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Great Belt East Bridge 1624 m Suspension Bridge Substructure

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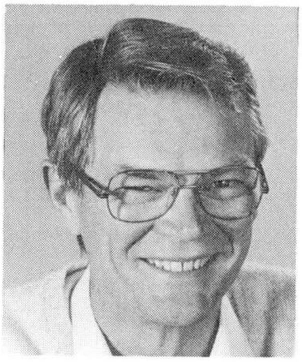

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Summary

This paper describes some of the important aspects related to the design and executing of the substructure of the 6.7 km long East Bridge in the Great Belt Link. All caissons for the bridge are performed as prefabricated elements. This construction method appears to have economical and technical advantages because the dimensions of several elements are identical and it is possible to use a very appropriate foundation method on stonebeds. The ship impact has a major influence on the design of the substructure as well as the superstructure.

1. Introduction

This paper describes some of the most interesting technical aspects related to the design and the construction of the substructure to the 6.7 km long East Bridge in the Great Belt Link. The main bridge is a suspension bridge with a main span on 1624 m and two side spans on 535 m. The length of the approach bridges is 2530 m and 1538 m on east and west side of the main bridge. The 19 pier shafts in the approach bridges and all caissons in as well the main bridge as the approach bridges are prefabricated in Kalundborg 30 nautical miles from the bridge site. The design of the East Bridge was performed by CBR, a joint venture between COWI and RAMBØLL Denmark.

2. Design Assumptions

2.1 Safety aspects

The design life for the bridge is 100 years. The design philosophy is based on limit states in accordance with the Danish codes of practice. In the ultimate limit state the required safety level is in principal achieved by means of the partial safety factors indicated in Table 1. The safety factors specified in Eurocodes are indicated in brackets.

Table 1. Partial safety factors

Material	Partial safety factor	Load	Partial safety factor
Concrete	$\gamma_c = 1.9$ (1.50)	Permanent load	$\gamma_G = 1.0$ (1.35)
Reinforcement	$\gamma_s = 1.5$ (1.15)	Variable load	$\gamma_Q = 1.3$ (1.50)

The fundamental differences between the safety factors in the design basis for the East Bridge and the safety factors in the Eurocodes are:

- The ratio γ_Q / γ_G is in Eurocodes $= 1.11$ and in the design basis for the East Bridge $= 1.3$
- The safety factor on permanent load is in the design basis = 1.0

The advantages with the safety factors used for the East Bridge are:

- The ratio $\gamma_Q / \gamma_G = 1.3$ in the design basis for the East Bridge ensure a more uniform safety level for different combinations of permanent and variable loads compared with the corresponding ratio in the Eurocodes.
- The partial safety factor $\gamma_G = 1.0$ on permanent load in the design basis for the East Bridge make it possible to make geotechnical analyses and analyses of interaction between structure and soil without difficulties. In the Eurocodes these analyses are very complicated because the partial safety factor on permanent load is different from 1.

Fig. 1: East Bridge 1998

2.2 Ship impact

With about 18.000 vessels passing the bridge each year ship impact has been considered as a very important load case. Probabilistically based design criteria have been set to define the required impact resistance of the bridge piers. The influence from ship impact on the piers in the approach bridges depend on the seabed level. The piers in the approach bridges have been designed for impact from vessels from 4,000 DWT near the abutments to 60,000 DWT near the anchor blocks. The anchor blocks and the pylons have been designed for impact from vessels on 250,000 DWT. In all cases the design impact speed was 10 knots.
Local effects from ship impact were analysed by means of the theory of plasticity. In the analysis of global effects of ship impact from the above mentioned vessels limited displacements of the pylons and piers are allowed. By this it is possible to absorb considerable loads from ship impact compared with a purely elastic approach. For the pylons the allowable displacement in the longitudinal direction is 280mm. For the piers the allowable displacements are in the longitudinal direction 500 mm and in the transverse 200 mm.
The bearing capacity of the substructure related to global effects of ship impact was analysed by means of programs ABACUS and SIAS were the interface between soil and structure was assumed having an ideal-elastic-plastic behaviour. In these calculations the load-deformation curves for the ships as well as the time history load aspects during the ship impact was taking into account. The analysis during ship impacts was performed with a complete analysis for each 10^{-4} sec during the impact.
The analysis of the piers in the approach bridges was carried out by taking into account the influence from the superstructure, which in this load case acts as a horizontal support. Though the stiffness of the superstructure is rather low compared with the stiffness of the piers it appeared, that due to the dynamic effect of the ship impact a considerable part of the horizontal force from the impact was transferred to the superstructure. An analysis of ship impact without taking the dynamic effects into consideration would have been completely misleading.
All caissons in the approach bridges are of the same rectangular size. The magnitude of the loads from ship impact on the piers near the navigation channel is significant these piers are therefore protected against ship impact by means of artificial islands.

2.3 Ice Loads

Ice loads on the substructure due to drifting ice are considered as accidental loads, corresponding to a probability of occurrence on 2×10^{-5}.
The design of the substructure is performed based on the ice thickness and strength indicated in Table 2.

Table 2. Ice Thickness and Strength

Probability pr. year	Thickness (m)	Compression Strength (MPa)
0.1	0.42	1.93
0.01	0.63	2.35
0.00002	0.99	2.8

The compression strength indicated in Table 2 is valid for global analysis. The local loads, i.e. loads which are acting on areas smaller than 0.1 m^2, are determined by a crushing strength varying between 12 MPa and 2.8 MPa depending on the size of the contact area.
Compared with ship impact ice loads had only minor influence on the structure.

3. Foundation

The foundation method for all the prefabricated caissons is identical. After excavation to the required level a crushed stone material is placed and screeded at the foundation level, whereupon the caissons are placed on the stonebeds. The caissons are equipped with skirts which penetrates into the stonebeds. The contact between the caissons and the stonebeds is secured by grouting. The underbase grouting was performed after pre-testing and a full scale trial grouting. The characteristic compression strength of the grout was 5 MPa. The grout between the bottom slab and the stonebed ensure a smooth distribution of the stresses between the bottom slab and the stonebed, which is very important in order to reduce the amount of reinforcement in the bottom slab.

Each anchor block has a rectangular form with the length 121.5 m and the width 54.5 m. This base is divided into three parts a front pad of 41.7 m, a centre part of 39.1 m and a rear pad of 40.7 m. Only the front and rear pads are in contact with the stonebeds.

Several different geotechnical analyses were performed in relation to the anchor blocks as reported by T. Feldt (1996). These calculations and the FEM analysis of the anchor blocks proved that the stiffness of especially the centre part of the anchor blocks compared with the assumed stiffness of the soil had a major influence on the position of the reactions from the soil and the stress distribution between the bottom slab and the stonebeds on the rear and front pads of the anchor blocks. The soil conditions had therefore a significant influence on the internal forces in the anchor blocks.

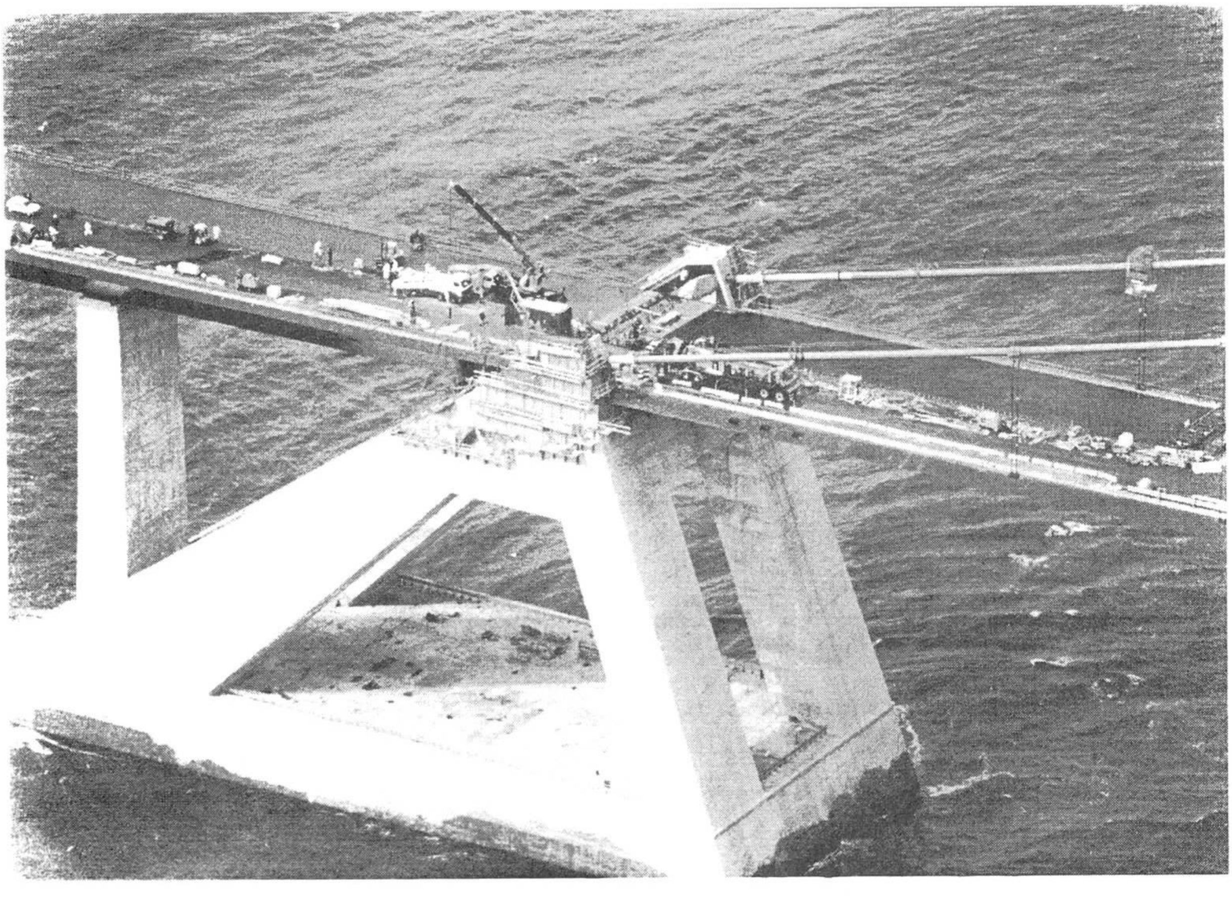

Fig. 2: Anchor Block

4. Anchor blocks. Massifs

The main cables in the suspension bridge are anchored in four concrete massifs in the rear part of the anchor blocks. The width and the height of each massif are approximately 10 m and 30 m respectively. In addition to the non prestressed reinforcement placed in three directions the massifs are from top to bottom prestressed with Macalloy bars in the same direction as the main cables. This prestressing consists of 444 Nos. of bars in each massif corresponding to a pressterssing force on approximately 470 MN.

5. Ballasting of Caissons

All caissons are ballasted with sand or olivine. Olivine is a heavy sand with a high content of silica the dry unit weight when compacted is approx. 24 kN / m^3 .
The pier caissons in the approach bridges were entirely filled with olivine ballast, while the olivine fill in the pier shafts was determined depending on the soil conditions and the horizontal forces mainly from ship impact to be transferred between the caisson and the stonebed.
The anchor blocks are ballasted with olivine in the rear part where the main cables are anchored in the concrete massifs, while the front and centre part of the anchor blocks are ballasted with sand.
The design assumptions in relation to the soil pressure on the walls from the ballast have a significant influence on the internal forces in the anchor blocks. Based on model tests and FEM calculations performed in relation to the design of the West Bridge it was concluded to calculate the soil pressure from the ballast by means of the rest pressure theory because the silo theory seems to be uncertain taking into account the long term behaviour and the properties of the submerged fill.
The knowledge about this item seems to be limited, though it has a significant influence on the structure.

6. Quantities

The quantities of concrete, reinforcement and prestressing steel are indicated in Table 3. The reason for the relatively low amount of reinforcement in the in-situ cast anchor blocks is, that the concrete massifs where the main cables from the suspension bridge are anchored are heavily prestessed with approximately 600 tons of Macalloy bars. Thus it has been possible to reduce the ordinary reinforcement in the 36,000 m^3 concrete massifs to 3,500 tons corresponding to a reinforcement density of 95 kg/m^3 .

Besides the massifs the following elements in the anchor blocks are prestressed, the bottom slab, the slab in level 10m, some of the vertical walls in the centre part of the prefabricated caissons, the walls in the cantilevered splay chamber legs and the cross beam supporting the superstructure.

In the Pylons the bottom slab, the slab in level 21m and the two cross beams are prestressed.

Table 3. Quantities of concrete and reinforcement

Structural element	Quantity		Reinforcement Density	Prestressing Steel
	Reinforcement tons	Concrete m^3	kg/m^3	tons
Anchor Blocks Pre-fab Caissons[1)]	6,600	38,000	174	870
Anchor Blocks In-situ[2)]	7,800	65,000	120	750
Pylons Pre-fab Caissons[3)]	3,700	23,500	157	150
Pylons In-situ[4)]	11,700	77,000	152	190
Approach spans 19 Piers and Caissons[5)]	8,300	47,000	177	0

[1)] Dimensions 121.5 x 54.5 m height 16.0 m Foundation level -12.0 m.

[2)] Level of Bearings 53.0 m.

[3)] Dimensions 78.3 x 35.2 m height 20.3 m Foundation level -23.8 m.

[4)] Level of top of pylon leg 254.0 m.

[5)] All piers except one are prefabricated consisting of three elements a caisson, a lower and an upper pier shaft. The foundation levels are from -5.5 m to -12.0 m. The level of the bearings for the superstructure is from 7.6 m to 46.0 m.

7. References

Feld,T. Sørensen, C.S. and Pedersen, F. (1996). *Structure-Foundation Interaction on the Storebælt Link East Bridge. Proc. of the 15th IABSE Congress in Copenhagen pp 809 - 818.*