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## **Great Belt's East Bridge – Tender Design of the Approach Spans**

**Appel d'offres pour les travées d'accès au Pont Est du Grand Belt**

**Ausschreibungsprojekt für die Rampenbrücken  
der Grossen Belt Ostbrücke**

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## **SUMMARY**

The paper describes the tender design for 4 km of approach spans leading up to the suspension bridge. The choice of concepts has been governed by the need for strength against ship impact and construction economy and reliability in fabrication of large units. Solutions with direct foundation of concrete caissons with bridge superstructures in concrete and steel have been elaborated for tender purpose.

## **RESUME**

L'article décrit le projet d'appel d'offres pour les 4 km de travées d'accès au pont suspendu. Le choix des solutions a été guidé par les exigences relatives à la résistance aux chocs de bateaux, l'économie de l'ouvrage et à la fiabilité de grands éléments préfabriqués. Des solutions avec fondations directes sur caissons en béton et superstructures en béton et en acier ont été retenues pour l'appel d'offres.

## **ZUSAMMENFASSUNG**

Der Artikel beschreibt das Projekt der 4 km langen Rampenbrücken zur zentralen Hängebrücke. Die gewählten Konzepte wurden von der Forderung nach Schiffsanprallwiderstand, der Ökonomie und der Ausführungssicherheit bei der Fabrikation und Montage der grossen vorgefertigten Elemente beeinflusst. Lösungen mit direkt fundierten Betoncaissons sowie Brückenträger in Beton und Stahl wurden für die Ausschreibung ausgearbeitet.



## 1. PREAMBLE

The Great Belt Fixed Link is the largest construction project undertaken in Denmark to this date. Various aspects of the project is dealt with in other articles at this symposium including a key note article and lecture on the the long span suspension bridge.

This article describes the design of the two approach bridges leading from Zealand and from Sprogø up to each end of the suspension bridge.

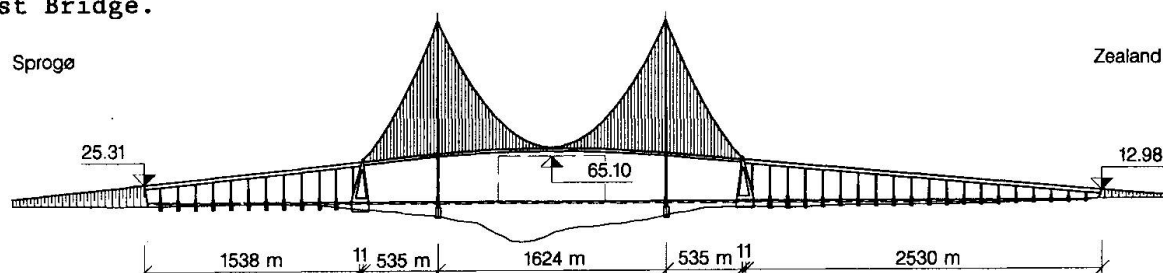
At the time of writing tenders have been submitted by 7 consortia based on tender design and tender documents elaborated from September 1989 to May 1990 by the consultant joint venture of Cowiconsult, B.Højlund Rasmussen and Rambøll & Hannemann.

The evaluation of the tenders will select the cost optimum solution during the early months of 1991 and a construction contract is planned to be awarded mid 1991.

## 2. FUNCTIONAL REQUIREMENTS

The approach bridges have to gap a bridge length of 4 km divided in 2 sections: the eastern approach of 2530 m length and the western approach of 1538 m.

4 lanes of motorway and two emergency lanes are carried from the bank of Zealand 13 m above the sea climbing 2 percent to allow 65 m clearance under the main suspension bridge span and then descending 2 percent ending 25 m above the sea. The bridge lands on a protruding embankment leading to Sprogø island and the West Bridge.



The East Bridge

Traditional bridge loads from the traffic, the wind, the waves and current, ice loading etc. have played a minor role in the determination of the most feasible concept for the 4 km of approach bridges. Two different and counteracting considerations have dominated the choice: the design against the navigational hazards and the requirement of an unchanged exchange of water through the Great Belt.

Located at the international navigation route with 20,000 vessel passages north/south each year, due allowance for the effect of ships in a mismanoeuvre or in stray must be given. Comprehensive collision studies for the purpose of design against this risk have been performed as also reported at the symposium.

The studies have developed a probabilistically based set of design criteria for the required impact resistance of the bridge piers. The criteria reflects the probability of a ship impact depending on the distance from the marked navigation route by decreasing the impact vessel size with increased distance. Nevertheless the ship impact is the governing load criterion for all piers.

The construction law for the link imposes that any blocking effect of bridge piers or embankments in the Belt must be compensated by dredging of the sea bed so as to achieve an unchanged water exchange to and from the Baltic Sea.

For the bridge piers the deepening of the Belt leads to deeper foundation, but more severe is the possible access by stray ships of larger draft and impact on the bridge piers. The natural protection of the structures from the sea bottom is to a certain extent removed.

### 3. CONCEPT STUDIES

The offshore conditions of the bridge site are thought to favour a maximized production on shore and minimum critical path time on the sea. The selffinancing scheme of the Link adds extra focus on the requirement to completion on time and on budget. Therefore, the design has focused on repetitive prefabrication of maximum sized units.

The optimization of the span lengths pointed at fairly large spans mainly due to the ship impact requirement. The heavier reactions on the piers from the larger spans is beneficial for the piers since a larger dead weight creates a larger ship impact resistance. Furthermore, fewer pier means lower probability of a ship hitting a pier and therefore the individual piers may be designed for a lower impact force. For the tender design 124 m concrete spans and 168 m steel spans were chosen.

For both types of superstructure continuous girders with expansion joints only at the ends were chosen. Lateral forces on the superstructure are transferred to the individual piers while longitudinal forces are resisted by a number of centrally placed piers.

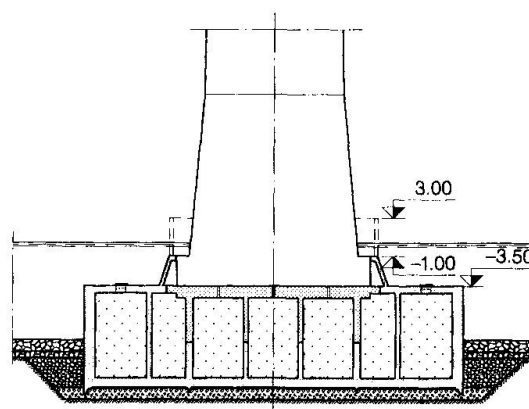
In addition to the tender design solutions described below, composite steel/concrete superstructure concepts were developed. Although an equally competitive economy was found in such a solution, it was decided to limit the tender designs as referred. The tenderers have, however, been free to propose hybrid solutions if they would find it competitive for their offer.

### 4. SUBSTRUCTURES

#### Design Concept

The approach span piers have been designed for impact from vessels ranging from 4,000 dwt near the abutment up to 60,000 dwt close to the main bridge anchor blocks. The design impact load from a 60,000 dwt vessel hitting at a speed of 10 knots is 336 MN.

The soil conditions favour direct foundation. A thin layer of sediments covers the heavily pre-consolidated till clay ( $C_u = 250 \text{ kN/m}^2$ ). A content of large boulders in the clay may prevent penetration of caisson walls and steel skirts into the clay.



Pier caisson and pier shaft

The seabed level is between level -3 m and -10 m. Due to the dredging works most of the piers are designed for seabed levels about -9.5 m.

Certain aspects are similar to those governing the design of concrete platforms in the North Sea.

- Large horizontal forces causing risk of sliding of the foundation
- Good soil conditions for direct foundation
- Preference of prefabrication at an on-shore site

The chosen concept for the piers is in fact an off-shore concept with a large bottom caisson placed on a prepared bed of crushed stones and grouting of the void between the bottom slab and the bed. The caissons can be prefabricated in a dry dock and towed to the site for placing.



The dead load of the superstructure, the pier shaft and the caisson together with the mobilization of the passive earth pressure on the caisson constitute the principal factors which can prevent the sliding of the foundation when hit by a vessel.

In order to achieve weight without increase of the dimensions of the caisson, heavy fill of olivine or iron ore shall be filled into not only the caissons but also into the pier shafts.

The largest caissons are 40 x 44 m with a height of 12 m. The thickness of the outer walls is 900 mm in order to resist local impact.

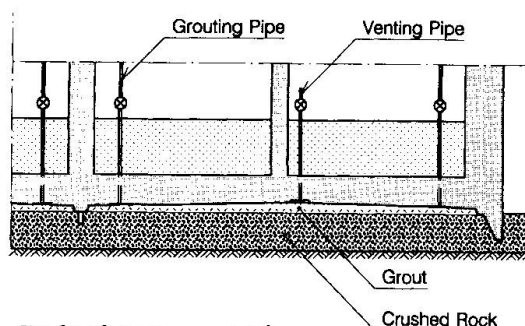
The top section of the caisson is designed to suit three purposes during the installation

- To give the caisson a floating stability during lowering and placing
- To admit adjustment of tolerances for the placing of caissons (200 mm) and tolerances for the casting/placing of pier shafts (20 mm)
- To provide a dry working area inside the upper external walls when used as a temporary cofferdam

Whereas the top level of the bottom caisson is lowered to -3.5 in order to allow passage of small vessels, the top section in level -1.0 is only extended about 1.5 m from the root section of the pier shaft. Outer walls of the top section from -1.0 to +3.0 m are to be demolished after finishing of the pier shaft.

The weight of pier foundations designed for smaller ship impact allows the use of other working methods, i.e. a barge crane for transport and installation.

Underneath the caissons grouting shall ensure a uniform bearing pressure in order to prevent deformations and cracks in the large caissons of limited height. The 150 - 250 mm void between the screeded stone bed and the bottom slab shall be filled with a self levelling grout. The void is divided into 150 - 200 m<sup>2</sup> compartments by skirts.



#### Aesthetical Considerations

The design of the pier is the result of aesthetical and technical considerations in good harmony.

The requirements to resistance against ship impact on the pier shafts and the superstructure means that the root section of the pier shaft needs to be rather large. Also, a desire to provide a volume for ballast above sea level has resulted in the design of the pier shafts of which the upper 2/3 slope 1:60 and the lower third is of pyramidal shape and slopes 1:6 and 1:11. As for the pylons, no part of the caisson should be visible above water level. This characteristic shift in slope is repeated in the design of the suspension bridge towers and all substructures for the East Bridge are thus in a harmony which reflects a robustness against impact, without appearing heavy or solid.

The arrangements are established in fruitful cooperation with the aesthetical consultants Dissing & Weitling.

#### Ship Impact Analysis

The design basis defined by the ship collision study gave two different ship impact load cases; one case covering the ultimate impact for which limited displacements of the pier are allowed and one case covering the smaller, but more frequent ship impacts where no displacements are allowed.

Displacement shall in the ultimate impact case be limited so that the reopening of the bridge to traffic after a short repair period is possible. This criterion has been converted into maximum translocations and rotations of the pier foundation depending on the type of superstructure.

The ultimate ship impact case turned out to be governing for the dimensions of the pier caissons and the pier shafts. A special computer programme was developed in order to simulate the dynamic behaviour of the pier during an impact of a vessel up to 60,000 tons dead weight.

This programme performs a "time-history" analysis of the impact taking a number of factors into account:

- The force deformation curve for the particular ship
- The time dependant properties of the subsoils including friction in the foundation level as well as passive earth pressure on the foundation sides
- The dynamic response of the structure including the effect of the stiffness of the superstructure and the adjacent piers

The programme solves the force equilibrium in time steps small enough to avoid instability in calculation sequences, and the result includes maximum deformations, displacements and sectional forces in the structure during and after the impact.

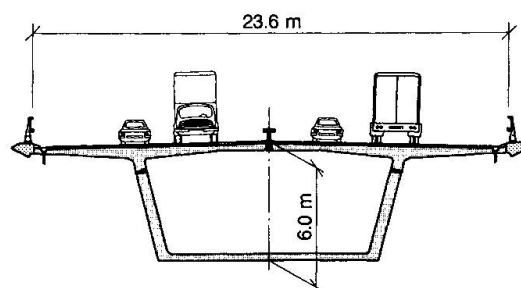
The programme proved to be useful during the optimizations of the different types of piers.

## 5. SUPERSTRUCTURES

### Concrete Girder

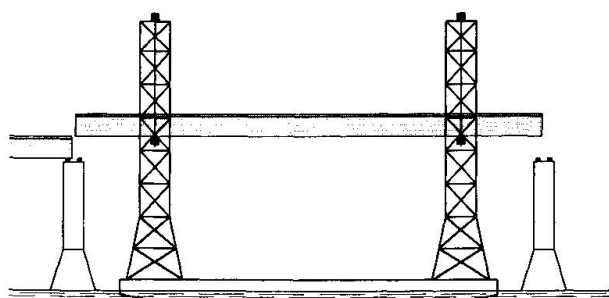
The concrete approach spans comprise 124 m identical spans with the exception of the end spans which are 112 m at the abutments and 62 m at the anchor blocks at the transition to the suspension bridge.

The bridge girder is designed as a continuous single prestressed box girder with cantilevered deck. The depth is constant, 6,0 m, and the width of the bridge deck is 23.6 m.

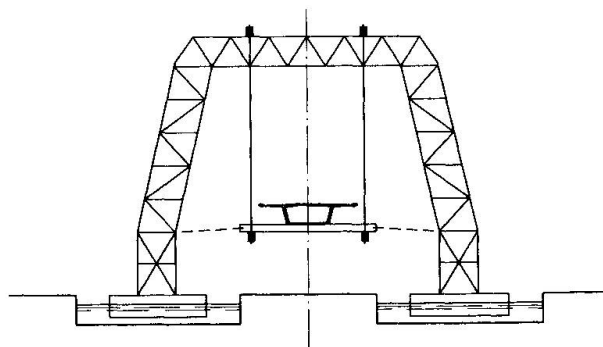


Cross section of concrete girder

The tender design is based on prefabrication of girders in span long elements cast and prestressed on a dedicated prefabrication yard near the site. The girders are assumed transported to the final location, e.g. by means of a large catamaran crane which also has the capacity to lift the girders into position on the piers.



Possible erection method





Alternatively the girders may be transported to the site on a barge and erected by means of a large off-shore crane or by means of derrick cranes placed on the pier tops.

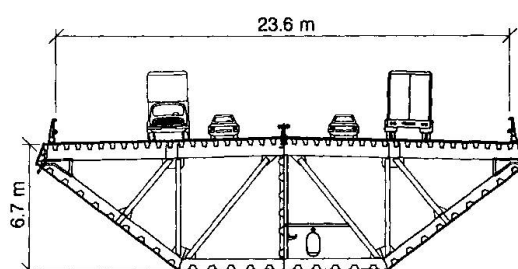
These erection principles involve large lifting weight, about 7,000 tons, combined with an installation height above 50 m and fairly shallow water at the outer spans. It is therefore necessary to dredge a temporary access canal along the bridge line in order to operate a floating crane in this area.

Despite these complications, the spanwise erection method is still found competitive compared to other methods, e.g. segmental free cantilever erection or spanswise in-situ casting on moveable scaffolding.

#### Steel Girder, Solution

The span length of the steel approach spans is 168 m with the exception of the end spans which are 135 m and 119 m at the abutments and 62 m at the anchor blocks.

The bridge girder is designed as a closed steel box girder with a central longitudinal bulk head. All stiffeners on the straight steel panels are placed internally in the box girder. The result is a smooth external surface which facilitates painting and easy maintenance.



Cross section of steel girder

The paint system to be used on the outside surfaces is a conventional one, consisting of a minimum 3-layer coating with a total thickness of 250 micron.

The inside of the box girders is not painted, but protected against corrosion by dehumidification. Each approach bridge is divided in interior sections corresponding to 4 or 5 span lengths closed at each end by a diaphragm with airtight doors. Each section operates one dehumidification plant.

The tender design is based on fabrication of girders in full span length on shore and transport of the girders on a dedicated barge to the final location.

The 1900 tons sections may be transported in low position on the barge and lifted upon arrival at the pier position.

The girders may be lifted by various methods:

- One or two floating cranes
- One floating crane and one derrick crane positioned at the end of the already erected girder
- A jack-up system arranged on the transportation barge

#### Aesthetical Considerations

For both the concrete and the steel approach span solution a constant construction depth has been chosen for the superstructure. This confirms to aesthetical preferences because a constant depth is in harmony with the complete East Bridge for which straight lines characterizes the girder, the towers, the anchor blocks and the piers.