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Autor: Kalhauge, Erik / Haas, Georg / Ostenfeld, Klaus

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VIII

Great Belt Bridge — Tender Projects

Le Pont de Grand Belt — Projets d'appels d'offres

Brücke über den Grossen Belt — Ausschreibungsprojekte

ERIK KALHAUGE

Chairman of the Board
Cowiconsult, Consulting Engineers and Planners AS
Copenhagen, Denmark

GEORG HAAS

Consulting Engineer
Cowiconsult, Consulting Engineers and Planners AS
Copenhagen, Denmark

KLAUS OSTENFELD

Department Head
Cowiconsult, Consulting Engineers and Planners AS
Copenhagen, Denmark

SUMMARY

Record breaking cable stayed and suspension bridge tender designs have been prepared for the Great Belt Bridge in Denmark. The development of the two main span concepts is presented as well as the special equipment incorporated to satisfy the very strict deflection criteria for the heavy duty double track railway. A comparison of cable stayed and suspension bridge types for very long span bridges is made, on the basis of the Great Belt Bridge tender projects.

RESUME

Les projets d'un pont à haubans et d'un pont suspendu avec portées records ont été préparés pour l'appel d'offres du Pont du Grand Belt au Danemark. Le développement des deux projets est présenté, ainsi que les dispositifs spéciaux pour satisfaire aux critères de rigidité extrêmement stricts pour le chemin de fer à double voie. Une comparaison de ponts à haubans et suspendus pour de très grandes portées a été faite sur la base des projets du Grand Belt.

ZUSAMMENFASSUNG

Für die Ausschreibung der Brücke über den Grossen Belt in Dänemark wurden Projekte für eine Schrägseil- bzw. Hängebrücke mit sehr grossen Spannweiten ausgearbeitet. Die Entwicklung der zwei Brückenlösungen wird erläutert sowie die speziellen Einrichtungen erwähnt, welche die sehr restriktiven Deformationskriterien für die schweren Eisenbahnlasten erfüllen lassen. Es wird ein Vergleich von Schrägseil- und Hängebrücken aufgrund des Grossen Belt Projektes angestellt.



1. INTRODUCTION

Tender documents have been prepared for the high level bridge across the East Channel of the Great Belt. A state agency, "Statsbroen Store Bælt" was established by the Danish Ministry of Public Works for the overall management of the Great Belt Bridge connection, whereas most of the design work was carried out by a consortium of three consulting engineering firms, Cowiconsult AS, B. Højlund Rasmussen, and Rambøll & Hannemann A/S [1].

Several state-of-the-art investigations (ship impact, fatigue, wind loads etc.), were made before the project was temporarily stopped by the Government in August 1978 for a period of 4-5 years, just 1½ month short of issuing tender documents and call for bids.

The selected 2 record breaking navigation span concepts for the East Bridge – a 780 m cable stayed solution, and a 1416 m suspension bridge solution designed for a heavy duty double track railway and a 6 lane motorway – incorporate however several interesting features which are described in the following.

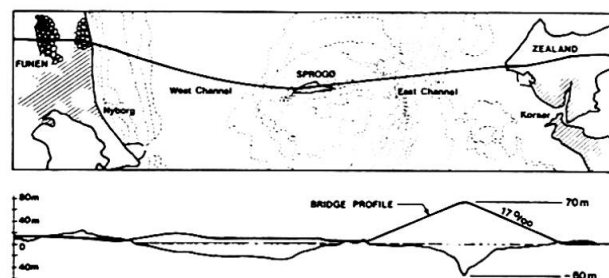


Fig. 1 Plan and profile.

2. DESIGN REQUIREMENTS

The safety and comfort of the railway imposed very strict deformation criteria. The relative vertical rotations at the expansion joints were limited to 4 o/oo for high speed trains (up to 220 km/h) and 6 o/oo for freight trains. Horizontal bends should be max. 1 o/oo and 2 o/oo respectively, and torsional rotation was generally limited to max 15 o/oo with gradient of max. 0.3 o/oo per m. Radius for load induced curvature should be kept above 10.000 m.

The navigation clearances, established after an international notification, should be either 2 separated channels ea. 325 m in width, or alternatively one channel 750 m wide, both with a free vertical clearance of 62 m and water depth min. 20 m. This would allow the biggest oil tankers of 250.000 dwt or even more to pass.

Equivalent static ship impact forces of up to 400 MN were established for the main pier design [2].

3. TENDER DESIGN DEVELOPMENT

3.1 Cross-section

Comparative studies indicated an economic advantage (about 5%) of a double deck structure with the railway at the lower level. This configuration also offered

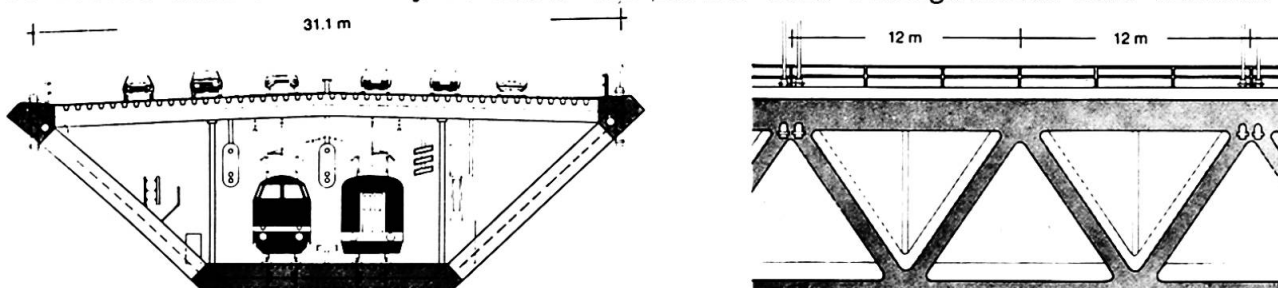


Fig. 2 Cross-section and elevation of stiffening girder.

operational advantages (separation of high speed trains from road traffic, possibility for reversing of traffic lanes, minimum climb of trains etc.).

The section is composed of a streamlined closed railway deck box member and an orthotropic roadway deck with edge box girders, interconnected by closed box diagonals. This cross section combines optimum lateral load transfer to the 2 suspension planes with adequate torsional and longitudinal rigidity, as well as very good aerodynamic performance.

The interior of the box members was to be dehumidified by air dehumidification equipment. Such equipment has successfully been in operation in the Little Belt suspension bridge box girder for 10 years and eliminates the need for interior painting [4].

Main span concepts	Approx. relat. constr. cost (%)
	122
	120
	120
	129
	126
	125
	123
	110
	120

Fig. 3 Relative constr. cost East Bridge.

3.2 780 m cable stayed solution

Several studies and cost comparisons of 2 span schemes with moderate spans, indicated the desirability of long single span bridges to reduce ship collision risk and eliminate the construction risks associated with very deep water intermediate piers.

The shortest possible single span satisfying the horizontal navigation clearance, a 780 m span, initially had a rather conventional configuration with short 230 m side spans and concentrated high capacity back stays.

During the refinement phase the back stay cables were distributed over the adjacent approach span.

Such stay arrangement has the advantage of simplicity because of the use of single, low capacity and easily replaceable stays equidistantly anchored to the roadway stiffening girder. The fans of cable stays are symmetrical about the pylons and thus in balance for permanent and uniform loads. All points of anchorage of stay cables may be of similar concept due to modest cable forces. The selected multistay system is geometrically aligned in slightly inclined planes parallel to the pylon legs.

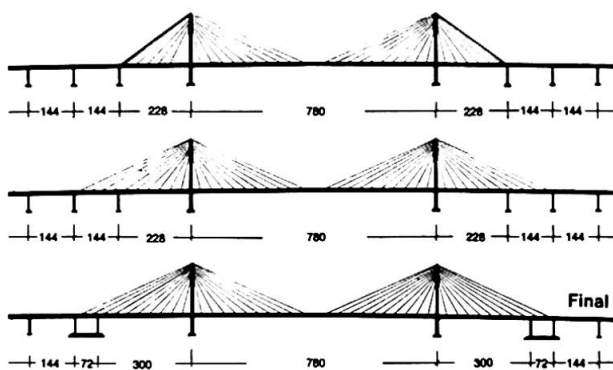


Fig. 4 Steps in cable stayed bridge development.

The intermediate anchor piers were moved closer to the adjacent approach piers to reduce deformations, and permit a common sand island ship collision protection.

Concrete pylon structures were selected for cost reasons, and because their mass



contribute advantageously to the ship collision safety of the bridge. Foundation conditions in Great Belt are excellent, and permit spread footings to be founded directly on the stiff moraine clay a few meters below the sea bottom.

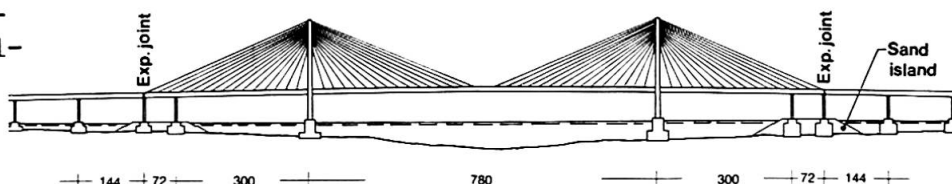


Fig. 5 Cable stayed bridge solution.

The cable stays are designed as prefabricated parallel wire cables using between 152 and 350 $\phi 7$ mm wires (ult. capacity max. 21.6 MN) enclosed in polyethylen pipes grouted with cement grout. Preliminary fatigue tests have been conducted at the Technical University of Denmark with stay models of parallel 7 mm wires anchored in Hi-Am heads, and with parallel 15 mm prestressing strands anchored by ordinary wedge prestressing anchorages combined with transition trumpets. The tests have indicated, that alternate anchorage systems exist, which, with today's technology, have adequate fatigue resistance for railway bridges [3]. Further testing was contemplated during the final design phase.

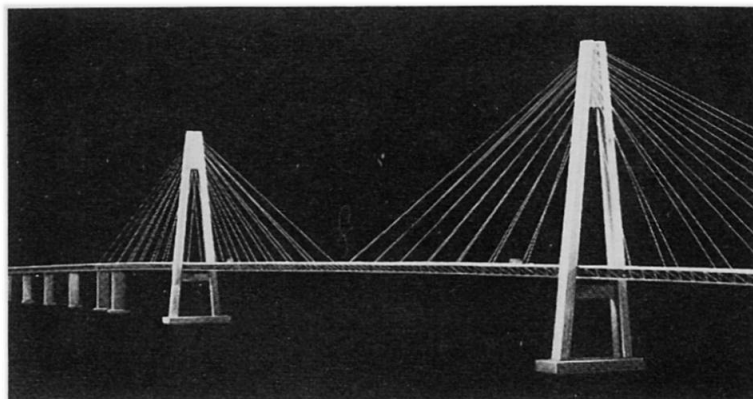


Fig. 6 Cable stayed bridge model.

3.3 1416 m suspension bridge solution

The Great Belt, being the only deep water connection between the Baltic and the North Sea, is heavily navigated by very large ships, and major ship collisions will, in spite of the required pier strength, imply a considerable risk for both the bridge and involved ships as well as for the general ecology in the area. This risk may be reduced significantly by a substantial increase of the main span. The piers on moderate water depths may be effectively and economically protected by ship deviating sand islands.

Very long span cable stayed designs are outside past experience and proved of higher cost; but, encouraged by the very large rail carrying suspension bridges (up to 1780 m) planned by the Honshu Shikoku Bridge Authority in Japan, feasibility studies were made for long span suspension bridge solutions for the Great Belt.

Initially it was believed necessary to stiffen the conventional suspension span by additional cable stays, similar to e.g. the famous Brooklyn bridge and the future provisions for the Tejo bridge. However the two different suspension systems proved poorly compatible at high live loads due to different behaviour and stiffness, leading to a rather inefficient and costly system.

For a conventional suspension bridge scheme the lower limit for main spans was determined to 1000 - 1200 m. Shorter spans would reduce the main cable tension to levels where the traffic load induced curvature would generate excessive deformations of the stiffening girder.

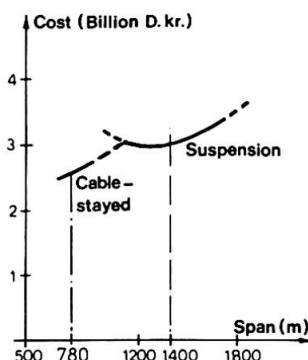


Fig. 7 Bridge costs.

Figure 1 is a schematic diagram of the bridge deck cross-section. It shows a long bridge deck with two main spans. The left span is labeled "Exp. joint" and the right span is labeled "Exp. joint". The deck is supported by piers. The cross-section shows a trapezoidal shape with a central pier. Dimensions are given in meters: 144, 108, 87, 360, 1416, 360, 87, 108, 144. A "Sand island" is indicated on the right side.

Fig. 8 Suspension bridge solution.

The deformations of the suspension bridge system are minimized by optimization of overall geometry and by incorporation of special equipment:

- The sag ratio of the main cables is slightly below the apparent economical optimum at $1/10$, and short side spans are selected for rigid horizontal support of pylon tops by the short, and almost rectilinear, main cables forming back stays.
- Continuous stiffening truss throughout the bridge, supported on double bearings 87 m apart on the anchor blocks.
- Fixed central node at midspan preventing relative horizontal movements of cable and stiffening truss, which would also be detrimental to the short suspenders.
- Incorporation of slow deflecting hydraulic dampers at the anchor blocks to prevent short term longitudinal displacement of the stiffening truss, without restricting slow temperature expansions. The dampers, comprising a system of double acting mutually connected hydraulic cylinders, are installed at the intersection of the inclined legs forming a trestle.

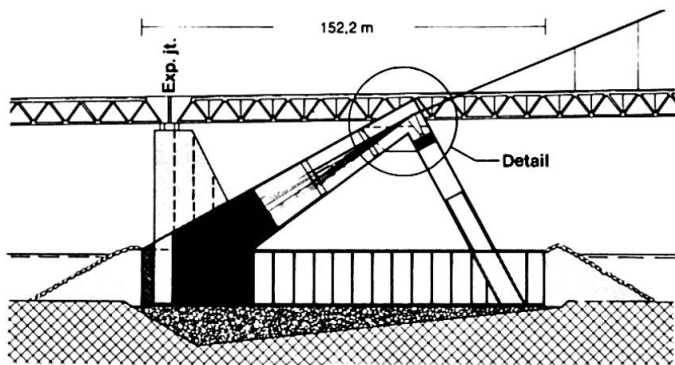


Fig. 9 Anchor block.

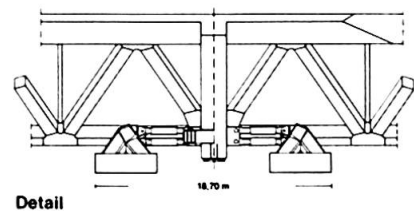


Fig. 10 Hydraulic dampers.

The dampers in conjunction with the central node reduces deflections for asymmetrical loads to about 2/3 of deflections without these provisions.

The main cables are designed as parallel wire cables erected alternatively as prefabricated strands with ea. 271 galvanized $\phi 5$ mm wires, or conventionally spun, at the contractors option.

4. COMPARISON OF THE SELECTED MAIN SPAN PROJECTS

The cost and technical investigations have justified the selection of both the



cable stayed and the suspension bridge solution. The location of the main piers and anchor blocks on reasonable water depths for the very long span suspension bridge is of course a major cost reducing factor.

The erection of a 1400 m suspension span is conventional and safe, employing conventional techniques pioneered more than 50 years ago for large American suspension bridges, and offers considerable flexibility as to sequencing of the different hoisting and assembly operations for the truss segments. The erection of a cable stayed span substantially longer than 800 m will require further development, in particular with regard to the stabilization of the long projecting cantilevers prior to closure.

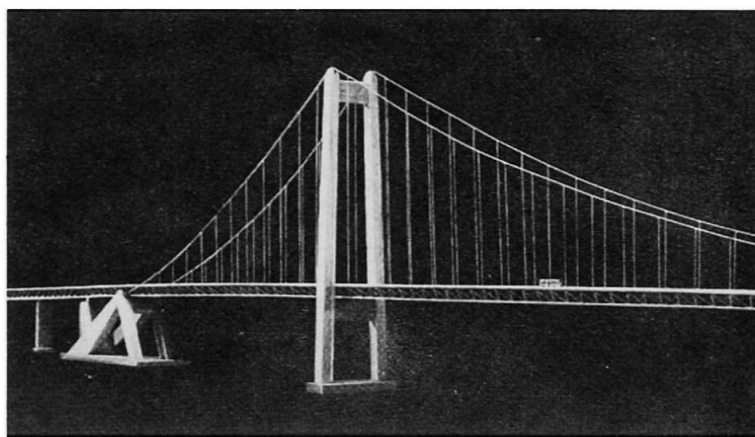


Fig. 11 Suspension bridge model.

Local failures of vital members in the stiffening truss caused by overloading, accidents, fire, sabotage etc., may be fatal for the axially loaded cable stayed bridge, as opposed to the conservative suspension bridge system, which is globally stable, even if complete truss sections are removed.

The main cables are of course not exchangeable in a suspension bridge, as cable stays should be, but the fatigue loads are modest and the durability of the wires has proved to be excellent in several existing, even very old, bridges.

5. CONCLUSION

Following the comprehensive studies made for the selection of the Great Belt Bridge tender projects, the authors believe, that long span suspension bridges in modern versions generally may be suitable and competitive even for heavy duty railways.

Although the stiffness of a cable stayed design naturally is greater, the stiffness of the long span suspension bridge is sufficient, in particular if deflection reducing systems are incorporated, as in the case of The Great Belt Bridge.

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