Construction of the Øresund Bridge

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The Bridge

A design and construct contract for the Øresund Bridge was signed with Sundlink Contractors in November 1995 (see page 34). The 7845-m-long bridge consists of three parts: two approach bridges and one high bridge.

The bridge is a two-level structure with an upper concrete road deck on steel trusses and a lower concrete deck for the railroad *(Fig. 1)*. Both concrete decks are in composite action with the structural steel. On the high bridge the lower deck is made as a steel box in order to reduce weight. The upper deck allows for four traffic lanes and the lower deck has a dual railway track.

Fig. 1: The Bridge seen from the Swedish side (February 1998)

The high bridge is a stay-cable bridge with a main span of 490 m. The cables are anchored by two 203-m-high pylons, which are the highest building structures in Sweden. The spans for the approach bridges are 140 m long, except those closest to the abutments, which are only 120 m long.

Sundlink's contract also included a 560-m-long viaduct on the man-made island Pepparholm, where the two-level bridge traffic is separated and brought to the same level.

Basic Concept

Based on the conditions in the Øresund region and on earlier experience from major bridge structures of similar size, it was decided at an early stage to utilise a very high degree of prefabrication. This can be said to be the state of the art for long bridges today, as *in situ* works are more vulnerable to environmental impacts, thus giving potentially higher risks for delays and increased cost.

Various concepts for lifting, transporting and placing of heavy bridge elements were studied during the tender stage. The options available during tendering in 1995 placed certain restrictions on the maximum weights of the elements that could be handled. The maximum lifting capacity possible was just below 4000 t, resulting in the need for a two-crane handling system when erecting superstructure elements. During the first part of 1996, however, an alternative arose due to the possibility of using the heavy lift vessel Svanen.

Svanen was initially built for construction of the West Bridge over the Great Belt in Denmark. After this project, Svanen was rebuilt to enable it to lift 8700 t, and it was raised in height by approximately 30 m to allow it to erect elements 70 m high. This rebuilding was carried out for the Prince Edward Island bridge project in Canada.

During 1996 it became evident that Svanen would be ready for use on the Øresund Bridge during summer 1997, which would fit very well into the overall time schedule for the Øresund project. The possibility of using Svanen for lifting, transporting and placing of bridge elements made it possible to increase the sizes of the concrete elements forming the substructure and to handle fully equipped superstructure elements.

Prefabrication of Approach Bridge Elements

The Bridge Factory

Concrete caissons, pier shafts and troughs for the railway deck of the approach bridges were prefabricated at Sundlink's production facilities in Malmö North Harbour. Construction of the concrete deck for the high bridge girders was also carried out here, as was reloading and outfitting of the approach bridge girders before erection in the bridge line.

The prefabrication facility in Malmö North Harbour was designed to allow a 14-day cycle when producing caissons, pier shafts and other parts of the bridge. This resulted in approximately one approach bridge span being erected each fortnight.

Next to the pier shaft production line are facilities for workshops, warehouses, a mooring for Svanen, the main office for Sundlink, and a quay including storage area for heavy fill material to be filled into caissons and pier shafts.

Caissons

Caissons were made as cellular structures with base sizes varying from 18 m × 20 m to 22 m × 24 m. The central part of the caisson, which has the same shape as the bottom part of the pier shaft, was designed to be 4 m above sea level to avoid the use of cofferdams. Thus, the amount of work and time with *in situ* joining of caissons to pier shafts was minimised. The fabrication of caissons was carried out with a high degree of prefabrication of reinforcement cages in a station system.

Although the design of caissons could have allowed for several variations in sizes, the number of types of caissons to be built was restricted to four in order to simplify the production. The bottom slab was cast first, followed by the lower walls, the intermediate part of shaft and the splash zone of the shaft. Each production line ends at a loading jetty where Svanen can pick up the caissons for final placing in the bridge line *(Fig. 2)*. The caisson weights varied between 2500 and 4700 t.

Pier Shafts

Alongside the batching plant is the production line for pier shafts. In contrast to caisson production, each pier shaft was made completely in the same position *(Fig. 3)*. The heights of the 51 pier shafts varied from 13 to 51 m and their weights from 900 to 3300 t. From each of the ten casting positions the ready-made pier shaft, including prepositioned bearings and other outfitting details, was moved to the central transportation line leading to the loading jetty where Svanen picks up and transports the pier shafts to the bridge line.

In order to move caissons and pier shafts, a system of coupled roller bogies with 400-t jacks was used.

Concrete Troughs

Approximately 700 trough elements, each 20 m long and just over 100 t, were produced for the lower level of the approach bridge girders. These elements were installed in the approach bridge girders in the reloading station at the far end of the yard area. Behind the girder reloading area are the two casting positions for the high bridge girder deck.

Fig. 2: Svanen picking up a caisson

High Bridge Substructure

Prefabrication of Pylon Caissons

The two pylon caissons, each approximately 19 000 t, 20 m high and with a base of 35 m × 37 m, were much too heavy to be handled by Svanen. Therefore, it was decided to produce these caissons in a nearby dry dock that was not in use. From summer 1996 until March 1997 the two caissons were constructed and outfitted with working platforms, crane footings, etc. At that stage the dock was flooded, and a specially made catamaran, consisting of two lifting pontoons coupled together with double superstructure trusses and equipped with two jacks with 20 530-t strands, was floated into the dock. The catamaran was used to lift the caissons individually. The catamaran, with the pylon caisson set at a draught of 6.5 m, was then towed to the bridge line, where the caissons were put down on three concrete support pads. The void between the underside of the caisson and the top of the limestone in the dredged pit, approximately 1 m, was injected with an underwater cement grout.

Pylon Legs and Cross Beams

After ballasting the caissons with sand, iron ore and ballast concrete, the pylon legs were cast. Casting was performed by a traditional climbing form technique, allowing for adjustment of the cross section of the leg during each climb. 50 steps, each of 4 m, were performed, with cycle times for each lift varying between 5 and 9 days. The cross beam between the legs at 50 m height was constructed by means of prefabricated formwork and reinforcement, lifted into position by a floating crane, and fixed to the leg before casting the first third of the cross beam *(Fig. 4)*. This first pour then served as a load-carrying member when the next two parts of the cross beam were cast.

The anchoring of stay cables was performed using prefabricated steel boxes, which were lifted into position and cast into every third lift from level +80 m upwards. This system enabled the fixation in the legs to be positioned exactly and minimised the production time for each climb, compared with that when cast-in anchoring details are used.

Fig. 3: Pier shaft production

Foundation of the Approach Bridges

Dredging

All the caissons were founded directly on the limestone in the Øresund and the depths varied between 8 and 18.5 m. To reach the prescribed foundation depth, dredging by back-hoe dredgers was executed along the bridge line at each pier position. Dredging was performed in foundation pits with depths varying between 5 and 10 m, giving a total dredging volume of approximately 250 000 m^3. To give Svanen access to the eastern part of the bridge a 700-m-long 150-m-wide and 5-m-deep channel had to be dredged, resulting in a doubling of the dredging volume.

Fig. 4: Pylon and cross beam construction

Fig. 5: Placing of approach bridge caisson

Placing of Approach Bridge Caissons and Pier Shafts

The approach bridge caissons were, like the pylon caissons, placed on three concrete support pads grouted on the limestone *(Fig. 5)*. The void between the underside of the caisson and the limestone was injected with underwater cement grout. When erecting the pier shafts on top of the caissons, flat jacks were used, enabling an exact positioning of the pier tops. The caisson and its shaft were joined by means of a traditional casting joint.

Due to ice and ship collision loads, all caissons and pier shafts have to be filled to approximately the full height with varying ballast materials, such as sand, mass concrete and iron ore. The caissons were filled using seagoing equipment just after placing, whereas the pier shafts were filled from the erected superstructure.

Backfilling

Backfilling and placing of scour protection was carried out shortly after placing and joining of caissons and pier shafts.

Protective Islands

To protect the pylons and the adjacent three piers on each side of the shipping channel Flintrännan, protective islands were constructed to reduce the risks of ship collision.

Approach Bridge Superstructure

Prefabrication

The contract to manufacture the steel trusses for the approach bridge superstructure, including the concrete road deck, was awarded by Sundlink to a steel company in Spain. 49 bridge girder elements with a total weight of 65000 t and approximately 70000 m^3 of concrete deck will be produced. Production began in 1996 and final delivery will take place during summer 1999. The bridge girders are transported in pairs by barge from Cádiz to Malmö. At the reloading station in Malmö, the concrete troughs for the lower railway deck are installed, as are gratings, walkways and railings. The combined weight of the specially made lifting tool (1800 t) and the heaviest bridge girder (6900 t) will be close to the maximum capacity of Svanen (8700 t).

Erection in the Bridge Line

For erection of the approach bridge girders *(Fig. 6)* the outer end of the girder was lifted approximately 0.5 m before welding the span to the previous erected span. In this way, a better moment distribution in the finalised structure is ensured. Joining of the roadway concrete deck and the railway troughs was performed at the bridge line after erection of the girders. The expected cycle time for erection of 14 days per span was followed.

High Bridge Superstructure

Prefabrication

The contract to produce the eight bridge girders for the high bridge, with lengths between 120 and 140 m, was placed with a firm in Sweden. Only the steel girders were produced in Karlskrona. After painting, the girders were transported individually by barge to Malmö North Harbour, where the concrete deck was cast.

In order to allow Svanen to lift and place the high bridge girders, recesses in the bridge deck had to be made and some of the steel outriggers, the steel consoles where the stay cables are anchored at bridge deck level, had to be fixed in temporary positions. These positions were finalised once the girder had been placed in the bridge line.

Fig. 6: Erection of bridge girder

Erection in the Bridge Line

Due to the shallow waters of the Øresund, it has proven cost effective to use three temporary towers placed on the seabed when erecting the high bridge. This resulted in an erection time schedule of approximately 9 months, which is extremely short compared with those for traditional methods.

Stay Cables

The stay cables for the high bridge are of the Freyssinet type, using twin cables with approximately 70 wire strands in each cable. Each strand consists of seven 5-mm single strands, which are galvanised and waxed and put into a plastic tube of high-density polyethylene to form a wire strand. The 70 strands are tensioned individually to the same load as for a reference strand. Each cable has a breaking load of 2000 t.

SEI Data Block

Owner:
Øresundkonsortiert

Structural design:
COWI, Denmark; VBB Anläggning, Sweden

Contractors:
Sundlink HB

Steel (t):	
Structural:	82 000
Reinforcement	60 000
Stay cables	2 300
Concrete (m^3):	320 000
Fill material (m^3):	600 000