Construction of elements for the Øresund Immersed Tunnel

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Summary

The western part of the Øresund Fixed Link between Copenhagen, Denmark and Malmö,Sweden consists of a 3.5 km long immersed concrete tunnel. The tunnel is divided into 20 elements each 176 m long, made up of 8 segments each 22m long. The outer crossectional dimensions are 8.5 m by 41.7 m enclosing two railway tubes, two motorway tubes and an escape gallery.
This paper describes the incremental construction and launch of the elements for the tunnel, the development of the various components of the cast and launch facility and relates the contractor's experience with the use of the facility and the quality assurance system developed and used for the design and construct contract.

1. Introduction

1.1 Øresund Link and Øresund Tunnel Contractors I/S

The Øresund Tunnel, currently under construction in Copenhagen, will be the largest immersed tunnel in the world. The 3.5 km long immersed tunnel under the Drogden Channel is part of the 16,4 km long Øresund Link between Kastrup at Copenhagen, Denmark and Lernacken at Malmö, Sweden. The tunnel with ramps and portal buildings is currently being constructed on behalf of the Øresundskonsortiet (a client company set up and owned by the Danish and Swedish governments) by Øresund Tunnel Contractors I/S (ØTC). ØTC is a joint venture comprising NCC AB of Sweden (leader), John Laing Construction Ltd of England, Dumez-GTM SA of France, Boskalis Westminster Dredging bv of The Netherlands and E.Phil & Søn A/S of Denmark.

1.2 Design and Construct Contract

The contract signed by Øresundskonsortiet and ØTC is a design and construct contract including the design, construction, inspection, testing and handing over of the completed immersed tunnel with ramps and portals and all related mechanical , electrical and local control and communication systems. This type of contract made it possible for the conceptual design of the tunnel to be developed concurrently with the construction methods for the tunnel.
Early in the tendering period ØTC recognised that the 3.5 km length of the Øresund Tunnel would justify the development of a high production precast facility tailored specifically to the tight time schedule and quality demands presented in the tender documents. It was further recognised that while such a facility would be expensive to design and build, it could be made economical if

recognised that while such a facility would be expensive to design and build, it could be made economical if the large casting basin normally associated with conventional tunnel casting operations could be eliminated and if the high cost of concrete cooling normally associated with tunnel casting could be significantly reduced.
During the tender period ØTC´s engineering staff worked in close co-operation with the tunnel structural designer Symonds Travers Morgan (STM) of England and the tunnel M&E design and construct sub-contractor SSB-Øresund, a joint venture of SEMCO of Denmark and Spie-Enertrans of France. Through this close co-operation ØTC and its design team were able to design a higher quality tunnel while reducing the construction cost of the tunnel by:

- standardising the precast segments to allow for a highly repetitive casting system
- eliminating all cooling of tunnel concrete
- substantially reducing the required size of the casting basin

1.3 Construction Schedule

The Contract was signed in July 1995 and Commissioning is scheduled to summer year 2000. See Figure 1.

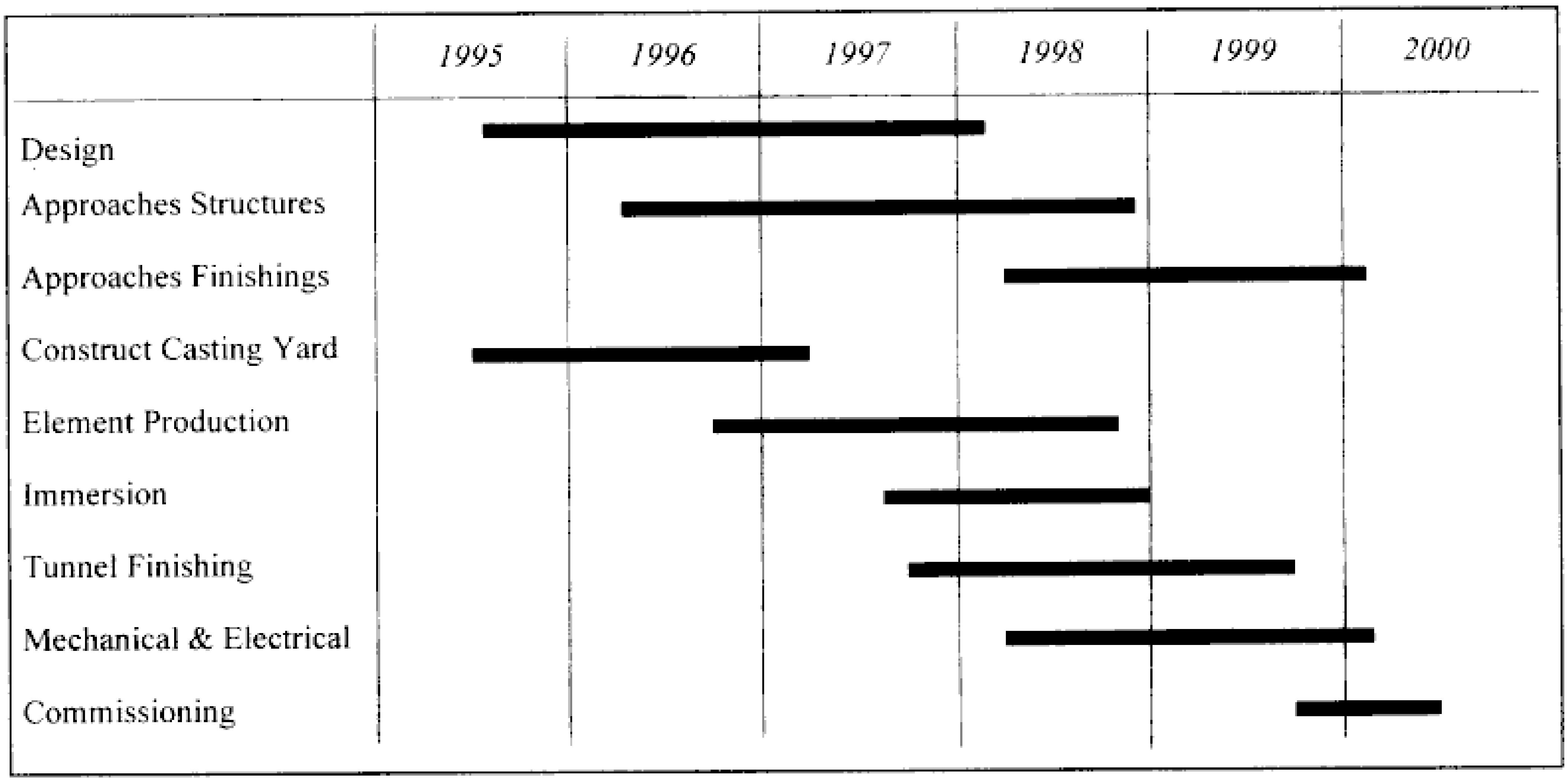

Fig. 1 ØTC time schedule for the tunnel

2. General description of construction method

2.1 Construction method

The immense size of the Øresund Tunnel made it economically feasible to invest in large facilities in order to achieve an industrialised construction sequence. Thus all construction activities for production of the twenty tunnel elements are performed in a rebar and precast building erected only for this purpose.
Different construction locations were studied including existing docks and shipyards and their impact on transportation techniques and cost. The final choice was The North Harbour of Copenhagen. Thus the tunnel elements are fabricated at the ground level on

two parallel production lines.
The factory is situated in the western part of the casting yard. At the eastern end is the launch basin, an area bounded by earth dykes to allow the impounding of water. The construction facility is shown on Figure 2.
The 3.5 km immersed tunnel comprises 20 reinforced concrete elements, each 175.4 m long. Each tunnel element is divided into 8 segments of 21.9 m weighing approximately 6500 tonnes. The outer crossectional dimensions are 8.5 m by 41.7 m enclosing two railway tubes, two motorway tubes and an escape gallery, see figure 3. The production facility will work on the principle of incremental launch method. The method involves the casting of each discrete segment on a fixed casting bed and then after a minimum curing period the segment is pushed clear of the casting bed for match casting of the next element in the same bed. Once a complete tunnel element of eight segments has been cast the entire element is pushed approximately 100 m into the shallow part of the launch basin for outfitting.
After outfitting flooding can be done allowing the tunnel element to be moved to the deep part of the basin. The basin is surrounded by earth dykes to the level 10 m above sea level. The entrance or the sliding gate forms the closure towards the fabrication building. The exit or floating gate forms the closure at the seaward end of the basin. Water level is lowered to sea level when the tunnel element has reached its position in the deeper part of the basin. The tunnel element will then be towed to the tunnel alignment in the Drogden channel between the peninsula near Copenhagen Airport and the artificial island.
Before flooding can be performed the tunnel element will be trimmed with ballast tanks and temporary bulkheads at the end to allow for the towing. Temporary prestressing will also be installed to act during towing and immersion.

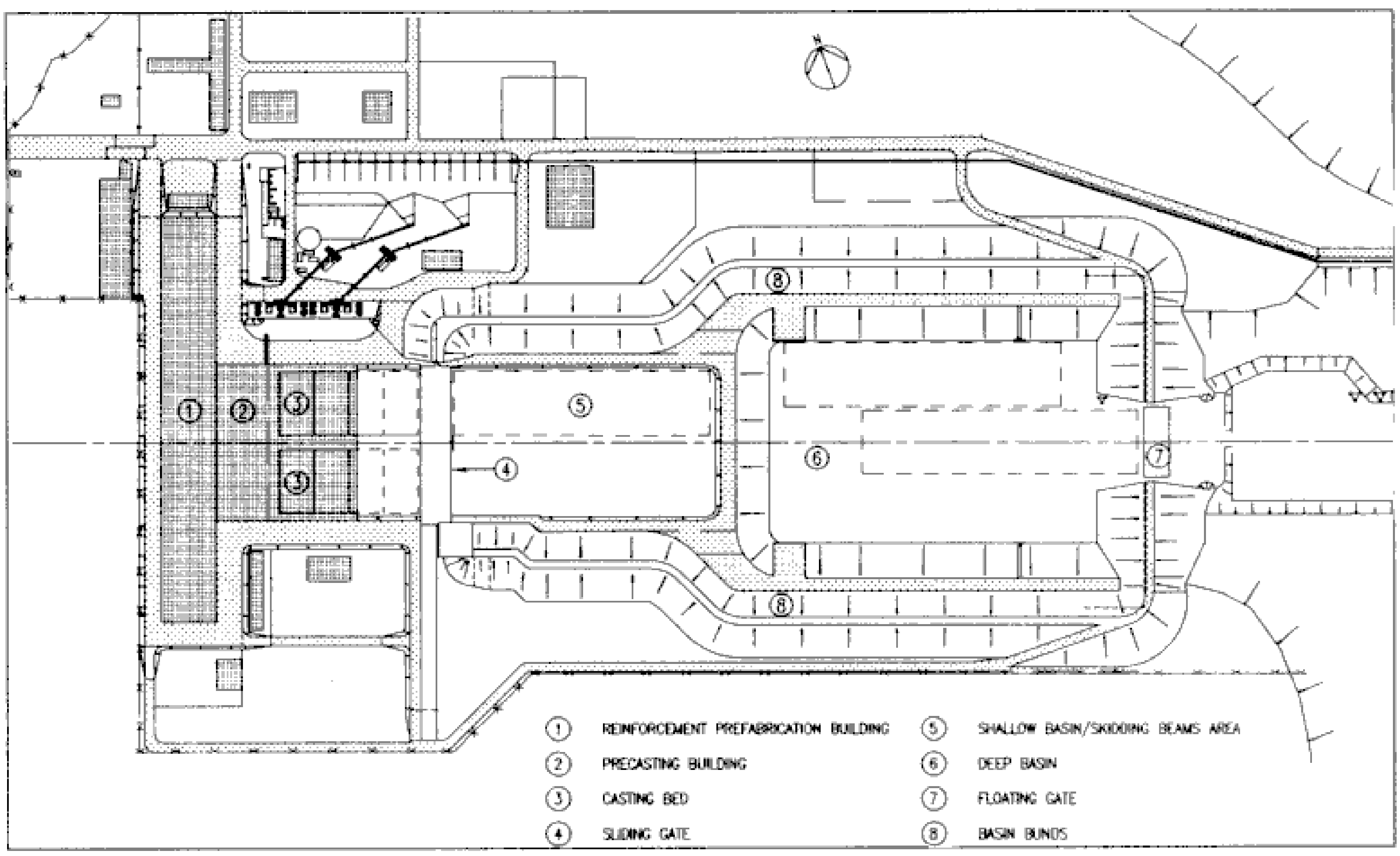

Figure 2. Plan of construction facility.

2.2 Concrete technology with respect to construction method

The contract documents stipulated a 100-year design life for the tunnel, implying high requirements on concrete durability and permeability. Moreover no early-age cracking were permitted. To achieve a high quality and construction efficiency a concrete with good workability was another requirement.

One characteristic feature of the construction method is that each tunnel segment is cast in one single poor.. By this method excessive measures for early-age crack control could be avoided, for instance installation of cooling pipes.

The incremental launch method also give rise to stresses to the young concrete which had to be considered in the process of selection of concrete mix, especially type of cement.

In the evaluation process two types of cement were tested: Std Portland Cement (OPC) and Blast Furnace Slag Cement (BFSC).

Six different concrete mixes were tested with respect to early age properties, three with BFSC three with OPC. Different coarse aggregates and content of additives were considered. The heat development and risk for early age cracking were analysed for the different mixes. The analyses were performed by the Dutch consulting company Intron SME. In the matemathical model used by Intron the influence of deformations in the skidding beams could be taken into account. The result of the study showed that the risk for early age cracking were similar and acceptable for some of the mixes with BFSC and OPC. The type of coarse aggregate had an impact on early age properties of the concrete implying that aggregates which gave a lower elastic modulus at early age were more favourable in that respect. Use of OPC mix enabled higher early strengths which meant the segments could be jacked forward earlier. As a resultant of this fact and of the analyses of risk for early age cracking a concrete mix with OPC were selected.

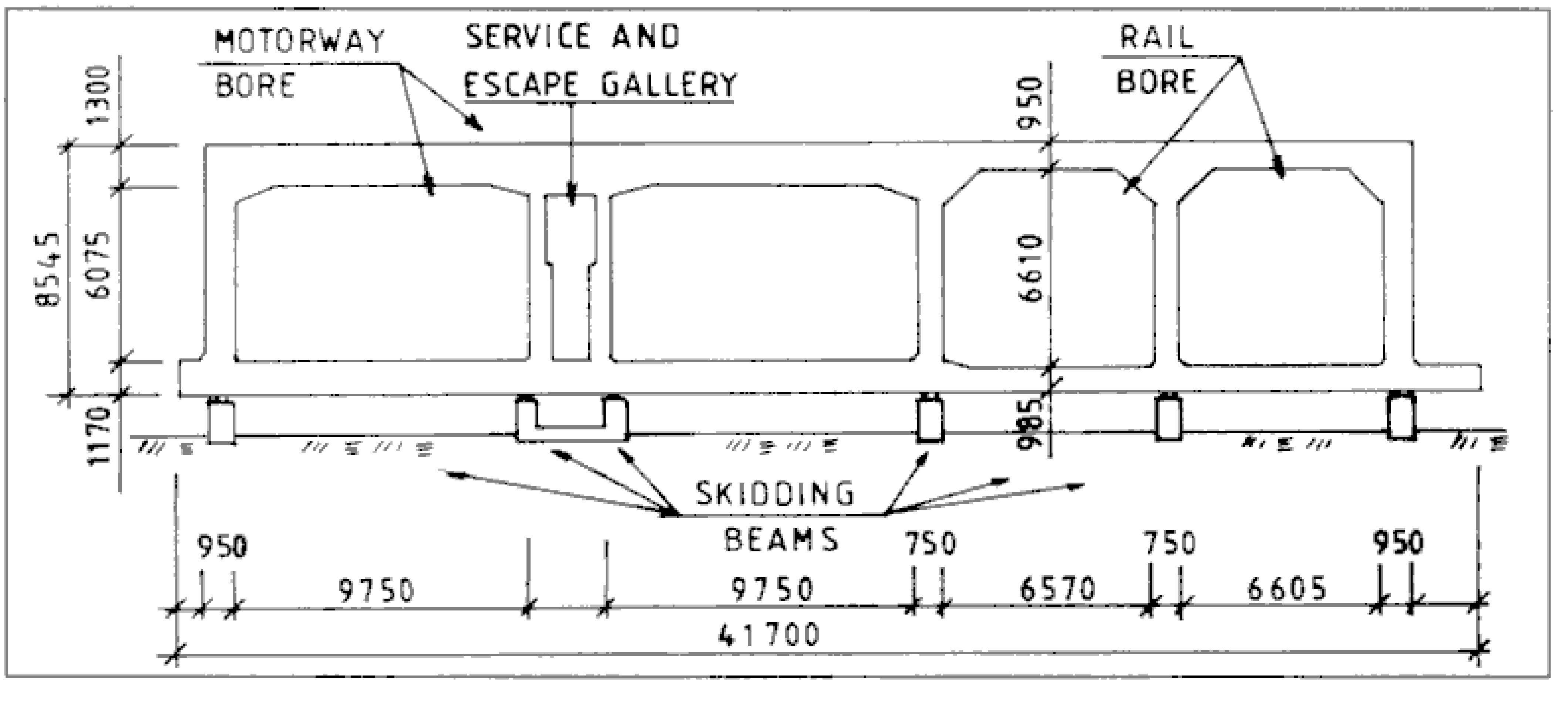

Figure 3. Cross section through tunnel and skidding beams.

3. Incremental construction and launch

3.1 Concept Selection and Development

During the tender period ØTC developed the following criteria for the casting method:

- **Schedule** – The first tunnel element should be launched within 18 months of contract award, and the entire 3.5 km of immersed tunnel should be cast and launched within an additional 24 months.
- **Standardization** – The casting method should take advantage of the relatively constant cross section of the tunnel to standardize the casting operation.
- **Weather Affect on Operations** – The casting method and associated facility should allow for year-round operation without shutdown by cold weather, rain, snow or ice.
- **Continuity of Work** – The method should allow for a continuous flow of work with a relatively balanced amount of work for the various crews working on fabrication of reinforcement, forming, casting, curing and outfitting of the tunnel elements.
- **Reinforcing Fabrication Economy** – The casting method should allow for an independent prefabrication of reinforcing .
- **Forming Economy** – The method should allow for use of steel forms casting on a fixed bed.
- **Concrete Quality and Workability** – The time between batching of the concrete and placement should be kept to absolute minimum by batching and mixing the concrete adjacent to the casting bed.
- **Concrete Cooling** – The casting method should allow the use of continuous full section casting and thereby eliminate the need for concrete cooling.
- **Match Casting** – The casting method should incorporate the use of match casting and the use of the water stops specified in the tender documents.

ØTC considered a number of different casting options including vertical match casting, casting on floating platforms, and casting with traveling forms in a conventional casting basin. The casting method which best met the above criteria however is a method which has been successfully used in bridge construction for over 30 years, incremental cast and launch. The method involves the match casting of identical segments on a fixed casting bed followed by incremental launching of the cast segments on a regular cycle.
A review of the various casting methods indicated that the segmental casting and incremental launch technique would only need a relatively small casting basin and that by casting the tunnel segments in one continuous pour it would be possible to totally eliminate the need for concrete cooling. This elimination of the cooling was later confirmed after a thermal analysis showed that the thermal stresses in the concrete could be maintained within acceptable limits by full section casting of tunnel segments.

The final conclusion was that a segmental concrete tunnel design combined with the incremental cast and launch techniques would be the most cost competitive solution. The key cost reduction factors were deletion of the concrete cooling for 440,000 m^3 of concrete in the immersed tunnel and reduction of the required capacity of the deep casting basin from 8 elements to 2 elements. An important feature of the cycle described in chapter 2.1 is that the casting of the tunnel segments is allowed to proceed on a continuous basis uninterrupted by the outfitting and launch of the completed tunnel elements. This is in sharp contrast to a conventional tunnel casting basin where all casting operations are halted during the typical outfitting and launch phase.
By allowing the casting to run concurrently with the outfitting and launch it was possible to cut over 6 months from the construction schedule.

3.2 Construction Sequence

The typical construction cycle for a tunnel segment takes 7 calendar days and approximately 2 months to cast, outfit and launch two complete tunnel elements.

The complete construction concept is summarised in the following sequence:

- Deliver cut and bent reinforcing to site and fabricate into complete cages
- Slide the reinforcing cage onto a pre-set casting bed positioned over 6 skid beams
- Insert internal steel forms and position external steel forms
- Cast the complete full section 21.9 m segment in one pour
- Cure the segment for 52 hours and release bottom forms and side forms
- Skid the completed segment 21.9 m, allowing the next segment to be cast
- After casting 8 segments push the entire element into the shallow basin for outfitting
- While outfitting the element continue with casting of segments as above
- Outfit the two tunnel elements for launch
- Close sliding gate and floating gate
- Flood basin to elevation + 9.9 m
- Ballast and trim tunnel element
- Winch tunnel element into the deep end of the basin
- Drain the basin back to sea level and lower tunnel element to sea level
- Open floating gate and tow completed tunnel element for additional marine outfitting and then to immersion site
- Open sliding gate and allow next completed tunnel element to be pushed in to the shallow basin for outfitting.

The various systems of the incremental cast and launch method are presented below.

3.3 Reinforcing Fabrication

The pre-fabrication of complete reinforcing cages for each segment is carried out in a 260 m long by 35 m wide building serviced by three 20-ton capacity gantry cranes. The total floor area allows pre-fabrication of two bottom mats 22 m by 42 m to be pre-assembled on a skid system built in line with the casting beds. At either end of the reinforcing building are wall templates equipped with self elevating work platforms which are set up for the pre-fabrication and storage of completed wall panels. Following completion of the bottom mat and erection of stabilizing templates, the overhead gantry cranes are used to set the wall panels. The reinforcing cage is after completion with the roof mat braced internally and rolled into a buffer area until the form system is ready to accept the completed cage. The pulling of the cage is performed with two winches.

3.4 Forming

The tunnel segments are formed on two parallel casting beds. The forming system for the tunnel consists of four main components: the vertically retractable bottom form, the retractable exterior wall forms, the telescoping interior forms and the stop-end forms. All of the forms are positioned and adjusted hydraulically. The bottom forms are mounted on pile supported concrete foundations and fitted to the six skid beams that pass through the centre of the casting bed. The interior tunnel forms are designed to roll on travelling steel trusses which telescope into each of the five tunnel bores. These trusses are used to position each interior form into the centre of each bore and are designed to carry only the dead weight of the side and roof forms. The vertical dead load of the fresh roof concrete is transferred by internal bracing and the side forms into the fresh concrete of the bottom slab. Two rows of standard wall ties are used in the interior walls and two rows of special waterstop ties are used in the exterior walls.

Prior to pushing the cured tunnel segment off the casting bed, the exterior side forms are retracted and the bottom forms are lowered, transferring the weight of the tunnel segment onto tunnel support bearings positioned on the skid beams. The tunnel segment is then pushed 21.9 m with the interior forms still in place. After resetting of the bottom form and installation of a new reinforcing cage, the support beams of the interior forms are telescoped back into the new reinforcing cage and the forms are then rolled on the support beams into position for casting the next segment.

3.5 Concrete Batching, Mixing and Placement

Concrete is produced in twin Sermec CF 150 batch plants with a rated capacity of 130 m^3 per hour each. A single plant has the required capacity for casting a typical segment. The second plant is provided as assurance of completing a segment should one of the plants break down. Both plants are located within 100 m of the two casting beds. All materials are delivered to the plant by truck except for the fine and coarse aggregate which are delivered by ship. Following mixing, the concrete is discharged directly into one of four concrete pumps and pumped direct to the casting bed via articulating booms. The pumps have a rated capacity of 70 m^3 per hour through the 125mm diameter booms. Each casting bed is serviced by 4 booms.
The typical placing sequence starts in the bottom slab, directly under each of the 6 walls and finishes at mid points in the roof slabs over each of the 4 tunnel bores. The 2700 m^3 of concrete in each segment is typically placed and compacted in a continuous 30 hour pour.
A system of external form vibrators and internal poker vibrators is used to compact the concrete.

3.6 Skid Beams

The skid beams support approximately 70 % of the tunnel segment dead weight during casting and initial curing. The beams provide an additional side benefit during the curing of the tunnel segments, by allowing the under side of the tunnel to cool off at the same rate as the other three sides. This helps to minimise the thermal stresses in the young concrete and minimises the risk of thermal cracking. The primary purpose of the skidding beams however is to provide support for the completed tunnel segments as they are pushed clear of the casting bed after 52 hours of curing.
There are six concrete skidding beams aligned with each casting bed. Each beam is centred under one of the six walls of a typical tunnel section. (See Figure 3) The reinforced concrete skid beams are 1500 mm deep by 700 mm wide supported at approximately 3 m centres by 400 mm square reinforced concrete piles driven into the underlying limestone. The number and size of the piles was determined by settlement limits for the support beams. Each beam has a low friction epoxy surface on its entire 285 m length. The beams are stabilised in the transverse direction by 1000 mm deep by 750 mm wide reinforced concrete ground beams located on about 10 m centres. In order to minimise deflection stresses in the young precast tunnel segments, the skid beams over the casting bed area were cast to a level tolerance of +/- 2mm and the remaining 260 m of the skid beams were cast to a tolerance of +/- 3mm. The anticipated variation in the elastic shortening of the support points was +/- 1mm.

3.7 Bearing System

The primary purpose of the bearing system is to ensure even load distribution of support reactions into the young concrete of the tunnel segments as the tunnel segments are skidded over the uneven surface of the skid beams. (Even with the tight level tolerances stated above, the theoretical vertical difference between any two support points could be as high as 12 mm.) Hydraulic bearings consisting of low profile piston jacks are provided under each tunnel segment at 3.65-m centres along the skidding beam. Each segment is supported on 36 bearings (6 bearings per skid beam) of 300 to 400-ton capacity for a total of 288 bearings for a complete tunnel element. The 36 jacks under each segment are interconnected into three separate hydraulic circuits. Each of the three circuits is connected to an accumulator to provide a spring like effect on a three point support. A PTFE pad is bonded to the bottom of each jack for sliding on the epoxy surface of the skid beam. Each jack is fitted with a flow control valve to lock off the jack if a break or excess leakage occurs in the hydraulic circuitry.

3.8 Pushing & Guiding System

The dead weight of a complete 175.4 m tunnel element is approximately 52,000 tons. The maximum friction coefficient measured is about 4% at break out and 1% moving. The pushing system consists of 6 pushing assemblies, one assembly mounted on each of the six skidding beams. Each of the six pushing assemblies is equipped with two 250-ton jacks for a total pushing capacity of 3000 tons. The stroke on each jack is 1200 mm. During a typical pushing cycle, the jacking assemblies advance in an inchworm progression. Each pushing assembly anchors itself to the skid beam by engaging four 370-ton capacity gripping jacks mounted on the side of the pushing assembly. Following completion of each push cycle, the gripping side jacks are released and the ram on each pushing jack is retracted which pulls the jacking assembly ahead to the next push point.

Two guiding devices are mounted on the underside of the tunnel element, one on the leading edge of the tunnel segments and one on the trailing edge. The devices consist of roller assemblies attached to 30-ton jacks which begin applying force if the tunnel strays more than 25 mm from true alignment. The 6 pushing assemblies and 2 guiding devices are controlled and monitored from one central station.

4. Launch Basin and Gates

To allow for the selected construction method a launch basin is created east of the tunnel factory. The launch basin is comprised of a shallow basin at 2 m above sea level and a deep basin with bottom at -10. The basin is surrounded by bunds to the level +10.2. The entrance or the sliding gate forms the closure towards the factory. The exit or floating gate forms the closure at the seaward end of the basin.

4.1 Bunds

The bunds or earth dykes which surround the basin are made up mainly of existing material from the excavation for the deeper part of the basin.The ground conditions generally consist of 7-8 m of fill, 1 m of sea deposits, 5-6 m of glacial deposits mainly clay till overlying the Copenhagen Limestone.The limestone is heterogeneous and sometimes has high permeability. Faces of the bunds are lined with 5m blanket of compacted clay to minimise seepage out of the basin and porepressure build-up in the dykes. Compaction of dykes and blankets are made in layers at optimum water content to a specified compaction degree.

4.2 Sliding gate

The sliding gate, approximately 100 m long, consists of reinforced concrete frames at 5.0 m nominal centres with a steel plate as watertight skin.
The task for the sliding gate is to form part of the closure of the basin during filling to + 9.9 without any leakage. After lowering of the water level the gate is moved to its parking area on an extended foundation giving place for the tunnel elements to be launched on the skidding beams.
The foundation of the sliding gate consists of reinforced concrete slab on vertical and inclined piles driven to refusal in the limestone. Steel piles were chosen with respect to the risk of excessive pilebreakage during driving. Dynamic measurements of pile performance and integrity were done. Deformations of the foundation should be small due to connection to skidding beam and due to loading/unloading effects.
Below the foundation a vertical sheetpile wall is installed in order to decrease waterpressure uplift forces as well as seepage below the foundation.Drainage layer and relief wells at 10m centers are provided to draw off any seepage before pressure can build up. Moreover, water pressure in the limestone under the sliding gate will be monitored to detect any risk of decreased safety.
The sliding gate with a weight of approximately 2000 tonnes are moved by the same pushing jacks as the tunnel elements.
Watertightness between the gate and the foundation is provided by a rubber membrane seal
The gate is connected to sheetpile wall abutments. Sheetpile wall is extended into the earth dykes to prevent seepage. Section of the sliding gate is shown in Figure 4.

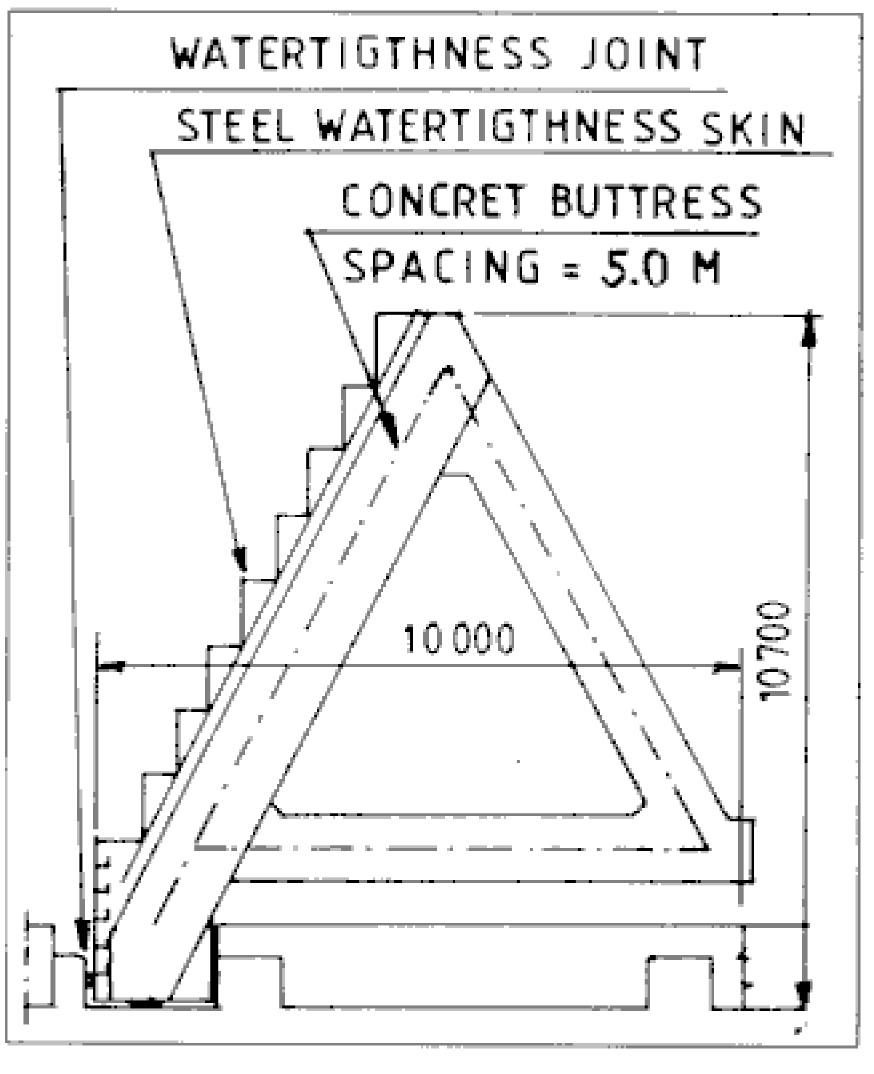

Figure 4. Sliding gate cross section

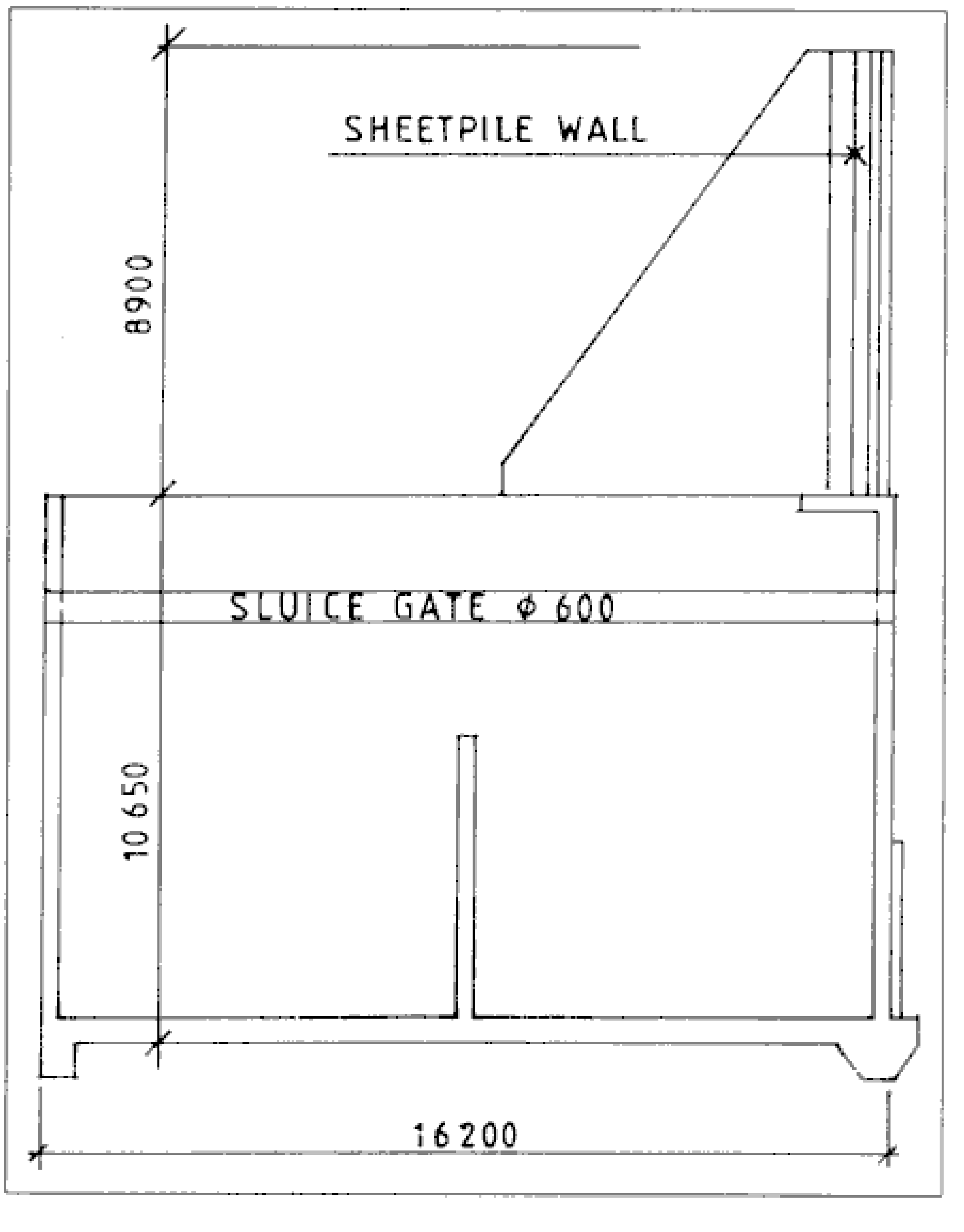

Figure 5. Floating gate cross section

4.3 Floating gate

The floating gate approximately 45 m long consists of concrete cells from bottom level at - 9 to level + 1. A steel sheetpile wall forms the part up to elevation + 10.
The floating gate is used to close off the seaward opening of the launch basin to enable the waterlevel in the basin to be raised for transportation of tunnel elements to the deeper part. After this operation and after lowering of the water level the floating gate is opened again and taken away to its parking position.
The gate is put on a RCC (Roller Compacted Concrete) foundation down to the Copenhagen Limestone. A grout curtain is performed to control seepage and uplift forces below the foundation.
Closing operation starts with transportation of the floating gate from its parking position with two tugs. The gate is positioned in its immersion position with winches and a Multicat and then lowered on its foundation by filling four ballast tanks. After having reached final position the gate is completely filled with water. Opening of floating gate is executed by emptying the ballast tanks. Section of the gate is shown in Figure 5.

5. Element outfitting and launch basin operations

5.1 Outfitting

After all the eight segments forming a tunnel element has been cast the whole element is pushed 100 m along the skid beams to the shallow part of the launch basin.
The element outfitting operations then take place in this part of the basin before floating and include installation of :

- Temporary ballast tanks
- GINA immersion seal
- Temporary bulkheads
- Temporary post-tensioning
- Some towing and immersion equipment
- Some ballast concrete
- Some mechanical and electrical items.

The main ballast tanks consist of five partitions (or bulkheads) dividing the southern motorway bore into four tanks. The bulkheads are sized to facilitate dismantling and transport by truck.
A homogeneous rubber softnose GINA seal is installed surrounding the primary end immersion joint. The GINA seal is bolted to the steel end frame of the immersion joint. In order to protect the seal during handling in the basin and towing a wooden cover is fixed.
Steel bulkheads are mounted at the conclusion of the outfitting operations in both ends of each tunnel bore before floatation. The bulkheads are re-useable and equipped with watertight doors for access to the immersion joint area between two bulkheads.
Temporary post-tensioning cables are installed to act during towing and immersion. The posttensioning consists of 24 tendons placed in the bottom slab and the roof slab. After backfilling of the tunnel elements the tendons are cut.
For mooring, towing and immersion the tunnel elements are equipped in the dock basin with among other things 600 kN bollards placed on the tunnel roof and 4500 kN immersion lugs for connecting the wires from the lowering system on the immersion pontoons.

Ballast concrete is calculated and cast to a quantity which guarantees level flotation. With empty ballast tanks the elements will have a minimum freeboard of approximately 30 cm in fresh water and some 50 cm in salt water.

Marine outfitting are done at the dolphin moorings just outside the basin such as:

- Immersion pontoons with associated winching system
- Guiding system on the roof of the tunnel element comprising a guiding nose, male part on the primary end and a receptor, female part on the secondary side of the element
- A laser tower and a survey tower carrying the survey installation
- A command tower carrying the main operators cabin or command unit with monitors for position and winch forces

5.2 Launch basin operations

Following the outfitting operation the floating and the sliding gates are closed and the basin is flooded to an elevation of 9,9 m above sea level by pumping sea water over the bund into the basin. Four diesel driven water pumps with a total aggregate capacity of 17.000 m^3/hr are used. The maximum allowable filling rate , from geotechnical boundary conditions, is 0.3 m/hr. The filling operation takes around 50 hours.
Before flooding of the basin the tunnel elements have been equipped with a system of fenders, wires and struts. The system keeps the elements at a constant distance and prevents relative movement during float up.
As soon as the tunnel elements starts floating the trim of the element is monitored by survey. Once full floatation is reached trim is adjusted till even trim .Acceptable trim deviations at this stage are less than 5 cm over full width as over full length.
After floatation both elements are moved together to the deep section of the basin. Six winches located on the bunds are required to achieve full travel. Four winches of 25 tons are employed in longitudinal direction, two pulling and two holding, plus two 10 tons winches in transversal direction.
After the tunnel elements are completely shifted to the deep part of the basin the waterlevel lowering commence. The sluice gates at the floating gate are partially opened so that basin water runs into the sea, resulting in a lowering speed of the basin waterlevel not exceeding 0.3 m/hr. When the basin waterlevel reach the sea level the floating gate is opened and towed to a mooring facility in Copenhagen North Harbour. The tunnel elements are towed out of the basin . During this operation the immersion pontoons are installed over the elements. The tunnel element is finally moored against dolphins with fenders at the south side of the channel to the basin. The marine outfitting is here completed before the element is towed to the tunnel alignment in the Drogden channel between the artificial peninsula outside Copenhagen Airport and the artificial island.

6. Quality assurance system

6.1 Quality system

Øresund Tunnel Contractors I/S (ØTC) has established and implemented a Project Quality Programme for the Øresund Tunnel Project. The Programme is based on the Quality System Requirements included in the Contract for the Tunnel Project, which in turn are based on the EN 29001 Standard.

The Programme covers ØTC quality management of the three areas :

- Permanent Works and Temporary Works (those affecting the quality of the Permanent Works)
- External Environment
- Working Environment (Health and Safety)

The Programme is documented by a Quality Manual including General Procedures and a number of Quality Plans. The Quality Plans cover planning, implementation and performance of the quality assurance and quality control activities specially adapted to the relevant activity.
The detailed planning of the work has been documented in a great number of Work Procedures describing "How to do" and "Who will do". The procedures are prepared generally by the site engineer and reviewed by the designer and quality assurance staff before approval by the appropriate manager.
The Work Procedure generally includes an Inspection & Test Plan (ITP), which clearly specify inspection points, inspection methods, extent of inspection, criteria for acceptance and schedule for documentation. The ITP also identify the specific stages of the construction activities - witness points and hold points - where the Client and/or ØTC Quality Control staff shall be called for witnessing and/or approval of the works prior to the execution of the following activities.
The quality system is subject to regular quality audits, both internal and by the Client, to ensure its continued adequacy and implementation.

6.2 Quality assurance/control organisation

A Quality Department is set up headed by the Project Quality Manager. The department consists of three sections: Quality Assurance, Quality Control and Document Control.
In the Quality Assurance Section the duties of three Quality Engineers include to prepare and review quality documents and to perform quality audits both internal and external. A major part of the departments duties is in the selection of suppliers and sub-contractors by review of the existing quality systems and visits to manufacturing plants to ensure consistent supplies.
The Quality Control Section headed by the Works Quality Manager includes three Quality Control Engineers working on respective sites. They are assisted by seven Quality Inspectors who perform the daily independent quality control on a random basis and also control and file all the quality records from site and suppliers/sub-contractors. The primary responsibility for quality control falls on the site management.
The Document Control Section headed by the Document Controller includes four Document Clerks using a computerised document management system and performing copy services.

7. Conclusion

The Øresund Tunnel project has shown that the teaming of design services to concurrently develop the design and construction methods for a structure is an effective way of improving the structure design while reducing construction cost.
This teaming effort on the Öresund Tunnel has successfully demonstrated that the incremental cast and launch technique is a viable construction option for long immersed tunnels. It has also shown that the application of full-section casting on an elevated form surface is an effective way of eliminating the high cost of concrete cooling in tunnels.