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The Future Fehmarn Belt Link

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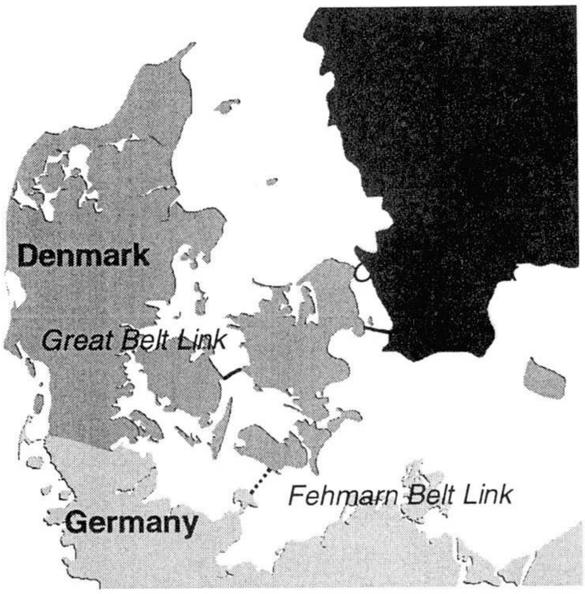
Summary

This article describes the Feasibility Study for a future fixed Link across Fehmarn Belt and focuses on the combined roadway and railway bridges solutions. The about 19 km wide and up to 29 m deep Belt is heavily trafficed by ships which are demanding large spans for safe navigation. Furthermore, the Fehmarn Belt is important for the exchange of waters to and from the Baltic Sea and major structures will influence the presently undisturbed flow of water. Environmental guidelines were developed to define an improved structural layout of the underwater part of bridge piers and pylons especially. The presentation will describe the general status of the Feasibility Study, highlight the investigations for the approach bridges and present the two alternative main bridge solutions studied. The study will be concluded in the summer of 1998, and a final decision for this link will not be available before 1999.

1 Introduction

In the treaty between Denmark and Sweden concerning the Øresund Link, Denmark has 1991 agreed to study possibilities for a fixed link across the Fehmarn Belt in the future and together with Germany. The traffic ministries of Denmark and Germany decided to initiate studies which are funded jointly by the two countries and supported by the European Community. This resulted in a Pre-feasibilty Study during 1992/93 - awarded to a Joint Venture between COWI (Denmark) and Lahmeyer International (Germany) - which defined the extent and a number of main structural solutions like tunnels and bridges or combinations thereof for the next study phase. The following Technical Investigations as part of the Feasibility Study was



in 1995 contracted to the same group of consultants and limited to the coast-to-coast connection between the islands of Fehmarn and Lolland, as illustrated in Fig. 1.

Parallel to the technical investigations the Client had contracted within the frame of the Feasibility Study a Geological-Geotechnical Investigation and an Environmental Investigation as well to provide relevant information for the three study teams.

Fig. 1 : Location of Fehmarn Belt Link

2 Development of the Technical Investigations

During the first phase of the study 7 solution comprising bored and immersed tunnels and bridges were reviewed, cost estimates developed and compared to each other. In the second phase - which has started in December 1997 - a total of 5 solutions with some modifications are studied in a conceptual design and later evaluated to recommend the most viable one within the three capacity groups under review. This article is limited to a description of the bridge alternatives only.

The bridge solution for the Fehmarn Belt is envisaged to comprise a cable supported bridge spanning the navigation channel and two approach bridges. The bridge will accommodate four lanes of motorway traffic and a dual track railway arranged in two levels.

Two scenarios for the ship traffic have been studied, east bound and west bound ship traffic in the same navigation channel with a 1,700 m clearance and east bound and west bound ship traffic in separate navigation channels with 2 times 700 m navigation clearances separated by approximately 700 m.

A vertical clearance of 65 m is required over the entire width of the navigation channel.

3 Long Span Bridge

Two cable supported bridge concepts have been studied matching the two principal arrangement of the ship traffic, a multi-span cable stayed bridge, with separated navigation channels and a suspension bridge, with one navigation channel.

3.1 Cable-Stayed Bridge

The cable-stayed bridge is outlined with three main spans of 720 m and a total length of 3,144 m.

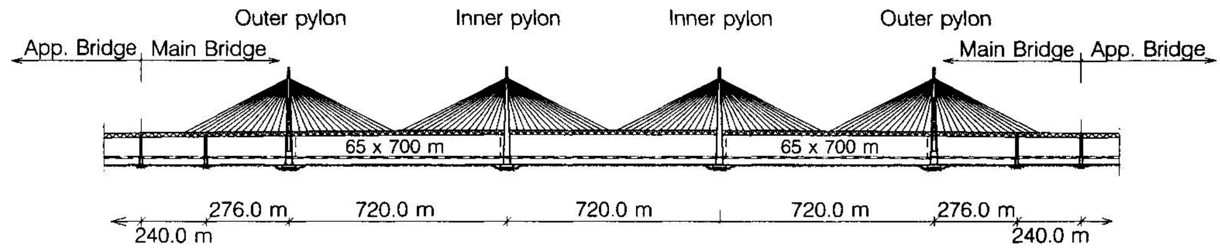


Fig. 2 : Cable-Stayed Bridge

Compared to a conventional single main span cable-stayed bridge, a multi-span bridge requires additional stiffness from either the cable system or from the pylons to minimise deflection from unsymmetrical distributed live load. Three solutions have been considered to provide the additional stiffness :
1. "Crossed cable" solution
2. "Triangulated pylon" solution (rigid pylon)
3. "Semi-rigid pylon" solution (semi-rigid pylon)

The investigations showed that the "semi-rigid pylon" was the optimal solution considering the site specific conditions.

3.1.1 Superstructure

For the cable-stayed bridge, where different conditions prevail for different sections of the girder, a combination of cross section types is appropriate. The investigations showed that the optimal solution has two layouts of the girder, a single composite, with a concrete roadway deck and lower steel deck, and a double composite with a concrete roadway deck and a lower railway deck.

The side spans are outlined with double composite girders to limit the uplift forces in the backspan piers. The 195 m of the girder closest to the pylons are outlined as double composite structures to carry the global compression forces efficiently by the concrete. The remaining parts of the girder are outlined as single composite structures. The girder depth of 15 m, is determined by the approach bridges. The girder is supported by the cable stays every 24 m. The cable stay force is transferred to the cross section in such a way that the vertical component is taken by the vertical strut and the horizontal component by the horizontal edge beam, in which the cable stays are anchored.

3.1.2 Substructure

Foundations
The pylon foundations are assumed to be constructed as prefabricated cellular caissons with an open outer base structure off site in a drydock and towed to the site. The caissons are to be placed on crushed stone beds in an excavation to allow the base structures to be fully

embedded into the sea bed and thus reduce the flow resistance as much as possible. At the sea level, the outer shaft walls are to be strengthened to sustain the ship impact forces.

Pylons

The pylon are proposed as concrete structures constructed by climbing formwork as recently applied on both the Great Belt and the Öresund bridges. The proposed layout requires that the inner towers are semi-rigid, and the outer towers are as flexible as possible. For architectural reasons, the inner and outer pylons have the same shape. The difference in stiffness is obtain by omitting material in the centre of the pylon.

3.2 Suspension Bridge

The suspension bridge is outlined with a main span of 1,752 m and side spans of 600 m.

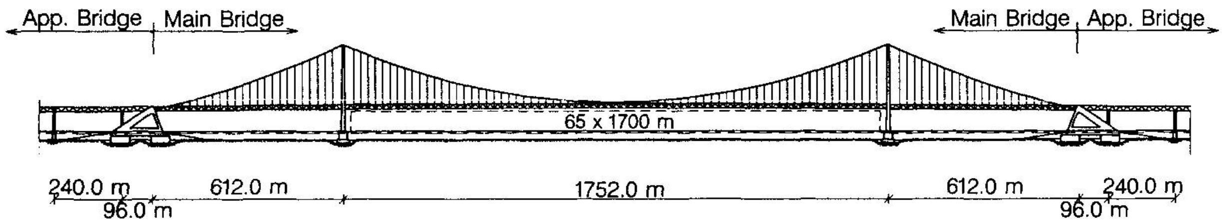


Fig. 3 : Suspension Bridge

The suspension bridge is outlined with a continuous girder between the anchor blocks. A number of advantages is obtained :

- the longitudinal movements are reduced, compared to a traditional system with joints at the pylons,
- the number of vulnerable elements as bearings and joints is minimised,
- the appearance is improved.

A torsional support is arranged at the pylons, and longitudinal supports are arranged at the anchor blocks. The optimal solution was found to be an all steel structure with a sag to span ration of 1/9. During the tender design in 1979 for a suspension bridge for combined road and railway across the Great Belt, extensive analysis were carried out to demonstrate that an all steel solution was adequate. The calculations showed that all requirements could be fulfilled with a light, all steel solution.

3.2.1 Superstructure

The roadway deck is outlined with as an orthotropic steel deck, supported by cross beams every 4 m. At the hanger anchorage a larger cross beam is provided together with a slender tension member, which connects the hanger anchorage and the lower truss joint and thus transfers the hanger force into the truss.

A distance of 28.5 m between the main cables has been selected, which preliminary calculations have demonstrated to be sufficient to ensure the aerodynamic stability of the bridge. Vertical hangers are arranged every 24 m. Twin hangers are foreseen at each position.

3.2.2 Substructure

Pylons
The design and construction principles are identical to the cable-stayed bridge pylons.

Anchor Blocks
The anchor blocks are to be divided into two separated caisson bases to support a high caisson beam. The caisson structure forms the support for a triangular structure which consists of the splay chamber and the front legs as support for the end span of the approach and the main bridge girders. The rear part of the caisson beam and the rear caisson base contain the massive cable anchorage.

The caisson bases and the lower part of the caisson beam are assumed to be produced off site in a drydock and towed to the site. The anchor blocks are protected from ship impact by streamlined artificial islands in the direction of the current flow.

4 Approach bridge

The approach bridges govern the costs of the link and have a determining impact on the water flow in the belt. The span length has been optimised to minimise construction cost. This minimum has proved to be almost constant in a certain range of span lengths. To minimise the environmental impact relatively large spans of 240 m have been selected. For aesthetic reasons all spans are identical. Expansion joints are arranged every five spans, i.e. every 1,200 m to limit the requirements to the railway expansion joint especially.

4.1.1 Superstructure

The girder has been chosen with a composite cross section with an overall depth of 15 m.

The road deck is outlined as a transversely post-tensioned concrete deck. Above the support, where the deck is subjected to large tension forces, a cross section without transverse post-tensioning will most likely have to be arranged, to be able to utilise the longitudinal mild reinforcement. The deck is 24.7 m wide between the outer parapets.

The railway deck is outlined as a closed steel box stiffened by troughs and has dual tracks with emergency walkways on both sides. Application of a lower deck in steel has proven to provide a robust structure, especially with regard to accidental loads such as fire, derailment and ship collision. The lower deck acts as a torsional stiff girder being able to distribute the load beyond the damaged areas. It has further an extra reserve in the overcritical area.

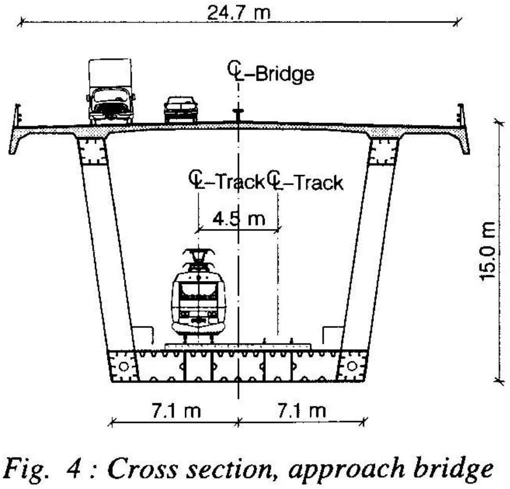


Fig. 4 : Cross section, approach bridge

All interior surfaces are to be corrosion protected by dehumidification. By keeping the relative humidity below 60% no corrosion will occur, and by avoiding to paint the interior surfaces substantial savings can be obtained.

4.1.2 Substructure

The geological profile for the chosen alignment generally shows two different soil conditions for the approach bridges. The profile allows for a direct foundation of the northern piers, whereas a piled foundation might be foreseen for the southern piers to reduce expected large settlements in the tertiary clay formations.

The approach bridge piers are to be divided into three parts, the pier shaft, the caisson shaft and the caisson base.

This division allows for extensive on-shore prefabrication. The caisson's base and shaft are assumed to be produced as one unit and the pier shaft as another unit. The caissons and the pier shafts will be produced in a drydock or a prefabrication yard and transported to the site.

The caisson shaft is to be designed to sustain and transfer ship impact loads to the base structure. Furthermore, the caisson shaft is to be shaped in a way to reduce resistance to the water flow in the Belt. An shape with circular ends has been chosen so far, but an improved elliptical shape is studied at present. The caisson unit can be rotated around a vertical axis with the caisson shaft main axis parallel to the current direction.

The caissons are to be constructed as prefabricated cellular structures with an open outer base structure. At the interface zone between the pier shaft and the caisson shaft a massive in-situ cast structural plinth is assumed.

The caissons are to be placed on a crushed stone bed's constructed in an excavation allowing for the base structure to be fully embedded into the sea bed. Where piles are required, the open cell caisson base is assumed to serve as a template for the construction of 35-45 m long bored Ø3 m piles. The bored piles are foreseen with a 4.5 m conical enlargement at the tip of the piles.

After drilling and casting of the piles the piletops are rigidly connected to the bottom of the caisson base, before the caisson will be ballasted with sandfill. For the piled foundations no crushed stone layer or underbase grouting have been foreseen.

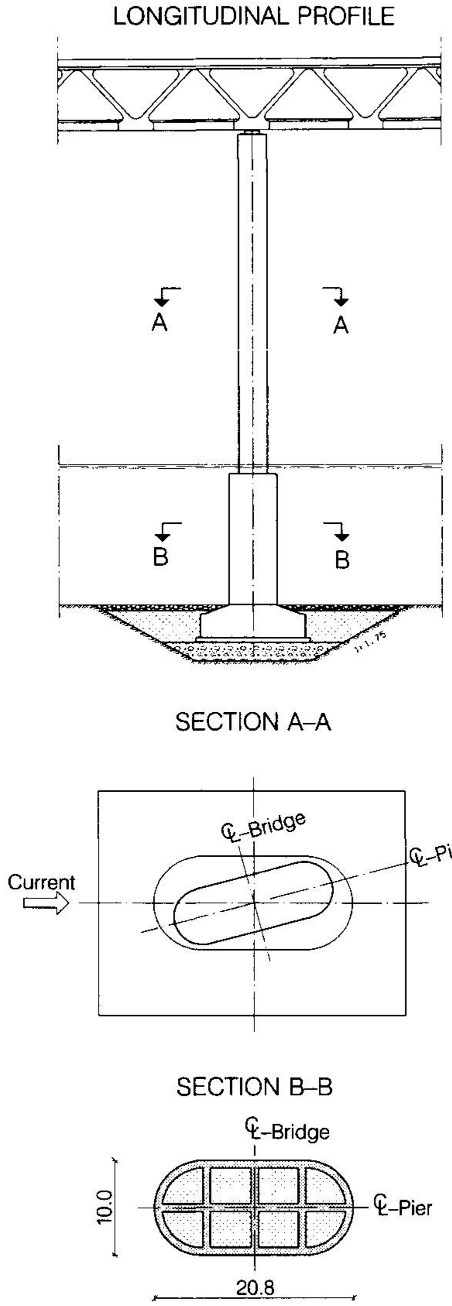


Fig. 5 : Approach bridge pier