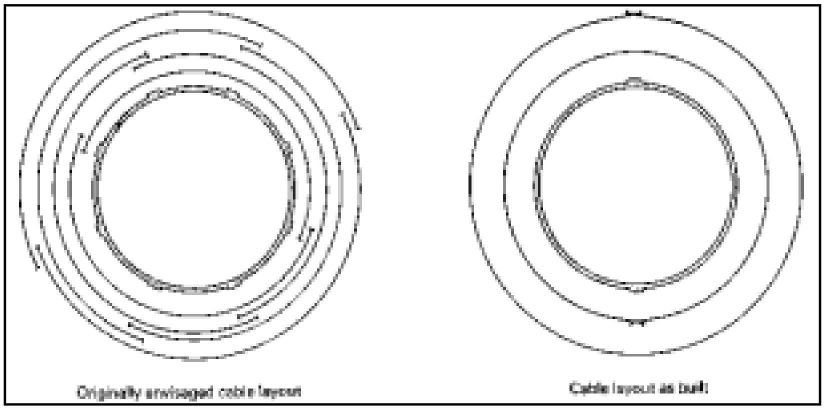


Figure 28: Tendon layout as originally envisaged and as built

bled by pushing through the strands. The tendons could be stressed when a concrete strength of at least 28 N/mm^2 had been reached.

2.1.6. Water tank, Leigh Creek South, Australia

Owner Electricity Trust of South Australia, Adelaide
Engineer VSL Prestressing (Aust.) Pty. Ltd., Mt. Waverly
Contractor Dillingham Australia Pty. Ltd., Adelaide
Post-tensioning VSL Prestressing (Aust.) Pty. Ltd., Mt. Waverly
Year of construction 1979

Introduction

This tank, with a capacity of 9000 m^3, is situated approximately 700 km to the north of Adelaide. The original design provided for it to be constructed in reinforced concrete with the wall fixed in the foundation. On the basis of a special proposal by the contractor and VSL Prestressing (Aust.) Pty. Ltd. the wall was prefabricated. The tank was constructed between June and December 1979.

Details of the structure

The internal diameter of the tank is 39.00 m, its wall thickness 200 mm and the height of the wall 7.50 m (Fig. 29). The wall is seated on an annular foundation by means of a continuous rubber bearing (Fig. 30). Four buttresses, each 1.80 m wide and 250 mm thicker than the wall, are provided for anchoring the tendons. The roof is a steel structure supported on columns.

Construction procedure

The annular foundation and bottom slab were constructed in in-situ concrete. The wall, as mentioned above, was prefabricated. On the site, 24 standard segments and 4 segments comprising buttresses were constructed (Fig. 31). After positioning (Fig. 32), the 200 mm wide joints between the elements were filled with concrete.

Post-tensioning

The wall is horizontally and vertically posttensioned. The vertical tendons comprise VSL bars Ø23 mm

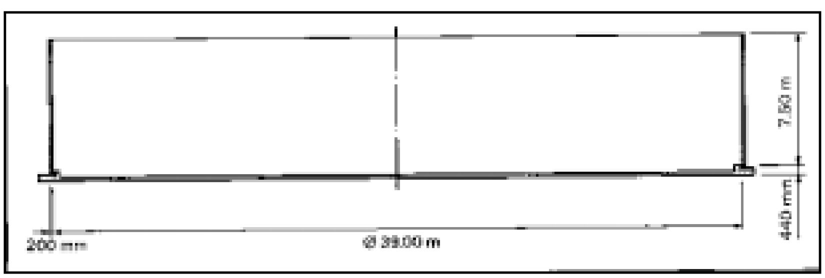


Figure 29: Section through the tank

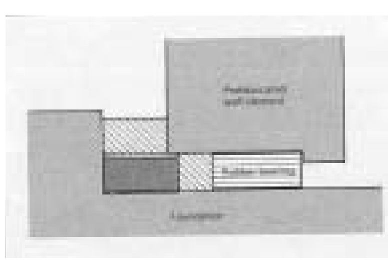


Figure 30: Detail of joint between wall and foundation

Figure 31: Prefabrication of segments on the site

Figure 32: Erection of segments

(ultimate force 448 kN). Each 4.17 m wide segment has four of these bars. Horizontally, there are 16 cables 5-4 and 2 cables 5-3 (ultimate force per strand 184 kN) per section. Each tendon extends around one half of the circumference, the anchorages of successive rings being displaced by 90°. The spacing of the tendons varies, from bottom to top, between 160 and 750 mm.
The vertical tendons were stressed before the elements were positioned, the specified minimum concrete strength at stressing being 25 N/mm^2.

Additional

A few months ago a similar tank was constructed in the same manner at a different location. For the vertical post-tensioning, however, cables SO/H 5-4 in flat ducts were used and for the horizontal post-tensioning cables of type Z 5-4. There are four cables in each 4.475 m wide segment (wall thickness 225 mm, height 7.625 m). The number of horizontal cables is 18. In this tank the 125 mm thick bottom slab was also orthogonally post-tensioned with VSL single strand cables EH 5-1.

2.1.7. Water tank, Aqila, Kuwait

Client	Government of Kuwait, Ministry of Electricity and Water
Engineer	Government of Kuwait, Ministry of Electricity and Water, Department of Water and Gas and VSL INTERNATIONAL LTD., Berne, Switzerland

Introduction

At the end of 1979 the Kuwaiti Government issued an enquiry for the constructionof two tanks, each of 172 500 m^3 capacity.
The dimensions of each were 187.10 x 183.50 m and on average the free internal depth was 5.46 m. It was intended that the tanks should be constructed of reinforced concrete. The roofs were divided into panels of 10 x 10 m (standard panel), separated from one another by expansion joints. Each roof panel was supported by four columns (spaced at 6.50 m).

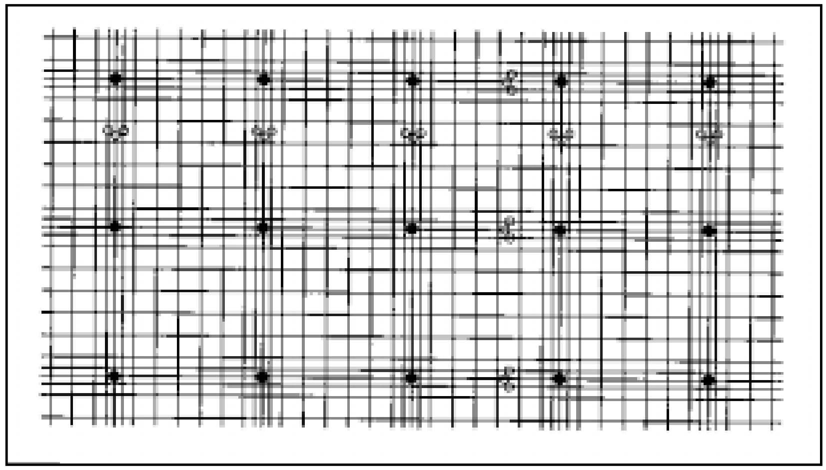


Figure 34: Cable layout in the roof slab

Alternative in post-tensioned concrete VSL INTERNATIONAL LTD. prepared an alternative proposal to .the Government design, which however was not constructed since the contracting group to which the proposal was presented was unsuccessful in obtaining the contract. The special proposal provided for dividing the 33 600 m^2 roof into only 16 parts, which would have been carried on columns at spacings of 5.75 and 5.65 m respectively. The thickness of the post-tensioned roof would have been 200 mm (for the reinforced concrete solution 230 to 260 mm). The bottom slab would also have been post-tensioned and its thickness would have been reduced from 200 to 150 mm (Fig. 33).
The post-tensioned bottom slab alone would indeed have been more expensive than the normally reinforced one, but its design would have been considerably improved by the prestressing. In spite of the greater cost of the bottom slab, the total structure in post-tensioned concrete would have been approximately 7% more economical. This was particularly on account of the savings at the columns, the roof and the expansion joints. By the reduction of these also the quality of the roof would have been considerably improved.
In this connection it may be mentioned that a similar solution had already been used earlier in Kuwait and that further proposals based on post-tensioning are pending.

Post-tensioning

The post-tensioning would have consisted of VSL monostrands Ø 13 mm. The bottom slab would have been centrally prestressed and the roof prestressed according to the bending moment diagram. For the bottom slab and the roof, 12 strands per span in each direction would have been required (Fig. 34). The calculations were based on strands of cross-section 99 mm^2 and an ultimate strength of 184.5 kN.

2.1.8. Water tanks, Dodoma, Tanzania

Owner	Capital Development Authority, Dodoma
Engineer	Project Planning Associates Limited, Toronto, Canada and VSL INTERNATIONAL LTD., Berne, Switzerland
Contractor	Saarberg Interplan GmbH, Saarbrucken, FR Germany
Slipforming and Posttensioning	VSL INTERNATIONAL LTD., Berne, Switzerland
Year of construction	1981

Introduction

Dodoma, the future capital of Tanzania, lies approximately 400 km to the west of the present capital of Dar-Es-Salaam. Two circular water tanks, each of approximately 17 500 m^3 capacity, have been built here and entirely covered with earth after completion. The stored water is used as drinking water.

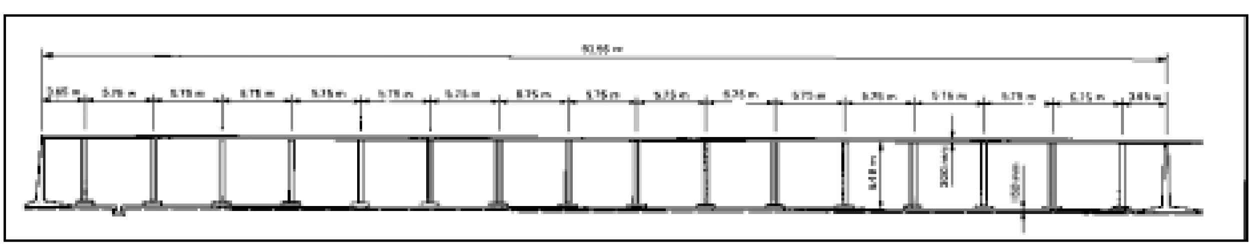


Figure 33: Section through the tank according to the alternative proposal by VSL INTERNATIONAL LTD.

Details of the structures

Each tank is 61.00 m in internal diameter and has a wall height of 6.92 m above the lower edge of the foundation. The wall thickness is 350 mm. The wall is monolithically connected with the foundation (Fig. 35). This type of transition between wall and foundation has in general proved to be the best solution. The monolithic connection provides the optimum in respect of failure behaviour and watertightness. Constraints arising from post-tensioning are avoided by leaving a construction joint open in the bottom slab and concreting it after stressing (see Fig. 35). Each tank has a flat roof, supported internally by individual columns (Fig. 36). These columns are on a grid of 5.80 x 5.80 m. The distance between centres of the two tanks is 65.00 m.

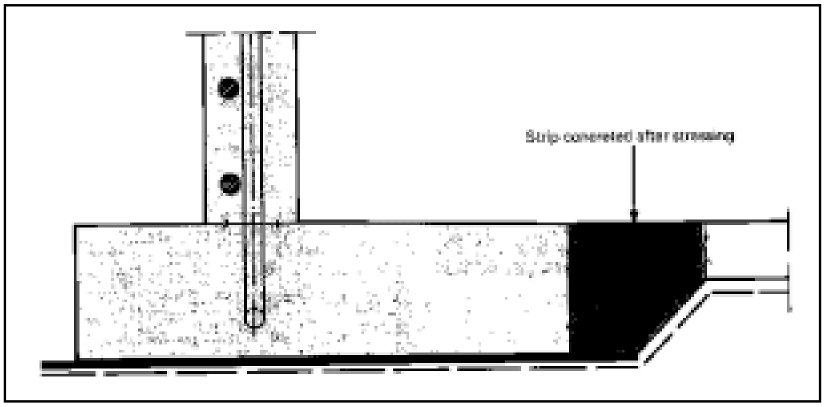


Figure 37: Construction of a wall segment by VSL Slipforming

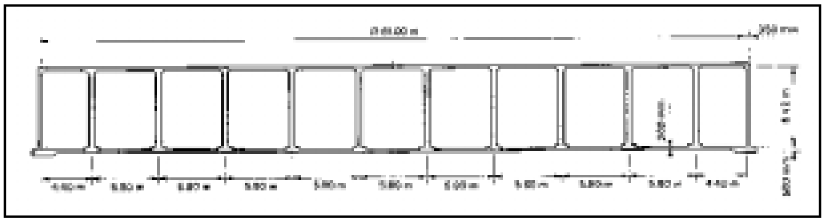


Figure 36: Section through a tank

Construction procedure

The walls of the tanks were constructed with the use of VSL Slipforming (Fig. 37). This method proved to be economical in spite of the low height of the wall, since each wall could be divided into eight segments, thus making possible rational use of the formwork. The total area constructed by slipforming was 5000 m^2. The rate of slipforming was 0.40 m/h, i.e. 15 hours were required for the construction of one segment. Erection of the formwork took ten days, and five days were required for transferring it to the next section.

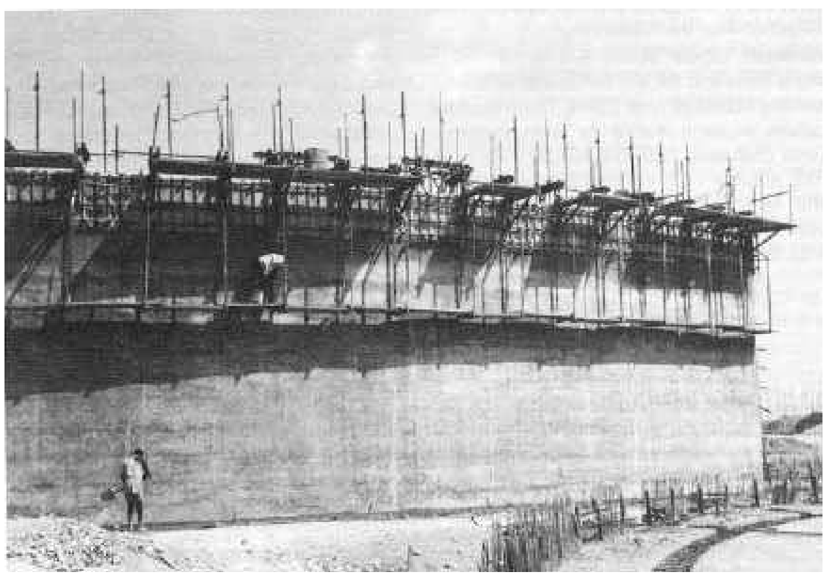


Figure 37: Construction of a wall segment by VSL Slipforming

Post-tensioning

It had originally been intended to prestress the walls by the winding method. VSL INTERNATIONAL LTD. put forward an alternative solution, involving the use of annular cables ZZ 6-6 (ultimate force 1566 kN) and vertical tendons EC/L/EC 6-7, which proved more advantageous (Fig. 38). Two Z-anchorages per annualr cable were chosen, on account of the large circumference of the wall.

Each wall thus comprises 12 annular cables, each possessing two anchorages VSL type Z, situated opposite to each other. The anchorages of two successive cables are displaced by 90°. The cable spacing increases from 350 mm at the bottom to 1000 mm at the top. The block-outs in which the anchorages were situated were 1400 mm long, 250 mm wide and of maximum depth 198 mm. They were on the external face of the wall. The axes of the annular cables are 100 mm from the external wall face.

The vertical post-tensioning consists, as mentioned above, of cables of type EC/L/ EC 6-7. The EC-anchorages are 1.50 m apart, this dimension corresponding to twice the radius of the loop. In total, 64 of these cables are provided in each tank.

The cables could be stressed when a concrete strength of 25 N/mm^2 had been reached. First of all, each alternate vertical cable was stressed, then the remaining vertical cables. Each alternate annular cable was then stressed, starting from the bottom and then, also from the bottom upwards, the remaining horizontal cables were stressed.

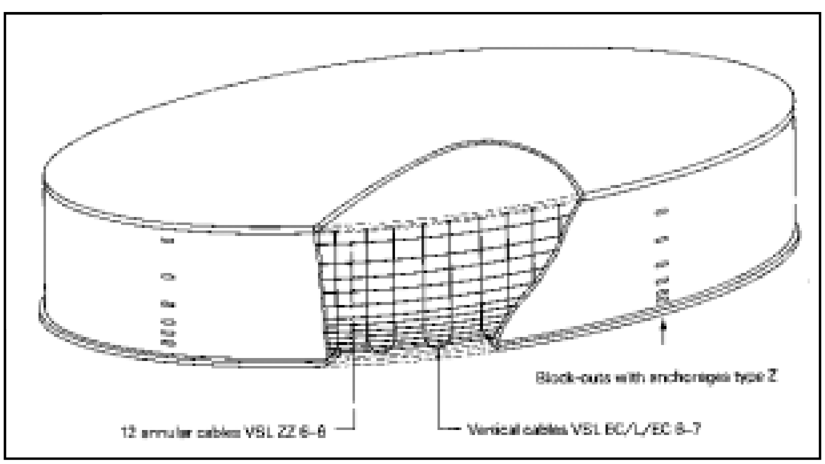


Figure 38: Diagrammatic representation of post-tensioning

2.2 Water towers

2.2.1. Introduction

Depending upon the pressure conditions it may be necessary to construct water tanks as high-level tanks, i.e. as water towers. Towers of this type usually consist of a cylindrical shaft and a conical tank shell. This form possesses advantages both in respect of construction and also from the architectural standpoint.

Water towers are, however, the type of structure in which from time to time very special forms are chosen, as illustrated by the example in Chapters 2.2.5. and 2.2.6.

The construction of the high-level tanks can be carried out in various ways:

- on a falsework supported on the ground around the tower shaft (Fig. 39; for example, see Chapter 2.2.5.),
- on a scaffold suspended from the tower shaft (Fig. 40; for example, see Chapter 2.2.2.),
- on a falsework close to the ground, followed by pushing the tank upwards as the tower shaft is constructed beneath it (Fig. 41; for example, see Chapter 2.2.8.),
- on a falsework close to the ground, followed by pulling up the tank from the previously erected tower shaft (Fig. 42; for example, see Chapter 2.2.3.).

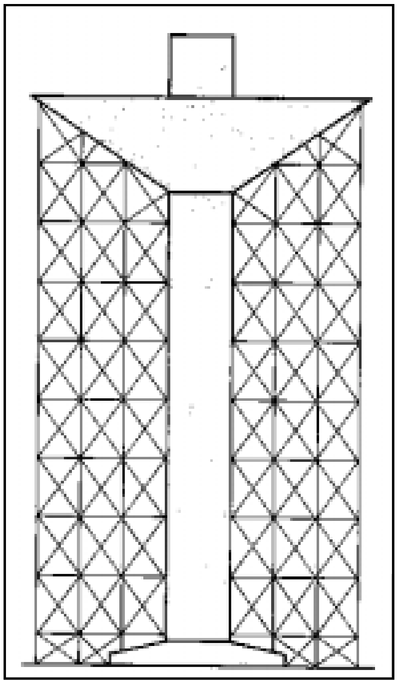


Figure 39: Erection of the high-level tank on falsework set up on the ground around the tower shaft

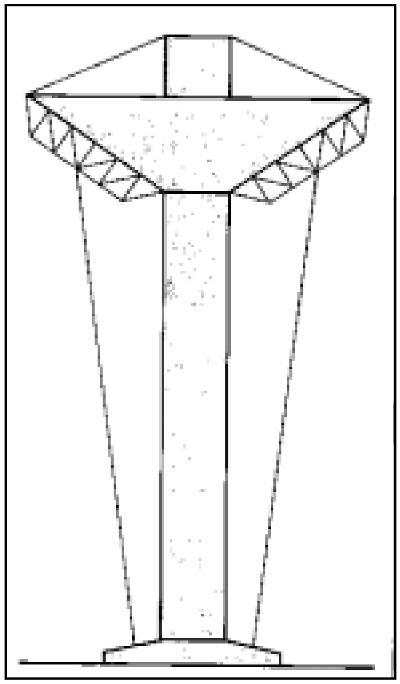


Figure 40: Erection of the high-level tank on a scaffold suspended from the tower shaft

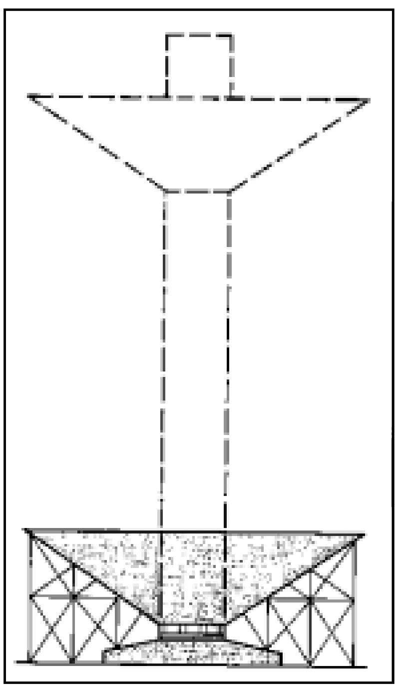


Figure 41: Erection of the high-level tank close to the ground, followed by pushing it upwards concurrently with construction of the tower shaft

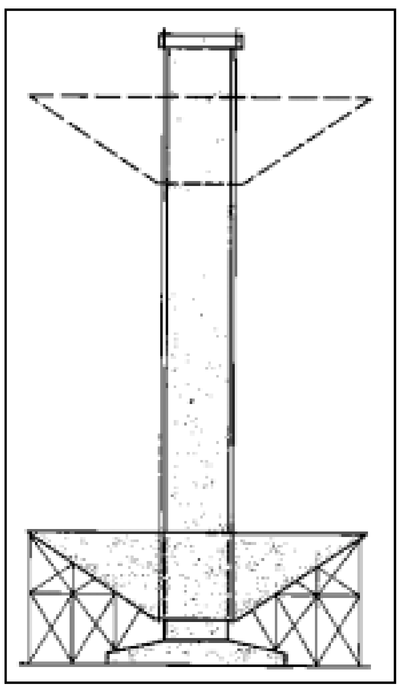


Figure 42: Erection of the high-level tank close to the ground, followed by pulling it up from-the previously erected tower shaft

The first method has two disadvantages: the cost of the falsework beyond a certain height is high and there is a risk when the shell is concreted that it may suffer unfavourable deformations. The second method can also lead to adverse distortions, but is the only one possible when space at the base of the tower is restricted. The third method can only be used if the tower shaft has a relatively large diameter compared with the lifting height and the tank diameter, since otherwise stability problems occur. Furthermore, the construction of the tower shaft takes a fairly long time.

In the majority of cases the fourth method is the most economical, since highly mechanised and efficient special methods can be used, namely slipforming for the construction of the shaft and heavy rigging for raising the tank. The building of the tank close to the ground is moreover advantageous, because it is easier to supervise the quality of the work and no operations need to be carried out at a great height. Thus, for example, the post-tensioning operations and the grouting of the cables can be completed before lifting, which naturally considerably simplifies their execution and thus makes them more economical.

The cables which are used for lifting the tank can, with the VSL system, subsequently be converted into suspension cables, by which the tank is fixed to the tower.

2.2.2. Water tower, Leverkusen, FR Germany

Owner: Stadtwerke GmbH, Leverkusen
Engineer: Leonhardt & Andra, Consulting Engineers, Stuttgart
Contractor: BaugesellschaftJ. G. Muller mbH, Wetzlar
Post-tensioning: VSL GmbH, Langenfeld
Years of construction: 1975-1977

Introduction

In the locality of Burrig of the large city of Leverkusen, to the north of Cologne, a water tower of 4000 m^3 capacity was built between 1975 and 1977 to assure the central water supply. In periods of low consumption the tower is filled with filtered water from the banks of the Rhine and it then supplies this water when required to consumers in various parts of the city. The tower rises more than 70 m above ground and carries, in its uppermost section, a shell having the form of a conical frustum with its apex downwards, which contains the two water chambers. Above the chambers there is a «croof storey».

Details of the structure

The water tower consists of the tower shaft of 74.80 m length and 8.00 m external diameter, and of the 17.35 m high tank (including «roof storey», which is 42.45 m in diameter. The wall thickness of the shaft is 400 mm. It houses a stair and a lift and the feed and return lines for the water supply. The conical shell for the storage of water is of post-tensioned concrete. Its thickness varies between 250 and 500 mm. The shell has an upward slope of 34° to the horizontal. At the outer edge it is reinforced by a tension ring, which is also post-tensioned. The remainder of the structure is of normal reinforced concrete.

The tower is founded at 5.00 m below ground level on the outcropping Rhine gravel, with a flat foundation 22.00 m in diameter. The foundation block increases in thickness from 1.50 m at the outside to 3.00 m near the centre and required 860 m3 of concrete for its construction, which amounts to approximately one third of the total quantity of concrete for the project (Fig. 43).

Construction procedure

After completion of the foundation, the tower shaft together with the lift shaft were constructed by slipforming. The prefabricated stairs and landings were installed afterwards. Construction of the conical shell imposed special requierement.

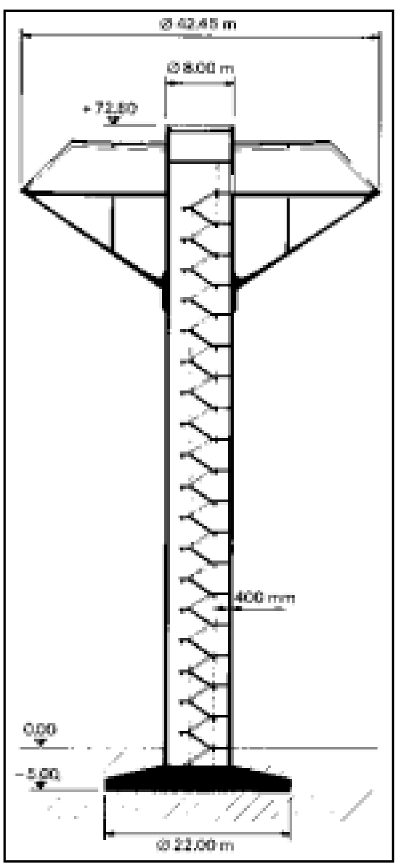


Figure 43: Section through the water tower


Figure 44: Tower with tank on falsework

posed special requirements. Although it had been envisaged in the tender documents that the tank would be constructed in a form resting on the ground and then raised into its final position, the contractor decided upon construction in the final position. The formwork of the high-level tank was therefore erected more than 50 m above the ground. It rested at its inner edge against the shaft and was suspended at its outer edge by a large number of suspension rods from the summit of the tower and additionally guyed to the foundation (Fig. 44).

The bottom layer of reinforcement was first placed on the formwork. Then the empty ducts of the prestressing tendons were laid in annular form. The tendons were installed in the ducts in a further operation by pushing through the individual strands with the VSL push-through machine (Fig. 45). As soon as the upper reinforcement had been placed and the forms for theblock-outs positioned, the shell could be concreted, commencing from the shaft and working outwards in a spiral. After the necessary hardening period the tendons were stressed, the block-outs concreted and the ducts grouted with cement grout. When the conical shell had been completed, it was covered with a slab, which also forms the floor for the roof storey. The works were completed with the fitting out of the «roof storey»and equipment for the water tower.

Post-tensioning

The post-tensioning of the conical shell exhibits some notable special features, since buttresses were not permitted and the concrete had to be impermeable without a special sealing skin. These requirements could be satisfied in an ideal manner by the VSL Post-tensioning System with the centre stressing anchorage type Z, which was used here for the first time in the Federal Republic of Germany on a water tower. A further advantage of the VSL system was that with the VSL push-through method it was possible to assemble the tendons directly on the conical form. In this way cumbersome cable transporting operations and expensive placing work could be avoided.

In total, 91 VSL annular tendons Z 5-6 (admissible stressing force 541 kN each) were required, with lengths ranging from 30.40 to 133.60 m. The total length of the cables used was almost 7.5 km. The Z-anchorages were situated in block-outs open towards the inside, 215 mm deep, 220 mm wide and 1400 mm long. These block-outs and therefore the stressing positions were spaced from one another by 60° and 120° respectively, so that an approximately uniform prestress was obtained. This layout resulted in six sets of cables. After completion of concreting, two tendons of the tension ring at the outer perimeter of the conical shell were first stressed and ten days afterwards stressing of the tendons of the shell was commenced (Fig. 46). The six sets of tendons were stressed successively in six steps, a minimum concrete compressive strength of 15 N/mm^2 being specified for stressing. A standard

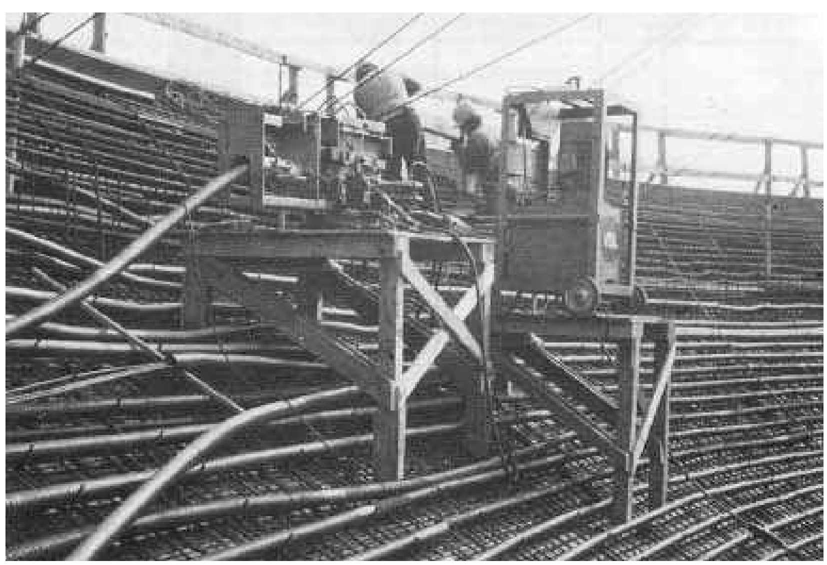


Figure 45: Pushing of the strands into the ducts

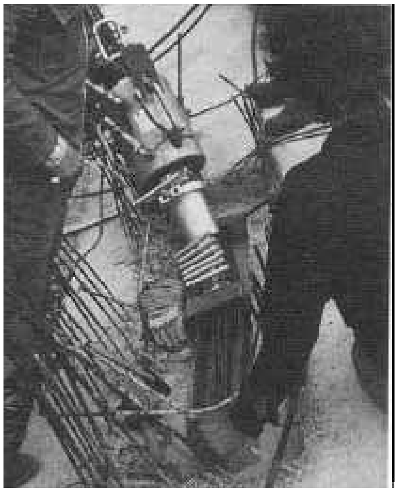


Figure 40: Stressing of a cable Z 5-6

standard VSLjack type ZPE-7, fitted with a curved chair for this application, was used for applying the stressing force. The curved chair bore directly against the centre stressing anchorage and guided the strands at the stressing end in a curve out of the block-out, so that the jack could remain outside. The dimensions of the block-outs could therefore be kept quite small.

2.2.3. Roihuvuori Water Tower, Helsinki, Finland

Owner Waterworks of the City of Helsinki
Engineer Consulting Office Arto Pitkanen, Helsinki
Contractor Oy Hartela, Helsinki
Heavy VSL INTERNATIONAL LTD.
Rigging Berne, Switzerland
Years of
construction 1976-1977

Introduction

In the eastern and north-eastern part of the city of Helsinki, the demand for water during the seventies grew on average by about 4 percent per year. This increase was expected to continue on account of continuing building development. The water pressure and the supply capacity had consequently become inadequate and it was therefore decided to construct a new water tower at the place called Roihuvuori. The storage capacity was fixed at 12 600 m^3, which will be sufficient until the nineties. A new water tower will then have to be built.

Details of the structure

The Roihuvuori water tower is of the mushroom type and consists of an approx. 28 m high cylindrical shaft of 15.00 m external diameter which supports a conical tank of 66.70 m diameter. The top of the tank, i. e. the summit of the cupola of the inner of the two compartments, is about 52 m above foundation level (Fig. 47).
Because of the dominant situation of the structure, its form was the subject of an architectural design. As a result the shaft, which consists of a 400 mm thick wall, is provided with 6 wide vertical buttresses of 1.50 m thickness, uniformly distributed around the circumference. The shell of the tank in general has a thickness of 350 mm. Towards the transition to the shaft, however, the thickness increases considerably. The cone has radial ribs and, in addition, is circularly structured. A special feature of the tank is the absence of any thermal insulation which, due to the severe winter conditions in the country, has previously been customary in Finnish water towers. The omission of the insulation enabled a saving of about 15% of the costs, which finally amounted to some 15 million Finnmarks, to be achieved. The effects of ice formation, however, now had to be considered in the design. Since no information about the treatment of this problem was available, however, it was thoroughly investigated by the University of Technology of Helsinki, to enable the necessary design data to be provided. These data related to the strength and deformation properties of ice as a function of time and temperature, and therefore specifically to the ice pressure on the shell of the tank.

Construction procedure

In the design stage, the following three construction methods for the water tower were considered:

- In-situ construction of the entire structure, i.e. construction of the storage tank in its final position by using formwork supported on the ground.
- Construction of the tank on the ground, followed by pushing it up from below at the same rate as shaft construction proceeds.
- Slipforming the shaft first and then constructing the tank on the ground and lifting it by pulling from above.

The third possibility was obviously the most economical in view of the size (diameter 66.70 m), the weight (9000 t) and the height above ground (28 m and more) of the cone. This method was therefore chosen by the contractor.
The foundation of the tower rests on rock. As already mentioned, the shaft, which has an internal diameter of 12.00 m, was constructed by slipforming. Its summit was provided with a prestressed concrete ring, on which the lifting equipment could be placed. A timber formwork erected on the ground served for the construction of the post-tensioned shell of the tank. The roof (except the central dome) was also added at this stage. After these operations were completed the tank was lifted into its final position and then connected to the shaft by in-situ concrete. Construction of the Roihuvuori water tower commenced in September 1976 and in February 1978 the tower was linked to the supply network.

Lifting

For lifting the cone, 33 no. VSL motive units SLU-330 were placed on the concrete ring at the summit of the tower shaft at uniform spacings of 1.50 m (Fig. 48). Each unit was provided with a bundle of 31 strands Ø 15 mm (0.6"), which was fixed to the base of the shell by a VSL dead-end anchorage type EP 6-31 (Fig. 49). The total nominal lifting capacity therefore amounted to 106.8 MN, or 21% more than the weight of the cone. A margin of this order is, however, generally required to allow for impact forces that might occur. The lifting units were hydraulically connected in groups of 11, each group being driven by one pump EHPS-33. The pumps were operated from a central console.
Before despatch from Switzerland to Helsinki, the entire hydraulic lifting equipment

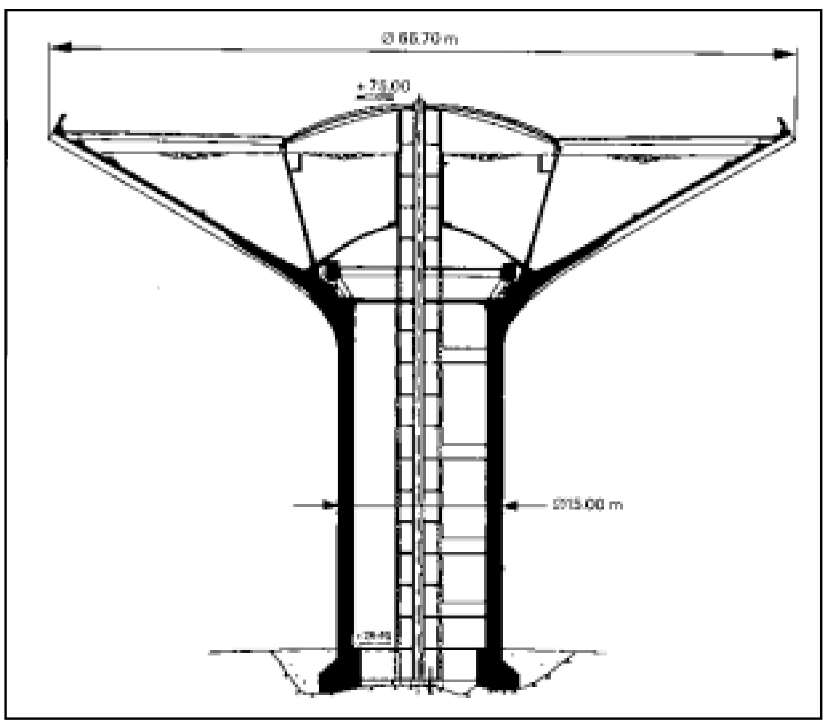


Figure 47: Section through the structure

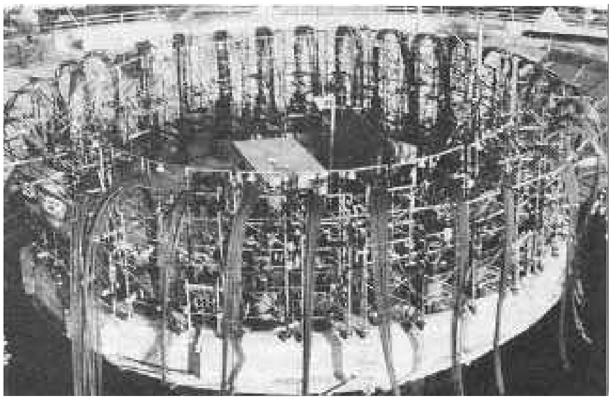


Figure 48: The 33 VSL motive units SLU-330 at the summit of the tower shaft

Figure 49: VSL dear-end anchorages of the lifting cables at the bottom of the shell

was tested at the VSL works. On site, it was installed during the three weeks before lifting. The installation work comprised the positioning of the motive units, pumps and central control desk, the assembly of the strand bundles, the insertion of these bundles into the motive units and the installation of all hydraulic and electrical circuits.
The actual lift started on 6 October 1977 (Fig. 50). The whole operation, including maintenance of the equipment, took 52 hours which, for the lifting distance of approx. 30 m, corresponds to an average speed of somewhat less than 0.6 m/h. This may seem low, but it must be remembered that in such a case speed is much less important than a smooth and safe lifting operation. On 11 October 1977, the storage tank reached its final position.

Figure 50: Commencement of tank lift

2.2.4. Water and Telecommunications Tower Mechelen, Belgium

Owner City of Mechelen
Engineers Design Office ITH, Mechelen
Prof. Dr. F Mortelmans, University of Leuven
Contractor Vanhout Vosselaar N.V., Vosselaar
Slipforming VSL INTERNATIONAL LTD., Berne, Switzerland (in Joint Venture)
Post-tensioning Civielco B.V., Leiden, Netherlands
Heavy Rigging VSL INTERNATIONAL LTD., Berne, Switzerland
Year of construction 1978

Introduction

As a result of the population increase and the expansion of industry in the north and south of the town of Mechelen, the municipal water supply system had to be extended and a new water tower had to be built in the southern industrial zone. Since, at the same time, television reception needed to be improved with new antennas, and the radio, telephone and telegraph services had to be extended, the construction of a multipurpose tower was decided upon.

In March 1977, the design of the structure was commissioned. Construction of the tower, the cost of which was estimated at 85 million BFr, commenced in February 1978. By the end of 1978 the basic structure was complete and the official opening took place on 15 September 1979.

Details of the structure

The tower rises to 143.00 m above ground level. Up to level 120.00 m it consists of a conical reinforced concrete shaft with an external diameter of 9.20 m at the base and 3.40 m at the top. An arrow-like tube of stainless steel, which has an aesthetic function only, tops the tower. The water tank, of 2500 m^3 capacity, is situated between elevations 44.14 and 53.40 m. Immediately above it are the parabolic antennas for radio, telephone and telegraph. A platform at 110.00 m level carries the television equipment.
The tower shaft stands on a circular foundation slab of 19.60 m diameter and maximum thickness 3.00 m, resting on 127 piles. The bottom of the foundation is 6.20 m below ground level. The tower wall has a thickness of 650 mm up to the bottom of the water tank, except in the area around the access door, where the thickness increases to 1030 mm. Above the bottom level of the tank, the thickness of the shaft wall increases to 1840 mm over a height of 7.81 m. There follows a ring beam of 10.64 m diameter and 1.00 m height. At level 52.95 m, the wall thickness is 500 mm; between 60.00 and 107.40 m the thickness is 400 mm. It then decreases linearly to remain constant to 200 mm over the last 6.20 m at the top.
The water tank has an external diameter of 40.00 m. It has the form of a flat conical shell with the bottom sloped at about 17° to the horizontal. It is radially stiffened by 16 internal walls, each 350 mm thick. The thickness of the tank shell is 300 mm. The tank is covered by a slightly sloping roof supported on the outer wall of the shell (Fig. 51).

Construction procedure

After construction of the piles and the foundation slab, the first 3.50 m of the tower shaft were built conventionally. Slipforming was then used for constructing the shaft. The slipforming work was completed as planned within 40 days (from 25 May to 4 July, 1978), although it was highly demanding on account of the conical form and the various cross-sectional changes in the wall.

The tank shell and the roof were constructed at ground level. Special attention was paid to the formwork of the tank bottom and the position of the radial walls was deliberately emphasized in order to give the structure a pleasing architectural character. After concreting, the shell and the roof were post-tensioned, the tendons were grouted and the block-outs filled. These two components were then made ready for lifting, and the lifting operation was carried out (Fig. 51). When the tank had reached its definitive position, the lifting cables were converted into suspension cables. As their number would not have been sufficient for the service condition, additional suspension cables were installed while the tank was still at ground level and lifted with it. The cables were anchored on the ring beam and then short concrete columns were cast around the sheathed tendons. When the concrete had reached the required strength, the suspension cables were stressed in order to keep the columns under permanent compression. Finally, tower shaft and tank bottom were connected by cast-in-place concrete.

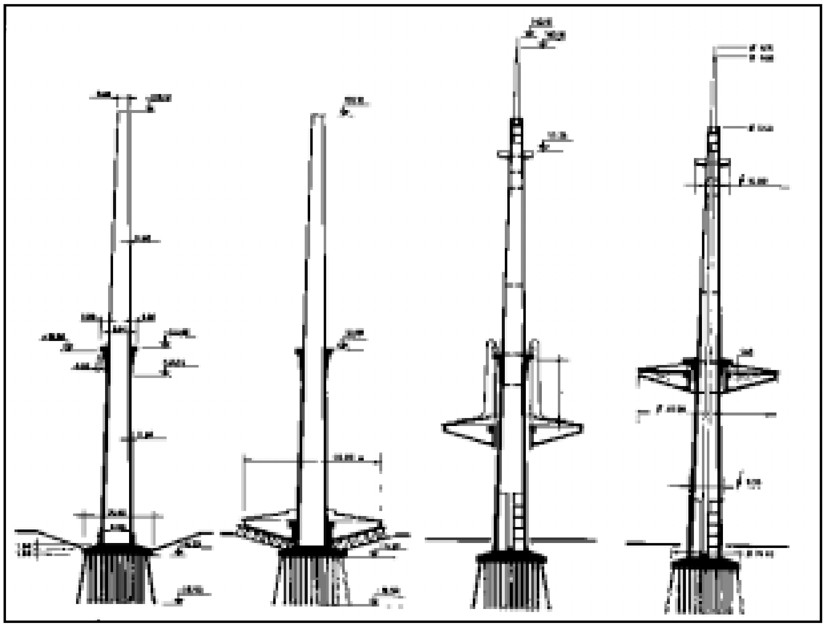


Figure 51: Phases of construction and section through the tower

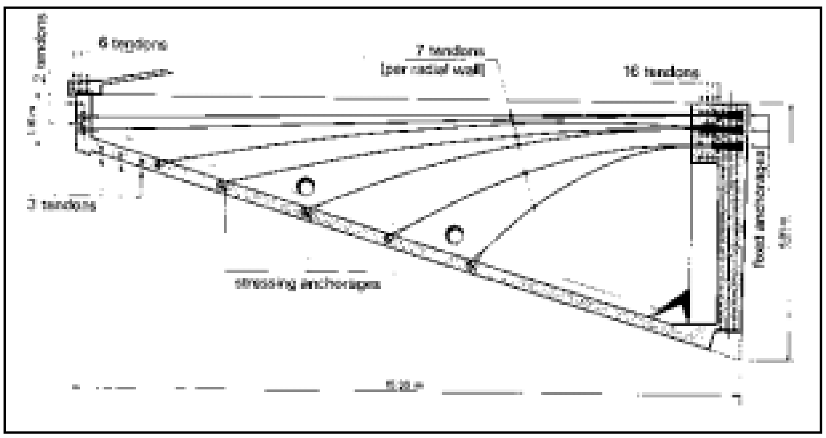


Figure 52: Arrangement of tank post-tensioning

Post-tensioning

The water tank is post-tensioned by means of radial and annular cables. Each radial wall contains 7 VSL tendons type EU 6-7 (ultimate force 1900 kN each). The deadend anchorages type U are placed in the ring beam topping the inner shell wall. The stressing anchorages are in the outer wall and in the shell bottom.

Annular tendons were required in the ring beam, in which the dead-end anchorages of the radial tendons are located, in the outer wall, in the outermost part of the shell bottom and in the tension ring of the roof. With the exception of the tendons in the inner ring beam of the shell which are of type EE 6-12, all the tendons consist of 7 strands Ø 15 mm, like the radial tendons. All cables are continuous around half the circumference, and therefore have lengths of 15 to 62 m (Fig. 52).

As already mentioned, post-tensioning was used also for suspending the tank from the tower (Fig. 53). For this purpose 16 VSL cables 6-31 (ultimate strength 8450 kN each) were required. Since these cables are short and straight, the strands were individually stressed.

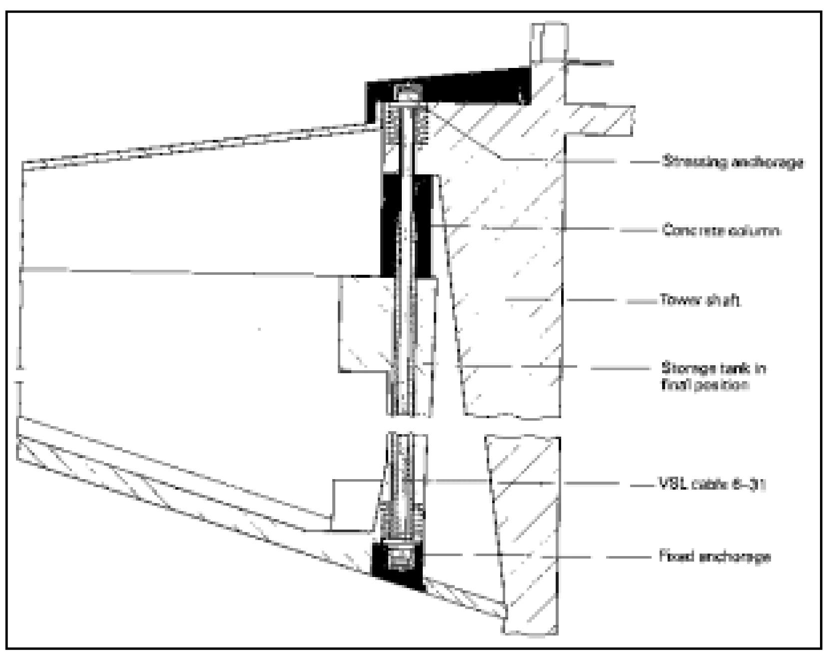


Figure 53: Suspension of the tank from the tower

Lifting

The tank shell, 2600 t in weight, was lifted from 6 to 8 November 1978 (Fig. 54). The total lifting distance was 46.36 m. Eight VSL motive units SLU-330 (each with a lifting force of 3234 kN), uniformly distributed around the bracket ring at the tower shaft, were used. Each lifting cable was anchored at the bottom in the inner ring of the shell by means of a VSL anchorage type EP 6-31. Four pumps EHPS-24 were used for driving the motive units. They were operated from one control console. The pumps and control console were also mounted on the bracket ring.

The lifting strands were cut to the required length on site, provided with compression fittings and bundled. They were then pulled

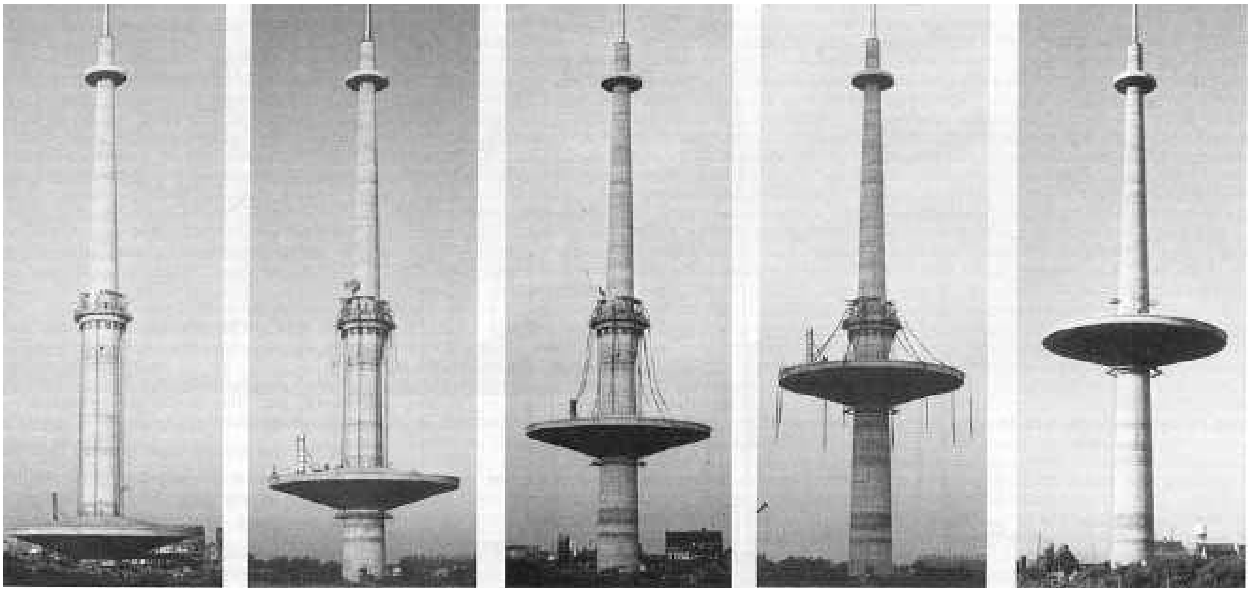


Figure 54: Phases of lifting the tank shell

Figure 55: The finished tower at Mechelen

into the inner ring of the vessel shell and the bracket ring on the tower by means of a large mobile crane, which was used for placing the precast elements of the platform at level 110 m.

2.2.5. Water tower, Buraydah, Saudi Arabia

Owner Buraydah Water Supply
Engineer VBB (Vattenbyggnads-byran), Stockholm, Sweden
Contractor Kumho Construction & Engineering Inc., Riyadh
Slipforming and Post-tensioning VSL INTERNATIONAL LTD., Berne, Switzerland
Years of construction 1982-1984

Introduction

The water supply of Buraydah, 300 km to the north-west of Riyadh, is being extended by a water tower. Construction of the tower commenced in spring 1982 and will continue until 1984. The tower not only serves for storing water but also contains (in addition to one storey housing supply equipment) a viewing platform with ornamental fountains and a storey comprising cafeteria and reception rooms.

Details of the structure

The tower stands, 8.00 m below ground level, on an annular foundation 26.00 m in diameter. A cylinder of 5.50 m radius extending 23 m high above ground supports a sphere of diameter 42.40 m. The cylinder contains the stairwell, two lifts and a service shaft. The lower part of the sphere houses the water tank itself (capacity 8400 m^3) and the upper part the rooms mentioned above (Fig. 56).

The lowest portion of the sphere, which strictly speaking is conical, has a wall thickness of 2.47 to 1.46 m and above the spherical wall is initially 0.50 m and finally 0.40 m thick. Further up, in the non-prestressed portion, the wall thickness continues to decrease.

Construction procedure

After completion of the foundation, the tower shaft was built using VSL Slipforming in a period of 28 days, including setting up and dismantling operations (Fig. 57). The shaft continues up inside the sphere and was therefore slipformed to a height of 49.69 m above ground. The conical portion was then built (Fig. 58) and one quarter of the post-tensioning force applied. This stage was followed by construction of the walls of the lower storey, the post-tensionned of the spherical wall

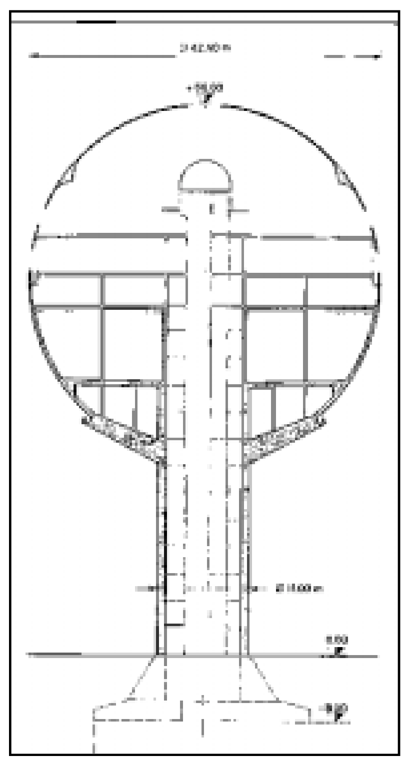


Figure 56: Section through the structure

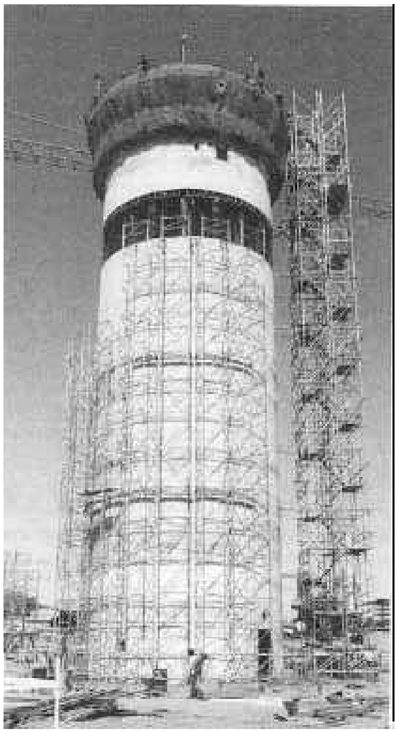


Figure 57: Construction of the tower shaft by VSL Slipforming

and further floors and walls inside the sphere. During these construction phases, the post-tensioning force was applied by steps up to full prestress. The upper parts of the sphere were then built.

Post-tensioning

The post-tensioning is concentrated in the lower part of the sphere, where considerable hoop tension forces are produced by the water loading. The number and size of the cables were established from a diagram provided by the engineer, which showed the prestressing force required in each step. VSL INTERNATIONAL LTD. prepared the corresponding detailed drawings. On account of the different forces required, cables of VSL types EC/EC 6-7, 6-12 and 6-19 were chosen. The ultimate strengths of these tendons are 1827, 3132 and 4959 kN. In the uppermost part of the cone, 2 x 18 cables EC/EC 6-19 were used, and after this in the spherical wall, firstly 2 x 24 cables EC/EC 6-12 and then 2 x 6 cables EC/EC 6-7 (Fig. 59). Each individual cable extends around one-half of the circumference. The anchorages of successive cable rings are displaced by 45° from one another. Eight internal buttresses therefore are used for anchoring the tendons (Fig. 60).

2.2.6. Water tower, Al Kharj, Saudi Arabia

Owner: Kingdom of Saudi Arabia, Ministry of Agriculture and Water, Riyadh
Engineer: Saudi Consulting Services, Riyadh and Prinsloo Graham Associates, Toronto, Canada
Contractor: Lotte Construction Co. Ltd., Riyadh
Post-tensioning: VSL INTERNATIONAL LTD., Berne, Switzerland
Years of construction: 1982-1985

Introduction

Al Kharj lies 95 km to the south-east of Riyadh, in an oasis. It is a town of 50 000 inhabitants. It supplies a large quantity of water from its underground reserves through a pipeline to Riyadh. The surrounding country grows food, which is marketed in the capital city and other locations.

Al Kharj is to be developed as a rest and recuperation area. The development plan includes a water tower housing a restaurant and designed to assure the town water supply. Construction of this tower commenced in April 1982 and is expected to take three years.

Details of the structure

The total height of the tower is 121.70 m, measured from the underside of the foundation. It consists essentially of 4 parts: the flat structures around the base of the tower, the tower shaft, the turret containing the viewing platform, the restaurant (the outer part of which revolves) and the service rooms, and the water tank itself of 7800

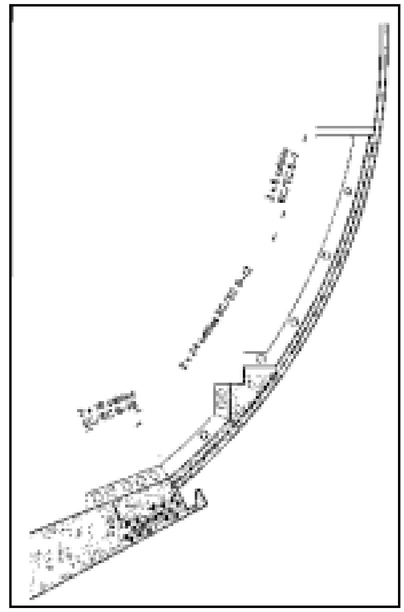


Figure 59: Section through the post-tensioned part of the water tower at Buraydah

m^3 capacity in the uppermost part of the structure (Fig. 61).

The shaft, with an internal diameter of 8.40 m and 900 mm wall thickness, stands on an octagonal foundation slab having an inscribed diameter of 35.20 m and maximum thickness of 8.00 m. The shaft possesses eight short and eight longer vertical stiffening ribs projecting radially from its external face.

The turret has three storeys containing the rooms referred to above. These can be reached by four lifts housed in the tower shaft. The maximum diameter of the turret, measured across the tips of the roof ribs, is 57.00 m.

The water tank has approximately the form of a water droplet. Its useful depth is 34.70 m and the maximum diameter is 23.66 m. The tower is closed by a roofed service platform.

Construction procedure

After completion of the excavation, the foundation was constructed. The tower shaft was then built by slipforming to below the water tank.

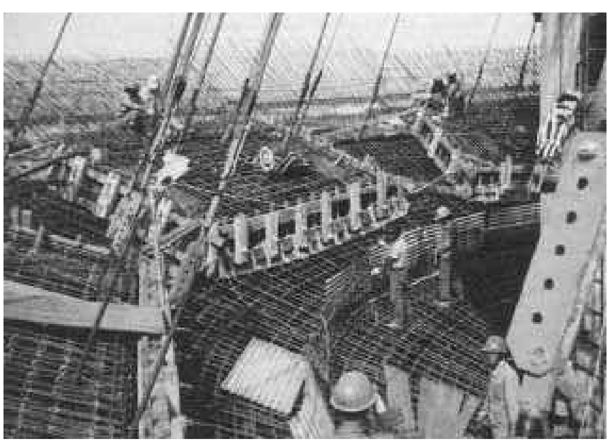


Figure 58: Construction of buttresses in the conical portion

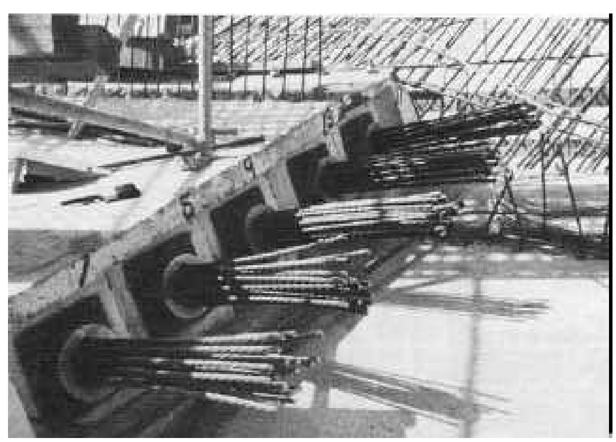


Figure 60: Cables in the conical porion stressed to 25%

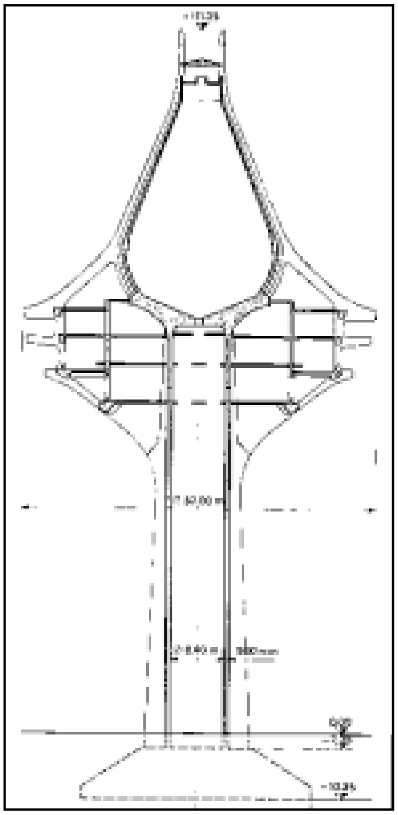


Figure 61: Section through the tower

Construction of the heavy tank base then followed (Fig. 62). The next stages comprised the construction of the storeys of the turret. Finally, the water tank and the summit of the tower were constructed in 12 sections.

Post-tensioning

Various parts of the turret and water tank are post-tensioned. The drawings contained in the invitation to tender were ready based on the VSL Post-tensioning System and this was the system actually used. In addition to the usual subcontractor services, VSL INTERNATIONAL LTD. also had to provide the construction drawings for the post-tensioning. The post-tensioning consists of the following parts:

a) Annular post-tensioning of the outer ring of the viewing platform,
b) Radial post-tensioning of the ribs between this outer ring and the tower shaft,
c) Annular post-tensioning of the outer ring of the restaurant storey,
d) Three-layer post-tensioning of the tank bottom (Fig. 63),
e) Annular post-tensioning at the edge of the tank bottom,
f) Vertical post-tensioning of the lower part of the tank wall,
g) Annular post-tensioning of the tank wall.

For the post-tensioning listed under a), c), d), and e), VSL cables EC/EC 5-31 (ultimate force 5620 kN) are used, for b) cables of type EC/H 5-12. Section f) comprises tendons EC/L/EC 5-12, while for g) cables of type EC/EC 5-12 are required in the lower region, EC/EC 5-7 in the middle region and EC/EC 5-3 in the upper region. All the annular post-tensioning is composed of cable pairs, each cable extending round one-half of the circumference and being anchored in buttresses. The buttress axes coincide with those of the longer ribs of the tower shaft. In general the cable axes are at a distance of 105 mm from the outer face of the wall. The spacings of the cables vary from 170 to 500 mm. The three-layer post-tensioning of the tank base can be compared with that of a dome (e.g. a reactor building). Anchorages of type L, that is loop anchorages, are the most suitable for the vertical tendons of the tank wall, because a construction joint is necessary between base and wall and the cables for practical reasons must be installed later.;

In general, the cables are installed by pushing through the strands after concreting. Exceptions are the tendons possessing Hanchorages, which must be installed before concreting and the cables possessing anchorages type L, which are pulled through (Fig. 64).

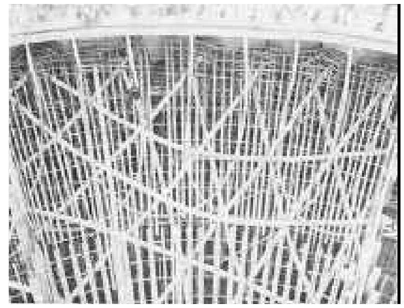


Figure 64: Cables in the lower part of the tank

2.2.7. Watertower, Bandung, Indonesia

Owner	PT Industri Pesawat Terbang Nurtanio, Bandung
Engineer	APARC, Bandung
Contractor	PT Bangun Tjipta Sarana, Bandung
Post-tensioning	PT VSL Indonesia, Jakarta
Heavy Rigging	VSL INTERNATIONAL LTD., Berne, Switzerland
Years of construction	1982-1983

Introduction

On the outskirts of the town of Bandung a water tower is being built for an aircraft factory at present under construction. It has the conventional mushroom form, i. e. it comprises a conical high-level tank and a

Figure 62: View during construction

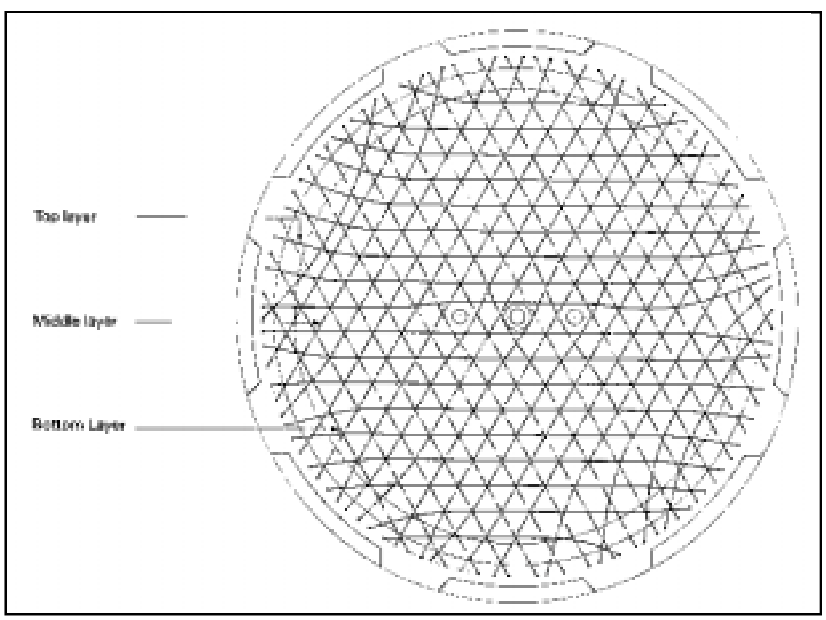


Figure 63: Three-layer post-tensioning of tank bottom

cylindrical shaft. For architectural reasons the tower has vertical ribs.

Details of the structure

The water tower consists of three parts: an underground tank of 1400 m^3 capacity, into which the foundation structure of the tower is integrated, the tower shaft and the high-level tank of 900 m^3 capacity.

The lower tank rests on limestone, is entirely below ground and is covered over with 0.50 m depth of soil. Its external diameter is 21.60 m and its total height 5.75 m: The tower shaft is 42.25 m high and its external diameter is 3.70 m. The wall thickness is 600 mm. At the summit of the tower there is a 1.80 m thick top slab 5.70 m in diameter, from which the conical high-level tank is suspended. This tank is 25.20 m in diameter and 9.20 m high and is covered by an annular domed roof. The conical shell has a thickness of 400 mm at the bottom and 160 mm at the top. It is post-tensioned, with eight anchorage buttresses on the external face giving an additional thickness of 200 mm. The high-level tank is constructed of concrete K-350, the remainder of the structure of K-225 (Fig. 65).

Construction procedure

After completion of the underground tank, the tower shaft was built by slipforming between 17 and 24 January 1983. The high-level tank was then constructed near to the ground on falsework (Figures 66 and 67).

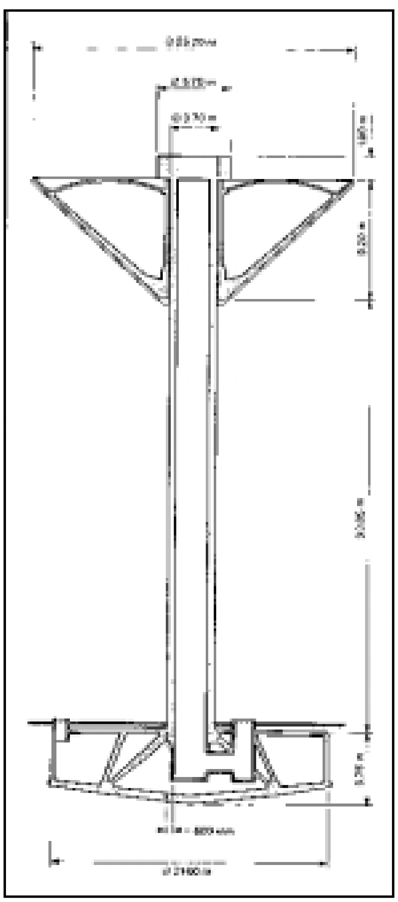


Figure 65: Section through the structure

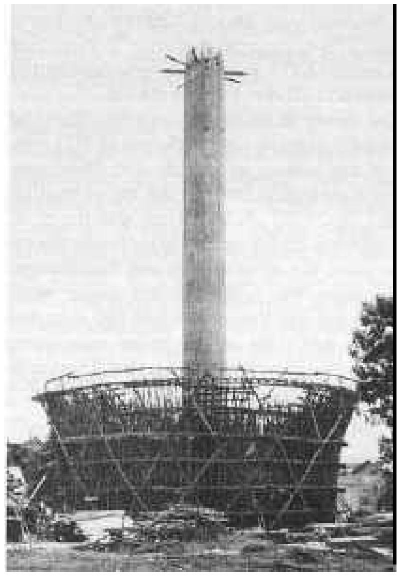


Figure 66: View during construction

67). After stressing and grouting of the tendons, the high-level tank was raised into its final position, where the lifting cables were converted into suspension cables.

Post-tensioning

The conical shell is prestressed with a total of 25 cable rings, each consisting of 2 cables (Fig. 68). The cables are VSL types EE 5-4, 5-5, 5-6 and 5-7 (ultimate force of the latter 1288 kN). The anchorages of successive cable rings are displaced by one buttress spacing.

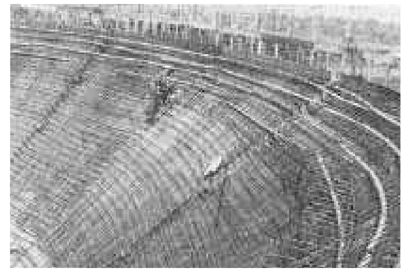


Figure 67: View inside the tank during construction

As already mentioned, the suspension for attaching the tank to the tower consists of post-tensioning tendons. Twelve cables 6-12 (ultimate force 3120 kN each) serve this purpose. The cables are stressed strand by strand and the anchorages on the top slab are later covered with in-situ concrete blocks.

Lifting

On the proposal of PT VSL Indonesia the high-level tank will be constructed on the ground and lifted into position The lifting of the approx. 900 t tank will take place in the second half of 1983. The lifting distance will be approx. 31 m. For the lift, twelve VSL motive units SLU-70 (lifting force each 730 kN) will be uniformly distributed in a circle of 4.30 m diameter on the summit slab. A cable 6-7 will run through each motive unit. The five additional strands per lifting point, which are necessary to form a suspension cable, will be installed before lifting and accompany the movement unstressed.

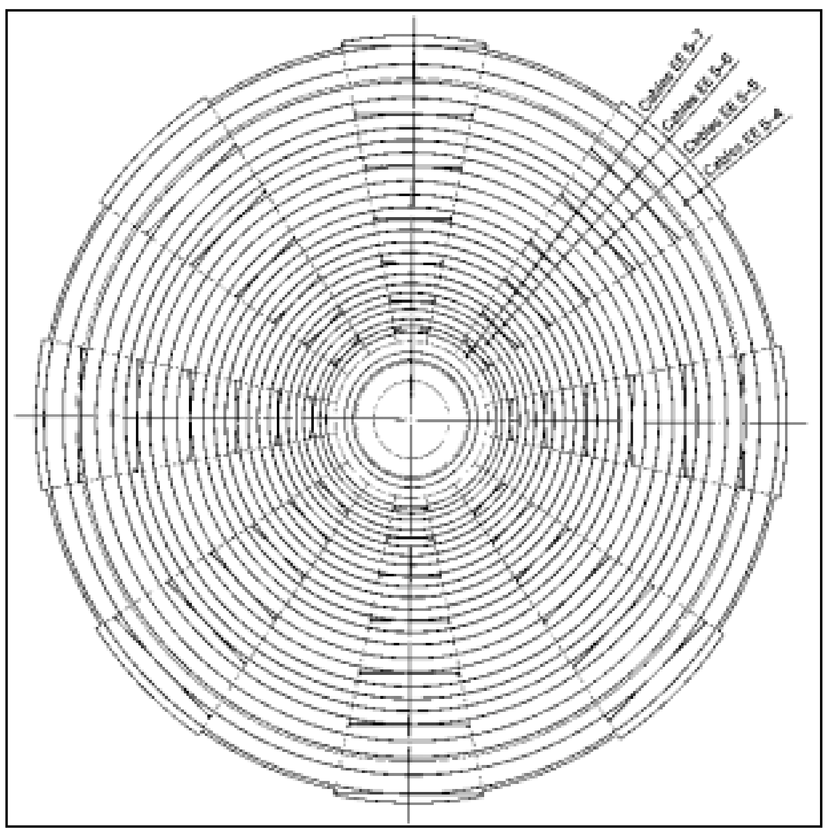


Figure 68: Cable layout

2.2.8. Water towers for the new railway stations at Riyadh, Hofuf and Dammam, Saudi Arabia

Owner: Saudi Government Railroad Organization (SGRRO), Dammam
Engineer: Technital, Rome, Italy
Contractor: Yamama Establishment, Dammam
Slipforming, Post-tensioning and Heavy Rigging: VSL INTERNATIONAL LTD., Berne, Switzerland
Years of construction: 1983-1984

Introduction

In connection with the extension of the railway line Riyadh-Hofuf-Dammam, new stations are being built in these three towns. Each of them will include a water tower of 150 m^3 capacity.

Details of the structures

The three towers are identical, except for the lengths of their shafts. They consist each of a conical high-level tank and a cylindrical tower shaft. The diameter of the tank is 11.50 m and its overall height 6.65 m, of which 1.74 m is accounted for by the roof, also conical. The tank wall is only 100 mm thick. It is inclined to the horizontal at 48° 10'.

At the centre of the tank there is a cylindrical wall also of 100 mm thickness and 1.70 m external diameter. The roof has a slope of 17° and is 100 mm thick at the edge and 70 mm thick at the top.

The tower shaft has an external diameter of 2.60 m and a wall thickness of 300 mm. For the towers at Riyadh and Dammam, the length of shaft from the top of foundation is 34.80 m, while for the tower at Hofuf it is 29.56 m. The latter tower stands on piles, the other two on slab foundations. Between the tank and the tower shaft there are eight steel tubes of 180 mm diameter and 0.92 m height for connecting these two components together. This detail is associated with the construction method (Fig. 69).

Construction procedure

The foundation slab is first built and into it eight steel beams HEA 140, each 2.78 m long, are cast in an upright position. These beams are uniformly distributed around a circle of radius 1.15 m. On each of them a jack with a 400 mm lifting stroke is placed. The tank is then built on this assembly and when complete it is raised by the jacks, the tower wall being constructed simultaneously. At each step, prefabricated concrete cylinders (Ø180 mm, length 400 mm) are placed beneath the jacks. The daily rate of progress will be approx. 2 m.

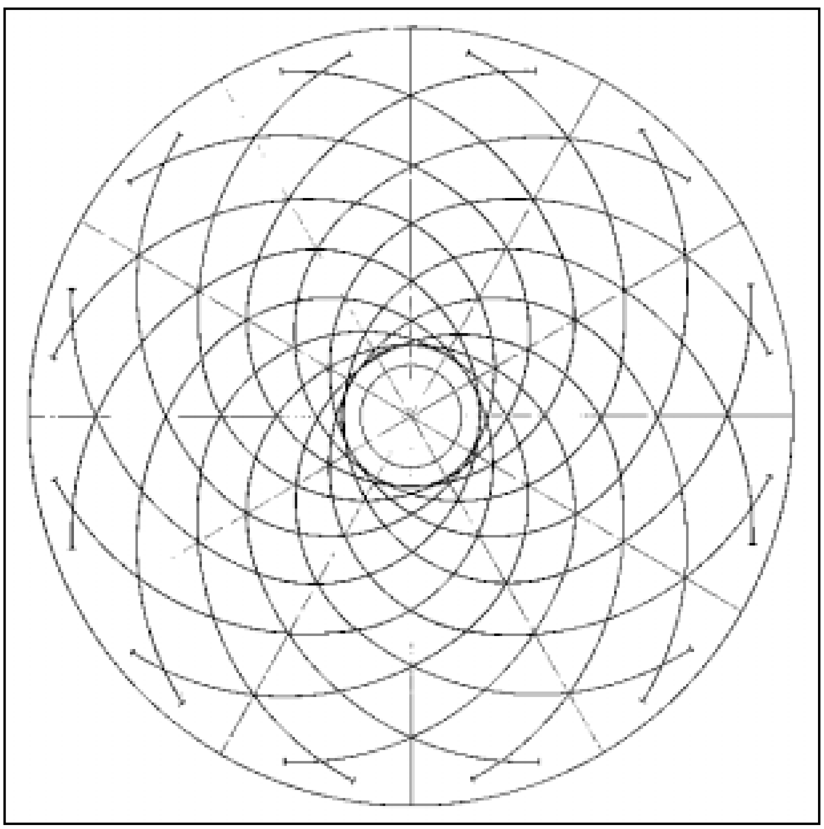


Figure 70: Cable layout in the tank shell

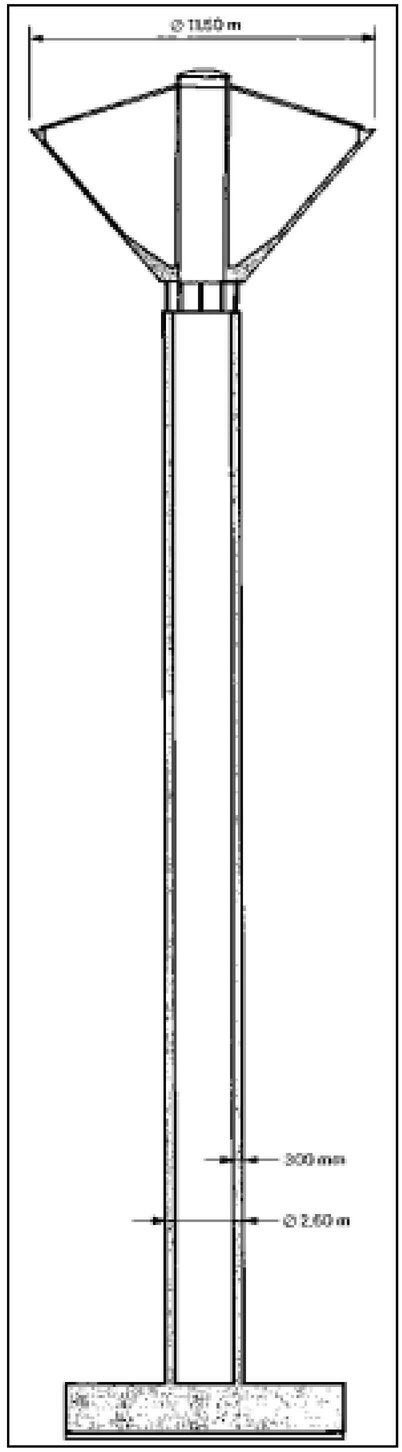


Figure 69: Cross-section through a tower

Post-tensioning

Both the tower wall and also the tank are post-tensioned with monostrands Ø 15 mm (0.6") Dyform (ultimate force 300 kN). In the shaft there are 8 strands, uniformly distributed around the circumference. The cable layout in the tank is shown in Fig. 70. The cables will be stressed at a concrete strength of 25 N/mm^2.

2.3. Sewage tanks

2.3.1. Introduction

In sewage treatment, sedimentation tanks, aeration tanks and sludge tanks are of particular interest for the application of VSL special construction methods. Sedimentation tanks are generally circular and aeration tanks rectangular, while sludge tanks are cylindrical or oviform. The oviform shape (egg-shape) has proved very advantageous for the sludge digestion process, and is therefore becoming increasingly common. Another reason for the increased interest in the oviform shape is that tanks of this form are no longer built in vertical segments but in horizontal rings, which greatly simplifies construction.

Sewage treatment plants are usually built in the vicinity of a drainage channel and the groundwater level around them is therefore usually high. High standards are therefore specified for the tightness of the structures. These requirements can be met by posttensioning, the bottom slabs and walls being furnished with post-tensioned cables.

2.3.2. Sludge digestion tanks, Prati Maggi, Switzerland

Owner: Sewage treatment authority, Mendrisio and District
Engineer: G. F Dazio, Bellinzona
Contractor: Mazzi & Co. SA., Locarno
Slipforming
VSL INTERNATIONAL LTD.
and Post-tensioning
(formerly Spannbeton AG/ Precompresso SA)
Year of construction
1974

Introduction

The sewage treatment plant of Mendrisioand District serves 12 communities. It issituated in the Plain of Rancate, in Prati Maggi. Components of the treatment plantinclude two digestion tanks, namely theprimary and secondary digestion tanks.

These were built as post-tensioned structures, to enable crack-free, watertight tanks to be obtained.

Details of the structures

Each tank consists of a circular bottom slab, sloping down towards the centre, a cylindrical wall and a domed roof of prefabricated elements (Fig. 71). The wall has an external diameter of 13.80 m, a thickness of 200 mm and a height of 6.50 m. It has 6 buttresses on the external face. In addition a 90 mm thick thermal insulation and 120 mm thick brick walling outside this were constructed as cladding.

Post-tensioning

The wall, which was built by means of VSL Slipforming, is post-tensioned with two polyethylene-sheathed, greased monostrands Ø 13 mm (0.5"). The two strands run helically through the concrete wall from the bottom to the top. The spacing between the rings, that is the pitch of the helix, increases from 117 mm (at the bottom) to 750 mm (at the top). Each strand has a dead-end anchorage at the lower end and a standard VSL anchorage E 5-1 at the top. The entire length of each strand is 430 m (Fig. 72).

To obtain a constant, average cable force of 111 kN, the two strands were anchored at 180° from each other and were stressed at each alternate buttress by means of a special stressing procedure. This procedure was as follows:

1. Placing of a first intermediate stressing anchorage followed by stressing.
2. Placing of a second intermediate stressing anchorage at the next-but-one buttress, followed by stressing; the first intermediate stressing anchorage now floats.
3. Placing of a third intermediate stressing ancho rage at the next-but-one buttress, followed by stressing; the second intermediate stressing anchorage now floats.
4. Removal of the first intermediate stressing anchorage and placing of same at the same buttress, but higher up by one pitch of the tendon.
5. As 2, etc.

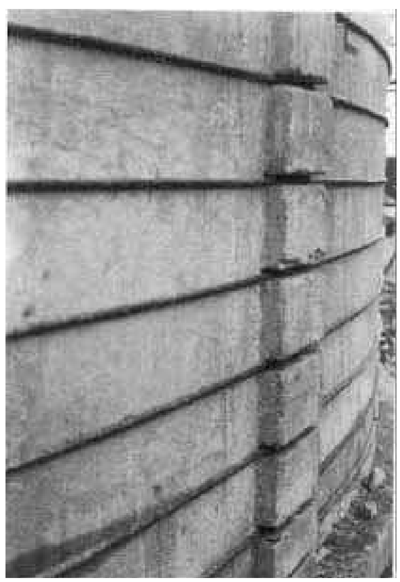


Figure 72: Wall after completion of post-tensioning

As a result of the use of polyethylene-sheathed, greased strands, which already possess excellent corrosion protection from the moment it leaves the factory, the friction losses with this method of post-tensioning are very low. It is therefore well suited to fairly small structures. It keeps the concreting and stressing operations completely independent from one another.

2.3.3. Sewage treatment plant, Groningen-Garmerwolde, Netherlands

Owner: Provinciale Waterstaat, Groningen
Engineer: Grontmij NV, Cultural and Structural Engineer Office, De Bilt
Contractor: Brand's Bouwbedrijf, Emmen
Post-tensioning
Civielco B.V., Leiden
Years of construction
1976-1979

Introduction

In 1974 the Consulting Engineers Grontmij received from the Owner instructions to prepare a design for a sewage treatment plant for a population equivalent of 300 000 persons for the Groningen agglomeration. In April 1976, construction commenced on the plant, the cost of which was estimated at 75 million Dutch Guilders. The site was a 12.5 ha area on the southern bank of the Ems Canal, approximately 7 km to the east of Groningen. After a construction period of almost four years, the plant was commissioned in 1980 (Fig. 74).

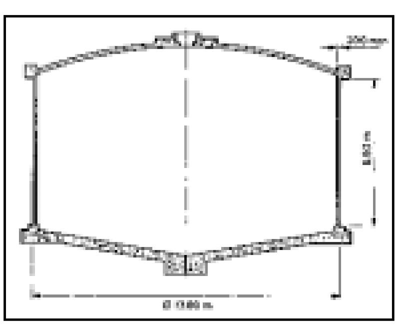


Figure 71: Section through a tank

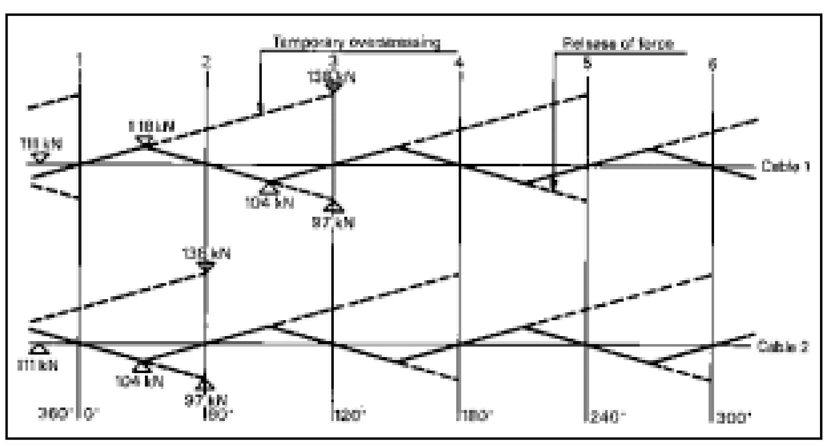


Figure 73: Diagram of cable force

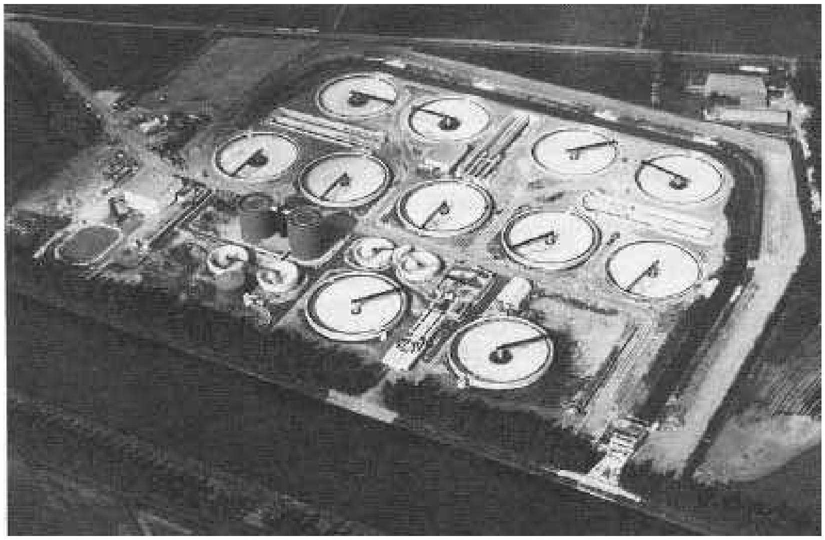


Figure 74: General view of the sewage treatment plant

Plant components with post-tensioning

Four parts of the plant comprise post-tensioning:

- the sedimentation and clarification tanks (Fig. 75),
- the aeration tanks (Fig. 76),
- the sludge digestion tanks (Fig. 77),
- the roof of the filter press building (Fig. 77).

In total, there are 11 sedimentation and clarification tanks with internal diameters of 48.40 m. Of these 2 are sedimentation tanks with a wall height of 3.20 m, 3 are preclarification tanks and 6 final clarification tanks (wall height 2.50 m).

The three aeration tanks have 2 compartments of dimensions 70.00 x 8.00 m. The wall height is 5.00 m.

The two sludge digestion tanks have an internal diameter of 18.00 m and a height of 19.20 m. Their walls were constructed by slipforming.

The roof of the filter press building is in lightweight concrete and is post-tensioned in two directions. This would appear to be the first time a roof of this type has been constructed in The Netherlands.

Details of the structures

For the circular tanks such as the sedimentation and clarification tanks, two basic types of construction can be chosen: retaining wall construction and annular wall construction. It was decided on this project to use annular wall construction, in which the wall rests more or less unrestrained on a rubber strip which acts as a seal at the transition between floor and wall.

The reasons for the choice of annular wall construction were:

1. The water pressure can be resisted by tensile hoop forces in the wall, which can be easily compensated by post-tensioning. The water pressure does not produce any bending moments in the wall.
2. Vertical joints are eliminated.
3. Deformations due to creep and temperature changes are not prevented, so that no stresses occur in the walls from these sources.
4. The requirements for materials are minimal. The thickness of the wall is determined only by the practicability of construction and water tightness. A wall thickness of 220 mm was chosen, the concrete cover to the reinforcing steel being 30 mm.

The use of post-tensioning presumed that the wall would be shuttered and cast in one operation. This was no disadvantage in the present case, as the formwork could be used 11 times.

The bottom slabs of the three aeration tanks were each built in one concrete pour, at least two joints and additional piles being saved by this method. To prevent shrinkage cracks, the bottom slabs were centrally post-tensioned in the longitudinal direction. This post-tensioning did indeed involve additional cost, but this was compensated by savings in reinforcing steel, the joints and the piles. In addition, posttensioning improved the quality of the floor slabs

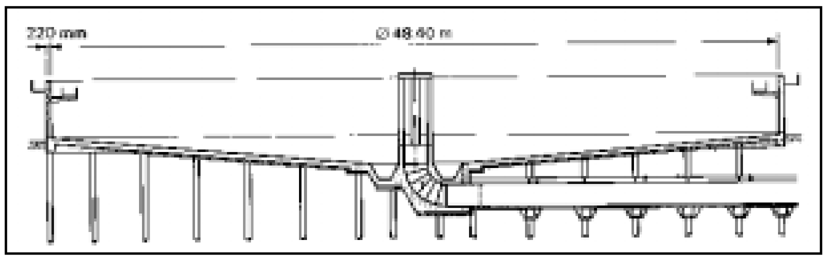


Figure 75: Section through a sedimentation tank

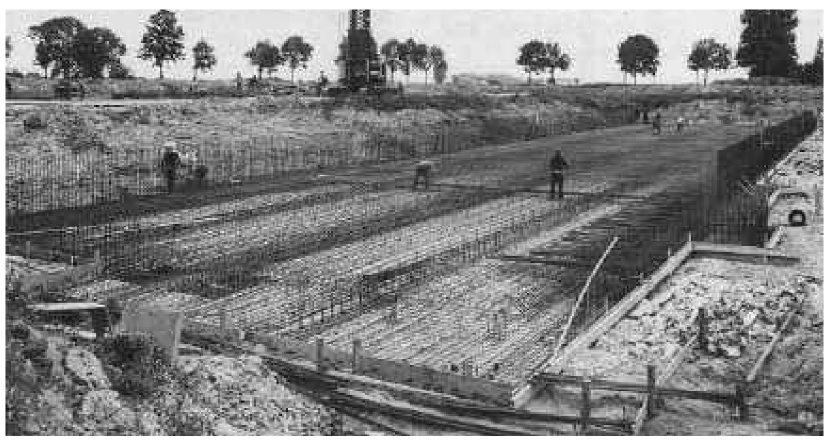


Figure 76: Aeration tank during construction

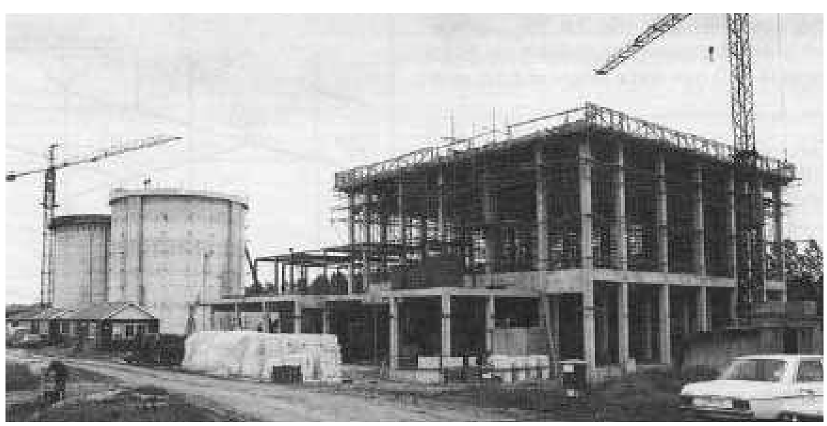


Figure 77: Sludge digestion tanks (left) and filter press building (right)

slabs.

Sludge digestion tanks must be airtight and water-tight, but nevertheless the minimum wall thickness possible is the objective. A figure of 250 mm was chosen here, which was possible as a result of horizontal posttensioning. This post-tensioning resists the large hoop forces caused by the liquid pressure. On account of the insulation provided the tanks had only ordinary reinforcement in the vertical direction. The circular roof rests freely on the wall. To reduce its selfweight, which amounts to 80% of the loading, lightweight concrete was used. Posttensioning would also have provided a saving in weight, but the post-tensioning of circular slabs leads to some constructional problems.

The roof of the filter press building has to span over a space of approx. 20 x 22 m. It is supported along the periphery and by a row of columns at 5 m distance from the side wall. Two types of construction were compared: one entirely of steel and one entirely of concrete. From the cost aspect, the steel construction was found to be the more suitable, but allowance had to be made for higher maintenance costs and lower fire resistance. A further aspect was the prevention of noise, which is achieved particularly by the use of large masses, which would have been lacking in the steel construction. Concrete was therefore chosen for the roof.

In order to limit the self-weight, the following measures were adopted:

- construction as a waffle slab with a total depth of 475 mm,
- the use of lightweight concrete,
- post-tensioning in two directions.

This would appear to be the first occasion on which this form of construction has been used in The Netherlands. With a ratio of slab thickness to span of 1:36, the result is a very slender slab.

Construction procedure

Sedimentation and clarification tanks: after the rubber bearing strip has been glued in position the inner formwork was set up. Next the inner reinforcement for the wall was fixed. The post-tensioning cables were unrolled around the tank. After the outer wall reinforcement had been placed, the post-tensioning cables were fixed to its vertical bars. The outer formwork could now be fixed and the wall concreted in one pour.

Aeration tanks: a layer of lean concrete was placed and the bottom transverse reinforcement laid on it. The post-tensioning cables were then laid in position. After the upper transverse reinforcement had been positioned, the cables of the upper layer were fixed to this reinforcement.

Sludge digestion tanks: the wall was constructed using slipforming. During raising of the form, the ordinary reinforcement and the ducts were placed, the latter being temporarily stiffened. After completion of the wall the cables and anchorages were installed.

Filter press building: the relatively high columns were constructed in two phases insitu. Steel posts were erected to provide support points in one direction and on these the waffle forms were laid. After concreting, the forms were removed and the supports left in position. In this way the waffle forms could be used three times.

Post-tensioning

Sedimentation and clarification tanks: in the standard case, there are 30 monostrands of nominal diameter 13 mm (ultimate force 184.6 kN) per section in the wall of the clarification tank. In the preclarification tank the number of strands is 21. Each strand extends around one-half of the perimeter. Four buttresses are provided for anchoring them. The stressing force was applied as a function of the concrete strength in two steps.

Aeration tanks: in total, 94 monostrand cables each having an ultimate force of 184.6 kN were installed. Stressing was carried out in two phases (Fig. 78).

Sludge digestion tanks: here the post-tensioning consists of 55 cables VSL 5-7, the net prestressing force of which has a minimum value of 520 kN and maximum value 635 kN. The cables were grouted.

Filter press building: each roof rib contains 1 to 4 monostrands of the above-named quality. In four ribs it was necessary to use 15 mm diameter monostrands to enable the required force to be obtained. The cables were stressed to 138 and 177 kN respectively.

Figure 78: Stressing of tendons of aeration tanks

2.3.4. Sludge tanks, Linz-Asten, Austria

Owner: Stadtbetriebe Linz GesmbH, Linz

Engineer: Office Dr. Lengyel, Vienna; Ed. ZGblin AG, Nuremberg, FR Germany

Contractor: Arge Regionalklaranlage Linz-Asten (Consortium comprising: ZGblin / Univer-sale / Mayreder / Dycker-hoff & Widmann / Strabag / C. Peters / Porr / Stuag / H. Weissel)

Post-tensioning: Sonderbau GesmbH, Vienna

Years of construction: 1977-1979

Introduction

At Linz-Asten, a regional sewage treatment plant was constructed in 1977 to 1979. An important part of this plant is formed by the three sludge tanks which, on the basis of a special proposal, were constructed as oviform, post-tensioned structures. This choice was substantially influenced by the successful application of this form of construction for the similar tanks, completed a short time before at Forchheim (Federal Republic of Germany).

Details of the structures

Two of the tanks, each of which has a capacity of 10 400 m3 were built in a first extension phase. A third tank was, however, planned at the same time and was built following the first ones (Fig. 79). All the tanks are identical in form and dimensions. Each is 42.95 m high and has a maximum external diameter of 24.40 m. In the upper 23.85 m the wall thickness is constant at 400 mm. It then increases gradually to 520 mm at the point of intersection with the ground surface and remains constant over a depth of 3.85 m. It then decreases again to 420 mm at the base of the tank (Fig. 80).

Construction procedure

The construction of each tank commenced with the excavation of a 6 m deep pit, in which the lower conical shell was constructed.

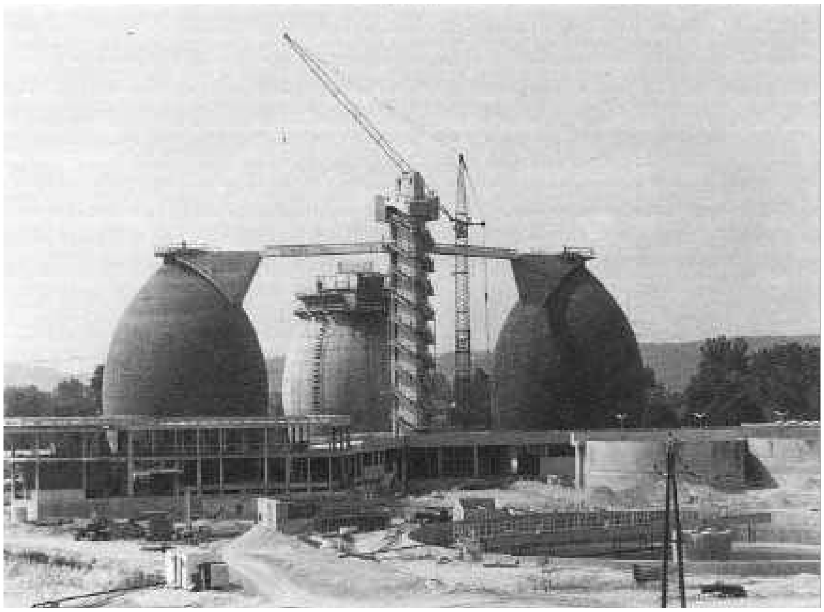


Figure 79: The three oviform sludge tanks

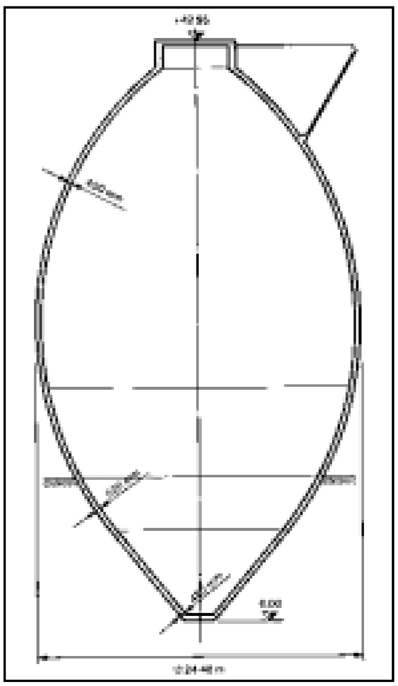


Figure 80: Section through a sludge tank

structed. The spherical part of each tank was then built in 15 horizontal rings, each approximately 2.30 m high (as measured along the axis of the shell), one week being required for each ring. In a final phase, the upper conical shell was completed. The concrete used was of quality B 40, i.e. it had a cube compressive strength at 28 days of 40 N/mm^2. For the formwork, a special annular climbing form was used, which could be built up from various panels to allow for the changes in diameter (Fig. 81).

Post-tensioning

The tanks were horizontally and vertically post-tensioned with VSL tendons. The horizontal cables are annular, i.e. they form a complete circle and possess only one anchorage. This is of type Z. The tendons are composed of 4 and 6 strands of 13 mm diameter. Their designations therefore are Z 5-4 and Z 5-6. The number of annular cables per tank is 153, of which 139 are of type Z 5-6 and 14 of type Z 5-4. The latter are situated in the uppermost part of the tank. The cables have ultimate strengths of 985 and 657 kN respectively. Their lengths vary from 28.18 to 76.09 m.

For the vertical tendons, the units EH 5-6 and ELE 5-6 were used. In each tank there are 28 of the first and 14 of the second type. They range between 31.51 and 59.75 m in length. The dead-end (H) anchorages of the EH cables are in the thirteenth, fourteenth and sixteenth ring. These cables were stressed at three different levels in the bottom cone. The cables with the loop (anchorage type L) all terminate at the construction joint between the fifteenth ring and the top cone. The loops themselves are situated in the fourth and sixth rings (Fig. 82).

With few exceptions, all the annular cables are situated 90 mm from the external wall surface. Their spacings vary from 123 to 548 mm. The vertical tendons are located in the centre of the wall, being slightly deflected towards the inside only at the stressing anchorages. The Z-anchorages were located during the construction phase in block-outs, which were concreted after stressing. The block-outs were 750 to 1100 mm long, 200 to 260 mm wide and 150 to 310 mm deep. The use

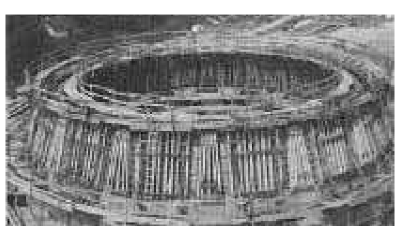


Figure 81: View on tank fromwork

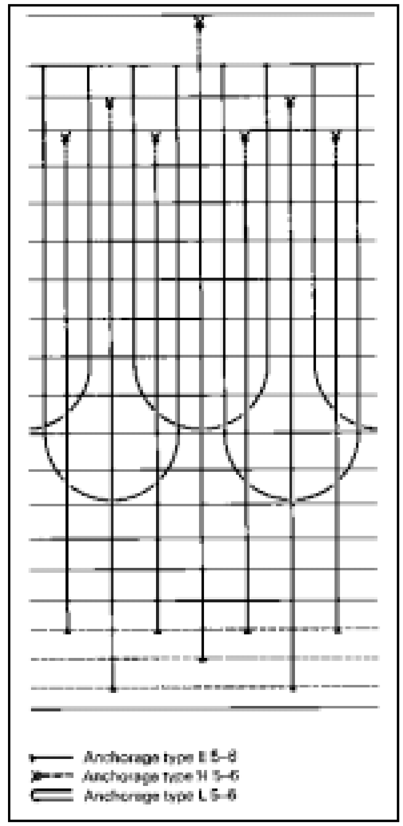


Figure 82: Scheme of vertical post-tensioning

of Z-anchorages enabled stressing buttresses to be completely dispensed with, thus simplifying the formwork.

Apart from a few exceptions, the blockouts were situated on the outer faces. They were arranged in several vertical rows, displaced by 45° from one another.

All the cables, both the horizontal and the vertical ones, were installed by the VSL push-through method. The annular tendons were not installed until after concreting. The strands of the cables equipped with H-anchorages had, of course, to be pushed through before the concreting of that ring in which the dead-end anchorage is situated. The cables comprising loops were installed after completion of the fifteenth construction step. Since their anchorages are located in the axis of the shell, they had to be stressed immediately afterwards and grouted, before the upper cone could be constructed. The remaining vertical tendons were not stressed until the last section had been completed. For the annular cables, a special stressing programme had to be observed, in which some cables had to be stressed shortly after concreting, others within three weeks of concreting and yet others only after the vertical loop cables had been stressed.

Additional items

After the construction of the three tanks and the operating tower, six beams each approximately 19 m long were prefabricated and stressed with two VSL cables 5-11 each. They were then positioned in pairs between the tower and the tanks and serve as support structures for the catwalks.

2.3.5. Sludge digestion tanks, Los Angeles, USA

Owner City of Los Angeles

Engineer Design Office of the Building Department of the City of Los Angeles

Contractor TG.I., Inc., Paramus, New Jersey

Post-tensioning VSL Corporation, Los Gatos

Years of construction 1977-1979

Introduction

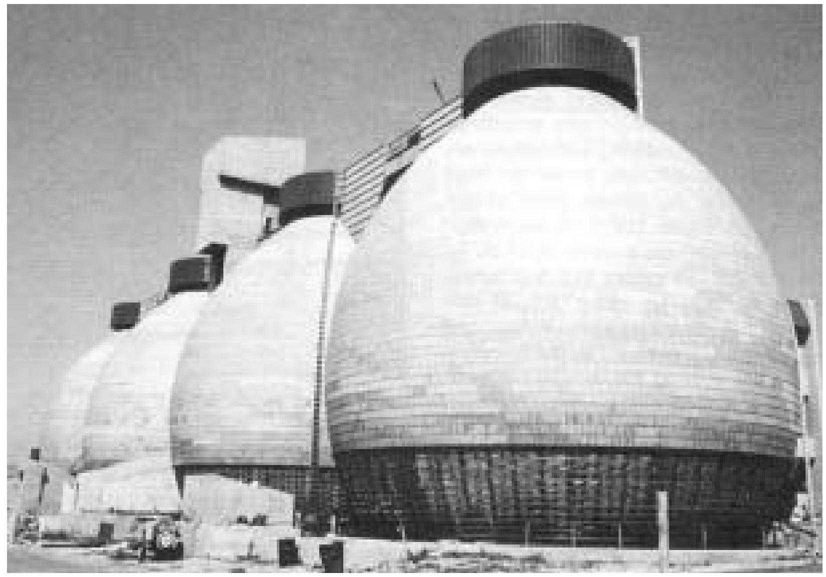
The Terminal Island sewage treatment plant of the City of Los Angeles has been extended by four oviform sludge digestion tanks (Fig. 83), this being the first time that this shape has been used in America. The oviform shape originates from Europe, where it has been established for some time, because an oviform sludge digestion tank has various advantages over a cylindrical tank.

Probably the most important advantage is that the curved surface causes the deposits to sink to the bottom of the cone, where they can be easily and continuously removed. The light particles that are produced during the digestion process ascend to the surface of the sludge, where they form a crust. Since the surface area in an oviform tank is smaller than in a cylindrical tank, the removal of the crust is less difficult. For the same reason, the heat losses are smaller. Finally, the oviform shape also contributes to a more efficient digestion process.

The design of the tanks was started in 1975, the tenders were submitted in October 1976 and in December 1976 the contract was awarded.

Details of the structures

Each tank is 30.65 m high and has a maximum internal diameter of 20.00 m. A foundation ring 18.00 m in diameter forms a basic part of each structure. It is located approximately at the natural ground level and rests on piles. The wall thickness decreases from 610 mm at the base of the cone to one half of this value at the summit of the tank, where the diameter is still 5.18 m (Fig. 84).



Construction procedure

The contract documents envisaged four different sections of construction: the bottom cone plus foundation ring, lower ring, segments and upper ring. The six segments were to have been erected vertically. The tanks were, however, constructed in annular sections. The bottom cone and the foundation ring were concreted in three steps against a sand slurry applied to the excavated surface. The foundation had conventional formwork. For the inner face of the cone a steel of the cone a steel form was used. An annular, movable inner and outer form was used for constructing the 1.22 m high rings of the tank wall which followed next. For each ring about 7 working days were required. In total 18 rings had to be concreted pertank.

Post-tensioning

For the vertical and horizontal post-tensioning, three types of VSL tendons were used, instead of the bar tendons envisaged in the initial design (Fig. 85).

In the foundation ring there are twelve cables 5-12 (ultimate force 2204 kN), equipped at every 120° with a Z-anchorage. The same applies for the 4-strand and 6-strand cables of the tank shell. The block-outs of

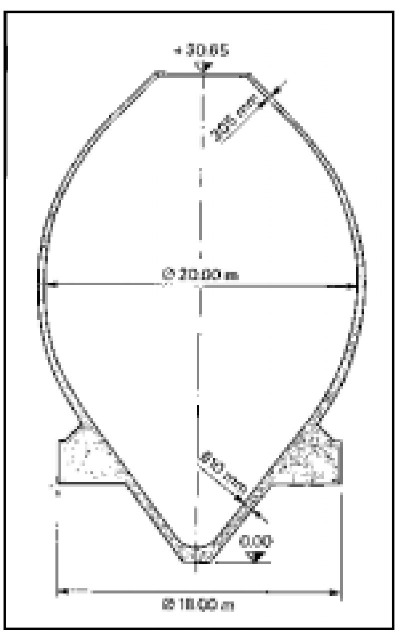


Figure 84: Section through a tank

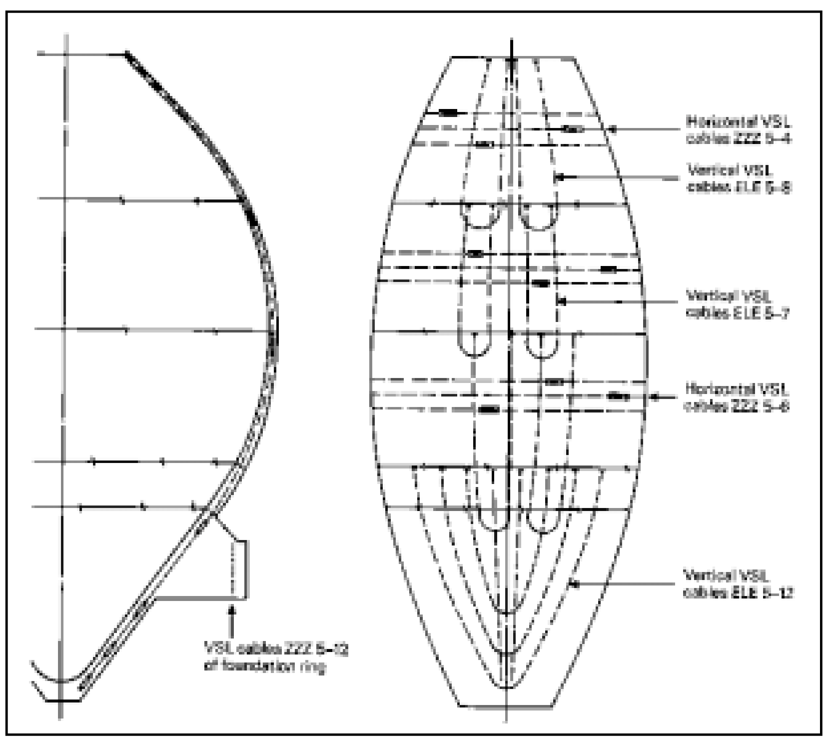


Figure 85: Arrangement of post-tensioning tendons

Figure 86: Environmental protection tank

immediately adjacent tendons are displaced through $71\frac{1}{2}^\circ$. The 49 cables 5-6 are located in the lower part and the 30 cables 5-4 in the upper part of the tank.

The vertical post-tensioning throughout consists of cables having a loop anchorage at one end. Their stressing anchorages are located at four different levels. At level 11.33 m above the lowest point of the structure, 24 cables ELE 5-12 are anchored. The same occurs at level 17.67 m. At 6.10 m higher, 24 cables ELE 5-7 terminate. At the top edge of the tank, 12 tendons ELE 5-8 are anchored.

The cables were stressed in the following sequence: first of all the vertical cables at level 11.33 m, then the horizontal cables in the foundation ring. Above this ring, the horizontal cables were stressed when a concrete strength of 28 N/mm^2 was reached in the relevant ring and a strength of 14 N/mm^2 in the ring above. The vertical cables were stressed when the concrete strength in the last ring reached 28 N/mm^2 and before the horizontal cables in the two rings immediately below the anchorages of the vertical cables were stressed.

2.3.6. Environmental protection tanks

Engineer Dr.-Ing. Helmut Vogt, Schleswig, FR Germany
Manufacturer PERSTRUP Beton-Industri ApS, Pederstrup, Denmark
Contractor Carsten Borg, Betonvarefabrik ApS, Tonder, Denmark
Post-tensioning SUSPA Spannbeton GmbH, Langenfeld, FR Germany

Introduction

The firm Borg constructs tanks of prefabricated reinforced concrete panels, which are used as sewage purification, water or manure tanks (Fig. 86). The panels are produced in steel forms and are of impermeable concrete B 45.

Details of the tanks

The tanks are built up of from 19 to 31 standard elements, each 2.40 m wide and 3.00 or 4.00 m high. They accordingly have a capacity of 460 to 1630 m^3 and an internal diameter of 14.00 to 22.70 m. The elements have strengthening zones in the form of edge and transverse ribs. The edge ribs are so constructed that adjacent elements fit together on the tongue-andgroove principle. The panels have a thickness of 60 mm and the ribs an additional height of 140 mm.

Construction procedure

A base slab is first constructed of in-situ concrete. On this slab the precast panels are then erected and temporarily supported. On the same day the tendons are pulled through, lightly stressed and the joints between the elements are concreted. The tendons are then encased in cement mortar. After the joint and protective mortar has hardened, the cables are stressed. Finally, the projecting ends of the strands are cut off, the anchorages are injected with grease and a protective cover and safety stirrups are fitted. The anchorage zones are then sealed with mortar.

Post-tensioning

The edge ribs have passages through them just above and just below the transverse ribs; through these passages VSL monostrands of diameter 15 mm (0.6") are pulled. The monostrands change direction at the passages to form a polygon. To prevent the plastic tube from being damaged by pressure against the concrete, the monostrand is additionally protected inside the passage by two extra polyethylene half shells. The width of the edge ribs and the maximum angle of deflection between two edge ribs have been chosen so that the minimum deflection radius is not less than 2.50 m. In addition the monostrands are stressed to only 55% of their ultimate force. The cables continue around the entire tank and are stressed first at the one end, then at the other end.

The anchorages are concreted into the edge ribs, so that when the elements are brought together at the joints the result is virtually an overlapping buttress anchorage. The polyethylene sleeves are sufficiently long to be able to pass through the opposite edge rib, so that a satisfactory connection to the monostrand is obtained (Figures 87 and 88).

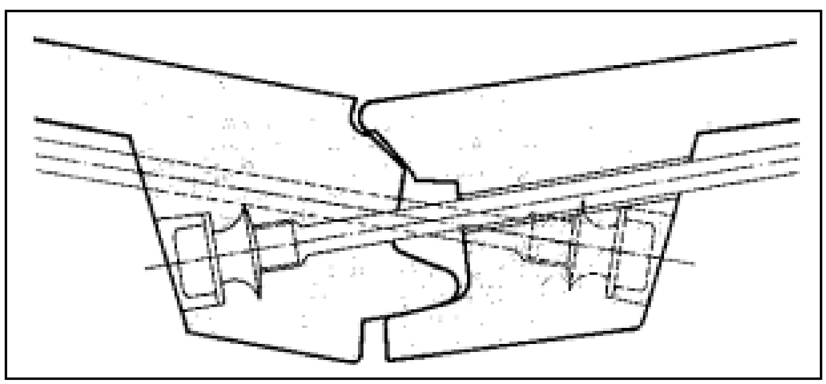


Figure 87: Anchorage zone

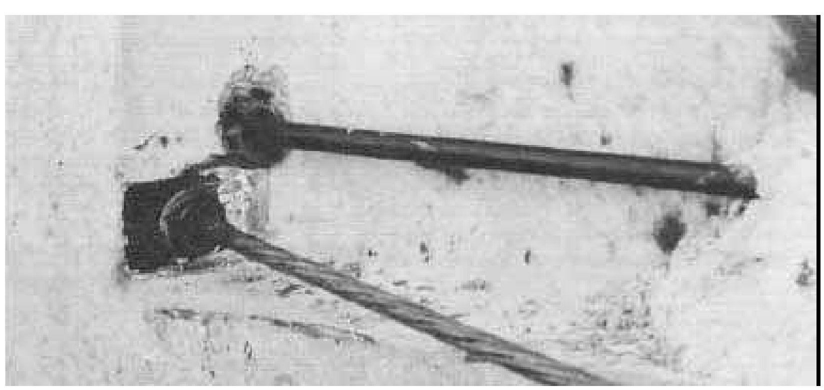


Figure 88: Anchorage of a monostrand at an edge rib

2.4. LNG and LPG Storage tanks

2.4.1. Introduction

LNG and LPG tanks are used for storing liquefied gases. LNG stands for «Liquefied Natural Gas», LPG for «Liquefied Petroleum Gase» (= a mixture on a basis of propane and/or butane). Some of the gases have to be very drastically cooled in order to liquefy them, i.e. they are stored at -5 °C to-165 °C. The upper range applies to LPG and the lower range to LNG. In the liquid state the volume is 1/240 (butane) to 1/630 (LNG) of the volume of gas. LPG must be stored under pressure, whereas LNG can be stored at atmospheric pressure on account of the very low temperatures.

A liquefied gas storage tank has to fulfil three functions:

- The liquefied gas must be stored without leakage,
- The heat absorption of the gas must be kept as small as possible,
- The tank must be leaktight in both directions.

It has been found that concrete tanks with a suitable lining are very well suited to these requirements. The lining, which is subjected to wide temperature fluctuations, in many cases is of nickel steel sheet. Between the lining and the concrete wall thermal insulation is incorporated. Another very satisfactory solution is provided by a steel sheet in the concrete wall and insulation externally on the concrete wall.

In the extreme case, the concrete and therefore also the prestressing cables may be subjected to the very low temperatures. They should therefore be capable of accepting these temperatures without damage, so that the gas cannot escape. This means that the prestressing steel and also the anchorages must withstand such very low temperatures. This is the case in the VSL Post-tensioning System, as has been demonstrated by tests. On the basis of these tests, the VSL Post-tensioning System has been approved by various authorities, owners and engineers for use in iquefied gas storage tanks.

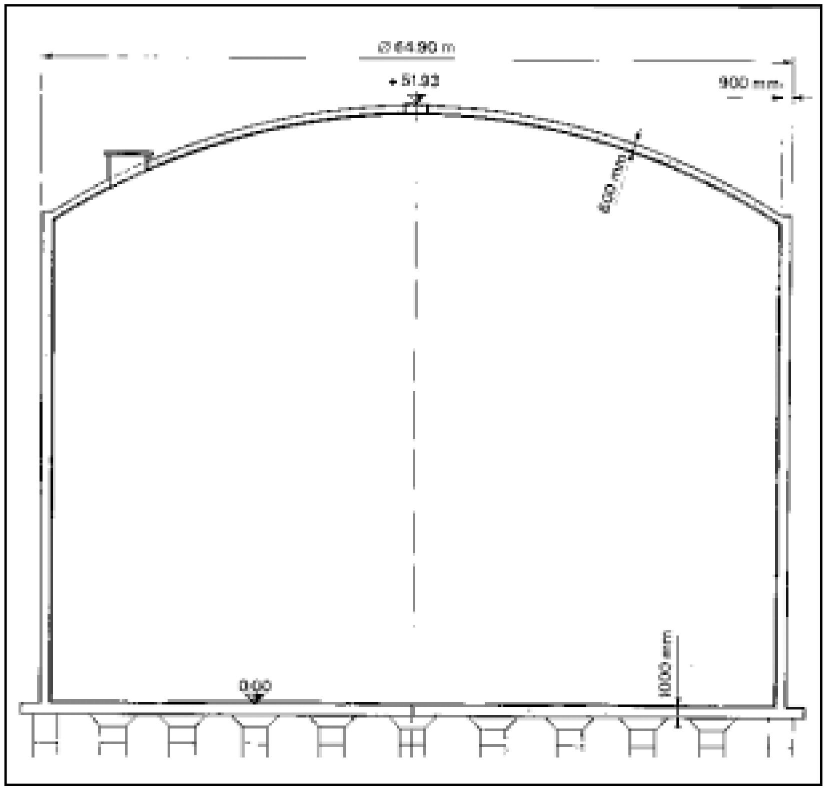


Figure 89: Section through a tank

2.4.2. Tanks at Montoir, France

Owner Gaz de France, Paris
Engineer Europe Etudes Gecti, Boulogne-Billancourt
Contractor Chantiers Modernes, Levallois-Perret
Heavy Rigging VSL France s.a rl., Boulogne-Billancourt and VSL INTERNATIONAL LTD., Berne, Switzerland
Construction 1978

Introduction

In the vicinity of St. Nazaire at the mouth of the Loire, a transit plant for liquefied natural gas was built from 1977 to 1979. This plant contains also two LNG tanks, each of 120 000 m^3 capacity. A further LNG tank of the same size was added in 1980.

Details of the structures

The tanks are of concrete, which is internally insulated with PVC panels and sealed with steel. Each tank has an external diameter of 64.90 m and a height (from the base slab to the highest point of the dome) of 51.93 m. The 1000 mm thick bottom slab rests 2 m above the ground, so that it can be well ventilated below. It stands on 113 square columns, which are carried on piles of elongated cross-section, 35 to 40 m in length. The thickness of the wall is 900 mm, that of the dome (radius 60 m) is 600 mm. The bottom slab has external hoop post-tensioning, the wall contains post-tensioning cables in the horizontal and vertical directions. The connections between wall and bottom slab and wall and dome are monolithic (Fig. 89).

Construction procedure

After completion of the foundation and the bottom slab, the wall was constructed by slipforming. This method was preferred to climbing formwork, on account of its better guarantee of tightness. In addition, it was possible to use the formwork twice, which offered economic advantages. The concrete dome was erected on the steel dome which served as seal and formwork skin.

Lifting

After the wall had been built, the steel dome was assembled on the base slab. This dome contains stiffeners, some of which were of a temporary nature. After the dome had been completed it was lifted as a unit into its final position. In the lifting state its weight was 600 tonnes.

For the lift, 12 lifting frames of steel were erected on the upper edge of the tank wall. Each of these brackets was fitted with a VSL motive unit SLU-70, through which a

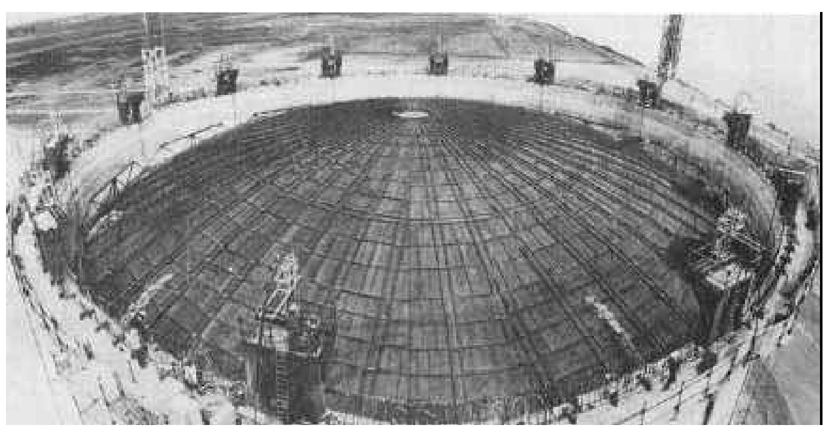


Figure 90: Lifting of the first dome

cable comprising 7 strands Ø 15 mm ran. The lifting distance was 32 m. The dome was raised to 100 mm above the bearing plane, and was then fitted with the ends of the beams, which came to rest on the bearings when the dome was set down.
The first dome was lifted in June and the second in July 1978 (Fig. 90).

2.4.3. Tanks at Terneuzen, Netherlands

Owner	Dow Chemical (Nederland) BV., Terneuzen
Engineer	D3BN, Rotterdam
Contractor	Amsterdam Ballast International, Amstelveen
Slipforming	VSL INTERNATIONAL LTD., Berne, Switzerland
Year of construction	1981

Introduction

The two tanks serve for storing LPG at - 50 °C. Each tank has a capacity of 50 000 m³. Each consists of a 600 mm thick bottom slab supported on piles (dimensions 450 x 450 mm) at 1.60 m above ground level, of an inner steel tank 47.00 m in diameter with a domed roof and of an outer concrete wall of 49.20 m internal diameter with a 200 mm thick domed roof.
The height of the concrete wall is 30.00 m.
The wall thickness is 600 mm at the bottom and then decreases uniformly through 9.00 m to 450 mm. This dimension then remains constant over the upper 21.00 m (Fig. 91). The walls are post-tensioned and possess four buttresses.

Construction procedure

The concrete walls were constructed with VSL Slipforming (Fig. 92). The external conical form of the walls in the lower part imposed special requirements on the formwork. The weight of the slipform alone was 60 tonnes. The number of jacks required was 108 (Fig. 93). To construct one tank, 10 days were required. The erection of the slipform took 11 days and its dismantling 12 days per tank.

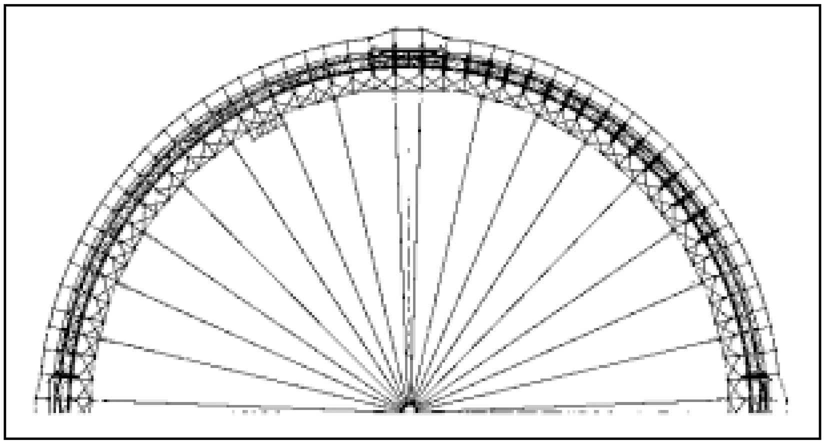


Figure 93: VSL Slipforming for the tank walls

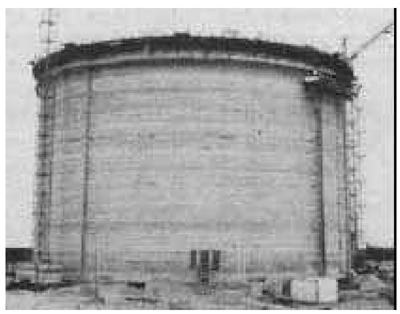


Figure 92: Construction of the one tank

2.4.4. Fife Ethylene Plant, Great Britain

Owner	Esso Chemical Ltd.
Engineer	D3BN, Rotterdam, Netherlands
Contractor	G. Dew & Co., Oldham
Post-tensioning	Losinger Systems Ltd., Thame
Years of construction	1981-1983

Introduction

The gas from the Brent field in the North Sea is brought by a 445 km long pipeline to St. Fergus in northern Scotland, where the methane is extracted from it. The remainder is supplied for processing into marketable products by a further 220 km pipeline to Mossmorran. There the gas is decomposed into its constituents. Mossmorran is only 7 km from Braefoot Bay (on the Firth of Forth) an almost ideal location for a terminal for shipping the products.
At Mossmorran the liquefied natural gas will be cracked to give propane, butane and natural light gasoline and also ethane. Approximately 2.14 million tonnes will be processed annually, of which 700 000 tonnes will be ethane. The construction of the plants, in which Esso is investing more than 400 million pounds, started in 1981 and will continue until 1985.

Post-tensioned tanks

The Esso plant at Mossmorran includes a tank of 18 000 m³ capacity, in which the ethane is stored at-101 °C, before it is processed to ethylene. This is then transported by pipeline to Braefoot Bay, where two further tanks, each of 10 000 m³ capacity, are located, in which the ethylene is stored at-104 °C while awaiting shipment.
The tanks are of post-tensioned concrete. All of them are 32.51 m in diameter. Their height is 25.39 m for the tank at Mossmorran and 14.79 m for those at Braefoot Bay. The latter have a spacing between centres of 64.00 m (Fig. 94).

Construction procedure

The walls were constructed in horizontal sections, the number of sections being 10 for the tank at Mossmorran, and 6 for each

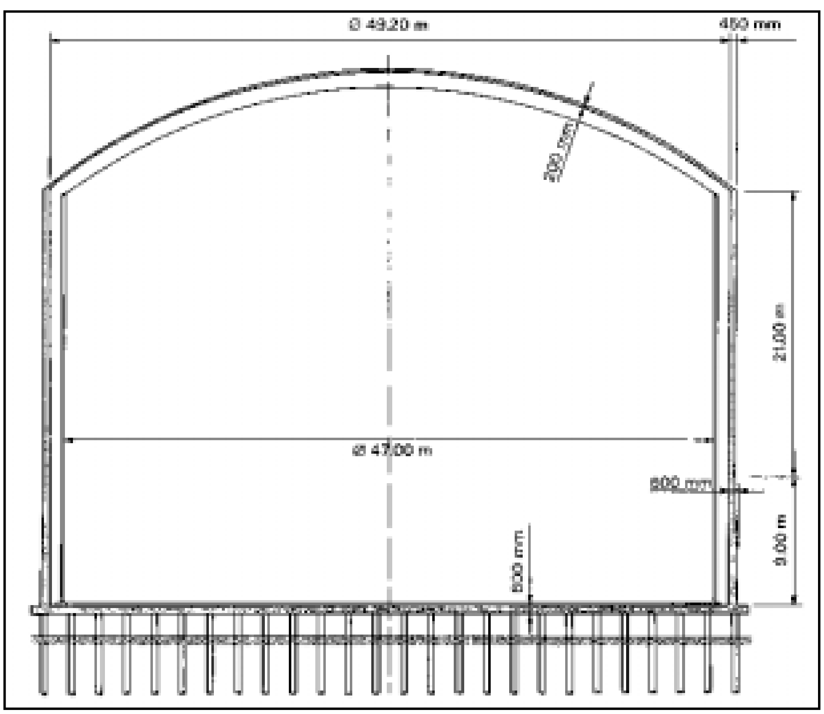
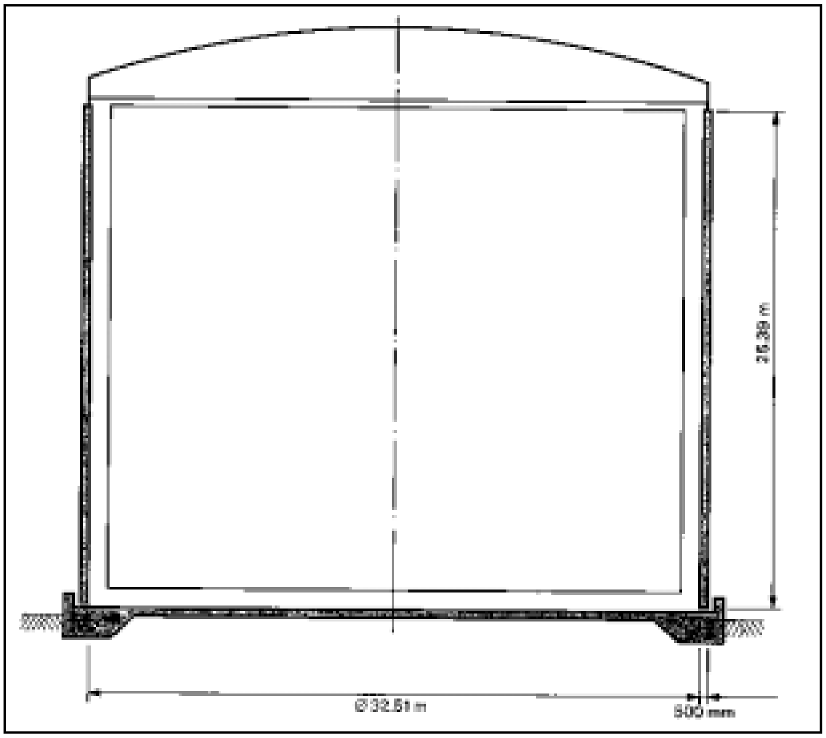


Figure 91: Cross-section through the tanks at Terneuzen



(Figure 94: Section through the tank at Mossmorran

at Braefoot Bay. Construction of each stage took 10 days. For the tank at Mossmorran this resulted in a construction time of 16 weeks, after which 8 weeks were required for installing the tendons, stressing and grouting the cables. The construction of each tank wall at Braefoot Bay took 10 weeks, plus 6 weeks for the above-named cable operations (Fig. 95).

Post-tensioning

The tank at Mossmorran contains 124 horizontal cables, each extending through 180°. Of these 62 no. are of type 5-19, 16 of type 5-16 and 46 of type 5-12. Four buttresses, each 4.00 m wide, are used for anchoring. The installation of the tendons was carried out by pushing through the strands individually.

Each tank at Braefoot Bay contains 72 horizontal cables, of which 32 are of type 5-14 and 40 of type 5-12. All the tanks are also vertically post-tensioned. For this purpose, VSL cables ELE 5-12 were used, these being pulled into the ducts (Fig. 96).

In the construction state, a 3.90 m high opening was left in each wall for erecting the inner steel tank. The cables at the opening were coupled with K-anchorages, when the opening was closed (Fig. 97).

The horizontal cables of the tank at Mossmorran are spaced at intervals ranging from 280 to 500 mm. The distance from the outer face of the wall varies. From bottom to top there are, successively, cable types 5-19, 5-16 and 5-12, with two further rings comprising cables 5-16 at the top. The vertical cables in the upper region lie in the centre of the wall, while in the lower region they are nearer to the inner face. This applies for all three tanks. The buttresses contain additional vertical cables.

2.4.5. Tanks at Antwerp, Belgium

Owner Antwerp Gas Terminal (Consortium of Transol, Rotterdam, Netherlands /V.E.R., Houston, USA/ A.C.P, Belgium)

Engineer Constructor, Antwerp

Contractor Joint venture Van Laere, Burcht / Ballast Nedam Benelux

Slipforming
VSL INTERNATIONAL LTD., Berne, Switzerland

Post-tensioning
Civielco B.V., Leiden, Netherlands

Year of construction
1982

Introduction

In the port and industrial zone of Doel-Kallo, approximately 12 km to the west of Antwerp, various plants have been under construction since 1982 for the transit and storage of gases. Construction is being carried out in two phases. In the first phase until August 1983 berths for ships, spherical tanks for storing butane, propane, propylene and butylene, and rail tracks and roads are being constructed. One year later, the low temperature storage tanks and piping should be completed.

Details of the structures

The two LPG tanks for the storage of propane, butane and mixtures of these two gases in the low temperature state (-45 °C) consist of an inner steel tank with a domed roof of 46.00 m diameter and 36.00 m height and an outer concrete wall of 48.50 m internal diameter and 500 mm wall thickness. Their height from the upper face of the 600 mm thick bottom slab is 30.50 m. The wall is fixed in the bottom slab. The tanks are founded on piles (Fig. 98). To allow for ventilation, the bottom slabs lie 1.00 m above ground level. Each tank has a capacity of 50 000 m^3.

Construction procedure

After completion of the foundations, the bottom slabs were constructed, a strip being left open near the perimeter, to be concreted later after partial prestressing had been applied. The concrete walls were then built by means of VSL Slipforming

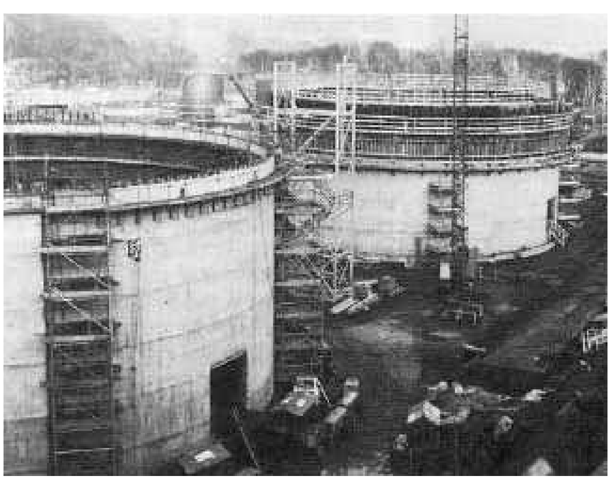


Figure 95: Construction of tanks at Braefoot Bay

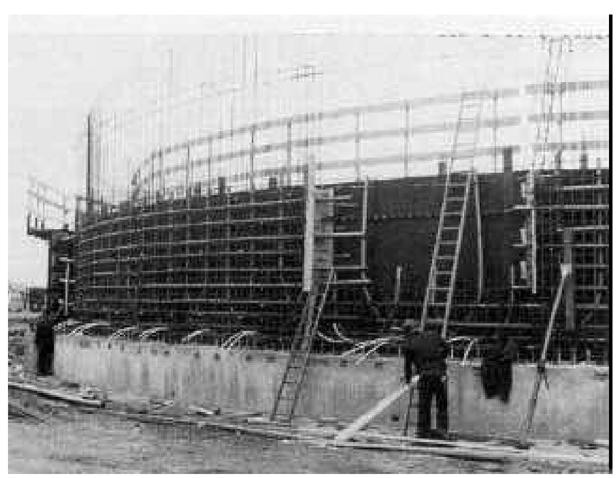


Figure 96: Ducts of horizontal and vertical post-tensioning

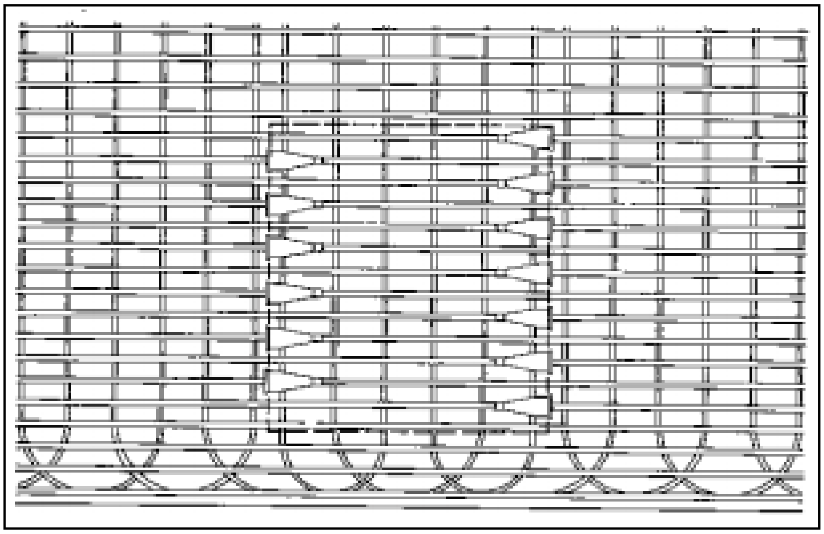


Figure 97: Cable layout in the region of the opening of the Fife Ethylene Plant tanks

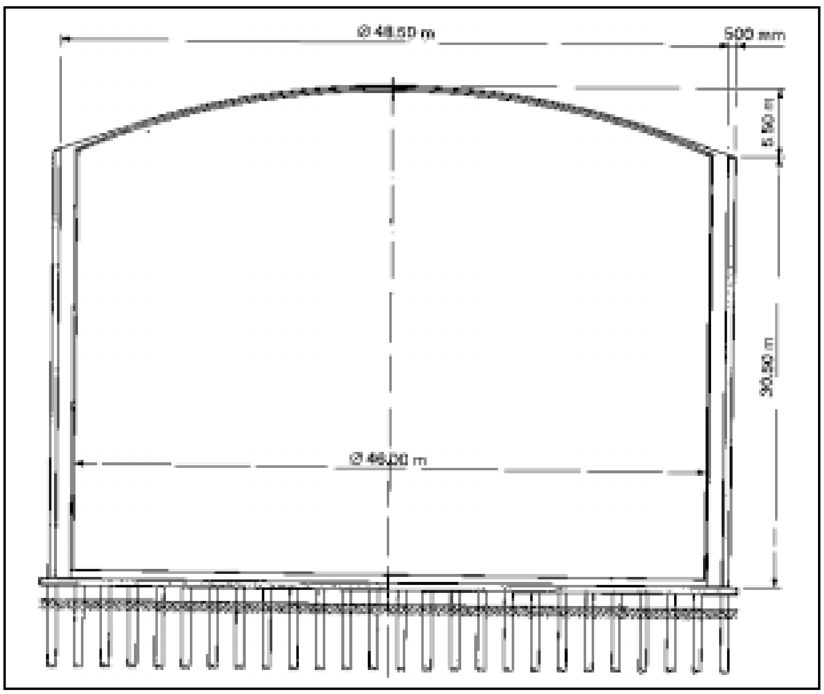


Figure 98: Cross-section through the tanks at Antwerp

Figure 99: Construction of the concrete walls (in the foreground VSL Slipforming, in the background VSL Post-tensioning in progress)

(Fig. 99). During advancing of the formwork, the empty ducts and bearing plates for the VSL cables were positioned. The time required for building one wall was 9 days. The maximum slipforming rate was 4.20 m/24 h. The concrete was brought to the placing position by cranes. The entire time required for the use of the slipforms for the two tanks, that is for erection, slipforming and dismantling, was 11 weeks.

Post-tensioning

The concrete walls are horizontally and vertically post-tensioned with VSL cables. The edge of the base slab acts as a ring beam. It contains 8 cables EC/EC 6-19 (ultimate force 5045 kN each), each extending around one half of the circumference. The horizontal post-tensioning of the wall consists of 164 semi-circular cables EC/EC 5-12 (ultimate force 2232 kN each), while 92 cables ELE 6-3 and 4 cables ELE 6-4 (ultimate force 984 kN) prestress the wall in the vertical direction. The last mentioned are located in the 4 buttresses.

The installation of the cables was carried out after completion of the wall by pushing through the individual strands. The strand coils remained on the ground, while the push-through machine was moved from one anchorage to another. The vertical cables with loop anchorages were also assembled by pushing-through. For this purpose, two hydraulic pumps were connected in parallel, thus providing twice the force at the push-through machine.

The post-tensioning procedure was in the following sequence:

1. Stressing of the cables of the ring beam to 60% of the final force,
2. Stressing of the horizontal cables in the lowest
2. 50 m of the wall to 60% of the final force,
3. Stressing of the horizontal cables in the next 5 m of the wall to 50% of the final force,
4. Concreting of the remaining open strip between ring beam and remainder of base slab,
5. Stressing of the vertical cables to full load,
6. Stressing of the ring beam cables to full load,
7. Stressing of the horizontal cables to full load.

The horizontal cables in the wall were simultaneously post-tensioned in pairs (to form a ring) at both ends. For this purpose, four VSL jacks ZPE-12/St2 and two pumps EHPS-3 were used at two opposite buttresses. To assure simultaneity of stressing, the stressing teams were supplied with walkie-talkie equipment and the force was increased by steps of 300 kN each. All the cable pairs anchored at the same buttresses were first stressed, and after this the remaining pairs of cables.

The cables of the ring beam were stressed individually, but simultaneously at both ends. For the vertical cables, stressing was carried out simultaneously first at the one ends of two opposite cables, and then at the other ends of the same cables.

After completion of all stressing operations the cables were grouted.

2.5. Safety walls

2.5.1. Introduction

Steel tanks which contain environmentally hazardous liquids are usually required today to be surrounded by a protective or safety wall of concrete, which would retain the liquid in the case of a catastrophic accident. For new tanks, steel and concrete walls are frequently constructed together, whereas older tanks now have to be subsequently provided with a safety wall.

These safety walls are very well adapted for construction by the slipforming method. They are usually cylindrical like the tanks they surround. As a rule, they are also posttensioned, monostrand cables being frequently used.

2.5.2. Safety wall for ammonia tank, Hopewell, USA

Owner Allied Chemical Company, Fibers Division, Petersburg, VA.
Engineer Dicta International, Gouda, Netherlands
Contractor VSL Corporation, Los Gatos, CA.
Post-tensioning VSL Corporation, Springfield, VA.
Year of construction 1978

Introduction

In 1978 the Allied Chemical Company had a safety wall erected around its existing ammonia tank. The tank, with a capacity of 15 000 tonnes, has a diameter of 36.58 m and a wall height of 19.76 m. It is of steel with a foundation slab of concrete.

Details of the structure

The safety wall of post-tensioned concrete is 305 mm thick, 18.29 m high and has an internal diameter of 40.23 m, so there is a space of 1.82 m between safety wall and tank. The wall stands on an annular foundation independent of the tank and immediately adjoining the foundation slab of the tank. The safety wall is seated on rubber strip bearings on the foundation ring. The annular space between wall and tank is roofed. The safety wall has 3 buttresses, each 1.22 m wide, on its external face (Fig. 100).

Construction procedure

The wall was constructed by means of slipforming (Fig. 101) although this method is not regarded as the most economical for a structure of these dimensions in the USA. Safety considerations relating to the existing tank had, however, a decisive influence upon the choice. The concrete (cylinder compressive strength at 28 days 27.6 N/mm^2) was placed by skips. It became evident during construction, however, that pumped concrete would have been quicker and more convenient. Gas masks had to be worn continuously for work in the space between wall and tank for safety reasons. The time for constructing the safety wall was 4 months.

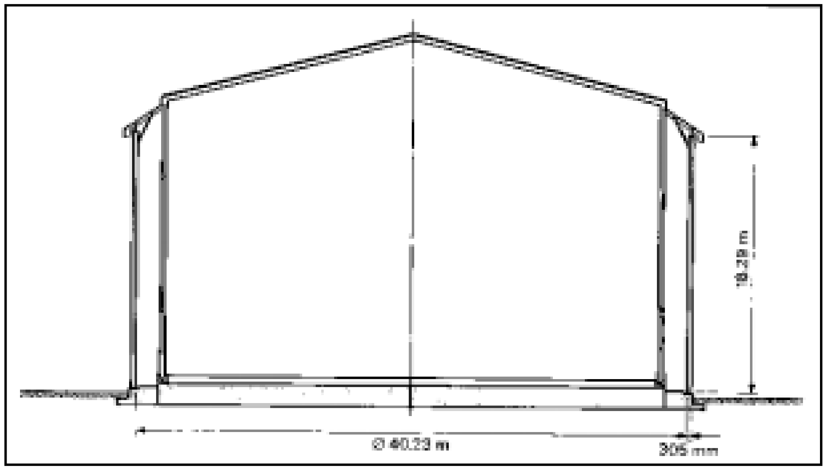


Figure 100: Section through tank and safety wall

Post-tensioning

The safety wall was post-tensioned with 144 bundles each comprising two VSL monostrand cables. Each cable bundle extended around two-thirds of the circumference, that is through 240°. This gave a cable length of approximately 87 m. Successive cable bundles are displaced by 120°.

The long cable length was found to be unsatisfactory for the monostrands from the standpoint of handling, so that for safety walls constructed later cables extending through 120° or 180° were chosen. The cable bundles are 57 mm from the outer wall surface and the spacings between them (vertically) are 178 mm at the bottom, and 1435 mm at the extreme top. The strands used are 13 mm in diameter and are coated with grease, therefore unbonded. The ultimate force per strand is 184.5 kN.

2.5.3. Safety wall for ethylene tank, Australia

Owner I.C.I. Australia Pty. Ltd., Sydney
Engineer (safety wall) Chicago Bridge & Iron Constructions Pty. Ltd., Sydney and VSL Prestressing (Aust.) Pty. Ltd., Thornleigh
Contractor Steel tank: Chicago Bridge & Iron Constructions Pty. Ltd., Sydney
Safety wall: Pearson Bridge (N.S.W.) Pty. Ltd., Sydney
Post-tensioning VSL Prestressing (Aust.) Pty. Ltd., Thornleigh
Years of construction 1979-1980

Introduction

I.C.I. is Australia's largest manufacturer of chemicals. In the vicinity of Sydney it has an important production and storage plant. This was extended with an ethylene tank of 4000 tonnes capacity. The tank is of steel,

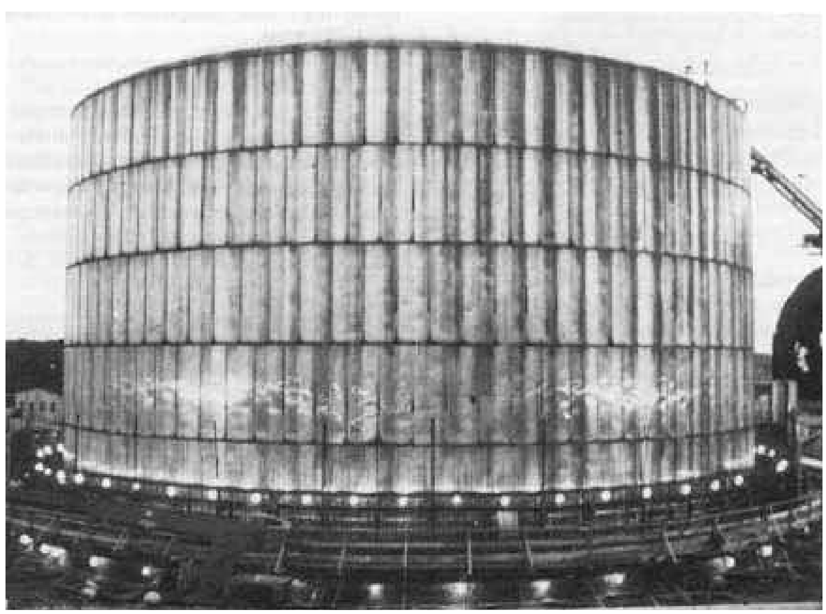


Figure 101: Commencement of construction of safety wall (slipforming)

but had to be surrounded with a safety wall of concrete.

Previously, tanks of this type in Australia were either constructed in the ground or built with an earth embankment. In a prelimary submission, VSL Prestressing (Aust.) Pty. Ltd. investigated, on the instigation of the steel tank constructor, whether a posttensioned concrete safety wall would be more economical and what costs it would involve. A tender was prepared and this was accepted.

Details of the structure

The wall is 20.72 m high with an internal diameter of 28.50 m. Its thickness is 360 mm. The wall has 4 buttresses, each 1.80 m wide. It was constructed by the slipforming method, only the empty ducts for the horizontal post-tensioning being placed during slipforming. The wall stands on sliding bearings and is therefore completely independent of the foundation.

Post-tensioning

The wall is horizontally and vertically post-tensioned. The vertical post-tensioning consists of VSL bars Ø 23 mm located at the centre of the wall. These were assembled by coupling together 2.40 m long bars. The spacing between the vertical tendons is 1.00 m, so that the force in the final condition is 126 kN/m.

Horizontally, there are 39 cables in the cross-section. These are VSL strand tendons, unit 5-7, each extending through 180°. Their spacing increases from 300 mm at the bottom to 875 mm at the top. The strands of the tendons were pushed through after concreting.

Alternate vertical tendons were stressed, followed then by the remainder. The horizontal tendons were then stressed in accordance with a specific programme.

2.5.4. Safety walls for gasoline tanks, Lalden, Switzerland

Owner Lonza AG, Basle
Engineer De Kalbermatten & Burri, Visp
Contractor Regotz & Furrer, Visp
Slipforming and Post-tensioning VSL INTERNATIONAL LTD. (formerly Spannbeton AG/ Precontrainte SA)
Years of construction 1980-1981

Introduction

Lonza AG operates a chemical factory at Visp, with a considerable demand for mineral oils. On account of the high fluctuations in price of these products, the firm decided to have two gasoline tanks each of 25 000 m^3 capacity erected in the adjacent community of Lalden, so as to have a certain reserve available. The tanks themselves are of steel and they are surrounded with safety walls of post-tensioned concrete.

Details of the structures

The steel tanks have a diameter of 38.14 m and the safety walls an internal diameter of 42.10 m. The axes of the two tanks are spaced 63.10 m

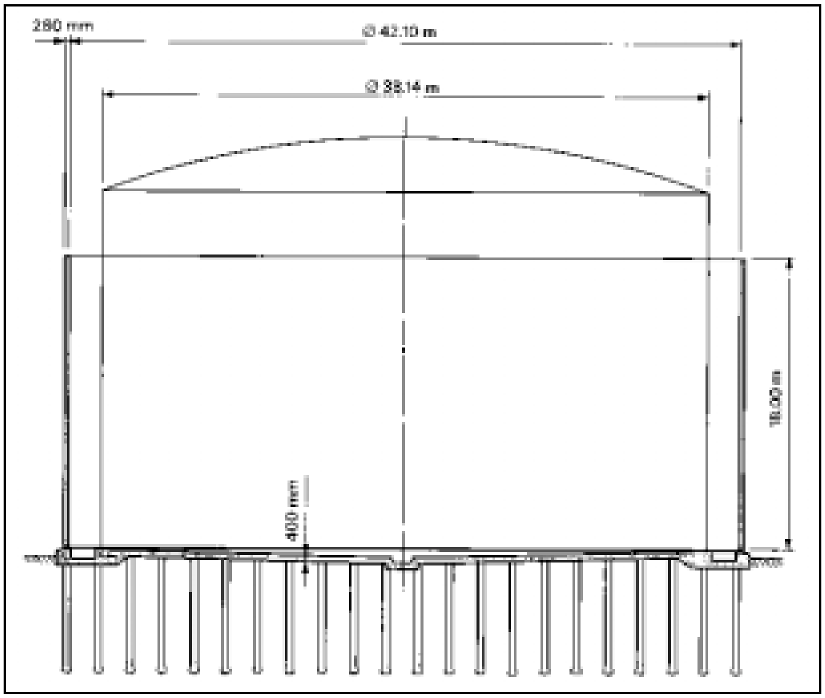


Figure 102: Cross-section

spaced 63.10 m apart.

A tank and its safety wall stand on a common foundation slab 400 mm in thickness. This is carried on 388 in-situ concrete piles Ø 520 mm with spread feet and each approx. 7 m long. In the region of the steel tank the piles are firmly fixed to the slab, while in the region of the safety wall there is a sliding foil between piles and slab.

The safety wall is 260 mm thick and 18.00 m high. It rests on the foundation slab by means of neoprene bearings. On its outer face the wall has four buttresses, 1.20 m wide in the final state, for anchoring the tendons (Fig. 102).

The two tanks and safety walls were constructed between the beginning of 1980 and summer 1981. The safety walls were constructed using VSL Slipforming in spring 1981, after completion of the steel tanks (Fig. 103).

Post-tensioning

Originally it had been intended to post-tension the safety walls with grouted VSL tendons each comprising 9 strands. It became apparent, however, that the use of monostrands was more economical, not least on account of the considerably lower friction.

VSL monostrand cables of type EE 6-1 were therefore used. Each strand has a nominal diameter of 15 mm (0.6"), a crosssectional area of 146 mm^2 and an ultimate strength of 257.8 kN. The stressing anchorages are standard anchorages E 6-1 with bearing plate and anchor head, and therefore not the same as anchorages for the VSL unbonded Slab Post-tensioning System.

The cable axes are 45 mm from the outer face of the wall. The monostrands are arranged in pairs, but with a small space between them. The distance between the cable pairs increases from 110 mm at the bottom by steps to 600 mm at the extreme top. Each safety wall contains 396 tendons of 67.87 to 68.40 m length. One cable therefore extends through 180°. The difference in length is due to deflections for bypassing manholes.

Installation of the monostrands was carried out during the execution of the slipforming work. The cables, individually coiled, were suspended by pairs in a special unreeling device on the slipform (Fig. 104). As each

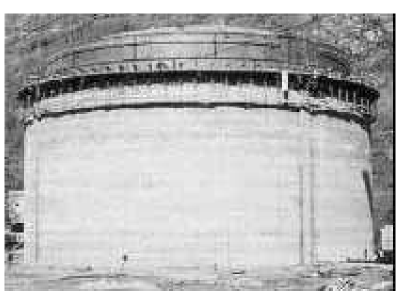


Figure 103: Safety wall during construction with VSL Slipforming

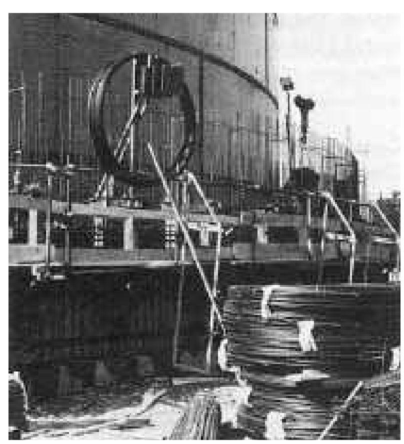


Figure 104: Cables in the unreeling device

monostrand came to be installed, the tip of the strand was attached to a bare prestressing steel strand, which was moved forwards in a circulating motion by a fixed VSL push-through machine, and thus the monostrand was installed. The relatively large number of monostrands in the lower part of the wall made very good co-ordination between the individual trades essential, so that the regular progress of construction required for slipforming could be achieved.

Stressing was carried out by steps. In the first step a number of pairs of cables were stressed at one end to 191.3 kN per cable. Approximately one month later all the remaining cables were stressed to this force at both ends and anchored at 180.5 kN. Finally, the initially stressed cables were also stressed at the other end.

2.5.5. Safety wall for oil tank, Vienna, Austria

Owner Osterreichische Mineralol-verwaltungs AG (OMV), Vienna
Engineer Industriebau GesmbH, Vienna
Contractor Industriebau GesmbH, Vienna
Post-tensioning Sonderbau GesmbH, Vienna
Year of construction 1981

Introduction

Austria possesses at Vienna-Schwechat one of the most modern refineries for mineral oil products in Europe. The tank storage plants at Lobau have been continually expanded since 1955 and the new tanks have been equipped with safety walls. The safety walls hitherto have been either earth embankments with an impermeable layer or of reinforced concrete. Their height was about 5 m. They were arranged in the form of a rectangle around the storage tanks.

The last tank to be constructed was a steel tank of 130 000 m3 capacity. For this large tank, at the time of construction the largest in Europe, a rectangular safety wall 5 m in height would no longer have been economical, either on account of the additional space requirement around the tank or on account of cost. A circular safety wall of post-tensioned concrete was therefore chosen as a new departure (Fig. 105).

Details of the structure

The maximum diameter of the safety wall is 97.40 m and its height inclusive of foundation 19.60 m. On the flat foundation of maximum depth 1.80 m the actual foundation ring of the wall rests. It is 2.20 m high and 1.20 m thick and carries 240 neoprene bearings, on which the wall rests. The wall thickness decreases from 800 mm at the bottom to 350 mm at the top (Fig. 106).

The foundation was constructed in 32 segments. The actual foundation ring, which is post-tensioned, had recesses for the Z-anchorages through the entire height of the ring.

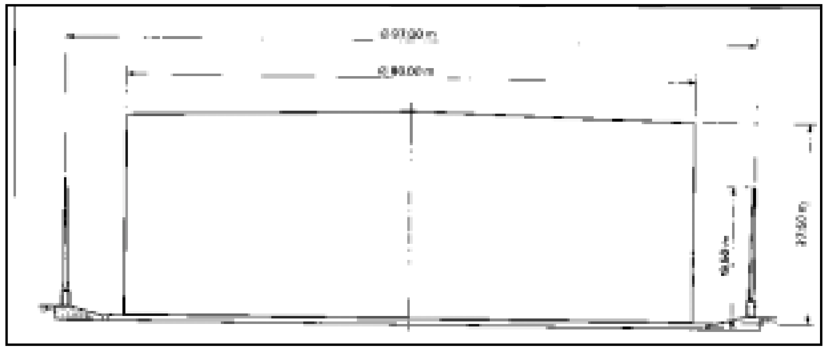


Figure 105: Section through tank and safety wall

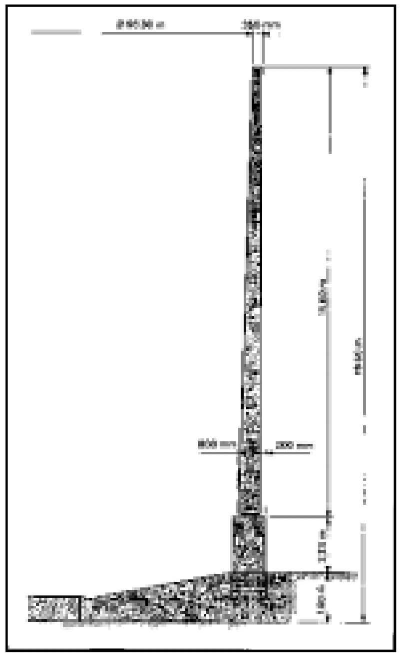


Figure 106: Section through safety wall

The wall was constructed by the slipforming method. The empty ducts were placed during construction. A construction time of only 13 weeks was available.

Post-tensioning

The post-tensioning of the foundation ring consists of VSL cables 5-12 with 4 Z-anchorages at the periphery. Four Z-anchorages per cable were chosen on account of the great length of the tendons.

The maximum cable force is 1412 kN. The crosssectional area of the strands is 100 mm2 and the steel quality is St 1570/1770.

The wall contains 45 cables 5-12 with four Z-anchorages at the periphery and also, at the extreme top, three cables 5-6, also with four Z-anchorages each. In the lowest part of the wall the cables are situated near to both the outer and the inner faces and the block-outs are accordingly arranged both internally and externally. All other block-outs are in the outer face (Figures 107 and 108).

Stressing was always carried out simultaneously at two mutually opposite Z-anchorages. For a total cable length of 303.00 m, the total elongation was 1822 mm.

Figure 107: Z-anchorages in block-out

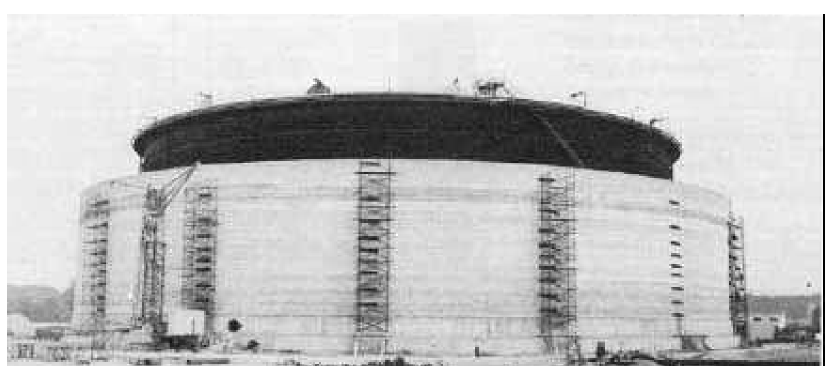


Figure 108: The wall during post-tensioning operation

2.6. VSL fuel oil tank

Introduction

In 1975 VSL INTERNATIONAL LTD. prepared a design for a 20 000 m^3 capacity fuel oil tank, consisting of an outer tank in post-tensioned concrete and a doublelayer, plasticized PVC inner tank. The concrete tank is designed to fulfil two functions: firstly to serve as a support for the PVC tank and secondly as a collecting basin for any leakages which might occur in the inner tank.

Details of the structure

The tank has an internal diameter of 36.00 m, a wall height of 20.00 m and wall thickness of 250 mm. It has a bottom slab at least 150 mm thick with an edge beam at least 400 mm thick. The roof consists of a reinforced concrete dome with post-tensioned ring beam. The minimum concrete thickness of the roof is 60 mm (Fig. 109). There are sliding bearings between the ring beam and the tank wall. As a transition between the bottom slab and the wall, a sliding bearing with an internal seal or a continuous neoprene bearing is installed. To improve the tightness of this joint, a proportion of the vertical tendons of the wall are continued through the joint and anchored in the base slab (Fig. 110). This transition between base slab and wall would today be constructed monolithically (Fig. 111).

Construction procedure

The bottom slab is concreted in one pour. To prevent shrinkage cracks, a proportion of the post-tensioning is applied after one to three days and the remainder after about two weeks.

The wall is built by the slipforming method, to give a monolithic structure without construction joints.

The roof dome can be constructed of T section precast components or of cast-inplace concrete. At the centre of the roof an opening of 2 to 4 m diameter is required for removing scaffolding; this is later closed with a prefabricated concrete element.

Post-tensioning

The post-tensioning of the base slab consists of VSL monostrands Ø 15 mm (0.6") of 146 mm^2 cross-sectional area.

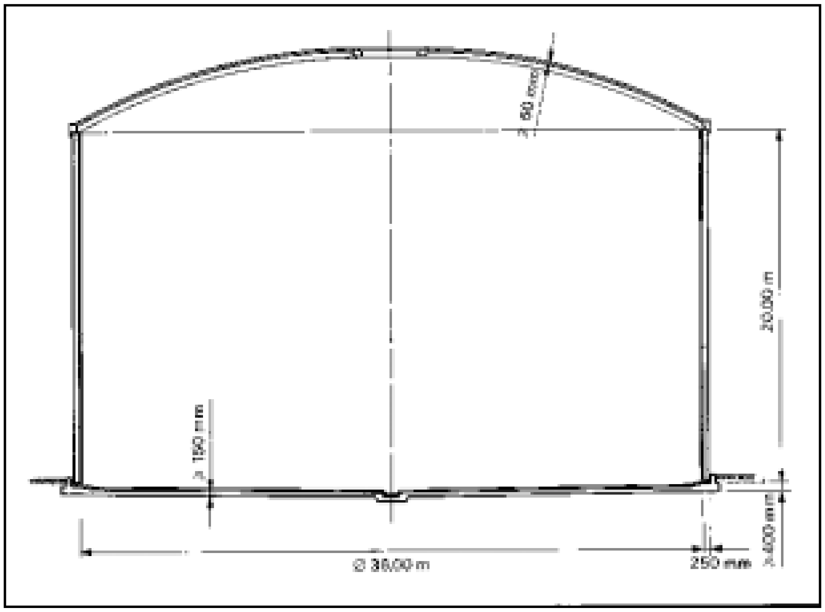


Figure 109: Section through the VSLfuel oil tank

The tendon layout is orthogonal. In each direction there are 48 monostrands, each having one dead-end anchorage and one stressing anchorage. The wall is horizontally and vertically post-tensioned. It comprises three buttresses. The vertical post-tensioning consists of 26 VSL cables EP 6-3 and 52 VSL cables EU 6-6. The strands used were again monostrands, as for the base slab. The horizontal post-tensioning is composed of 18 cables EE 6-7 and 33 cables EE 6-12, each 95.50 m in length. Alternatively, it could consist, for example, of cables ZU 6-4 and 6-6, in which case the buttresses could be omitted. In the tension ring of the roof there are three cables type ZU 6-4.

Safety considerations

In connection with this project, which at that time was not constructed in practice on account of the fall in steel prices, the safety of the post-tensioned concrete tank was investigated for normal and catastrophic loading and compared with that of a steel tank.

Normal loading was assumed to include self-weight, filling with fuel oil and test filling with water, prestress, creep and shrinkage, snow loading, possible above-atmospheric or sub-atmospheric pressure, wind loading and temperature. For these loading conditions the post-tensioned concrete tank exhibited a safety factor at least equivalent to that of the steel tank.

For the catastrophic loading, a fire inside and a fire outside a tank were considered. For a total fire lasting 90 minutes the structure remains completely intact in spite of cracked outer zones and the stored liquid does not escape.

In addition, the effects of weapons and sabotage were investigated. In the comparison with a steel tank, the post-tensioned concrete tank comes out rather better.

Concluding comment

Since the preparation of the project design, new knowledge has become available in regard to lining. Today a lining would be chosen which would enable the post-tensioned concrete tank to be used for storing other liquids also, or the lining would be designed for the particular liquid to be stored. With this modification, the project can still be regarded as up-to-date.

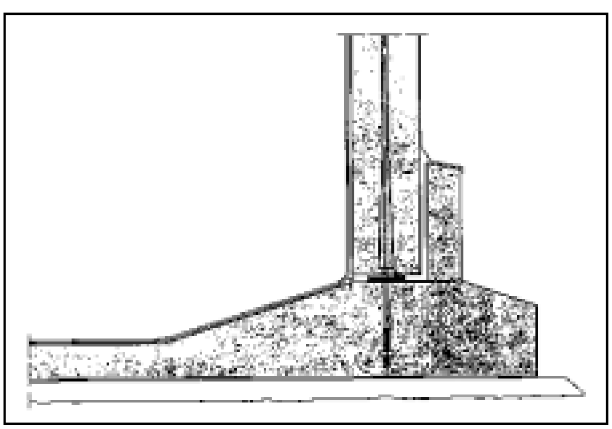


Figure 110: Transition between base slab and wall with joint

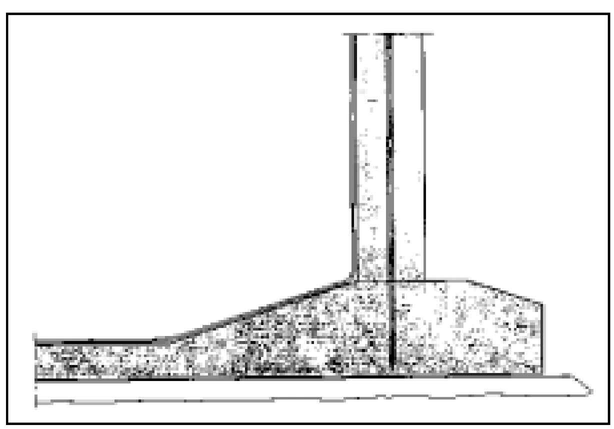


Figure 111: Monolithic transition between base slab and wall

3. Tanks for the storage of solids (silos)

3.1. Cement and clinker silos

3.1.1. Introduction

Silos for the storage of cement and clinker as a rule are of cylindrical form, since this is the most suitable for the frequently changing loads. Beneath the actual storage space, the silos normally have a trough for discharging the contents and an access for loading transporting equipment, as the silos are filled from the top but emptied from the bottom.

Silos are usually comparatively large structures, particularly in the vertical direction. Their walls are therefore normally constructed with slipforming and post-tensioned.

3.1.2. Clinker silos, Pedro Leopoldo, Brazil

Owner CIMINAS (Cimento Nacional de Minas S.A.), Sao Paulo
Engineer H. Trachsel & H. J. Schibli AG, Olten, Switzerland
Contractor Joint venture M. Roscoe/ Moura, Schwark Ltda., Belo Horizonte
Post-tensioning Sistemas VSL Engenharia S.A., Rio de Janeiro
Years of construction 1973-1974

Introduction

Each of the two clinker silos has an internal diameter of 26.00 m and a wall height of 42.00 m. The wall thickness is 320 mm. The base slabs, which each rest on 232 piles, are 1.70 m thick (Fig. 112). The distance between the centres of the silos is 32.00 m.

Construction procedure

The silo walls were constructed by slipforming. During slipforming only timber.

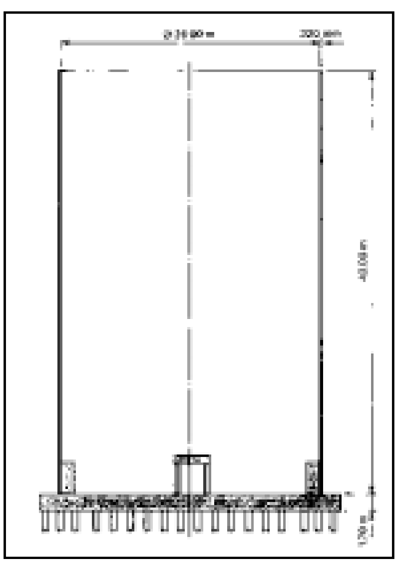


Figure 112: Cross-section through a silo

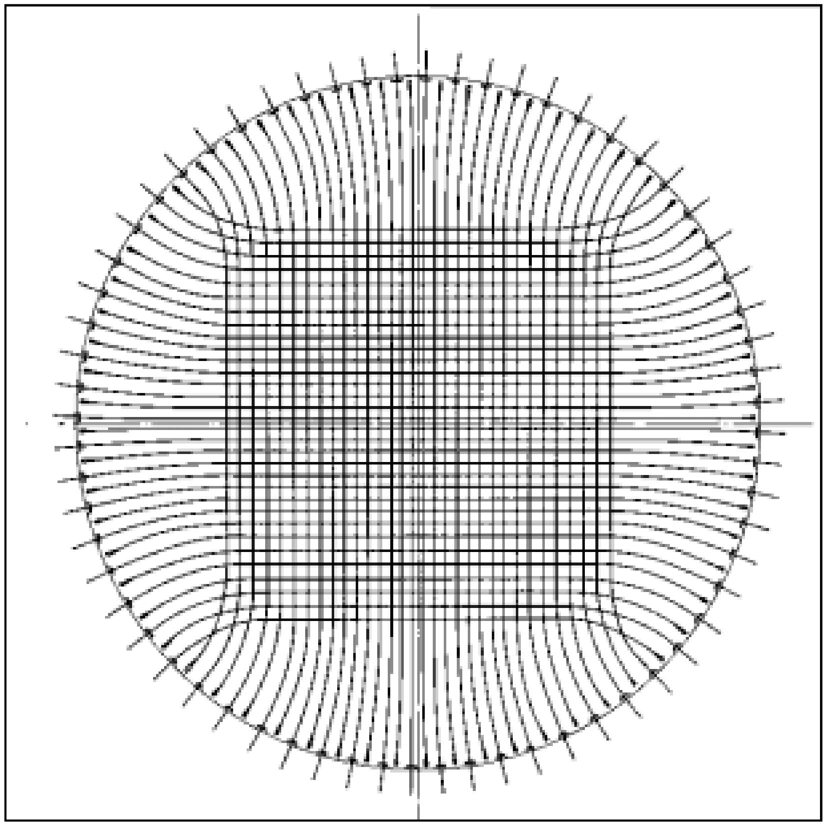


Figure 113: Cable layout in the base slab

formwork strips with the anchorages fixed to them and the empty ducts were placed. Construction of the first wall lasted 9 days and that of the second 7 days.

Post-tensioning

Each base slab was post-tensioned with 144 VSL cables EU 5-12 in 2 layers. The first layer is located 400 mm above the lower face of the foundation slab and the second 400 mm below the upper face. The cables are curved at their ends, in order to lead the cables axes radially from the edge of the slab. In the central region of the slab the cables cross one another. Cable lengths vary from 25.50 to 31.50 m (Fig. 113).

The silo wall is horizontally post-tensioned with 104 VSL cables EE 5-12 and 55 cables EE 5-7.

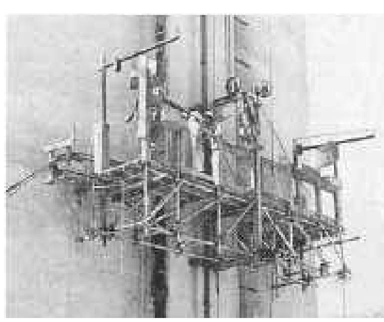


Figure 114: Susperidea scaffold for post-tensioning operations

The cables each extend around one-half of the circumference. They are anchored alternately at the four buttresses. The cables were pulled into the empty ducts by working from a suspended scaffold (Fig. 114). The cable axis is 100 mm from the outer face of the wall. The cable spacing is 220 mm minimum and 810 mm maximum.

3.1.3. Cement silos, Chekka, Lebanon

Owner Societe des Ciments Libanais, Chekka
Engineer H. Trachsel & H. J. Schibli AG, Olten, Switzerland
Heinzelmann & Co. AG, Brugg, Switzerland
Contractor R. Fakhry, Beirut
Slipforming and Post-tensioning VSL INTERNATIONAL LTD., Berne, Switzerland
Years of construction 1974-1975, 1977-1978,1981

Introduction

The cement factory of Chekka is approximately 60 km to the north of the Lebanese capital of Beirut close to the shore of the Mediterranean. From 1974 to 1978 the plant was extended and five new cement silos were built (Fig. 115). The construction time for the extension was originally

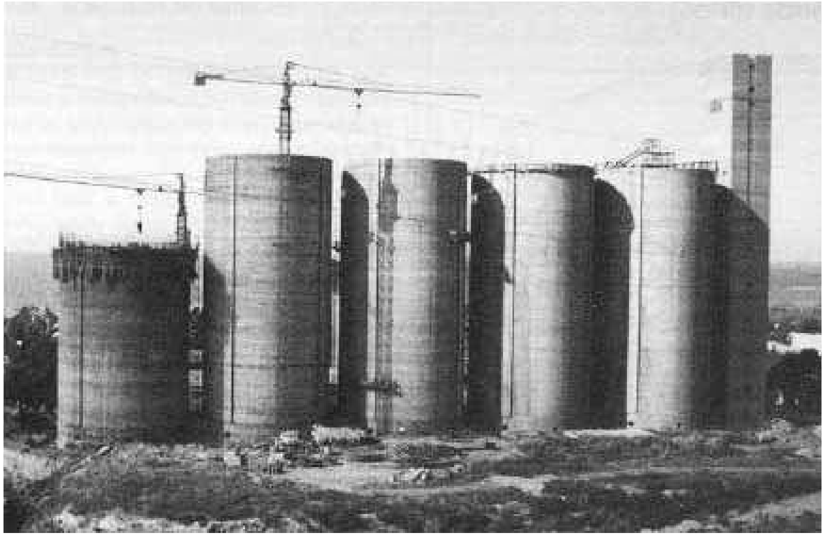


Figure 115: View of the five silos and the feed tower during construction

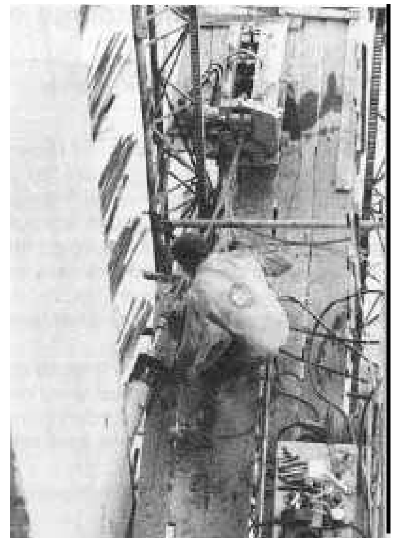


Figure 118: Pushing-through of strands

mated at two years, but as a consequence of the internal disturbances in the country the work had to be suspended for two years, from summer 1975 to summer 1977. In 1981 two further silos and a tower were added.

Details of the structures

All five silos of the first extension stage are identical in form and dimensions. Their overall heights are 63.00 m and the internal diameters 25.00 m. Each silo has a working capacity of 25 000 tonnes of cement, with a density of 1.2 to 1.4 t/m3. Conveyor belts, which are enclosed in a 7 m high steel construction, lead from a feed tower over all five silos. The charging equipment is situated in the uppermost 8 m of the concrete structure. Each silo is equipped with two discharge hoppers, from which the cement is discharged again onto conveyor belts, which feed it to the loading plant. The actual silo storage space commences 7 m above the foundation slab. From here upwards the silo wall is 340 mm thick. The silos are circumferentially post-tensioned and therefore have four vertical buttresses each, in which the tendons are anchored. The silos are arranged in a straight line, the distance between their centres being 30.00 m (Fig. 116).

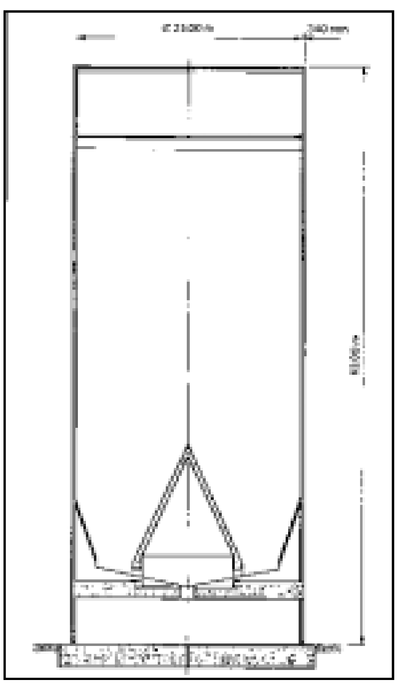


Figure 116: Section through a silo

Construction procedure

The silo walls and also the feed tower were constructed by means of VSL Slipforming (Fig. 117). During slipforming, the bearing plates, sleeves and spiral reinforcement of the cable anchorages and also the empty ducts and the ordinary reinforcement were placed. The cables themselves were not installed until at least two silos had been completed.

Slipforming on the first silo was started on 9 May 1975, after the corresponding foundations and lower structures had been completed. The daily rate of progress was 3.60 to 5.00 m (per 24 hours).

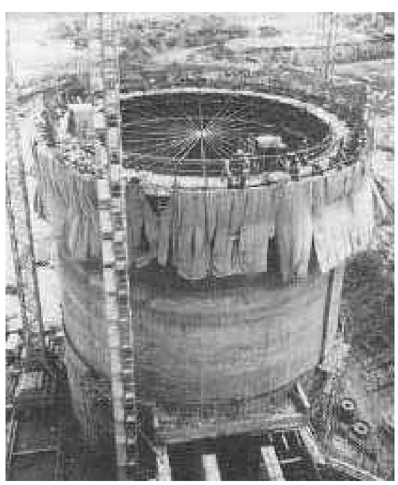


Figure 117: Construction of a silo with VSL Slipforming

Slipforming of the second silo could then be commenced as early as 23 June 1975. After this had been completed construction work had to be suspended, as already mentioned, on account of the civil war. Silo No. 3 could therefore not be started until two years later, on 15 August 1977. The remaining two silos followed at intervals of approximately five weeks each. The total area constructed by slipforming was 52 600 m^2.

In May 1977 installation of the VSL cables on the first two silos could be commenced. The push-through method was used (Fig. 118), which is especially well adapted to this type of structure. The strands are simply pulled from the reels on the ground and pushed into the empty ducts by the pushthrough machine. In this way transporting and tedious pulling through of tendons are avoided. Only a relatively light working platform is required, on which the pushthrough machine is placed. The platform is subsequently used also for stressing and grouting the cables.

The silos built in 1981 have internal diameters of 16.00 m and heights of 38.00 m. The tower measures 8.50 x 9.60 m in plan and is 43.00 m high. All three structures were constructed with VSL Slipforming. The slipformed area was 10 500 m^2.

Post-tensioning

Each silo of the first extension phase is horizontally post-tensioned with 186 VSL cables

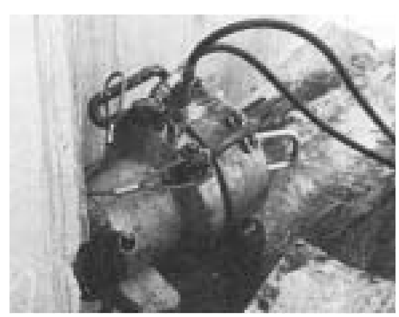


Figure 119: Stressing of a tendon

bles type EC/EC 5-12 (ultimate strength each 1970 kN). Each tendon extends around one-half of the circumference, so that their individual lengths are 42.10 m. The anchorages are so arranged that each second pair of cables is anchored in the same buttress. The axes of the tendons are 100 mm from the outer wall face of the silo. The mean distance between tendons increases from 400 mm at the bottom to 580 mm at the top. The wall post-tensioning commences at level 22.76 m and extends to level 64.41 m (Fig. 119).

3.1.4. Clinker silos, Wetzlar, FR Germany

Owner Buderus Ironworks, Wetzlar
Engineer Wayss & Freytag AG, Frankfurt
Contractor Wayss & Freytag AG, Frankfurt
Post-tensioning VSL GmbH, Langenfeld
Year of construction 1975

Introduction

Each of the two silos has an internal diameter of 34.00 m and a wall thickness of 300 mm. The wall height is 43.00 m. The distance between centres of the structures is 55.00 m. Each silo has a capacity of 50 000 tonnes (Fig. 120).

Post-tensioning

The silos were post-tensioned with VSL tendons EE 5-12. These are anchored alternately in two opposite buttresses, i.e. each cable extends around the entire circumference. The width of the buttresses at the extreme bottom (the first 4.10 and 4.40 m respectively) is 7.50 m, and above this 2.30 m. The tendon spacing increases from 485 mm at the bottom to 1000 mm at the top. The distance from the outer face to the

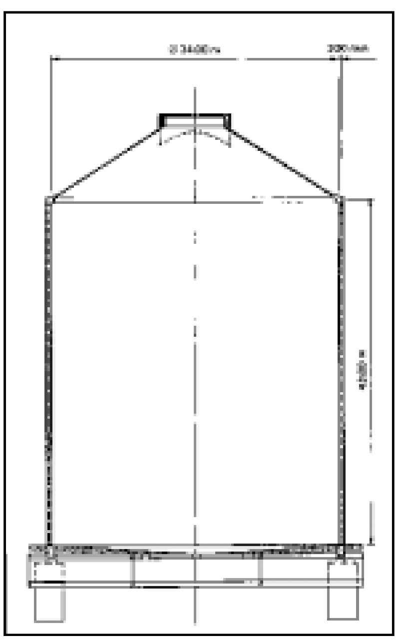


Figure 120: Cross-section

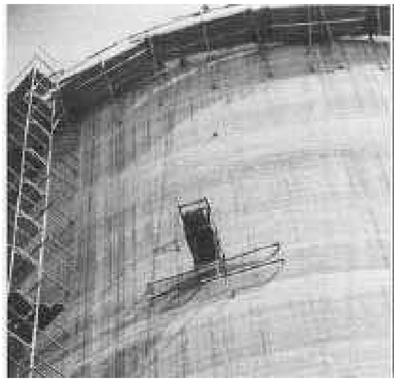


Figure 121: Dispenser on the wall

cable axis is 100 mm. The anchorages were installed in the buttresses in blockouts which were formed by timber inserts during slipforming.
The cables were installed in the empty ducts by pushing through the strands. For this purpose the dispenser (Fig. 121) was fixed to a frame, which rested with rollers against the tank wall and was also suspended, so that it could easily be moved along.

3.1.5. Clinker silos, Rombas, France

Owner Societe des Ciments Francais, Paris
Engineer Europe-Etudes, Clichy
Contractor Muller Freres, Boulay Moselle
Slipforming VSL INTERNATIONAL LTD., Berne, Switzerland
Post-tensioning VSL France s.a r.l., Boulogne-Billancourt
Years of construction 1977-1978

Introduction

Between autumn 1977 and spring 1978 the cement factory of Rombas was extended by a raw meal silo and a clinker silo.
Both the silos have the same dimensions, external diameter 15.60 m, wall height 34.50 m, wall thickness 300 mm. Each silo has four buttresses, 1.30 m wide.
The silos are founded on shaft foundations 1.30 and 1.50 m in diameter. These are fixed into a 2.00 m thick base slab, on which the 16.00 m high, square discharge and loading equipment stands. Above this is the silo itself. It is covered by a ribbed slab roof (Fig. 122).
The raw meal has a density of 1.3 t/m^3, an internal angle of friction φ = 30° and a maximum temperature of 100 °C.
The walls of the silos were constructed by VSL Slipforming one after the other in November and December 1977 in 9 and 8days respectively (Fig. 123).

Post-tensioning

The silos are horizontally aryl vertically post-tensioned with VSL cables EC/EC 5-6. The raw meal silo contains 140 horizontal and 28 vertical cables, and the clinker silo 154 and 26 respectively. The tendons were installed by pushing through.

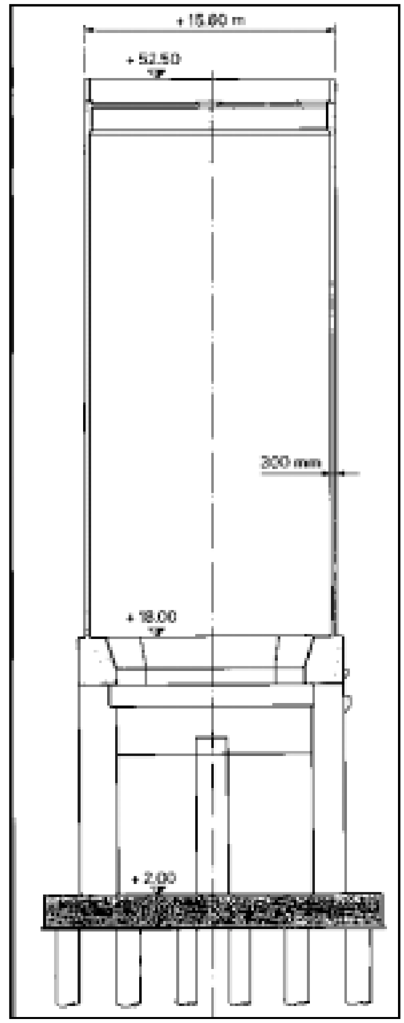


Figure 122: Cross-section through the raw meal silo

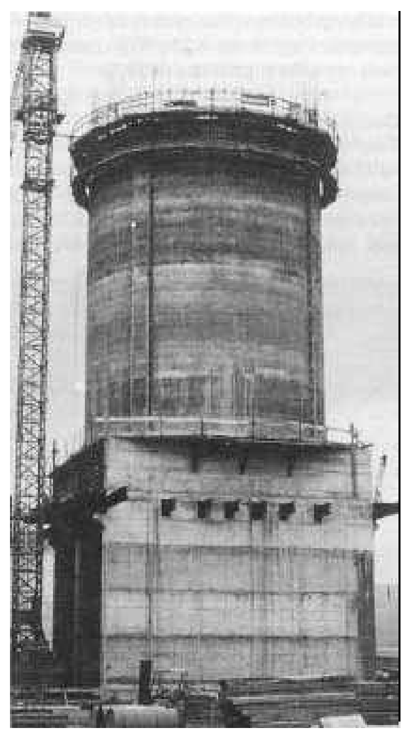


Figure 123: Slipforming of one silo

The minimum spacing of the horizontal tendons is 320 mm and the maximum spacing 1104 mm. The horizontal cables are 100 mm from the external surface, while the vertical cables are located in the centre of the wall. The horizontal cables extend around one-half of the circumference. Block-outs were formed for their anchorages in the buttresses and were concreted in after grouting.

The cables could be stressed when a concrete strength of 32 N/mm^2 was reached. All the vertical cables were stressed first, at the upper anchorage, followed by the horizontal cables which were stressed at both anchorages.

3.1.6. Cement silos, Slite, Sweden

Owner Cementa AB, Danderyd
Engineer Skanska AB, Malmo
Contractor Joint venture Slitebygget (Skanska /Armerad Betong Vagforbattringar / Byggproduktion AB)
Post-tensioning Internordisk Spannarmering AB, Danderyd
Years of construction 1977-1979

Introduction

At Slite on the island of Gotland Cementa operates a cement factory with a production of 2.1 million tonnes per year. In recent years approximately 150 million US dollars have been invested in the factory, to expand production capacity for export and for modernization. It is now one of the most modern factories in the world and the most modern in Europe.

The extension commenced in 1976. A complete new plant was built alongside the old one. Production in the new plant is by the dry process, which reduces energy consumption by about 40%. The new plant was ready for production in 1979.

Details of the structures

Two identical clinker silos were built in 1977 to 1978 and two identical raw meal silos in 1978 to 1979. The clinker silos have an internal diameter of 33.00 m, a wall height of 36.30 m and a wall thickness of 340 mm. The corresponding dimensions for the raw meal silos are 20.00 m, 48.75 m and 300 mm (Fig. 124). The capacity of each clinker silo is 45 000 tonnes and that of each raw meal silo 15 000 tonnes (Fig. 125).

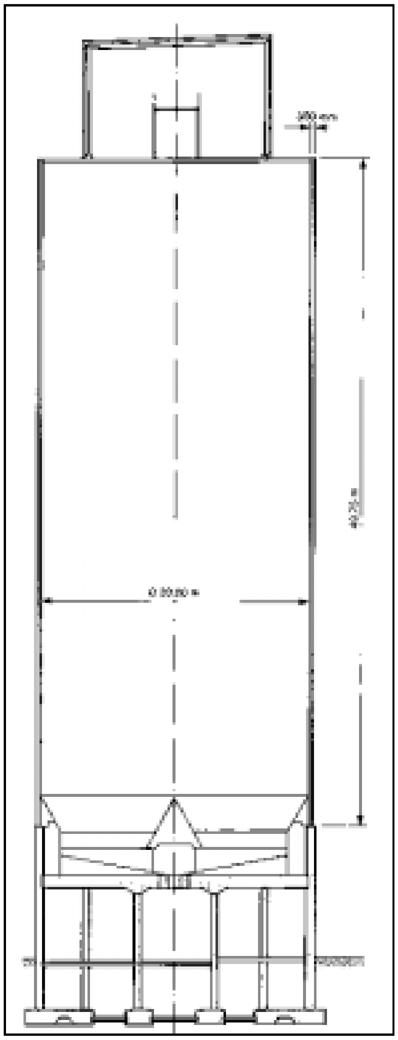


Figure 124: Section through a raw meal silo

Post-tensioning

During construction of the silo walls by the slipforming method the empty ducts were placed in the wall. Platforms were then erected at the buttresses. The pushthrough machines were suspended from electric hoists to facilitate handling of them. The strands were pulled from the dispenser standing on the ground and were pushed into the duct. An automatic stop device stopped them when the final position was reached (Fig. 126).

The clinker silos each contain 20 cables VSL EE 5-5, 5-7, 5-10, 5-11 and 5-12. Each cable is 54.50 m long, i.e. it extends around one-half the circumference. The strands have an ultimate strength of 184.6 kN.

For each of the raw meal silos 252 cables VSL EE 5-5, 5-6 and 5-7 were used. These cables again lead through 180° and are each 34.00 m long. The strand quality is the same as described above.

For stressing, four automatic 200 tonne jacks were used. The cables were then grouted, finally the ends of the buttresses were reinforced and the sides fitted with formwork and the anchor heads were covered with two layers of gunned concrete. This method is more rapid and cheaper than the traditional concreting method.

In the clinker silos the duct axes are 150 mm from the outer face of the wall and in the raw meal silos 120 mm from this face. The cable spacing is 300 mm minimum and 350 mm maximum for the clinker silos and varies from 300 to 500 mm for the raw meal silos.

3.1.7. Cement and clinker silos at Cibinong, Indonesia

Owner PT Perkasa Indonesia Cement Enterprise, Jakarta
Engineer Peter T K. Loh, Kuala Lumpur, Malaysia
Schalcher & Partner, Zurich, Switzerland
Contractor PT John Holland Construction Indonesia
Ting Tai Construction, Taiwan
Post-tensioning PT VSL Indonesia, Jakarta
Years of construction 1979-1980, 1982-1983

Figure 125: View of the finished silos

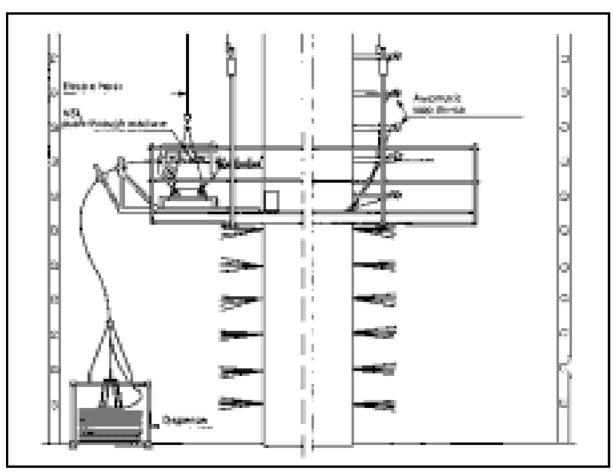


Figure 126: Push-through equipment with automatic stopper

Introduction

The cement factory of Indocement is situated at Cibinong, 30 km to the south of Jakarta. Since 1975 extensions have been carried out in a nine-stage programme with the objective of raising production from 500 000 to 6 500 000 tonnes per year.

Certain phases of this extension include the building of silos: in phase IV two cement silos, two homogenization silos and four clinker silos were built (Fig. 127). Phase VI comprised two cement silos, two raw meal silos, two clinker silos and one silo each for clinker from the underburner-type kiln and for clinker dust (Fig. 128).

Details of the structures

Phase IV.- the four clinker silos are of interest here, since they were post-tensioned. Each silo has an internal diameter of 27.00 m and a wall height of 46.50 m. The wall thickness is 400 mm. There are four buttresses in each silo. The capacity of each silo is 25 000 tonnes (Fig. 129).

Phase VI.- the cement silos are 53.00 m high with an internal diameter of 22.00 m. The wall thickness is 400 mm. Each silo has three buttresses. The capacity per silo is 25 000 tonnes (Fig. 130). The height of the raw meal silos is 58.75 m, the internal diameter 18.00 m and the wall thickness again is 400 mm. These silos have only 2 buttresses and their capacity is

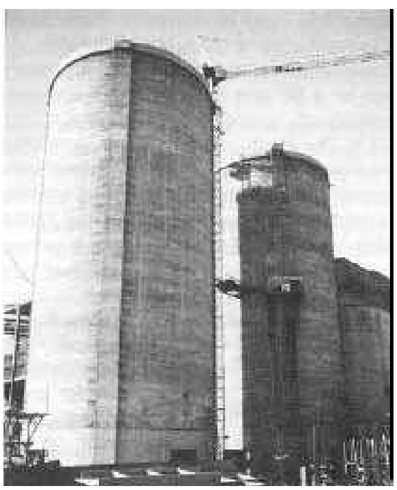


Figure 127: Clinker silos of phase IV

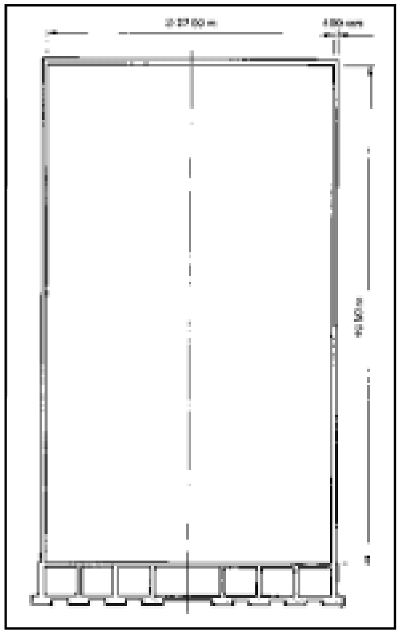


Figure 129: Cross-section through a clinker silo of phase IV

20 000 tonnes of raw meal each. The clinker silos have a height of 47.00 m, internal diameter 30.00 m and wall thickness 400 mm. There are 4 buttresses per silo. The capacity of each silo is 45 000 tonnes. The silo for clinker from the underburner-type kiln has the following dimensions: diameter 12.00 m, height 12.00 m, wall thickness 250 mm. There are 2 buttresses. The silo for clinker dust is 19.00 m high and 12.00 m in diameter. Its wall thickness is 250 mm and it has two buttresses.

Construction procedure

All the silos were built by the slipforming method (Fig. 131). Those of phase IV were built from November 1979 to August 1980 and those of phase VI from October 1982 to January 1983.

Post-tensioning

Phase IV- for the clinker silos which were built in phase IV, VSL cables EE 5-12 were used. Each silo contains 151 of these cables in the wall and two in the upper ring beam. The ultimate strength of each cable is 2200 kN.

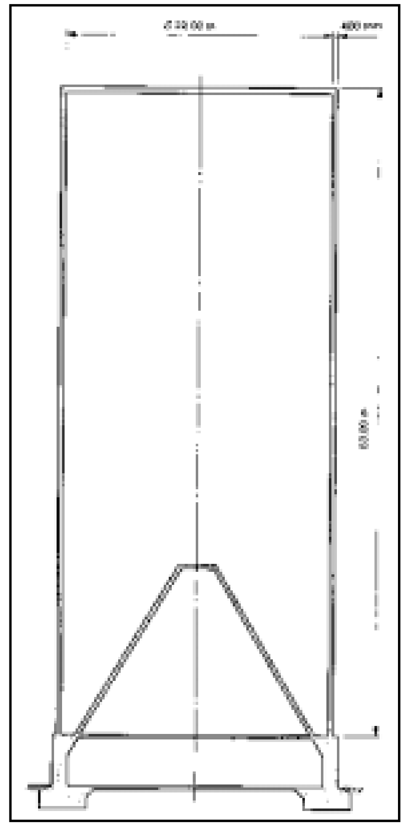


Figure 130: Cross-section through a cement silo of phase VI

The cables extend around onehalf the circumference and are 120 mm from the outer face of the wall. The distance between tendons varies from 560 to 1350 mm.

Phase Vl: the walls of the cement silos contain 159 cables EE 5-7, with an ultimate strength each of 1288 kN, and 8 cables EE 5-19 in the upper zone of the substructure. All the cables extend through 270'. Their distance from the outer wall face again is 120 mm and their spacing varies from 225 to 500 mm.

Each raw meal silo comprises 74 cables EE 5-7 in the wall and 8 cables EE 5-19 (ultimate strength 3496 kN each) in the upper part of the foundation. The latter cables extend round one-half the

Figure 128: Various silos of phase VI (from left: cement, clinker, raw meal silos)

Figure 131: The two cement silos of phase VI during construction; in the foreground, prefabricated VSL tendons

circumference and the wall cables around the entire circumference. The tendons are located at 140 mm from the outer face of the wall and the spacing between cables varies from 300 to 1100 mm.

All the cables of the clinker silos are of VSL type EE 5-7. For the one silo the total number is 220 and for the other 230. The cables extend around one-half of the circumference, the distance from the outer wall face is 140 mm and the cable spacing varies from 250 to 700 mm.

The silo for clinker from the underburnertype kiln is post-tensioned with VSL tendons EE 5-3. Each of the 41 tendons has an ultimate strength of 552 kN and extends around the entire circumference. The cable spacing is constant at 400 mm and the distance from the outer face of the wall is 90 mm.

The data for the silo for clinker dust are the same, except for the number of cables. Here there are 23 cables, since only the upper part of the silo is post-tensioned.

The cables were assembled on the ground, raised by a winch onto the slipforming platform and placed from there. The cables were stressed from a suspended platform or from of a scaffold, in some cases by steps.

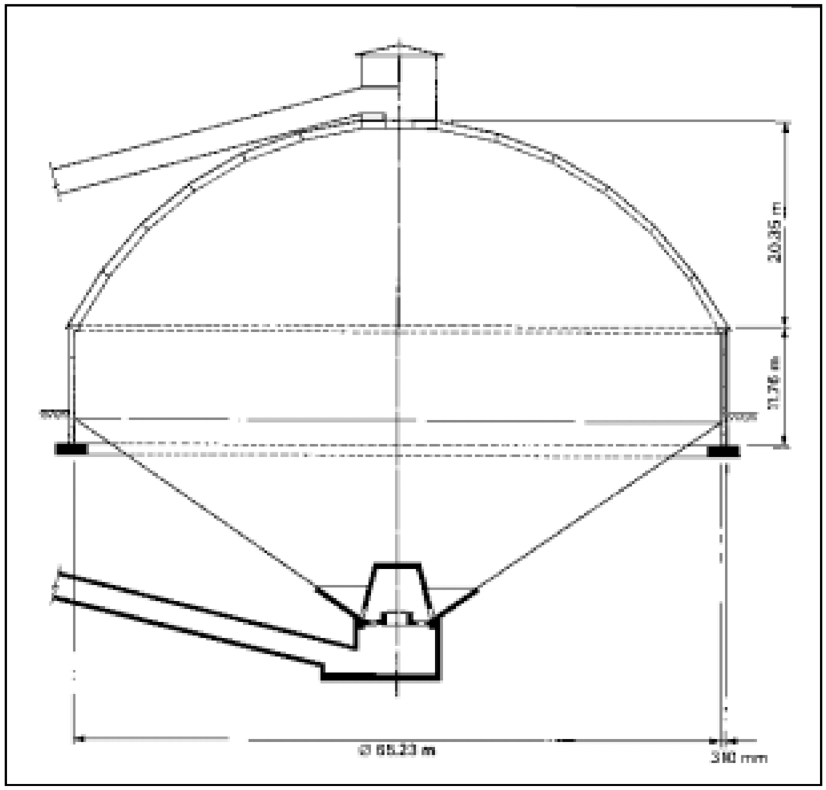


Figure 132: Section through the silo

3.1.8. Clinker silo, Exshaw, Canada

Owner Canada Cement Lafarge Ltd., Calgary

Engineer Lafarge Consultants Ltd., Montreal

Contractor Supercrete Inc., Edmonton

Post-tensioning VSL Corporation, Los Gatos, USA

Year of construction 1981

Introduction

With the objective of making the storage of clinker more efficient, the engineers of La-farge Consultants Ltd., Montreal, have developed a new type of silo consisting of a cone at the base, a cylindrical wall and a domed roof. A silo of this type with a capa-city of 115 000 tonnes was built in 1981 at the cement factory of Exshaw, Alberta.

Details of the structure

The silo has an internal diameter of 65.23 m. The wall, 11.76 m high and 310 mm thick, carries a steel dome 20.35 m in height. The wall stands on a flat foundation and has 6 buttresses each 426 mm thick (Fig. 132).

Construction procedure

The silo wall was constructed from precast com-ponents, which were connected together by cast-in-place concrete. The insitu concrete joints were formed to-resemble columns for architectural rea-sons. Of the sixty-six precast elements, sixty were 2.80 m wide and 310 mm thick and the remaining six were 2.60 m wide and 426 mm thick...

These latter elements contained the block-outs for the cable anchorages,

The prefabricated components were erected on a 50 mm thick neoprene strip and temporarily supported on the inside (Fig. 133). The in-situ concrete piers were then concreted. The upper edge of the wall was monolithically connected with a post-tensioned ring which carries the steel dome (Fig. 134).

Post-tensioning

The wall was post-tensioned with 29 VSL tendons Z 6-8 (ultimate strength each 2116 kN). The Z-anchorages were distributed over the 6 buttresses in order to achieve the most uniform force distribution possible. A concrete strength of 35 N/mm^2 had to be reached before stressing was carried out.

Figure 133: Positioning of a precast element 40

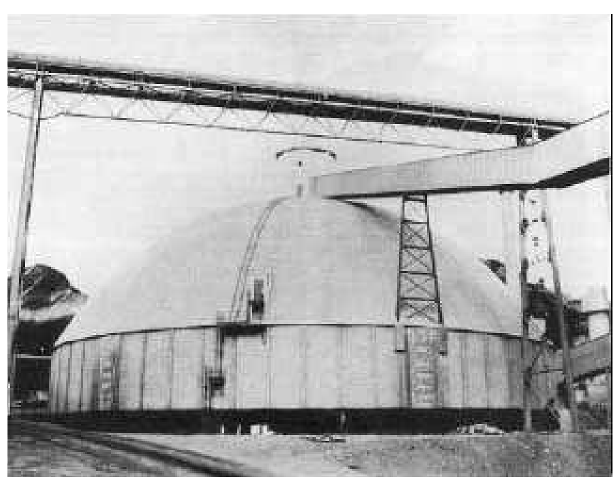


Figure 134: The finished silo (photos: PCI Journal)

3.2. Tanks for other solid materials

3.2.1. Alumina silos, Portoscuso, Italy

Owner Eurallumina S.p.A., Rome

Engineer Dr. Gian Carlo Giuliani, Milan

Contractor Tecnosystem Costruzioni S.p.A., Milan

Post-tensioning and Heavy Rigging VSL Italia S.p.A., Milan

Years of construction 1971-1972

Introduction

At the bauxite processing factory of Eurallumina, at Portoscuso on the island of Sardinia, three alumina silos have been built (Fig. 135). Shortly after the alumina has been processed, it is fed by conveyor belts into the silos, where its temperature can be up to 100°C.

Details of the structure

All three silos have the same dimensions (Fig. 136). Each is cylindrical and is covered by a domed roof. The external diameter of the walls is 42.50 m and the thickness 250 mm. The height of the wall from the foundation slab is 35.95 m. The dome rises 6.05 m above this and is 60 to 120 mm thick. The silo base is approximately 5 m above the foundation slab and the space below contains machinery and equipment for discharging the alumina from the tanks. Compressed air is used for «liquefying» the settled material.

The walls of the silos are arranged so that they can slide on the foundation slabs. At their upper end they are reinforced by torsionally stiff ring beams, from which the domes are suspended, completely independent of the walls. This separation prevents the transmission of deformations and stresses due to asymmetrical wall pressure from the alumina, temperature differences and the shrinkage and creep of the concrete.

Construction procedure

The substructure of each silo was constructed by traditional methods, whereas the slipforming method was used for the wall. A special construction procedure was chosen for the domed roof. This was constructed on a form erected on the silo floor and was then post-tensioned. It was then raised approximately 0.50 m to allow the formwork to be removed and then the 490 tonnes dome was pulled up to the ring beam of the wall. The entire lifting height was 27.60 m. The dome was then suspended by 30 bars Ø 26.5 mm from the ring beam. To relieve the lifting units of load, the dome was raised a further 20 mm and then lowered onto the suspension bars. The bars were finally coated with a corrosion preventing agent and the joint between the wall and the dome was sealed.

Post-tensioning

Wall and domes are horizontally post-tensioned with VSL cables. In the walls there are tendons EE 5-3, extending each through 120°. They are anchored in a total of 6 vertical buttresses on the outer face of each silo. Each wall contains 180 cables in total. The cable spacing varies from 250 mm at the bottom to 2140 mm at the top. The distance of the cables from the outer face of the wall is 70 mm.

The post-tensioning of each of the domes consists of 18 cables, comprising 6 each of types 5-3, 6-3 and 6-7. The tendons were completely preassembled, i.e. the strands were cut to the required length, bundled and ducted. The cables were placed by hand. The length of the cables varies from 23.15 to 46.00 m.

Lifting equipment

In total 60 motive units SLU-10, each with a capacity of 104 kN, were used, uniformly distributed around the circumference of the ring beam (Figures 137 and 138). All the units were connected to a central pump and control station, from which they could be remotely controlled. A strand Ø 15 mm passed through each lifting unit

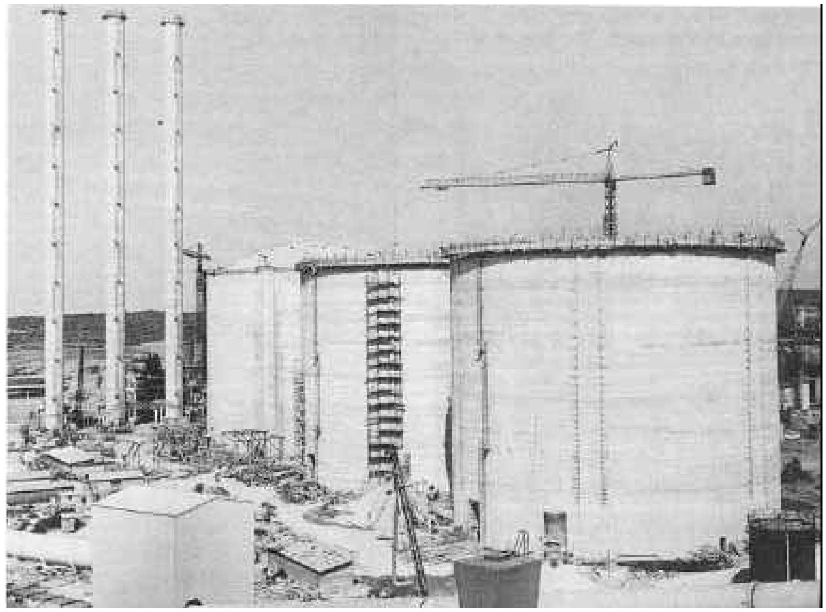


Figure 135: View of the silos during construction

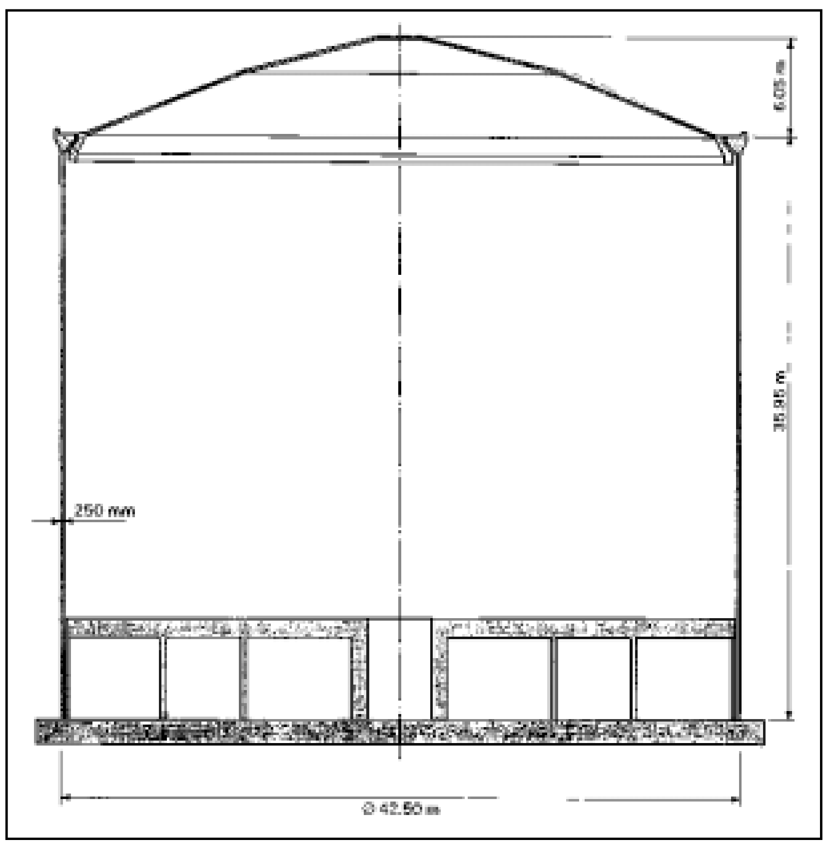


Figure 136: Cross-section through an alumina silo

and was fixed by a VSL dead-end anchorage to the lower face of the dome. The rate of lifting was 4 m/h.

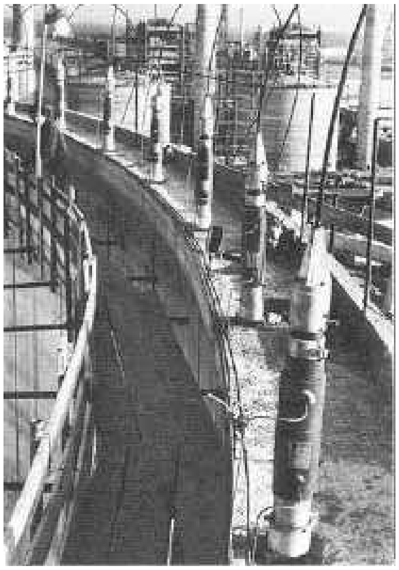


Figure 137: Motive units SLU-10 on the ring beam

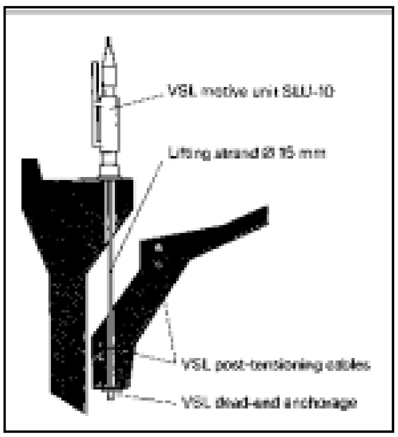


Figure 138: Lifting equipment

3.2.2. Alumina and coke silo, Richards Bay, South Africa

Owner: Alusaf (Pty) Ltd., Richards Bay
Engineer: ALESA Alusuisse Engineering Ltd., Zurich, Switzerland
Contractor: Futurus Engineering (Pty) Ltd., Johannesburg
Post-tensioning: Steeledale Systems (Pty) Ltd., Johannesburg
Year of construction: 1980

Introduction

Alusaf commissioned the construction, in the harbour area of Richards Bay, of a coke silo from February to May 1980 and an alumina silo from March to June 1980, in order to increase the storage capacity for raw materials. The new silos are filled through openings in the roof and discharged through openings in the floor into railway wagons. The walls of the silos were constructed by slipforming. The roofs were assembled on the ground and pulled up into the final position (Fig. 139).

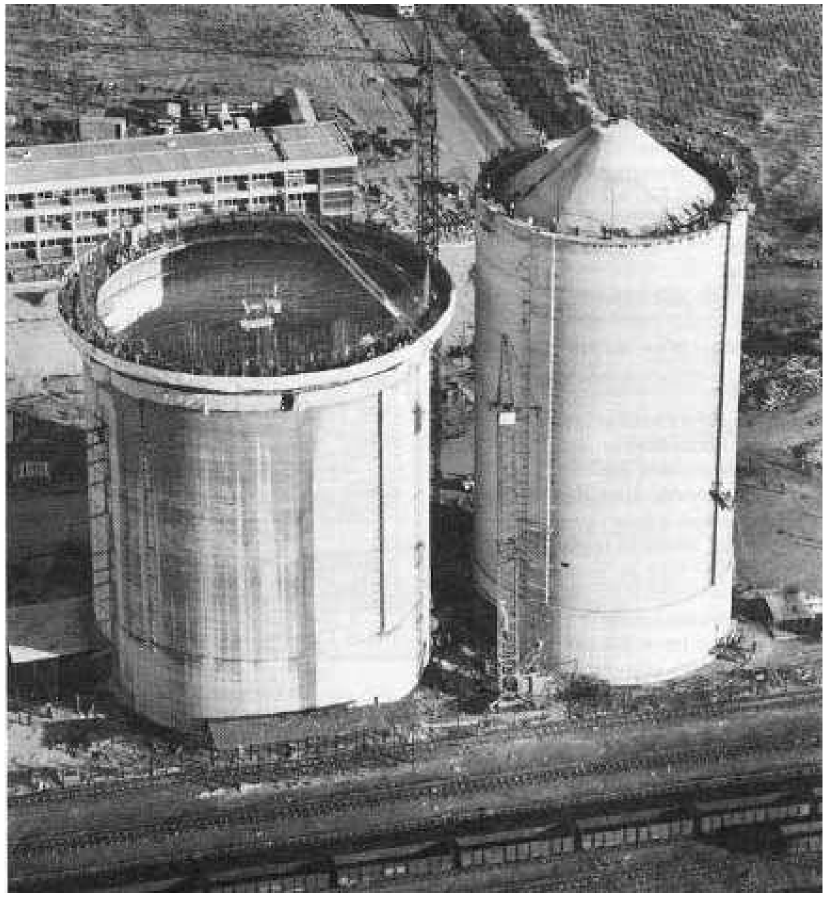


Figure 139: The two silos during construction

Details of the structures

The alumina silo has an external diameter of 35.90 m and an overall height of wall plus dome of 42.14 m. The wall is 350 mm thick. The silo can contain 35 000 tonnes of alumina (Fig. 140). The coke silo has a capacity of 18 000 tonnes. Its external diameter is 28.60 m, and its wall thickness 300 mm. The total height of wall and roof is 51.60 m.

The transition between wall and bottom slab in both silos consists of bearings, whereas the roof is suspended from the collar ring of the wall. Between the ring beam of the roof and the collar ring there are neoprene plates.

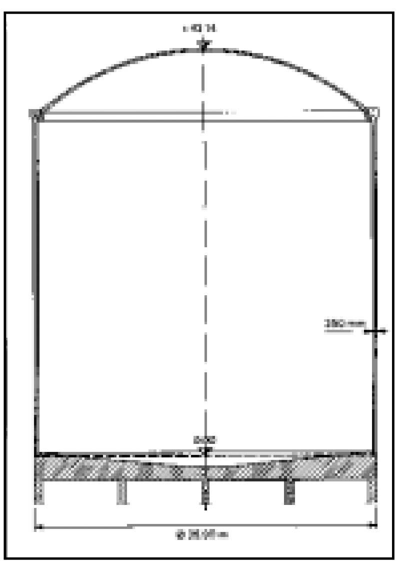


Figure 140: Section through the alumina silo

Post-tensioning

The silos are horizontally post-tensioned with VSL cables, which extend through 180°. The anchorages are situated in 4 buttresses. The alumina silo was provided with 84 cables 5-12, 40 cables 5-10 and 42 cables 5-7. The minimum cable spacing is 400 mm and the maximum 650 mm. The coke silo contains 184 cables 5-17, at spacings of 420 to 800 mm. The requirement of prestressing steel was 47 tonnes for the coke silo and 78 tonnes for the alumina silo.

The cables were assembled on a platform alongside the slipforming equipment and were pulled through during the slipforming work. This was therefore a relatively slow procedure.

For stressing the cables, scaffold towers were erected at all 4 buttresses. The stressing jacks and pumps were suspended from the top of the silo. Stressing was carried out simultaneously at 2 opposite buttresses, working from the top to the bottom. The grouting equipment was set up on the ground. The pressure was sufficient to grout the highest cables.

3.2.3. Sugar silo, Enns, Austria

Owner Ennser Zuckerfabriks-AG, Enns
Engineer Prof. Dr. H. Wycital, Vienna
Contractor Universale-Bau AG, Linz
Post-tensioning Sonderbau GesmbH, Vienna
Year of construction 1974

Introduction

Silo IV (capacity 20 000 tonnes) was built in the spring of 1974. In March the silo wall had been constructed by slipforming within one week, the preassembled tendons being installed at the same time. In May the tendons were stressed and grouted, whichagain required one week.

Details of the structure

The internal diameter is 31.60 m and the wall thickness 220 mm. The height of the wall is 33.70 m. There are four buttresses for anchoring the tendons. These are 2.50 m wide. An inner silo wall of 250 mm thickness and 14.00 m internal diameter is only ordinarily reinforced. The silo has a conical roof (Fig. 141).

Post-tensioning

The post-tensioning consists of 102 VSL tendons EE 5-6. Each tendon extends around one-half of the circumference. The cable spacing varies from 400 mm at the bottom to a maximum of 1500 mm at the top. The distance of the cables from the outer face of the wall is 60 mm. The preassembled tendons were installed with the help of conveying rollers.

3.2.4. Sugar silo, Frauenfeld, Switzerland

Owner Zuckerfabrik Frauenfeld AG, Frauenfeld
Engineer A. Keller AG, Weinfelden / J. Bierett, Frauenfeld
Contractor Joint venture Stutz AG, Hatswil / Herzog AG, Frauenfeld / Christen & Stutz AG, Frauenfeld
Slipforming and Post-tensioning VSL INTERNATIONAL LTD. (formerly Spannbeton AG, Lyssach)
Year of construction 1981

Introduction

The storage capacity of the sugar factory at Frauenfeld has been increased by a silo of 35.50 m height and 30.00 m internal diameter. The silo has a 260 mm thick wall, with external insulation 60 mm thick. The silo comprises 4 buttresses.

Construction procedure

The silo was erected between the 4 and 14 May 1981 by means of VSL Slipforming. The external insulation was brought up concurrently with the wall (Fig. 142). The slipforming equipment was also used for suspending, inside the silo, a 48 tonne steel support grid, which had to be lifted through a distance of approximately 29 m. The grid

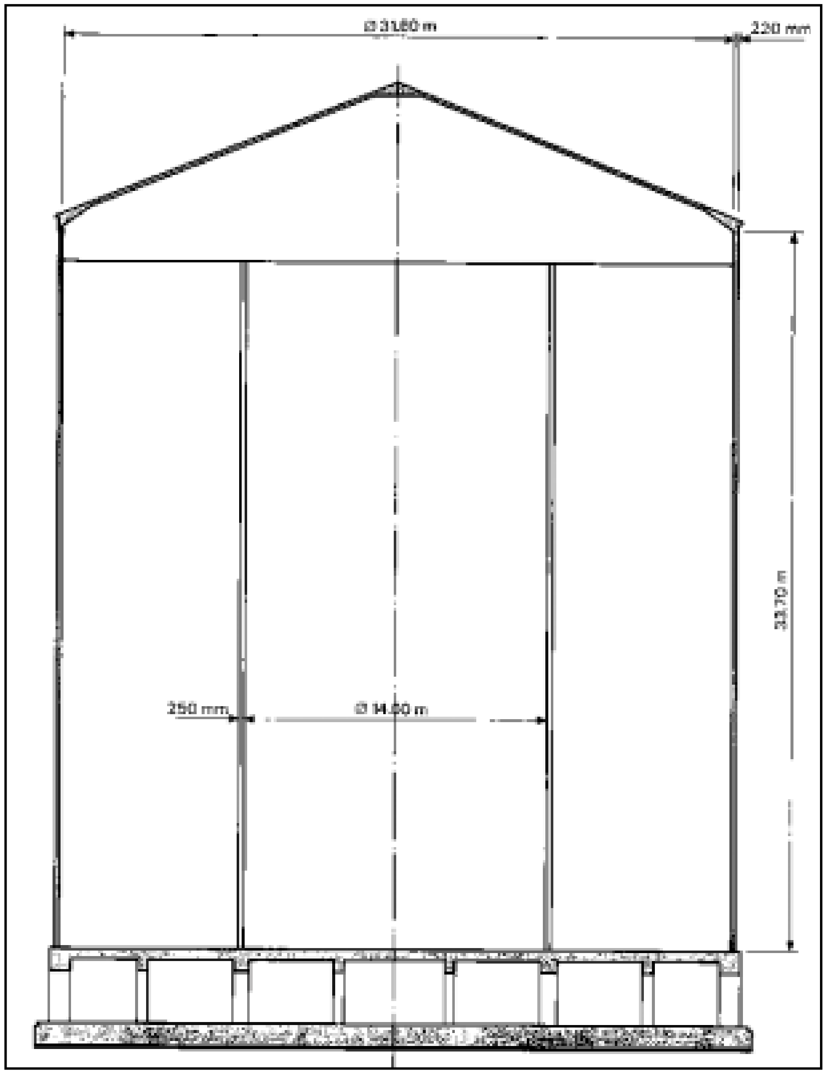


Figure 141: Cross-section through the sugar silo at Enns

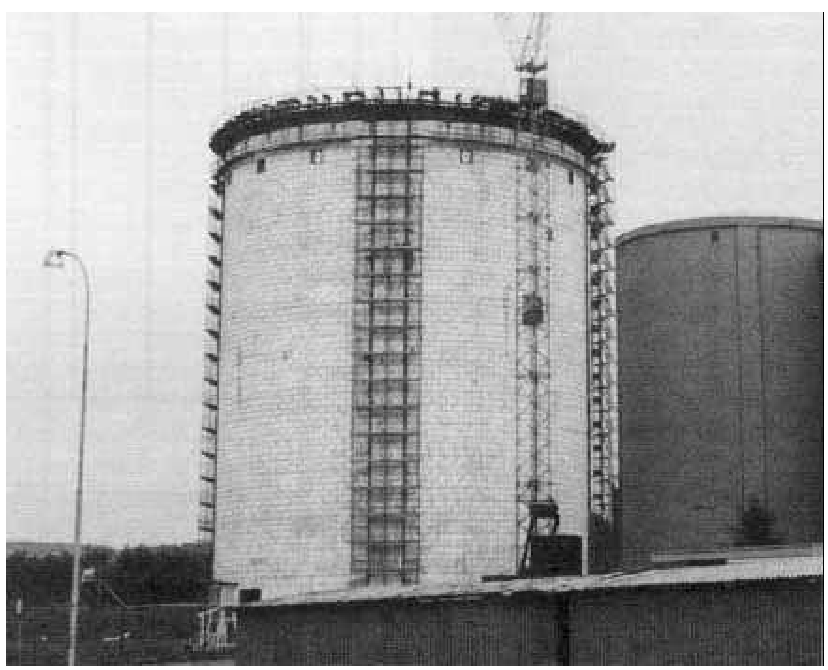


Figure 142: Silo at Frauenfeld during construction, of wall and insulation

was suspended by means of rods from transverse beams, each placed across two transverse yokes of the slipform. In total there were 16 suspension points.

Post-tensioning

The silo wall is post-tensioned with a total of 76 VSL tendons. Of these, 50 are of type EE 6-4, 8 of type EE 6-3, 4 of type EE 6-2 and 14 of type EE 6-1 (ultimate strength each 257.8 kN). Each cable extends around one-half of the circumference, resulting in a length for each cable of 50.16 m. The spacing of the cables varies from 500 to 1400 mm.

The bearing plates were fixed in advance by the main contractor to the timber formwork boards. For the ducting, special corrugated metal tubes with 0.5 mm wall thickness were used. These were delivered in lengths of 5 m and coupled together by sleeves. The ducts were placed empty. The cables were assembled by pushing through the strands immediately before the ducts were concreted in.

Four VSL push-through machines together with the associated pumps were permanently installed on the outer scaffold walkway of the slipform directly in front of the buttresses, an arrangement which greatly facilitated pushing through of the strands (Fig. 143). For each push-through machine there was a strand dispenser, which was set up at the foot of the silo. This equipment enabled the pushing-through operations to be carried out with a small amount of labour and always in due time.

The cables were post-tensioned in two steps: the first step 3 days after the last concrete was placed and the second step 18 days later. The cables of one level were always synchronously stressed by four jacks. Radio communication assured that out simultaneously.

Grouting was carried out following the last stressing operation, after the anchorages had been concreted in. To improve the conditions for grouting, the cables had been placed with a continuous slope of 0.4%.

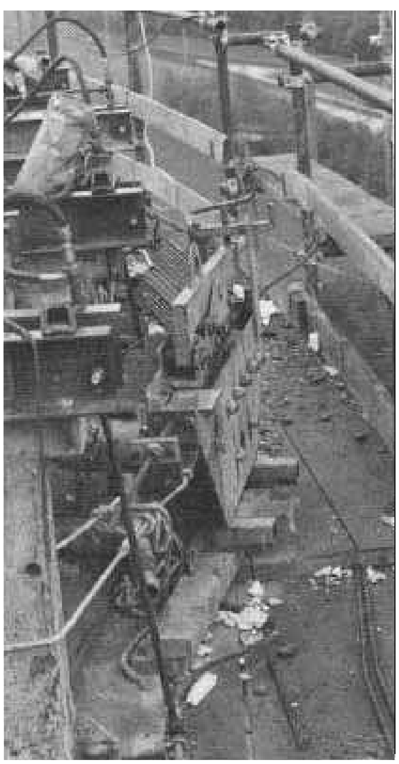


Figure 143: Push-through equipment

3.2.5. Flour and grain silos, Kuwait

Owner Kuwait Flour Mills Co. (S.A.K.), Kuwait
Engineer Dr. M. Attiyah, Beirut, Lebanon
Consulting Engineer A. Kramer, Zurich, Switzerland
Contractor Losinger Ltd., Berne, Switzerland
Slipforming VSL INTERNATIONAL LTD., Berne, Switzerland
Years of construction 1973-1974, 1980-1981

Introduction

The entire silo plant consists of three parts: a flour silo block, a wheat silo block and a circular cell block. Construction of the silo walls by means of VSL Slipforming was carried out in five steps from 18 March 1973 to 22 February 1974.

Details of the structures

The flour silo block measures 26.58 x 20.18 m in plan. It comprises 40 cells of 3.12 x 3.82 m size. The wall thickness is 180 mm. The height of the cells is 18.80 m, but in some cases only 10.61 m (Fig. 144).

The wheat silo block has base dimensions of 19.48 x 5.81 m. The 18 cells have measurements of 3.04 x 1.17 m, 3.06 x 1.17 m, 3.04 x1.19m,3.06x1.19m,3.04x2.77m and 3.06 x 2.77 m. The outer walls are 180 mm thick and the inner walls 160 mm thick. The height of the cells is 16.79 m.

The circular cell block consists of two parts, each comprising 9 integral circular cells. Their internal diameter is 8.04 m, the wall thickness is 180 mm and the height of the cells 29.40 m.

Construction procedure

In a first step, one half of the flour silo block was built. This took 7 days, which corresponds to a slipforming rate of 3.10 m per 24 hours. The second half of the flour silo block was built in 6 days. Since the cells were of different heights, a part of the formwork was assembled at level + 7.64 m and the other part at + 15.83 m. As soon as the lower part of the formwork had reached the upper, the two were coupled together and the remainder of the cells were constructed using this combined form (Fig. 145).

In the third step the wheat silo block was constructed, while the fourth step comprised the first part of the circular cell block and the fifth step the second part of this block (Fig. 146). Eleven days were required for each of these steps, corresponding to a slipforming rate of 2.85 m/24 h.

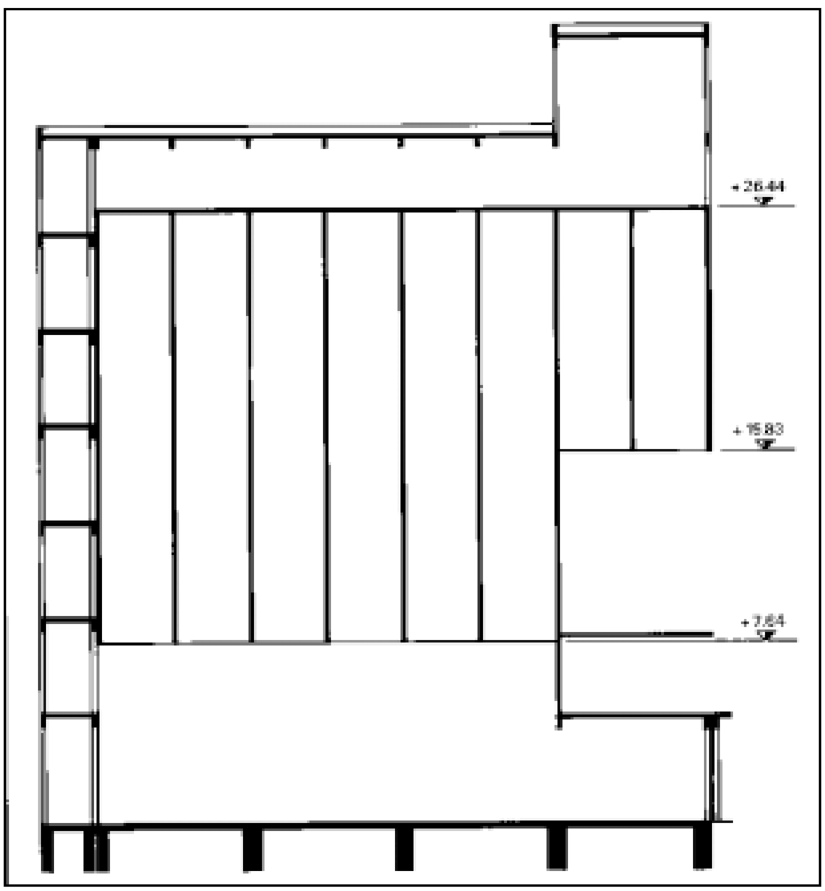


Figure 144: Section through the flour silo block

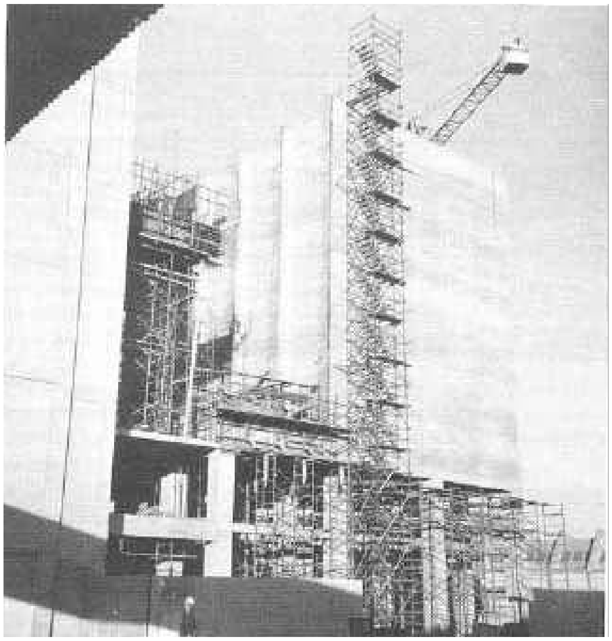


Figure 145: Construction of the second stage of the flour silo block

Figure 146: Part of the circular cell block during construction

Further extension of the plant

During 1980/81 further silos were constructed, the contractor on this occasion being M. A. Kharafi, Kuwait. The following were built:

- Grain silo:
  3 blocks of 9 cells 5 blocks of 12 cells Cell sizes were 5.00 x 5.02 m and 5.02 x 5.40 m, the slipformed height of each being 49.84 m and that for the machine house 63.30 m.
- Mixing silo:
  36 cells, constructed in 2 steps Plan area 9.80 x 24.30 m
  Slipformed height 20.64 m - Flour silo:
  24 cells, constructed in 2 steps Plan area 21.30 x 16.18 m Slipformed height 22.16 m
- in addition one stair well, 2 lift shafts and 2 external cells.

The works were built with the use of two slipforms in 14 steps. The total area in VSL Slipforming was 143 000 mz.

3.2.6. Ore silo, Grangesberg, Sweden

Owner	Grangesbergsbolaget, Strassa
Engineer	Jacobson & Widmark, Lidingo
Contractor	Widmark & PlatzerAB, Stockholm
Post-tensioning	Internordisk Spannarmering AB, Danderyd
Year of construction	1969

Introduction

During the period from January to November 1969 a silo for the storage of ore was built at the plant of the Grangesberg Mining Company. This silo has an internal dia-
meter of 14.30 m, a wall thickness of 350 mm and a height of 43.45 m (Figures 147

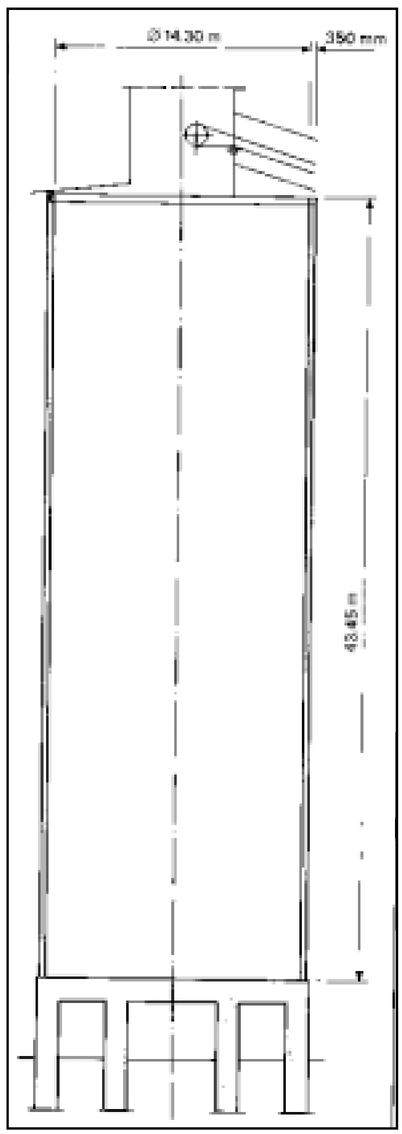


Figure 147: Section through the ore silo

Figure 148: The ore silo

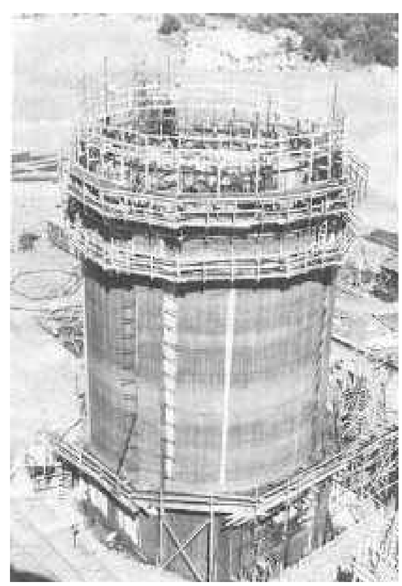


Figure 149: Construction of the silo

and 148). It rests on an octagonal substructure. The silo comprises 4 buttresses for anchoring the post-tensioning tendons. Its capacity is approx. 7000 m3. The silo wall was built by the slipforming method (Fig. 149). On top of the silo there is a steel structure for the charging equipment.

Post-tensioning

The silo wall is post-tensioned with 160 VSL cables EE 5-7 Dyform, each 24.70 m in length. Each cable extends around one half of the circumference. The distance of the cables from the outer face is 70 mm and the cable spacing varies from 450 to 1000 mm.

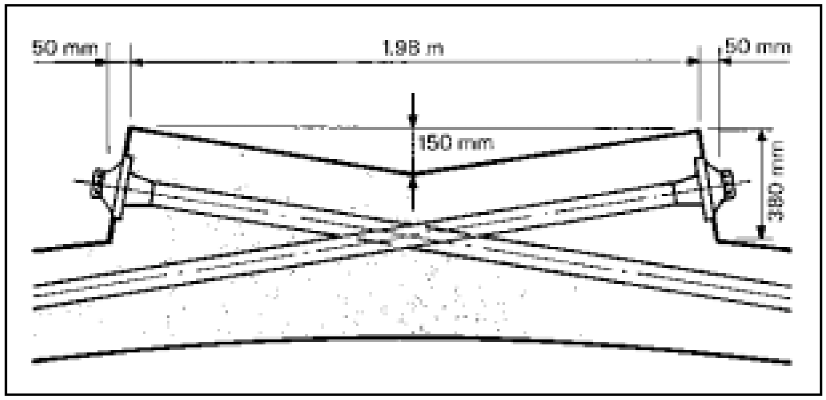


Figure 150: Buttress with anchorages VSL type B

3.2.7. Coal silos, Gillette, Wy., USA

Owner	North Antelope Coal Co., St. Louis, Mo.
Engineer	SMH Engineering Inc., Lakewood, Col.
Contractor	The Nicholson Co., Marietta, Ohio
Post-tensioning	VSL Corporation, Dallas, Tx.
Years of construction	1982-1983

Introduction

At the North Antelope coal mine three silos each of 20 000 tonnes capacity were built between September 1982 and June 1983. Beneath the silos there are rail tracks on which the trains move forward slowly during loading with coal.

Details of the structures

Each silo has an internal diameter of 21.34 m and a wall thickness of 350 mm. The height of the wall is 60.15 m and there are 4 buttresses each 1.98 m wide for anchoring the tendons. The roof is of steel girders, resting in recesses in the silo wall, and of a profiled metal sheet covered with concrete which projects slightly beyond the silo wall. The roof is not connected with the wall, but the wall is fixed in the substructure.

Post-tensioning

The silos are post-tensioned with cables 5-4, 5-5 and 5-6. The largest units, cables 5-6, are located in the central region of the wall. All the tendons extend around onehalf of the circumference. For the anchorages, VSL type B (Fig. 150) was chosen. The distance from the outer face of the silo wall to the axes of the cables is 89 mm and the cable spacings vary from 560 mm minimum to 1520 mm maximum.

During construction of the wall by the slipforming method, only the empty ducts were placed. After the wall had been completed, the strands were pulled by hand from the dispenser set up on the roof, were pushed into the duct and cut to length. When all the strands of a cable had been installed, the anchorages were fitted (Fig. 151).

The cables were first stressed to 20% and immediately afterwards to 100% of the required force. At this stage the concrete strength had to be at least 24 N/mm².

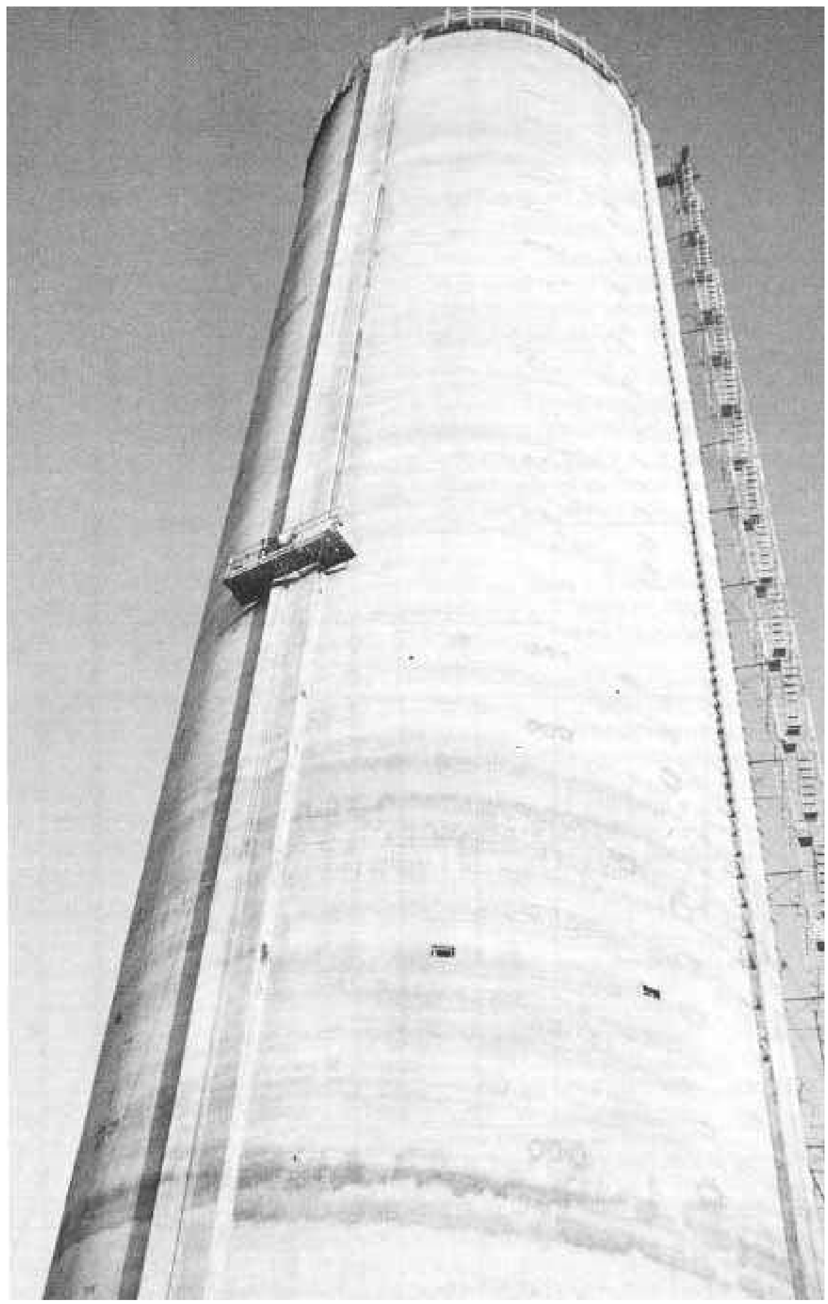


Figure 151: One of the silos during the post-tensioning operations

4. Repairs

4.1. Introduction

Regular maintenance or even repair of tanks is required from time to time. Reinforced concrete tanks can develop excessive cracking. In the case of older post-tensioned concrete tanks the prestressing force can be considerably reduced, for example, by corrosion, so that finally crack formation also occurs.

For repairs to circular tanks with a smooth outer surface (i.e. without buttresses) VSL cables with centre-stressing anchorages (type Z or ZU) are especially suitable, since they require no support. The strand can be applied directly onto the wall to be repaired. After the repairs, the surface of the wall is still free of buttresses.

Individual monostrands are also very suitable for repair work. They already have excellent protection against corrosion when they leave the factory, as has been mentioned before several times, and the friction losses during stressing are very low.

4.2. Cement silos, Linz, Austria

Owner Chemie-Linz AG, Linz
Engineer Mayreder, Kraus & Co., Linz
Contractor Joint venture Mayreder
Porr, Linz
Post-tensioning
Sonderbau GesmbH,
Vienna
Year of repair 1978

Introduction

During the course of general repairs to tanks at the cement factory of Chemie-Linz AG the existing tank walls were encased in post-tensioned gunned concrete shells. The two tanks repaired have an internal diameter of 12.00 m, a height of approx. 24 m and an original wall thickness of 200 mm (Fig. 152).

The repair work

The tanks were first surrounded in scaffolding to their full height and then the rendering which had been applied over the original annular reinforcement was chipped off. The vertical steel strips with the support stirrups were then fixed to the tank wall and the empty ducts were placed.

Since tendons with centre-stressing anchorages VSL type Z were used for the new prestressing, timber boxes had to be constructed as forms for the block-outs and also had to be fixed to the tank wall (Fig. 153). To prevent dirt getting into the boxes, they were packed with paper. The supporting gunned concrete shell of 100 mm thickness was then applied. The empty ducts were not stiffened in this case.

After the necessary strength of the gunned concrete had been reached the strands were pushed through and the tendons were stressed. A grout tube was then introduced into the end of the duct

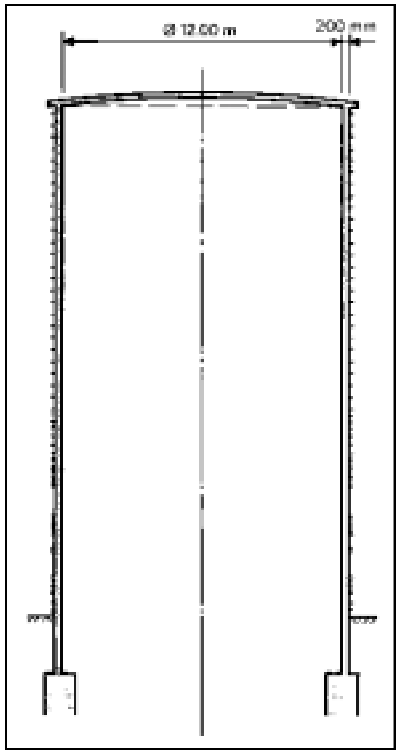


Figure 152: Cross-section

adjacent to the block-out and the duct end itself was closed with a plug of putty. The block-outs were then filled with gunned concrete and after this had hardened grouting of the tendons was carried out.

Post-tensioning

To provide the required prestressing forces, 36 VSL tendons type Z 5-4 and 21 of type Z 5-2 were required per tank. The larger tendons are in the lower part and the smaller ones in the upper part of the tank. The individual length per cable was 39.50 m. The quantity of prestressing steel required per tank was approximately 6 tonnes. The use of cables with centre-stressing anchorages of type Z proved to be especially advantageous, since no buttresses at all were required and thus no formwork had to be used.

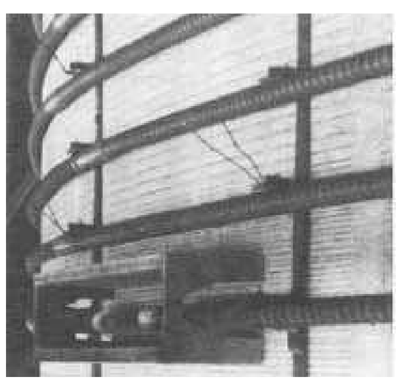


Figure 153: Ducts of the VSL tendons and timber box as block-out formwork

4.3. Sludge digestion tank, Meckersheim, FR Germany

Owner Sewage disposal authority,
Meckersheimer Center
Engineer Office Kordes, Mannheim
Contractor Hellenthal, St. Ingbert
Post-
tensioning VSL GmbH, Langenfeld
Year of repair 1980

Introduction

The ordinarily reinforced sludge digestion tank has an internal diameter of 13.00 m, a wall thickness of 400 mm and a wall height of 17.80 m (Fig. 154). Even before it was brought into use it exhibited appreciable cracks at the first test filling. A subsequent prestressing by a winding method was not possible on account of the piping and working bridge already in position. Repair was therefore carried out by means of individual tendons.

The repair work

A total of 30 VSL tendons ZZ 5-4 without ducts were placed around the tank. Each tendon therefore possesses two anchorages of type Z. In the region of these anchorages (Fig. 155) a topping concrete was applied to enable the anchorages to move freely during stressing. The anchorages of successive cables were displaced by 90°. Flat steel strips with angles were used for cable supports (Fig. 156). After stressing (Fig. 157) a test filling was carried out and the tendons were then covered with gunned concrete.

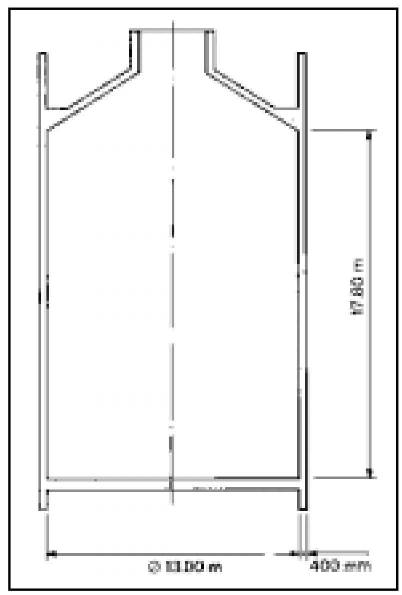


Figure 154: Section through the sludge digestion tank

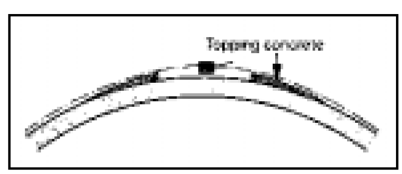


Figure 155: Region of the Z-anchorages

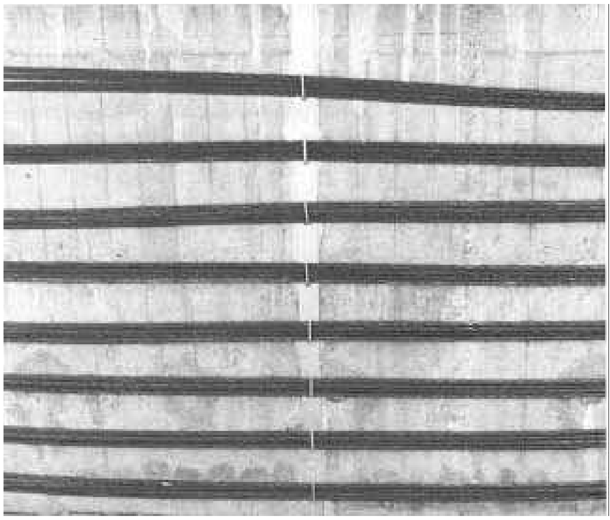


Figure 156: Installed tendons with supports

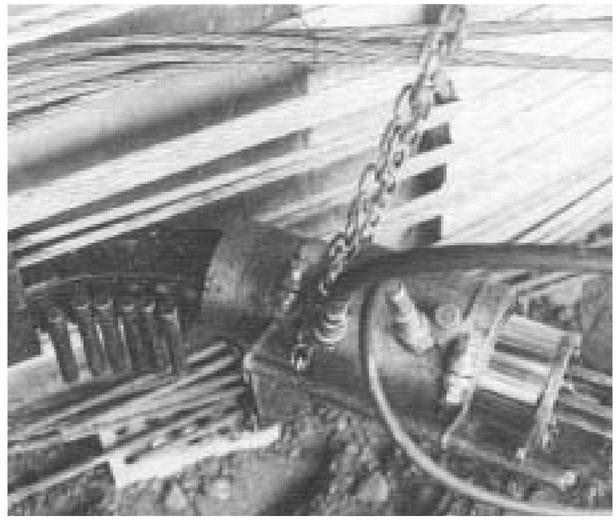


Figure 157: Stressing of a tendon at a Z-anchorage

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