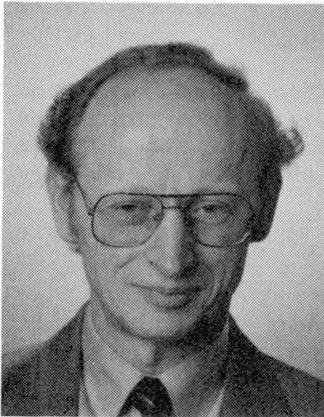# Suspension Bridge over the Eastern Channel of the Great Belt

Pont suspendu sur le canal oriental du Grand Belt

Hängebrücke über den Ostkanal des Grossen Belt

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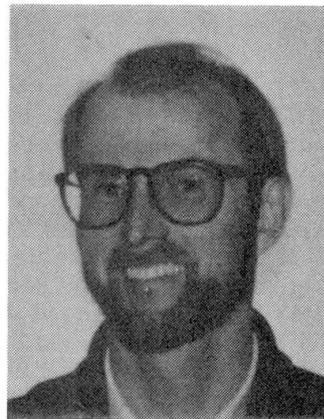
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SUMMARY

This paper focuses on the tender design of the world record 1624 m main span suspension bridge on the Great Belt Link. The navigation conditions must be maintained, and the construction must be executed with no effect to the environment. Main spans ranging from 900–1800 m with different safety provisions have been investigated, and construction costs compared. The overall favourable solution turned out to be the abovementioned bridge.

RESUME

Cet article décrit le projet d'appel d'offres pour le pont suspendu avec la travée principale la plus grande du monde (1624 m), un des éléments de la liaison du Grand Belt. Les conditions de navigation doivent être maintenues, et l'exécution des travaux doit être entreprise sans effets sur l'environnement. La portée principale s'étend de 900 à 1800 m, selon des investigations des mesures différentes de sécurité et après une comparaison des coûts de construction. La solution la plus favorable s'est avérée être le pont mentionné ci-dessus.

ZUSAMMENFASSUNG

Dieser Artikel beschreibt den Unternehmersentwurf für die Konstruktion der Hängebrücke mit einer Spannweite von 1624 m. Die Voraussetzungen für die Navigation müssen beibehalten werden, und die Konstruktion muss ohne Konsequenzen für die Umwelt durchgeführt werden. Spannweiten mit einer Länge von 900–1800 m mit verschiedenen eingebauten Sicherheitsmassnahmen wurden untersucht, und die Baukosten wurden verglichen. Die oben erwähnte Brücke erwies sich als vorteilhafteste Lösung.

INTRODUCTION

Through decades, more or less realistic projects have been elaborated for a fixed link across the Great Belt. 18 km wide, the Belt is part of the inland sea area, and divides Denmark's population and economy into two nearly equal halves. A fixed link will connect the capital of Copenhagen to the Continent with road and rail, and will upgrade the traffic infrastructure with related investments in a number of motorway stretches. Altogether a great leap forward to develop Danish trade and industry's competitiveness within the EEC.

The Great Belt Link may also be the first major step towards an improvement of the entire northern European transportation network. Negotiations are in progress to complete a fixed link between Denmark and Sweden, and a further connection from Denmark to Germany is a realistic possibility.

Organization

In 1986 the Danish parliament established a political agreement for construction of the Great Belt Link. The Link should comprise a double track railway to be opened for service in 1993, and a 4-lane motorway with emergency lanes to be inaugurated in 1996.

As the Great Belt is divided into two channels which are separated in the middle by the tiny island of Sprogø, it was decided to establish the fixed link in three major structures: A twin tube bored railway tunnel under the eastern channel, a combined rail and road bridge across the western channel, and a high level motorway bridge to span the eastern channel.

In 1987 a limited company, Great Belt A.S., was founded by the Danish State with the objective to design, construct and operate the Link. The construction works will be financed by loans. The Danish State Railways will amortize the debt concerning the railway link by annual payments to Great Belt A.S., whereas the expenditures for the road bridges will be covered by toll paid by motorists in rates at approximately the same level as the previous ferry fares.

This paper will focus on the 1624 m main span suspension East Bridge. Various aspects of the Great Belt Link are dealt with in other articles in this symposium including the design of the two approach bridges, altogether 4 km long, and leading up to each end of the main span.
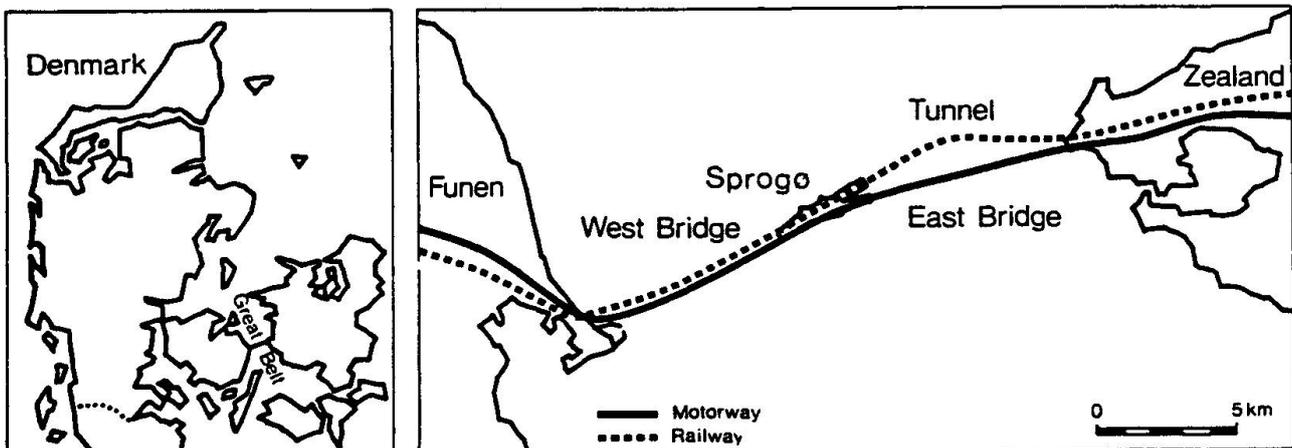
Fig. 1. The Great Belt Link.

World Record

The main span of 1624 m will hold the world record until it is surpassed by a Japanese 1990 m suspension bridge in the end of this decade. Both projects are interesting links in the chain of progress of bridges. Reports tell about primitive suspension spans as early as 200 BC in China, but apparently, the age of the suspended span with a horizontal travelway opened with the first days of the 19th Century.

The location of the first one was Jacob's creek in Pennsylvania. The bridge was completed in 1801. The inventor was James Finley, an American Justice of

Peace, who received a patent for his invention, and by 1808 had built some 40 bridges. All of these early attempts were flimsy and of relatively short span. In those days 90 m was a big span. Unfortunately, quite many collapses followed, and suspension bridges seem to have gone out of fashion for about 25 years in America because they were so prone to destruction by relatively light loads and winds.

Telford's famous Menai Straits Bridge with a span of nearly 190 m was completed in 1826, followed 8 years later by the Swiss Freiburg Bridge with a record span of 250 m. Many imposing bridges were built in the decades to come. One of them was the Tacoma Narrows Bridge which caused the great awakening for aerodynamic analyses when it was destroyed by a 20 m/s beam wind in 1940.

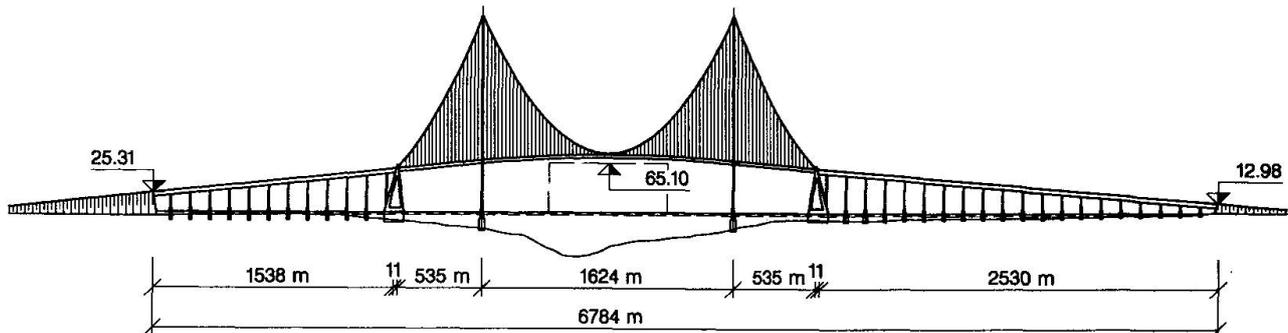*Fig. 2. The East Bridge will carry a 4-lane motorway with two emergency lanes.*

Aerodynamic analyses were the objective of the post Second World War bridges to be completed with still longer main spans and elegantly designed towers and girders, as we have in view for the future East Bridge.

FUNDAMENTAL REQUIREMENTS

Ship Traffic

International ship traffic between the Baltic Sea and the North Sea navigate the Route T which will be crossed by the East Bridge. Approximately 18,000 ships per year traffic Route T. In spite of a separation arrangement in north and south oriented channels, 61 ship accidents have occurred in the area since 1974, such as groundings, ship-ship collisions, and ship-lighthouse collisions.

A comprehensive investigation programme of the future interaction between the ship traffic and the planned bridge structures has been carried out. The objectives were to maintain the navigation conditions at the same level after the bridge is built, and to provide a probabilistic basis for bridge design against ship collision based on an accepted maximum risk of bridge disruption.

In all phases of planning and design adequate and consistent safety considerations are carried out, ensured through a safety management system. Defined Safety Objectives and Responsibilities concerning ship collision and other risks have been established in the form of quantitative risk acceptance criteria for the risk of disruption of the traffic for a long period, and for the accident risk to users of the Link.

Environment

The environmental design criteria are set up in the Public Works Law for the Fixed Link across the Great Belt: "The construction shall be carried out so that when completed, the marine environment in the Baltic will remain unchanged, and the water exchange through the Great Belt is guaranteed."

This criteria implies that the construction must be executed with no effect to the water flow through the Belt to the Baltic. It is called the "Zero Solution", and is achieved by increasing the cross section of the Great Belt by dredging. Due to short ramps, long spans, and hydraulic shaped piers and pylons elaborated in the design, the blocking effect to be compensated for is only about 0.5% of the total flow to the Baltic Sea.

The environmental considerations are treated in detail at the IABSE symposium in May 1991 at Hotel Nyborg Strand in Denmark.

SEARCH FOR THE RIGHT SOLUTION

Outline Solutions

Many solutions have been studied through the history. The present work commenced with an intensive study of four alternative main span bridge concepts elaborated by the Danish consultant joint venture of COWIconsult, B. Højlund Rasmussen and Rambøll & Hannemann with subconsultants Leonhardt, Andrä und Partner and ACER Freeman Fox:

Type of bridge:	Main span:
Cable Stayed Bridge	916 m
Cable Stayed Bridge	1204 m
Suspension Bridge	1448 m
Suspension Bridge	1688 m

The outline solutions are illustrated in Figure 3.

Ship Collision Investigations

Manoeuvering simulations were performed by use of computer based simulators, and included two ships in loaded and ballasted conditions, a 200 m long 40,000 DWT car carrier, and a 300 m long 150,000 DWT tanker. The modelling of the manoeuvering behaviour included propulsion forces, rudder forces, effects from wind, currents, and water depths between keel and sea bottom.

Bridge spans from 800 to 1800 m were investigated in combination with navigation route alternatives ranging from the existing one with an angle of 68° with the bridge line, to a route perpendicular to the bridge line. The ships were navigated through the different bridge spans by pilots with up-to-date piloting expertise in the Great Belt.
The pilots concluded that:

- A bridge span of 1600-1800 m in the existing navigation route would not change the present conditions.
- A bridge span of 1400 m would maintain the present conditions provided the crossing angle be altered to 76°.
- A bridge span of 1200 m or less would reduce the navigation conditions considerably.

The pilot's evaluations were of significant importance in the clarifi-
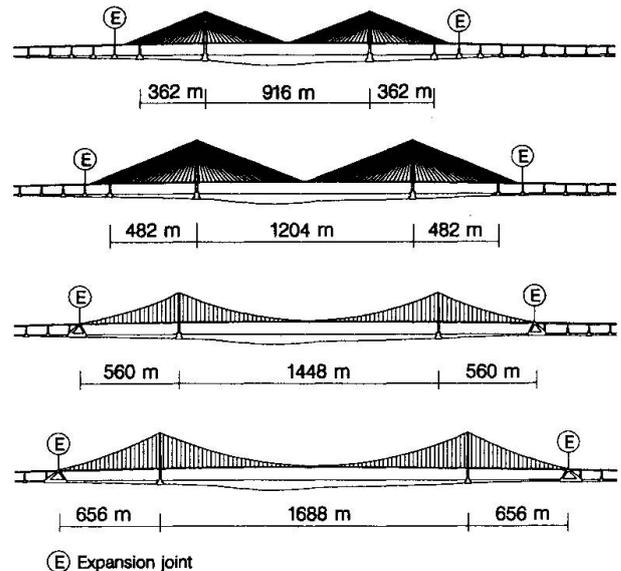
(E) Expansion joint

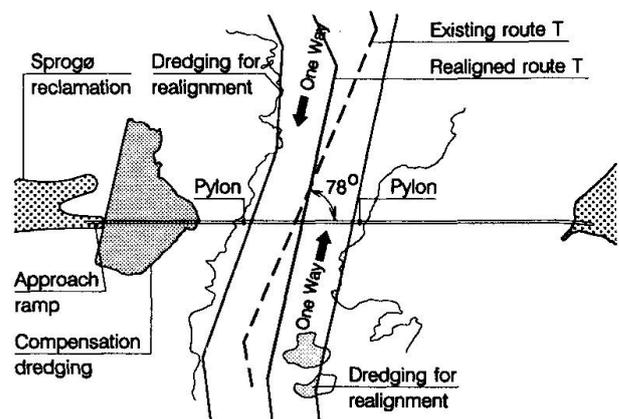Fig 3. The solutions investigated in the outline design.

Fig. 4. The existing and realigned Route T with dredgings for realignment, and compensation dredging at Sprogø to achieve the "Zero Solution".
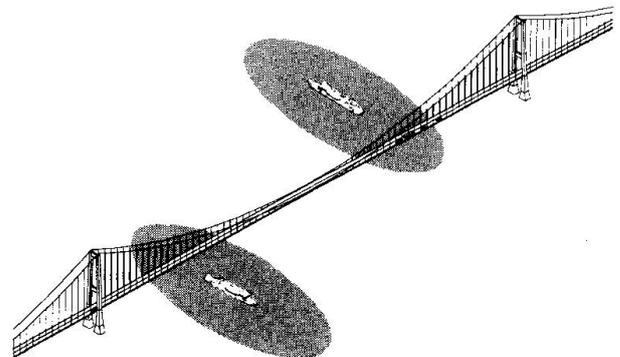

Fig. 5. Illustration of the domains of north and south going vessels.

cation and verification of the overall design requirements to the bridge arrangement. Experience gathered from bridges worldwide have confirmed these design requirements.

Observations of the distances which ships tend to keep to each other under different navigational conditions have been analyzed mainly by Japanese researchers, and generalized in terms of ship domain. These observations indicate that aversion manoeuvres normally are the result of ship encounters with overlapping domains.

New analyses elaborated by COWIconsult regarding recorded ship collisions with North American bridges showed a marked reduction of collision frequency for bridges with spans fulfilling the domain theory.

The required length of the navigation span was also studied based on the ship domain theory and the objective to avoid encounters with overlapping ship domains. The study concluded that a span length of about 1500 m would be needed in full agreement with the result of the manoeuvering simulations.

An improved ship-bridge collision model has been established. Based on ship traffic, bridge arrangement and bridge impact capacity, the model can estimate frequencies of ship-bridge collisions and bridge collapse due to ship collisions.

Requirements to bridge impact capacities have been established on a probabilistic basis using the above mentioned ship collision model. A more refined formulation of the design loads to be applied to the bridge structures in various collision situations has been facilitated by detailed Finite Element Method calculations.

Investigations of methods to reduce the risk of ship collision to the West Bridge have resulted in a decision to implement a Vessel Traffic Service system for the entire Great Belt area. Intended for the operational period of the bridges, the system will be able to give guidance to the ship traffic and detect whether aberrant vessels leaving the main route could endanger the bridges.

Altogether the investigations have provided basis for the following decisions:

- Length of the East Bridge main span 1624 m.
- Navigation route crossing the East Bridge will be straightened from a crossing angle of 68^0 to 78^0, the nearest bends will be located 2300 m from the bridge axis, and dredgings to a depth of 19 m for south going ships and 17 m for north going ships will be performed.
- Types and positions of navigation marks at the East Bridge.
- Impact strength requirements to the East Bridge structure.
- Implementation of a Vessel Traffic Service system for the Great Belt.

Special Requirements to Cable Stayed Bridge

Found in the navigation condition studies, the cable stayed bridges with main spans of 900-1200 m had an increased risk of ship collision. The overall most favourable protection proved to be subsea barriers, built as artificial reefs. They were cost competitive compared to structural strengthening of the bridge piers for higher impact loads.

The reefs had to be located on water depths up to 20-25 m, and were assumed to be constructed from till and post/late glacial sand and gravel excavated for the purpose of the "Zero Solution". Self-stabilization as has developed for the existing natural reefs was anticipated.

Construction of a 1204 m main span cable stayed bridge attracted considerable attention during the Outline Design, because erection of the main span would be a leap into the unprecedented range for cable stayed bridges by almost doubling the length of free cantilevered construction ever tried.

The governing design parameters were found to be static and dynamic wind effects. These effects would be accentuated during free cantilever erection, where the horizontal girder moment, due to lateral winds, would be enhanced by second order effects caused by the action of cable forces on the deflected girder. A satisfactory design for the bridge girder under lateral wind loading implied an increase of the width from 31 m to 36 m for the main span section.

In the side spans temporary piers were foreseen to stabilize the main span cantilever. In the main span no supports would be possible, due to the navigation channel.
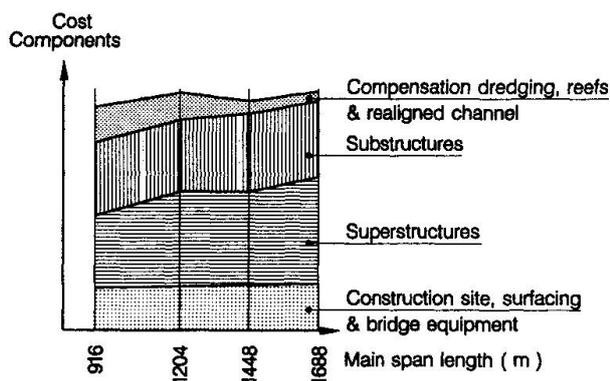
Comparison of Different Solutions

Fig. 6. Cost graphic.

Total costs for the bridge structures including their different safety providing arrangements were compared. Construction costs for the bridge increased naturally with main span lengths, primarily for the superstructure costs component. The costs of the substructures did not vary to the same extend due to a reduced number of piers and the more shallow water depths for foundation.

However, the increase in costs related to the main span length were fully outbalanced by the costs for safety providing arrangements such as artificial reefs and realignment of the navigation route. As a consequence, the total costs came out very equal. Any solution in the range from 900 to about 1400 m main span would lead to approximately the same total costs. A bridge with a main span of 1688 m was assessed to give a cost increase in the range of 5%.

Based on the assessment of almost equal costs, the final selection could be settled upon other benefits such as navigation safety, environmental advantages, related navigation risks, and extent of earthworks required in the sea bottom. Therefore, the longest span bridge was found to be the overall favourable solution, and a suspension bridge of 1624 m in a 78⁰ relocated navigation route was chosen for further elaboration in tender design.

TENDER DESIGN WORK

Design Basis

A dedicated design basis has been established due to the factual requirements in order to comply with:

- Risk acceptance criteria relating to accidental events.
- General requirements to adequate structural safety of long suspension spans.
- Aesthetical requirements.
- Environmental requirements.

The Design Basis has been adjusted to the current results of the ship collision study in order to define acceptable damage levels, design criteria and design loads.

Ice loading has been defined as accidental loads, and is added to the general risk level. Ice loads are of importance only to a few piers closest to the abutments.

Fig. 7. The architect's view of the East Bridge.

Environmental loads are initially in accordance with Danish codes, but whenever supplementing data are available for the conditions in the Great Belt, design parameters are derived in accordance with the principles for safety behind the codes.

Specifications of the extreme wind climate on the site are based on a study through ten years of continuous measurements from a 70 m high mast on Sprogø island. The mean wind speeds are slightly diminished compared to standard code figures, whereas the turbulence level is increased to maintain the level of gust wind speeds.

Within the past year, the wind monitoring programme has been extended to cover detailed measurements of turbulence and cross wind coherence.

Reliability Studies

Prior to tender design, a special task group was initiated to elaborate reliability studies of the primary elements of cable supported bridges. The studies were based upon probabilistic modelling, and the design recommendations were to some extent based upon classical Bayesian decision analyses.

Probabilistic modelling of traffic loads on a long suspension bridge was elaborated. Basic input parameters were determined from available traffic data, supplied with new measurement campaigns. The models showed characteristics similar to British investigations. The result of the study confirmed the specified levels of traffic loads for the approach spans, whereas the loads on the long main span were slightly reduced due to the averaging effect over the long span.

The safety of the main cables was assessed by representing the cables with a system of parallel strand elements. The analysis showed a very high level of reliability of suspension bridge cables. The result supported the chosen safety level, which corresponds to the lowest levels applied elsewhere for suspension bridges.

The required minimum flutter speed was confirmed in a probabilistic study of the phenomenon. Also performed were probabilistic modelling of pylon and anchor block foundation failures. The results confirmed the design. Savings were indicated, if a reduced soil strength variation could be documented through additional sampling and testing.

Soil Conditions

The investigations of the geological conditions and the geotechnical properties of the soil layers have included seismic profiling, borings with sampling and in-situ testing, and site and laboratory testings.

The results are presented partly in reports, partly in a computerized database, Geomodel. The Geomodel is an EDP-tool open for contractors and consultants, containing geotechnical, seismic, and topographical data. It is implemented on the central computer at Great Belt A.S.

The users can extract selected reports, i.a. in the form of drawings such as location of borings, seabed contour maps, navigation lines for seismic survey and topographical maps. Drawings of cross sections of bridge and tunnel alignments in 2D and 3D can be created on work stations. Scanned profiles of borings and cone penetration tests can also be transferred to work stations.

Compensatory Dredging

The location and extent of the compensatory dredging to achieve the "Zero Solution" is designed by use of an advanced two-layer mathematical hydrodynamic modelling system. It has been established by the Danish Hydraulic Institute in 1987-88 on the basis of field data and physical model tests. The work is carried out in co-operation with LIC Engineering.

A large hydraulic field programme is continued in the Great Belt, providing field data for the running, calibration and verification of the mathematical hydrodynamic model. 14 stations are permanently installed and connected on-line to a main database at Great Belt A.S. The field programme will be running throughout the entire dredging period, continuously improving the basis for the mathematical model.

About halfway through the dredging operation, the predicted hydraulic effects of the excavation were verified against field data from the area. This process will be repeated immediately before completion of the entire dredging operation and final design.

However, the environmental effects caused by the Link cannot be completely avoided. In local areas, the bridge piers, pylons, and approach ramps will create certain disturbances in the environment compared to the previous situation. Therefore a large Biological Monitoring Programme is undertaken with the objective to ensure a minimal influence on the near field environment.

Aerodynamic Investigations

The shape of the girder profile is a key issue in the design of long cable supported spans. Experience gained from Danish bridges reveal considerably lower construction and maintenance costs for box girders compared to truss or plate

Flutter Instability – Section Model Tests			
Cross Section	Critical Windspeed (m/s)	Cross Section	Critical Windspeed (m/s)
	Smooth 75.6 Turbulent –		Smooth 69.5 Turbulent 62.5
	Smooth 75.7 Turbulent –		Smooth 69.2 Turbulent 63.7
Tender design section	Smooth 74.2 Turbulent 70.2	Tender design section with wind screen	Smooth 70.4 Turbulent 71.2

Fig. 8. Sample of investigated box section shapes.

girders. Adequate torsional stiffness can be built into shallow box girders, and the design can favour a desirable aerodynamic performance by introduction of streamlined edge fairings.

During tender design, 16 different box section configurations were designed and subjected to wind tunnel section model tests at the Danish Maritime Institute (DMI). The tests comprised critical wind speeds for onset of flutter and measurements of steady state wind load coefficients. Test results were evaluated against design criteria and compared to theoretical predictions.

Fig. 8. presents a representative sample of box section shapes investigated during the section model tests and corresponding critical wind speeds encountered in smooth and turbulent flow. The results indicate that the sections tested perform quite similarly under smooth and turbulent flow conditions despite differences in geometry. Deep sections reach slightly higher critical wind speeds than shallow sections due to enhanced torsional stiffness. Critical wind speeds for the sections tested are well predicted by the two degree of freedom Theodorsen flutter theory. As an example, the Theodorsen theory predicts a critical wind speed of 75.5 m/s for the tender design section, allowing for a structural damping of 0.2% relative to critical, as employed in section model tests.

To selected section models, wind screens of 50% perforation and lifted 0.6 m above the crown of the roadway were fitted. Tests revealed that this type of wind screen can be arranged with insignificant reduction in the critical wind speed, even for iced up conditions. However, obstruction of free air flow over the top surface of the section, i.e. by snow accumulation between the top slab and the guard rail, may lead to a change in the mode of flutter. A dramatic reduction of the critical wind speed is anticipated if blocking is allowed to occur.

The deck section which was selected for tender was subjected to a series of confirmative section model tests in smooth flow and in grid generated turbulence. The aerodynamic performance of the tender design was further investigated by means of "taut strip" tests which allow a realistic representation of the turbulent properties of the wind, and the structural vibrations of the bridge deck as compared to section model tests.

The results of the wind tunnel tests demonstrated that the aerodynamic stability of the tender design held a comfortable margin over the specification, set by the Design Basis. Buffeting response of the bridge models to gusty winds compared well with the theoretical predictions for the prototype, and was safe

within acceptable limits, set by structural durability and user proficiency criteria.

Some vortex excitation of the girder was encountered during smooth flow experiments at very low structural damping levels. Increase of the turbulence level to nominal conditions at the Great Belt site, or increase of the structural damping to levels measured on other long span suspension bridges suppressed the vortex shedding action.

Aerodynamic investigations will continue for the detailed design of the bridge. In collaboration with DMI, Great Belt A.S. is presently construction a new dedicated wind tunnel facility for the implementation of aeroelastic full bridge model tests.

The tunnel cross section will be 14 x 1.6m, which will allow testing of a 1:200 scale model under simulated turbulent wind conditions.

The continued testing will address the optimization of the design of the final bridge as well as the intermediate construction phases.

Statical Main System

The main span is outlined with a cable sag corresponding to 1/9 x span length. Vertical hangers each 24 m support the girder. The bridge is arranged with an innovative statical main system allowing the girder to be continuous over the full length of 2.7 km between the two anchor blocks. The traditional expansion joints at the tower positions are avoided. Compared to a system with joints at the pylons, analyses have indicated an approximately 25% reduction in the longitudinal deflection of the girder from traffic load.

If free movements were allowed, the extreme horizontal movement from the characteristic traffic load at the expansion joints would be 1.8 m. In order to limit longitudinal movements, hydraulic buffers are arranged between the anchor blocks and the girder. The buffers allow for slow horizontal movements up to ± 1 m and free rotation of the girder. The remaining portion of the theoretical movement will be balanced by restraining forces in the girder.

The advantages of the continuous girder concept are:

-   A very simple structural and mechanical arrangement at the pylons.
-   Reduced installation and maintenance costs for the expansion joints at the anchor blocks.
-   Improved stiffness of the overall suspension bridge system.
-   Improved aerodynamic stability.

The first hanger is arranged approximately 50 m from the anchor block in order to obtain sufficient hanger length to avoid detrimental bending stresses in the hangers, caused by relative movements between the girder and the main cable.

Fig. 9. Arrangement of bridge girder at the pylons.

The support at the pylons secures that:

-   Vertical movement of the bridge girder is unrestrained.
-   Horizontal movement transverse to the bridge axis is limited by horizontal buffer bearings which allow for only 10-15 mm transverse movements before the contact is reached between the girder and the pylon legs.
-   Horizontal movement along the bridge axis is unrestrained.
-   Torsional deflection of the girder about the bridge axis is restrained by a cross coupled hydraulic system in order to safeguard the aerodynamic stability of the suspension system.

The girder is connected rigidly to the main cable at the centre of the main span for improved aerodynamic stability and eliminated relative movements between the girder and the main cable.
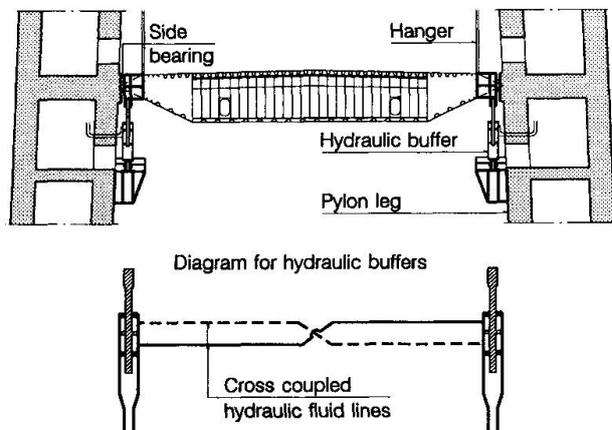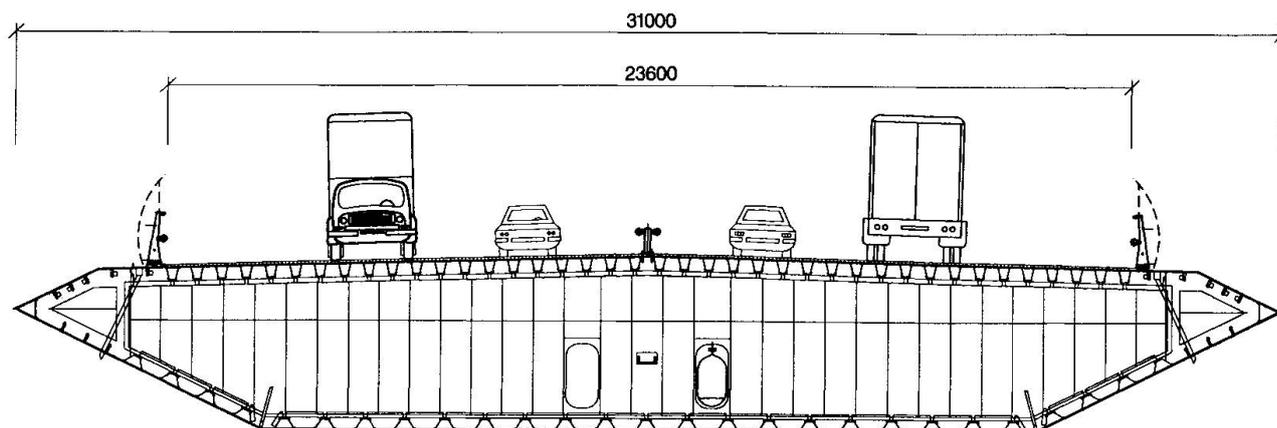
Fig. 10. Cross section of closed internal dehumidified box girder.

The Girder

The girder cross section is arranged as an aerodynamically shaped fully welded closed box section with a stiffened steel top deck. With a completely smooth exterior surface and all stiffeners arranged inside, the box girder is suitable for rationalized repetitive fabrication, e.g. assembly line production of flat panels to be joined to box sections, which are erected and welded for continuity. The interior box surfaces are unpainted and protected by dehumidification of the inside air volume.

Aesthetical Requirements

Co-operation between engineers and architects in the design of major construction projects is a tradition, supported by the Great Belt A.S. In order to obtain the maximum aesthetical results, architects Dissing + Weitling in joint venture with landscape architect Jørgen Vesterholt were nominated in 1987.

One obvious problem for the architects to solve was to make the anchor blocks appear anything but discordant monoliths to the detriment of the effect as a whole. Another aesthetical effect to be attended to was the shape of the pylons. Both concrete and steel are considered for use, and the two materials spread the loads in the bearing structures in different ways.

Pylons

Different concepts in steel and concrete have been developed for the pylons in a close collaboration between Engineer and Architect.

Rising 254 m above sea level, the pylon has slightly tapered legs with a rectangular, hollow cross section above the girder. Below girder level, the leg cross section is widened in order to resist the large horizontal forces from wind on the girder. The most obvious visual difference between the two concepts is the four cross beams on the steel pylon and the lower foot, compared to the concrete pylon's higher foot and two cross beams only.

Altogether 20,000 tons of steel plates with a thickness of 50-60 mm are estimated for the steel pylons, whereas 50.000 m³ of concrete in wall thicknesses of 1.5-2.0 m will be used for the two concrete pylons.

Each tower will be placed in water depth of approximately 20 m on a
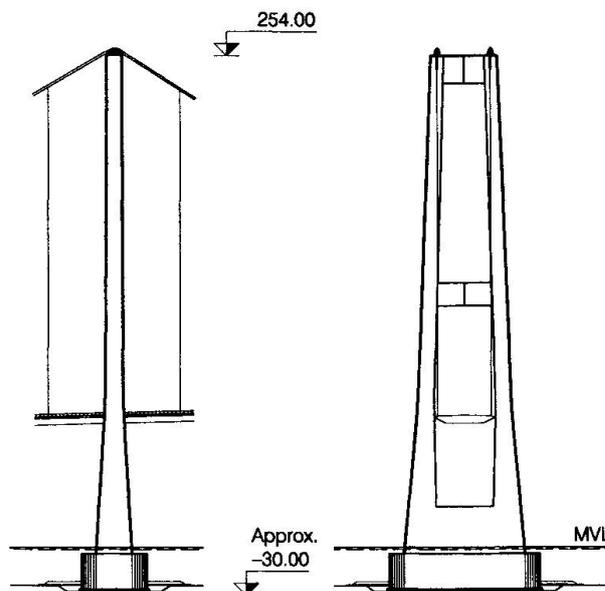

Fig. 11. Concrete pylon layout.

cellular, sand filled caisson on an excavation with a trimmed bed of crushed stone. The tower foundations are designed to resist impact from ships up to 250.000 DWT without permanent deflections.

Anchor Blocks

At a water depth of approximately 10 m, the anchor blocks must resist a cable force of around 600 MN. An excavation down to 25 m below sea level is necessary for the construction works.
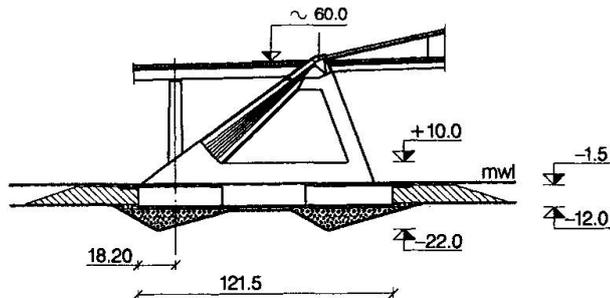

Fig. 12. Anchor block layout.

The soil conditions are stiff, preconsolidated glacial boulder clay under a thin postglacial cover. It means that the stability of the natural soil deposits is of minor importance compared to the risk of sliding along the thin weakened zone of the excavated boulder clay surface. This problem is solved by introduction of two wedge shaped stone beds which will reduce the shear stress in the layer. Reconsolidation pressures are achieved at the two inclined excavation surfaces, and shear strength of the remoulded clay is improved. The contact between the foundation pads at the front and the rear ends of the caisson and the stone beds will be secured by underbase grouting.

Two gravity based concepts have been developed for tender. One solution is based on a large cellular sand filled caisson, cast in a dry dock and floated into position. The other concept assumes cast in-situ in a dry construction pit on an artificial island.

On top of the caisson, inclined legs reach above the bridge girder to accept the main suspension cables into an interior saddle point. Between the apexes of the legs a cross beam is provided, where the expansion joint between the main bridge and the approach spans is arranged.

Artificial islands will be constructed around the anchor blocks in order to ease the water flow around the large structures. The islands are favourable as a protection against ship impact, and may furthermore act as depots for soil dredged in the Belt.

Cables

The cable length will be approximately 3000 m. The steel area in the main cable will be 0,44 m^2 leading to an outer diameter of 0.81 m.

The main cable design includes two alternatives: aerial spinning (AS), and prefabricated parallel wire strands.

The AS-method comprises 37 strands, each with approximately 500 galvanized wires, 5,38 mm in diameters, or 18,500 wires for each cable. In case of prefabricated strands, the main cable will be arranged as a hexagonal grouping of prefabricated strands, each consisting of 127 wires, 5,11 mm in diameters. The total main cable comprises 169 strands.

Comparing the two erection principles, the prefabricated strands are expected to offer a greater speed of construction, lesser sensibility to cross wind, and assured quality control for uniform wire length.
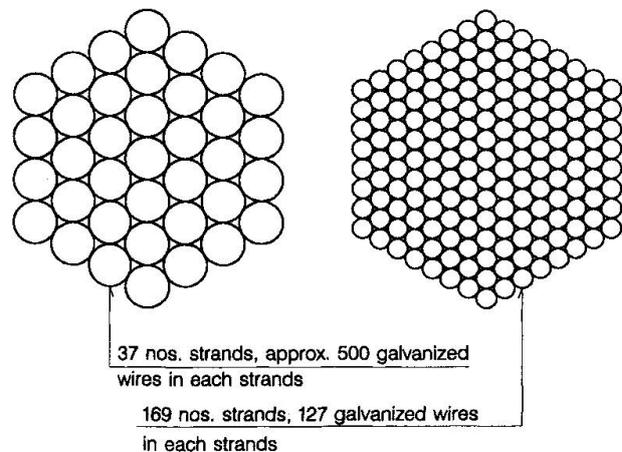

37 nos. strands, approx. 500 galvanized wires in each strands

169 nos. strands, 127 galvanized wires in each strands

Fig. 13. Main cable alternatives. Left: air spun cable section. Right: prefabricated cable section.

However, handling the strands requires heavier equipment at the anchorages and the pylons.

Erection

The erection of a box girder suspension bridge presents particular aerodynamic stability problems due to temporary lack of torsional stiffness and mass in combination with full exposure of the girder surface to the wind.

When deck erection proceeds symmetrically from midspan, the natural frequency in torsion is significantly lower than for the completed structure which leads to low critical wind speeds. During construction, critical wind speeds may be enhanced through choice of an alternative erection sequence where girder erection proceeds simultaneously from towers and midspan leading to an increased natural frequency in torsion.

During construction, critical wind speeds may further be enhanced by provision of eccentric ballast distributed along the windward cable plane.

Enhancement of critical wind speeds through choice of erection sequence or provision of eccentric ballast has been studied experimentally and theoretically. The studies will continue during the future design phases.

Drawings in Digital Form

Preparations of the drawings for all the projects of the Fixed Link are 100% computerized, from conceptual to detailed design. Each drawing is plotted on paper which represents the legal document, but it also exists in a digital form.

Through the design and construction, drawings in digital form are exchanged between the companies involved. Thus the various discipline designs are used directly as reference for other design works.

Project Time Plan

On the 18th of December 1990, tenders were received from prequalified bidders. At the time of writing, the tenders are under review and detailed evaluation.

The development of the East Bridge project has been made in a quick pace with tender designs and documents elaborated from September 1989 to May 1990, tender period until December 1990, and tender evaluation until March 1991.

The construction contracts are expected to be signed in mid 1991 for immediate start of the works. The bridge is planned to open for traffic by the end of 1996.