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The Oeresund Bridge

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Summary

The Øresund Bridge is part of the Øresund Link currently under construction across the Sound between Copenhagen, Denmark and Malmö, Sweden. The Link, scheduled to open in the year 2000, is a toll-funded motorway and railway crossing. The 16km coast-to-coast part of the Link consists of a 4km immersed concrete tunnel, a 4km artificial island and an 8km bridge. The 490m main span will be the longest cable-stayed span in the world carrying both road and rail traffic. Minimum headroom in the main span is 57m. Øresundskonsortiet, owned 50/50 by the Danish and Swedish governments, is the Owner of the Link. ASO Group is Consultant responsible for the bridge concept, the construction monitoring and the quality auditing. The Contractor for the bridge is Sundlink Contractors HB.

1. Introduction

On 23rd March 1991 the Danish and Swedish governments finally entered into a binding treaty to establish a fixed connection between Copenhagen and Malmö. The Link would accommodate two tracks for high-speed passenger trains and heavy goods trains together with a dual two-lane motorway. There would be a tunnel under the Drogden channel adjacent to Copenhagen Airport, an artificial island 1km south of the island nature reserve Saltholm, and a high-level bridge crossing the navigation channel Flintrännan.

Øresundskonsortiet is owned jointly by the two governments and is responsible for financing, planning, construction and subsequent operation and maintenance of the Link. The finance is raised on the international markets, with the two states acting as guarantors, ensuring the most favourable borrowing terms. The money will be paid back through user payments over a period estimated currently to be about 27 years.

Five groups of engineers and architects were invited to take part in a design competition for the Link in the early part of 1993. Two groups, ASO and ØLC were chosen to develop their bridge designs further. In the following only ASO's design is described as this turned out to be the economically most advantageous to the Owner and is the design currently being built. ASO Group is led by Ove Arup & Partners (UK) with SETEC (F), Gimsing & Madsen (DK) and ISC (DK). Georg Rotne (DK) is the group's architect.

The tender documents were issued in November 1994 and the bids returned in June 1995. After tender evaluation, the contract was awarded to Sundlink Contractors HB in November 1995. Sundlink Contractors is led by Skanska (S) with Hochtief (D), Monberg & Thorsen (DK) and Højgaard & Schultz (DK). CV Joint Venture consisting of COWI (DK) and VVB (S) carry out the detailed design for the Contractor.

2. The Bridge

The bridge carries the traffic at two levels with the road at the upper level and the railway below. This arrangement was chosen for its safety, operational and visual advantages. An important safety aspect is that the high-speed trains, which will be travelling at up to 200kph do not disturb and interfere with the road traffic. The operational flexibility is increased; during lane closures caused by road accidents or maintenance works traffic can anywhere along the bridge be directed on to the other carriageway. It is an important aesthetic and visual advantage, in particular to the road user that the view during the journey is unimpaired by the installations and fencing associated with an electrified railway. A curved alignment was chosen for the bridge to further enhance the experience of crossing the Sound.

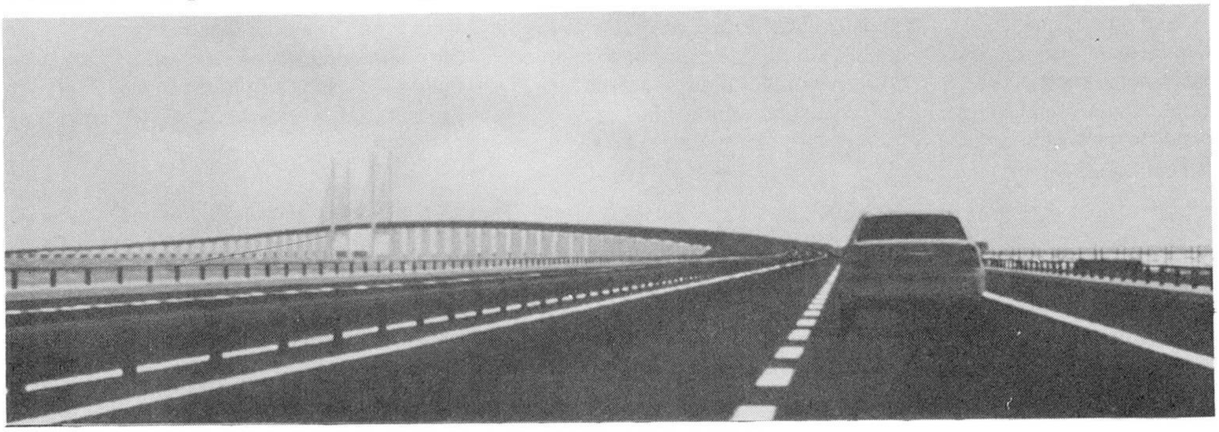

Fig. 1 View when driving towards Sweden

2.1 The Approach Spans

The approach spans make up 85% of the length of the bridge and it was therefore important that an economical deck solution was found for this part. To ensure a unified design for the whole bridge the solution should also be able to act as girder in a cable supported span over the navigation channel. The most economical solution for the two-level deck was found to be a double composite solution consisting of a concrete road deck supported on two parallel steel trusses placed on either side of the concrete railway deck.

The Warren type trusses are designed with a more open bracing than is generally used in existing steel truss bridges. With an inclination of the diagonals of 45° instead of 60° the number of nodes in the trusses is almost halved offsetting the extra cost of the longer span of the chords. Truss bay length is 20m, members are closed boxes, corners at nodes are rounded and all connections are welded. The bridge appears lighter and is more transparent so railway passengers also enjoy better views of the Sound.

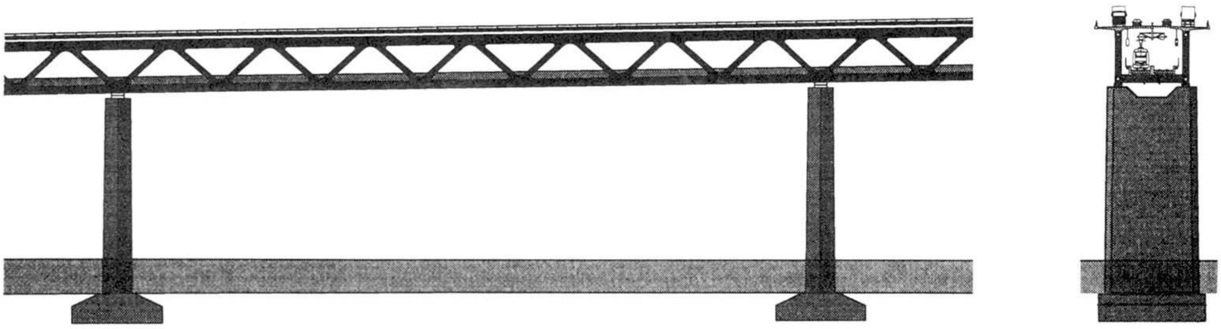

Fig. 2 Typical 140m approach span

The pairs of trusses are connected at the lower level at each node position through transverse steel box beams 3m wide, which in turn carry the railway. The railway deck consists of twin concrete troughs spanning between the transverse beams. The webs of the troughs contain the ballast for the railway tracks, act as containment barriers in case of derailment and reduce noise emission. The deep girder leads to longer spans, with both visual and environmental advantages. Span lengths vary from 120m near the shore to 140m further out.

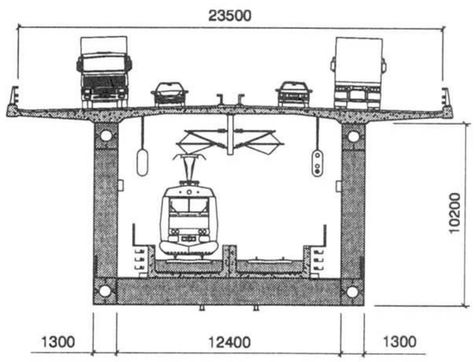

Fig. 3 Approach spans – Cross-section

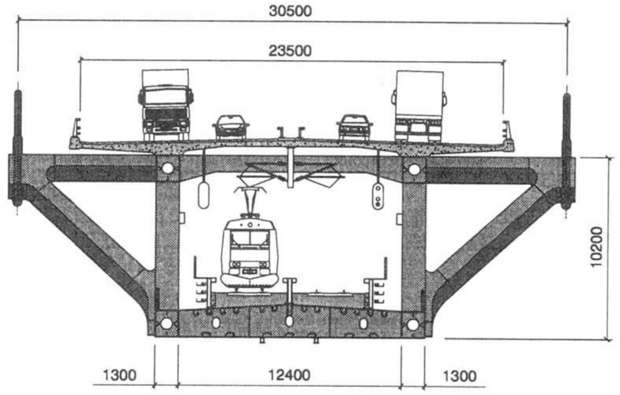

Fig. 4 Cable-stayed spans – Cross-section

2.2 The Cable-Stayed Spans

The basic girder cross-section for the cable-stayed spans is similar to the approach spans except for the lower railway deck. In order to save weight the railway is carried on a continuous steel box acting as part of the lower chords of the trusses. Longitudinal steel parapets provide containment in case of derailment.

The inherent stiffness of the deep girder was a factor in the choice of cable configuration. The bridge is subjected to considerable live loading which normally would suggest a fan configuration to control moments and deflections; however, this does not apply to the same degree with a deep stiffening girder. By optimising the position of the side span anchor piers adequate stiffness of the system is readily achieved with a harp configuration. An important reason for choosing this configuration is the natural affinity of the harp with the repeating geometry of the truss. The affinity is emphasised by modifying the inclination of the diagonals in the cable-stayed spans so that every other diagonal has the same inclination as the cables.

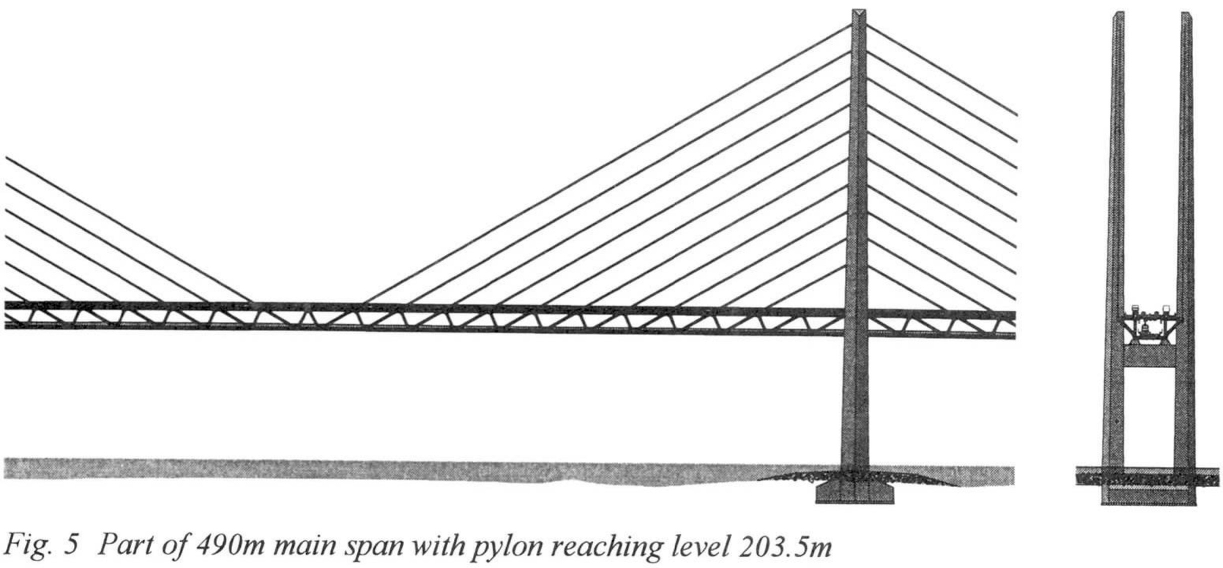

Fig. 5 Part of 490m main span with pylon reaching level 203.5m

The visual formality of the harp is particularly apparent when the cable planes are vertical. The effect is further enhanced here because independent free-standing towers above deck level support each cable plane. To achieve this the cable plane must coincide with the centroidal axis of the tower in order to avoid permanent transverse bending in the towers due to vertical loads on the deck. The deck passes between the concrete towers with the cable planes at a safe distance from the roadway, well protected from damage due to accidents on the road. The stay-cables are anchored to inclined triangular frames attached to the outside of the truss.

Fig. 6 Drivers' view

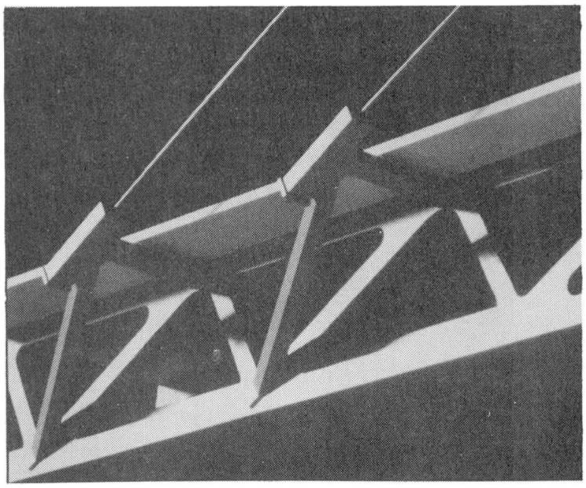

Fig. 7 Anchoring of stay-cables

2.4 Definition Drawings

Prior to tender, extensive consultations were held with authorities in the two countries on matters like aesthetics, environment, road and railway operation, navigation, safety, etc, and risk analyses were carried out to identify major risks and measures to alleviate them. The design was markedly influenced by these activities and included many features over which the client wished to maintain control. Some of these could be expressed as functional requirements but some important design features could not. The tender documentation for the 'design and construct' contract therefore included not only the usual design and construction requirements but also Definition Drawings describing those design features, geometry and materials that had to be retained in the successful contractor's design. The documents also included for the contractors' information an Illustrative Design as an example of a comprehensive design that fulfilled the Owner's requirements.

3. Detailed Design

The basis for the detailed design is the Eurocodes extended with the Owner's Project Application Document and Design and Construction Requirements. The aim is to produce a robust structure with a service life of 100 years using established and environmental-friendly techniques,

The Contractor is responsible for the detailed design, which has been carried out by his designer. This has the advantage that, as long as the Design Requirements including the Definition Drawings are adhered to, the design can be refined and optimised to suit the precise construction methods used. The erection concept includes prefabricating and handling of a large number of heavy structural elements, caissons, pier shafts and whole span elements, much design effort has gone into optimising dimensions and weight of these elements.

4. Construction

Erection based on extensive prefabrication of very large elements is nowadays used on most long bridges being constructed offshore. Some important advantages using this concept are, that the influence of the climate on the construction programme is reduced, elements are produced under factory conditions and adverse environmental impact of the works is easier to control. There is less risk of delays and therefore also less risk of the cost of the project escalating.

4.1 Substructure Construction

Prefabrication of caissons and pier shafts for the approach spans is carried out in a purpose-built yard in Malmö North Harbour, close to the bridge line. The caisson bases vary in plan size from 18m x 20m to 22m x 24m. The central top part of the caisson, being the bottom part of the shaft is constructed to 'installed level' +4m. However, for the pier positions closest to the shore the complete pier, caisson and shaft are prefabricated in one piece. A high degree of prefabrication of reinforcement cages is used in a station system along two production lines in the yard. Each line ends in a load-out jetty, where the Heavy Lift Vessel Svanen can collect the caissons that are finished and ready for transportation and placing in the bridge line. The weight of the caissons at load-out varies from 2500 tons up to 4700 tons. Production started towards the end of 1996.

The caissons for the two pylons (35m x 37m) weighing 19,000 tons each were too heavy for HLV Svanen, which has a lifting capacity of 9,000 tons. The pylon caissons were therefore constructed in a nearby dry dock in Malmö Central Harbour. A purpose-built catamaran barge was used, after flooding of the dock to lift, transport and place the two caissons during April 1997.

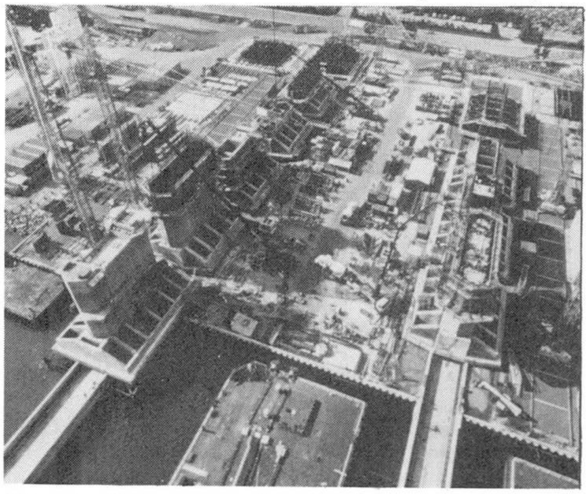

Fig. 8 Caisson production lines

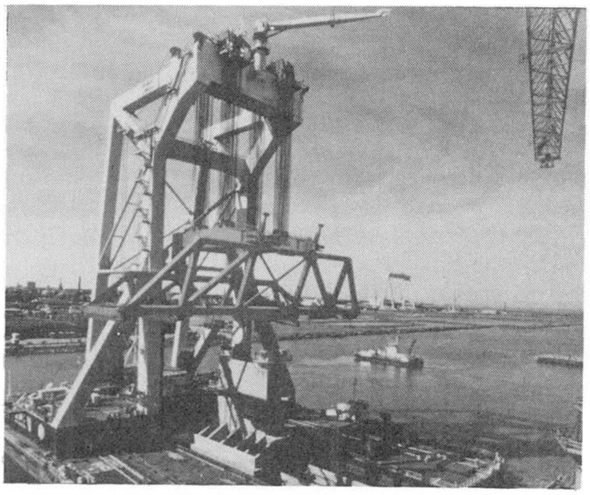

Fig. 9 First pier at load-out jetty

Seabed levels at pier positions vary from -3m to -9m and foundation levels from -8,5m to-18.5m. Foundation pits are excavated by backhoe dredgers. After cleaning and inspection of the pit the caisson is placed on three pre-positioned concrete pads. The space between the limestone and the underside of the caisson is grouted with a special mortar and the caisson ballasted. Backfilling up to seabed level and scour protection complete the foundation.

Prefabrication of pier shafts takes place at a separate area in the yard. The shafts, from 'installed level' +4m to the top, are produced fully finished in one position, before being moved to the load-out jetty. Also here a high degree of prefabrication of reinforcement is used. Each pier shaft is cast in 4m lifts. The pier shafts vary from 13m to 51m in height and from 900 tons to 3300 tons in load-out weight. Pier shaft production started early 1997.

HLV Svanen takes the shafts to the bridge line and places them on the top part of the already positioned caisson at level +4m. The lower 2m of the shaft is recessed to accommodate the construction of an in-situ joint between shaft and caisson. The pier shafts are to a varying degree ballasted in accordance with the detailed design.

The 203.5m pylons are the only major element of the bridge to be constructed in-situ.
A traditional climbing form, each lift being 4m, is used in constructing the towers. Construction began July 1997 and will be completed during the second half of 1998. Protective reefs are

constructed around the pylon footings. Reefs are also constructed at the three piers each side of the pylons. The pylons will be completed in parallel with the erection of the cable-stayed deck.

4.2 Superstructure Construction

The approach span deck girders are being prefabricated in Cádiz in southern Spain. Here 49 deck elements, 7 nos. 120m and 42 nos. 140m are produced. The two steel trusses, joined by the lower transverse steel box beams and the transversely prestressed top concrete road deck, form a deck element. Fully painted, these elements are transported in pairs on ocean-going barges from Cadiz to the yard in Malmö North Harbour where the prefabricated lower railway troughs are installed. Erection in the bridge line is by HLV Svanen. At load-out, deck elements weigh from 5500 tons to 6900 tons, close to the lifting capacity of HLV Svanen considering its purpose-built 1800 tons lifting gear. Production started in Cadiz early 1997 and final delivery in Malmö will be during the second half of 1999.

The cable-stayed deck girder is produced in Karlskrona, Sweden, some 200km from the site. Steel sections 120m and 140m long are transported on barges to Malmö North Harbour where the upper roadway deck is cast. The section is then transported out and put in place by HLV Svanen. The shallow waters of Øresund, and the fact that the navigation channel Flintrännan is being realigned as part of the construction of the Link, give a special advantage when erecting the cable-stayed bridge. The main span can be erected in four sections supported by temporary towers founded on the seabed at level -8m to -10m. This speeds up the deck erection, and greatly reduces the construction risk compared to the common cantilever construction of cable-stayed bridges. After completion of the main span the shipping traffic is moved to its new channel. The cable-stayed bridge will be erected during 1998.

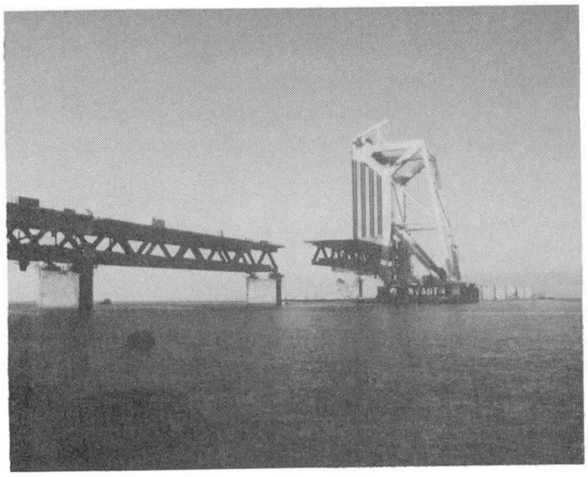

Fig. 10 Svanen positions 120m span

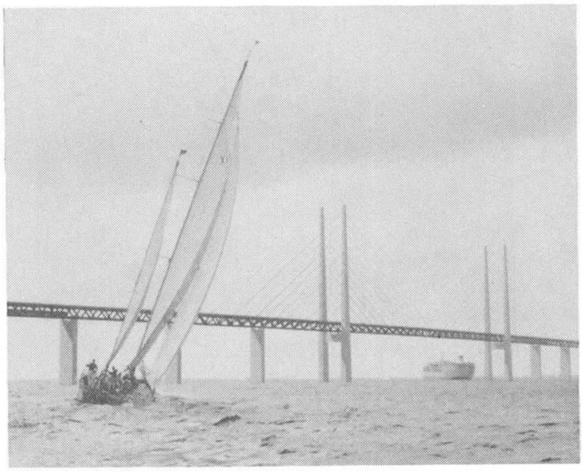

Fig. 11 Sailors' view year 2000

5. Conclusion

The form of contract developed for the bridge has worked successfully. The Contractor is responsible for delivering the quality assured construction works in accordance with the Owner's requirements. He is also responsible for the detailed design, which can be tailored to the precise construction method. By including comprehensive Definition Drawings, as part of the Contract Documents the Owner will receive a bridge that not only fulfils his quality requirements on materials and workmanship but also looks aesthetically like the bridge he envisaged before he signed the contract.

When the Link is opened in the year 2000 the Øresund Bridge will, with its main span of 490m rank as joint number 9 among the cable-stayed bridges around the world. However, the bridge will at that time be the only cable-stayed bridge with both road and rail traffic among the world's twenty longest cable-stayed spans. The bridge will also be the longest railway-bridge in Europe.