

**Zeitschrift:** IABSE reports = Rapports AIPC = IVBH Berichte  
**Band:** 82 (1999)  
  
**Rubrik:** Session: Øresund

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## Build a Link - Goals, principles, strategies and results

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Peter Lundhus graduated in 1965 from the Technical University of Denmark as M.Sc in civil engineering. From 1965 to 1988 he worked for an international contractor, covering all aspects of design, bidding and construction of civil engineering works. From 1988 he joined the owner organisation responsible for the construction of the Great Belt Link. In 1992 he was appointed Technical Director for the Øresund Link

### Abstract

The decision to build the Øresund Fixed Link was taken by the Danish and Swedish governments in 1991. Some time elapsed, however, before the detailed planning, let alone the construction phase, could commence. These debates did not deter Øresundskonsortiet. The time was spent laying down the strategy. The dual-nationality of the project, for instance, necessitated a detailed examination of the different legislation in the two countries.

In March 1995, the Danish Minister of Transport approved the Øresund project's environmental quality objectives as well as the criteria and requirements for the control and monitoring programme. And in a verdict in July 1995, the Swedish Water Court gave permission to construct the Fixed Link.

In the light of the political requirements from the two countries, Øresundskonsortiet adjusted the original alignment as well as the link's technical design. The objective was to optimise the link in order to reduce any harmful effects on the environment.

In 1994, Øresundskonsortiet invited tenders for the link's main contracts. The tender process itself did not follow traditional methods. Due to the dual-national aspect, Øresundskonsortiet was able to lay down its own tendering strategy.

In a traditional tendering process, the client undertakes the detailed planning and then opens up for a number of contracts for international tendering. Øresundskonsortiet wished to handle the process differently.

For instance, the consortium wanted to avoid the discussions, confrontations and arbitrations which are often inherent in conventional client-contractor relationships. The aim, of course, was to build the facility at the agreed price and at the agreed time – and also to create a working relationship which ensured fair and constructive collaboration.



The basic concept was "partnership". One consequence of this was the introduction of the Design+Construct philosophy which provided the contractors with strong draft proposals – and, not least, a free hand to improve the project.

The concept is that responsibility for detailed planning and execution should be clearly assigned. This limits the conventional working relationship's potential for confrontation and provides the individual contractor with greater opportunity for solving his task efficiently. This again creates committed contractors who become involved in the detailed planning, initiate improvements and who feel total responsibility for the execution.

The basic premise for Design+Construct is the illustrative design where the client has developed one or more designs which meet all specifications set out by, for instance, the authorities and the client. Since, however, the contractor possesses considerable knowledge, the project will inevitably be improved once the contractors have examined it.

The Design+Construct working relationship also reduces the number of potential conflicts compared to conventional methods. By establishing a Dispute Review Board, Øresundskonsortiet has further reduced the likelihood of a dispute.

The principle is that a Dispute Review Board – a panel of three experienced, independent and internationally respected engineers – is set up for all contracts. In the event of a dispute, the Dispute Review Board functions as chief arbiter.

### **The Environment**

The governments of the two countries and their environmental authorities have laid down rigorous regulations for the acceptable environmental impact of the link. In many areas, Øresundskonsortiet has, therefore, had to develop new strategies and methods in order to limit the effects on the marine environment in Øresund and the Baltic Sea. The fact that the project extends across national borders has played a special role, too. In many instances, the project has had to obtain double approval from the authorities.

### **The Experiences**

The Øresund Fixed Link must be ready by the summer of the year 2000. This is the overall objective which Øresundskonsortiet and the contractors are working towards. The secret behind the new time schedule is a "parallel works" approach. The purpose of "parallel works" is improved utilization of time. Thus, any surplus time on one project is transferred to another contractor who lacks time. It's obvious, for instance, that the bridge has to be welded together before rail tracks are laid. But the rail contractor can begin preparations before the high bridge is ready.

Øresundskonsortiet could not have operated the Parallel Works method over the last two years unless co-operation procedures had allowed for planning across the contracts. With the parallel works method, we created a common understanding of the project's time schedule – and an openness and knowledge of time schedules etc., which has made it possible for everyone to pull together in the final months.



## The Øresund Bridge:

### Project Development from Competition to Construction

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Klaus Falbe-Hansen is Project Director of the ASO Group, the bridge consultant to Øresundskonsortiet.

Örjan Larsson is Contract Director responsible for the Øresund Bridge Contract.

### Abstract

Øresundskonsortiet is owned jointly by the two states Denmark and Sweden and is the Owner of the Øresund Link, responsible for planning, designing, financing, constructing, and after completion of the road and rail Link of its operation and maintenance. ASO Group was formed by Ove Arup & Partners of the UK with SETEC of France and Gimsing & Madsen and ISC of Denmark. Georg Rotne of Denmark is architect to the group. ASO Group, engaged by Øresundskonsortiet in 1993 after an international design competition, is responsible for the bridge concept and is presently integrated in the Owner organisation with particular responsibility for monitoring the construction works of the bridge. The paper describes the project development that took place for the bridge from the design competition to the construction. Also described are the Owner's construction contract strategy, the quality management policy and the Owner's active role through cooperation with the Contractor in achieving the earliest possible opening of the Link.

The design competition took place in the early part of 1993 and the result was that two proposals were chosen. They included two very different bridge designs: ASO Group's two-level concept and ØLC's proposal for a single-level bridge. Øresundskonsortiet decided to develop both designs further in parallel before choosing between them. Only the two-level solution is described in any detail as that in the end proved the successful concept.



*The two-level bridge*

A number of alternatives for the layout of the whole Link were prepared and evaluated. The main issues were the environmental impact of the Link and the economic consequences of alleviating the impact. The critical factor was the blocking of the water flow through Øresund due to the physical obstruction of the Link. The environmental investigations carried out by Øresundskonsortiet and their consultants proved that a 'zero solution' could be achieved without serious economic consequences, and on this basis the two governments gave their approval in the summer of 1994 to constructing the Link. However, the Swedish environmental legislation requires that the Swedish Water Court, which is independent of the Swedish government, had to rule on the effect on the water regime of constructing the Link as a prerequisite of giving the permission to construct the Swedish part of the Link.

In July 1995 the Water Court gave its ruling on the construction of the Swedish part of the Link and this cleared the main legal obstacles for the construction of the Link. The timing and content of the ruling was critical considering that the tender documents for the bridge had been issued to the prequalified bidders in December 1994 and their bids received in June 1995 i.e. before the ruling of the Water Court.



The bridge was issued to the bidders in two packages, the High Bridge and the Approach Bridges. Both bridge concepts were offered. The evaluation of the bids led to the award of one combined contract for the whole bridge to Sundlink Contractors HB in November 1995. Sundlink consists of Skanska of Sweden, Hochtief of Germany and Monberg & Thorsen and Højgaard & Schultz of Denmark. The Contractor's designer is a Joint Venture of COWI of Denmark and VBB of Sweden. Sundlink's bid was based on ASO's two-level concept.

At an early stage Øresundskonsortiet had decided to base the construction contracts for the Link on the design & build concept. It means that the Contract specifies a number of requirements on function, aesthetics, safety and environmental protection that the finished product shall fulfil. The Contractor has undertaken to design and construct works that fulfil the requirements, while the Owner has undertaken to pay the contract price. The undertaking of the Contractor includes everything required for the total completion of the "Portion of the Link" to a state in which it is "fit for its intended purpose". Excluded from the Contractor's undertaking are only those items that are expressly excluded by the Contract. This runs contrary to the principles of a traditional construction contract. Basically the Owner has specified what the Contractor shall achieve, and the Contractor determines how to achieve it. As a logical consequence of the design & build concept the Owner has adopted the basic quality assurance principle of self-control. The Owner is monitoring the Contractor's compliance with his Quality System and the requirements of the Contract.

In general the Owner does not need to nor does he want to approve materials, which are to be incorporated in the works. The Owner does not get involved in the day-to-day inspection and approval of construction work. The Owner is of course present at the sites and may from time to time test materials or inspect the works. However, it is vitally important that the Contractor sees the Owner's monitoring as a supplement to and not a replacement of his own supervision and QC function.

Areas requiring approval by the Owner are limited in order to maintain a clear division of responsibility. The most important approval by the Owner is the approval of the Contractor's Project Quality Programme, which forms the basis for the Owner's monitoring. The Quality Plans are crucial for the planning, execution and control of the works and are therefore subject to scrutiny by the Owner. No work activity is allowed to commence until the Quality Plan covering that particular activity has been approved by the Owner. The Quality Plans are the proof that the Contractor has understood the specified requirements and knows how he will achieve them.

Several simultaneously running contracts make up the Link and in order to coordinate the activities the Owner has taken an active role in optimising the planning of the so-called Parallel Works. The clear objective is to have the Link completed and inaugurated as early as possible and within budget. Close cooperation between the Owner and the various contractors has led to the success of this combined effort.

The Owner's strategy of cooperation, trust and openness has been a success. The bridge Contract is on time and on budget and the quality of the permanent works is to the Owner's satisfaction. There have been no disputes so far and therefore no significant claims against the Owner. This is not usual for a project of this size and complexity and can to a large degree be attributed to the spirit of partnership between Contractor and Owner, which has been allowed to develop throughout this truly international project soon to connect the two countries Denmark and Sweden.



*The cable-stayed bridge nearing completion*



## Getting the Balance Right The Øresund Bridge - Design Concept

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Georg Rotne is the ASO Group's architect.

### Abstract

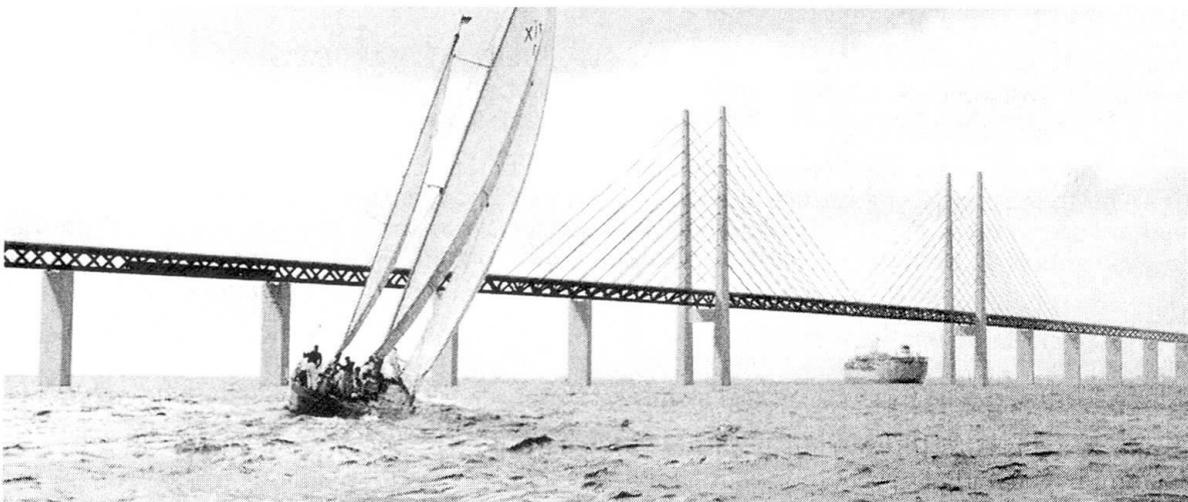
Vitruvius set the agenda: good architecture is about the proper balance of Firmitas, Utilitas and Venustas - or firmness, commodity and delight. And so during the Renaissance designs for bridges, as for buildings, aimed to meet this ideal.

With the invention of industrialised processes and new materials and technology, a new profession was created: the engineer. The new materials and technology were used in the building of bridges and other structures. Firmness in particular was the domain of the engineer; commodity was interpreted as function but more interest was shown in inventiveness and efficiency than in delight.

The first engineers built remarkable bridges of iron, and later of steel and reinforced concrete. They used a rational and economic design approach – form follows function – which worked hand in hand with the current belief in progress.

Following the end of the Second World War, an urgent need for new infrastructure meant that bridges, like other structures, became more and more mass-produced. Efficiency dominated; which left little room for inventiveness and experimentation.

Sometimes architects were involved in the design of the more prestigious bridges, but mostly in a secondary role. This has now changed. Architectural competitions are increasingly being held for bridges. Delight is firmly back on the agenda.





## The Øresund Bridge

The Øresund Bridge is very long. Technical, functional and economic issues are critical. It includes approaches, where shorter spans are suitable and a much longer span over the navigation channel. The structure should appear as a whole and not a collection of parts; it should be economic for the approach spans as well as for the main span.

A small team of designers developed the design concept. A larger team, which also included the client and various public authorities, developed the tender design, and the contractor's team carried out the detailed design within a design and construct contract. And because it is very large, the client had divided the project into a number of contracts to be handled by different contractors, and different teams might therefore handle the final design. The continuity of the design process would thus be broken. In these circumstances, how is it possible to ensure unity and the proper balance of firmness, commodity and delight?

The right design would ideally be functional, economic and beautiful. Given the huge scale of the project, emphasis should be put on developing a consistent and robust design befitting the unique site.

It is often the relationship to its site that gives a bridge its special character. This bridge would stand in a seascape without any dramatic natural forms to set it against. The landscape on both sides is gentle and friendly, with small and rolling hills and curved coastlines where the land merges with the sea. The bridge rises gradually from the tunnel at the artificial island like from a hole in the sea. The Link would often be seen at a distance: from the shores, the sea and the air. Those travelling on the bridge would mostly see it at speed, but they could, given a suitable design, have exceptional views of the sea, the islands, the coastlines and the cities of Copenhagen and Malmö.

A small team of engineers and an architect, working alongside each other, created the competition design. They shared an approach to design that had been formed over some years as they worked together on a number of other bridge projects.

Our design strategy was to use a simple and straightforward design: to express function and structure in a direct way without unnecessary detail. We used well proven design concepts, materials and construction methods to create a strong and robust form, capable of safely being divided into smaller parts, which could be detailed by different contractors and still make a harmonious and coherent whole.

The form of the alignment is important for the experience of the journey across the bridge. We chose a curved alignment to give a more interesting journey across the Øresund.

We also decided to separate the road and the railway traffic on the whole Link, a decision that meant that the bridge would have two levels. The Link should provide a dual two-lane motorway and two tracks for high-speed passenger trains and heavy goods trains. Separating the traffic gives obvious operational advantages and flexibility. During lane closures, whether caused by accidents or maintenance, road traffic can be directed onto the other carriageway, and on the railway, crossovers can be placed freely. With the motorway carried at the upper level and the railway below it, users are also given ample comfort and security. Cars are separated from the high-speed trains and travellers can have free and excellent views of the Øresund.

We decided finally that the high bridge would be cable-stayed. For a two-level bridge, the most economical structure is to use steel trusses with diagonals connecting the upper and lower decks. The deep girders naturally lead to longer approach spans, which has environmental advantages and gives a lighter and more elegant appearance. They are also rigid enough for a cable-stayed bridge to comfortably span the Flintrännen navigation channel with a main span of 490m.

The full illustrated paper describes the design of the bridge, the design process and the issues which the design team considered important in "Getting the Balance Right".



## The Øresund Bridge: The Tender Project

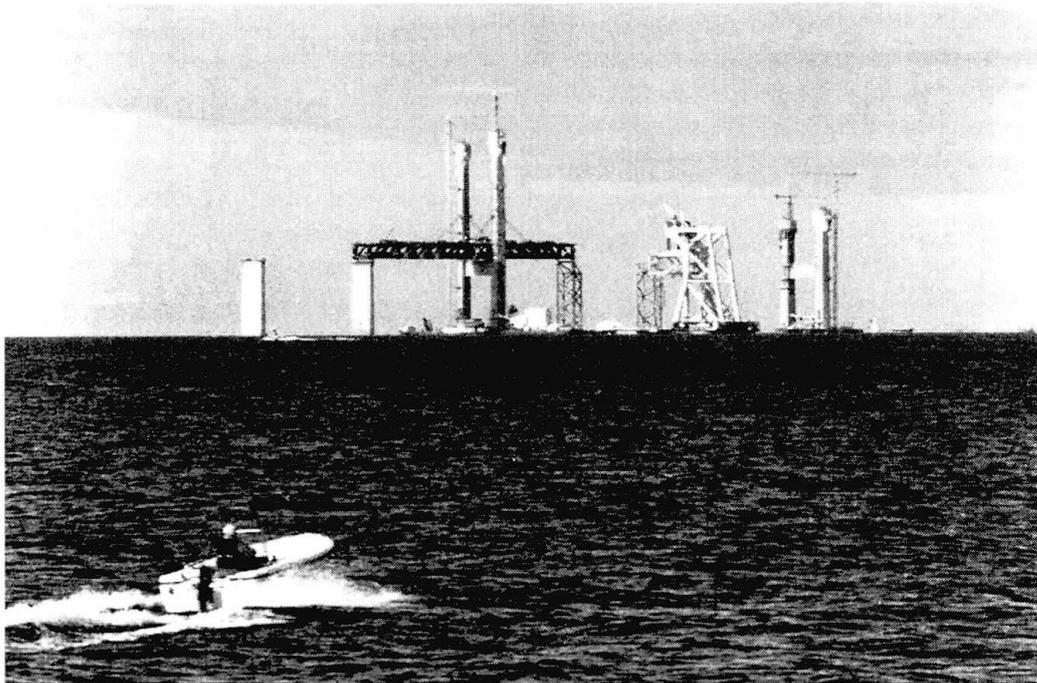
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Øresundskonsortiet

### Abstract

ASO Group was formed in December 1992 in order to prequalify for the design/consultant competition for the Øresund Link. The outcome of the competition was that ASO Group was retained by Øresundskonsortiet to develop their two-level bridge design further in order to make it suitable for tendering.

Tender documents were issued to prequalified contractor consortia for two separate 'design and construct' contracts: one for the 1.1km cable-stayed High Bridge and one for the 6.7km Approach Bridges. Due to Owner's preferences and due to the possibility of having two different contractors along the bridge, the detailed geometry of the bridge was contractually defined in the tender documents by so-called Definition Drawings.

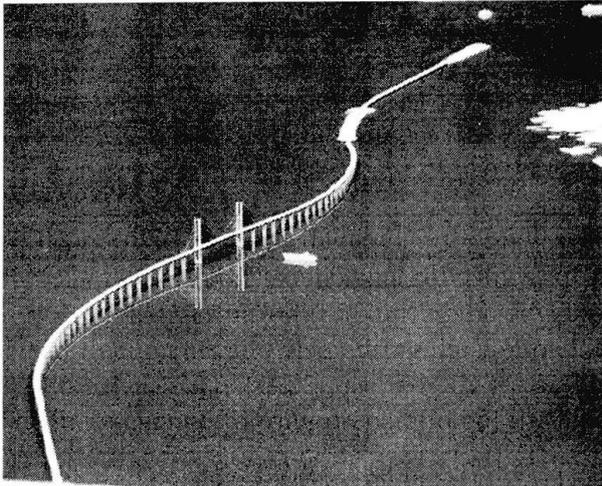


*The Cable-Stayed High Bridge during Construction*

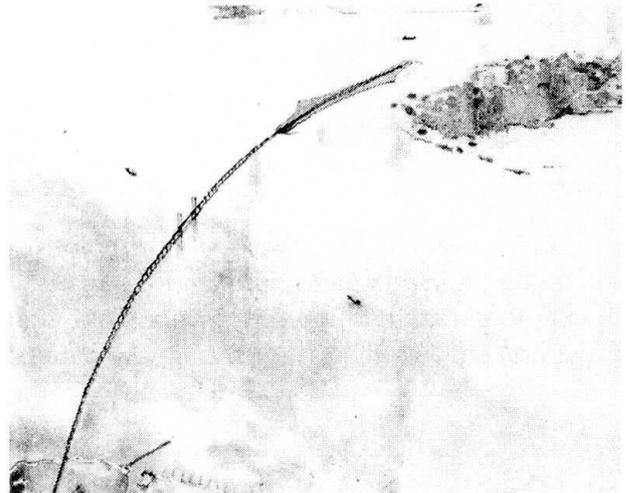
The paper will describe the tender design, issued to the bidders in December 1994, and will demonstrate the consistency and robustness of ASO Group's competition design by highlighting the very few changes introduced during the development of the design during the preparation of the tender documents and also during the contractor's detailed design and construction of the bridge.

The main changes during preparation of the tender design were:

- a revised horizontal alignment when an S-curve was superseded by a gentle C-curve,
- the pylon cross section was modified from being hexagonal to being pentagonal and
- the cross section of the lower railway deck was modified - a flat concrete slab acting compositely with a longitudinal trapezoidal steel stringer was changed to double concrete troughs spanning between transverse steel box beams.



*S-curve alignment*

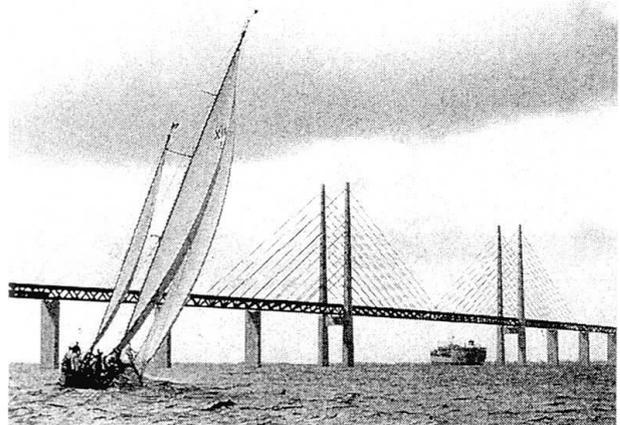


*C-curve alignment*

A further slight modification introduced in the 'Definition Drawings' was that the contractors were given a certain freedom in choosing the span length of the approach spans. The competition design had assumed 120m spans but the contractors were given the choice of 100m, 120m or 140m. If several span lengths were chosen the shorter span should be positioned closest to the shore.

During the construction of the bridge very few changes has been necessary, the most important being a modified pier top detail to provide space for the larger bearings required due to the successful contractor's choice of 140m spans. A service walkway below the emergency walkway at the railway deck has been incorporated and small modifications have been made to the two abutments.

The design as-built has followed the Definition Drawings and the finished bridge will have the appearance the Owner envisaged when he signed the construction contract.



*The Øresund Bridge in the year 2000*



**From Eurocodes, Special Investigations and Risk Analysis  
to  
Design Requirements for the Øresund Coast to Coast Structures**

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Civil engineering degree 1970 and  
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Director ES-Consult from 1990

### **Abstract**

Establishing a physical link of the magnitude and importance such as the Øresund Coast to Coast calls for early and focused attention towards developing and implementing a coherent strategy dealing with the Design Requirements for the structural parts of the link.

Design Requirements are instrumental in securing the owner and ultimately the Society, that issues such as structural safety and durability are addressed for each and every part of the Link, in a uniform manner and independent of the contract form and contract division.

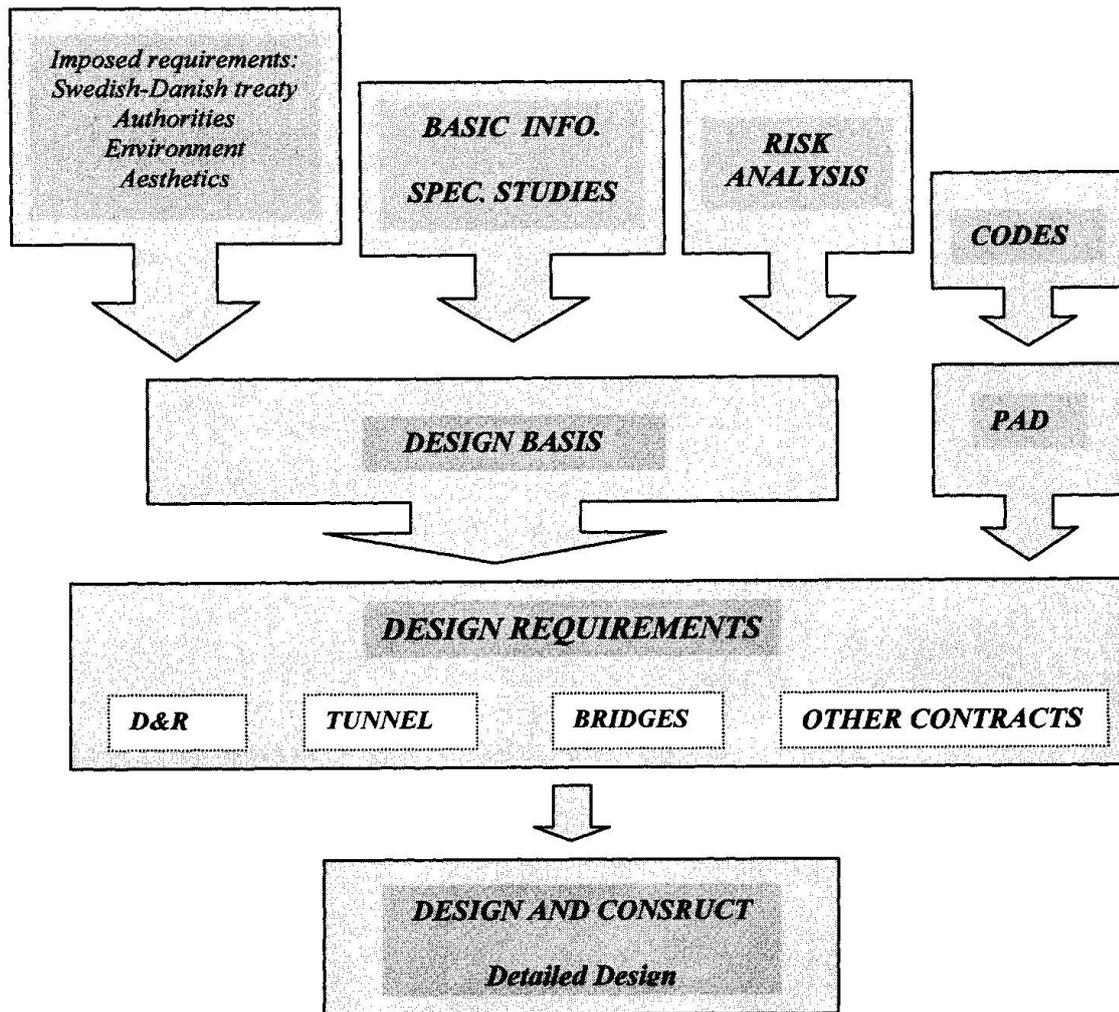
The owner addressed these issues at an early stage of the present project. This paper briefly gives a picture of the options available at the time, the strategic decisions taken and the organisation of the work leading to the final preparation of the Design Requirements.

Some of the questions to be answered were:

- *Which set of structural codes shall be/can be applied?*
- *Can the chosen set of basic structural codes properly fit the project at hand or will amendments have to be prepared?*
- *Does project specific features call for additional preparatory investigations?*

A brief expose of the considerations behind these questions as well the answers arrived at and the ensuing need for clarifications and further preparation is given.

Furthermore a brief expose of the process leading to the Design Requirements for the various contracts is presented. This has been illustrated by the figure:



The Design Basis, prepared as an internal technical document is a key document, containing technical specifications and serving the purpose of being a common platform for the technical contract documents – the Design Requirements for the various contracts.

The elements in the process of establishing the Design Basis – the Basic Information, Special Studies and the Risk Analysis and their interrelationship are explained illustrated by a few examples.

It is concluded that the experience from the process has confirmed that early attention and consistent implementation related to these issues make a manifest contribution to the ultimate result.



## Detailed Design of the Cable Stayed Bridge for the Öresund Link

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Mr. Hauge graduated from the Technical University of Denmark in 1986. Since 1990, he has been employed by COWI, where he at present is head of the department for design of major bridges. Mr Hauge was in charge of the detailed design of the cable-stayed bridge for the Øresund Link

### Anton PETERSEN

Dir., Bridges  
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Mr. Petersen has since his graduation from the Technical University of Denmark in 1974, been employed by COWI. He is currently director for bridges. Mr. Petersen has been the project manager for the detailed design of the Øresund Bridges.

### Abstract

The 7.7 km long Øresund bridge is a major part of the Öresund Link between Denmark and Sweden. The most significant element of the entire Link is the cable stayed high bridge spanning the navigation channel. The bridges were tendered on a design-built basis leaving the responsibility for the design with contractor. Sundlink was awarded the contract to built the bridges in 1995 and subcontracted the design to CV Joint Venture, comprising COWI from Denmark and VBB from Sweden. This article describes the detailed design of the High Bridge.

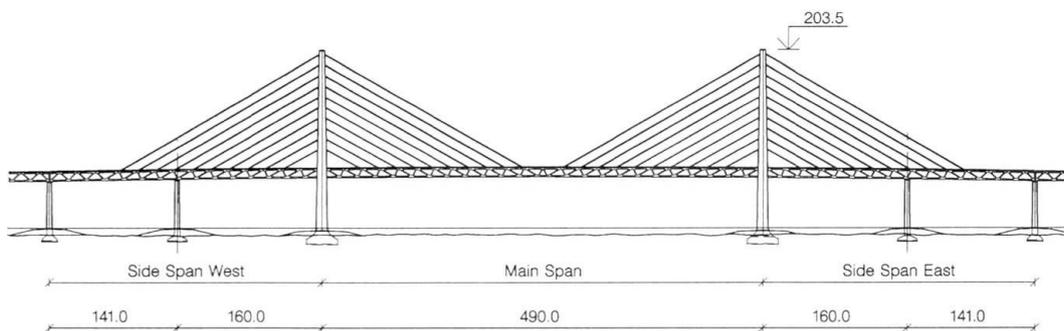


Fig. 1 High level bridge, Elevation

The bridge will carry a four lane motorway with emergency lanes and dual tracks for a high speed railway, and will when completed be the longest cable-stayed bridge for high speed railway. The traffic is arranged in two levels with the roadway on the upper deck and the railway on the lower deck. The rails are laid in ballast over the entire length of the bridge.



## 1 Pylons

Rising 203.5 m above the sea level, the pylons of the cable-stayed bridge will be the landmark of the entire link. The pylons are designed as clean Hs without an upper cross beam. This resulted in almost 150 m free standing legs in the transverse direction of the bridge alignment, which lead to heavy vertical reinforcement above the cross beams of the legs where the pylon legs are designed to resist an accidental impact load of 8 MN in any direction.

The pylons are founded directly on Copenhagen limestone in level -17 m and level -18.5 for the east and west pylon, respectively. The foundation structures are cellular caissons with a footprint of 35 m x 37 m. The dimensions have been governed by ship collision

One of the key issues in the design has been to keep the dimensions and the weight of the caissons as low as possible because of the size of the available dry-dock facilities and the available draft during tow-out.

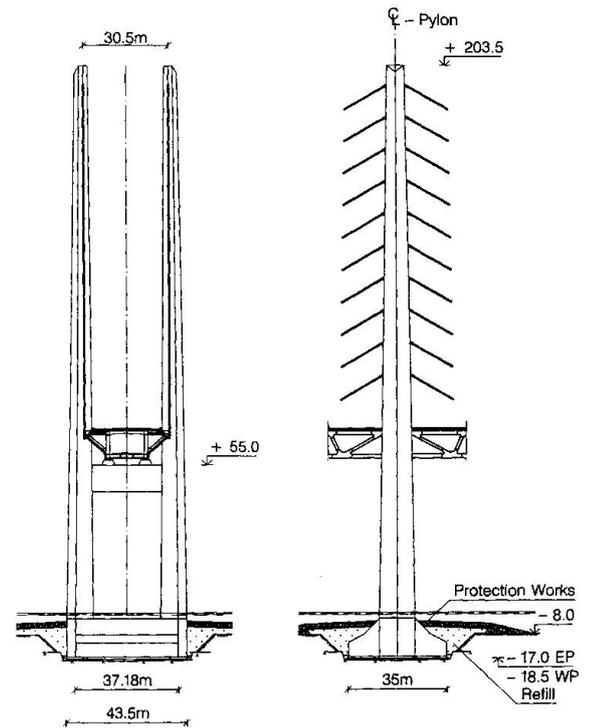


Fig. 2 Pylon, elevation

## 2 Bridge Girder

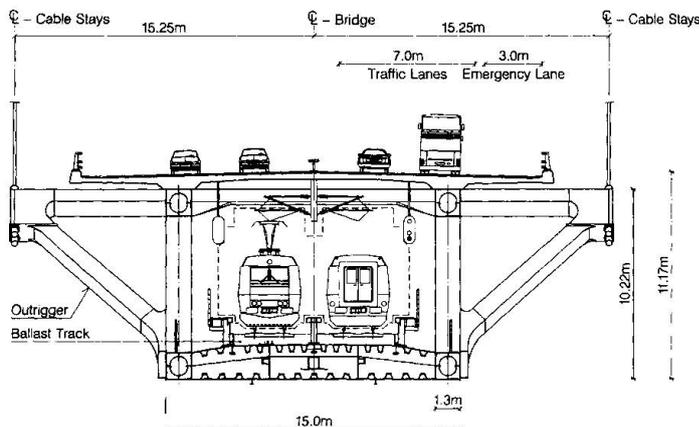


Fig. 3 High Bridge girder, cross section

designed in S355 (EN10113).

## 3 Cables

The cables (PWS) are arranged in a harp system with all cable stays in parallel. The effects from buffeting, vortex shedding, forced vibrations of the supports and rain/wind induced vibrations have been investigated analytically. The cables are designed with an outer PE-sheeting with helical ribs as a countermeasure for rain/wind induced vibrations.

The bridge girder for the high bridge is arranged as a steel truss girder with an upper transversely post-tensioned concrete roadway deck and a lower deck for the railway, designed as a closed steel box. The inclination of the truss members is arranged with approximately 30° and 60°, respectively. The cables are anchored to the girder on outriggers with the same inclination as for the flat diagonals and the stay cables. Diagonals, chords and the railway deck are in steel grade S420 (EN10113) except for the secondary elements inside the railway deck which are



## Design coordination of a design-build project

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Ingvar Olofsson is head of the Division for Design of Bridges and Civil Engineering Structures within Skanska Teknik AB, a subsidiary of Skanska AB.

### Abstract

The architectural and structural design in a design-build project developed through all the different phases of the project. The conceptual design, where the general and functional requirements for the project are defined, is carried out by the Owner and his consultants. Pre-tender designs, tender design, basic design and detailed design are performed by the Contractor and his consultants, during the latter phases in close contact with the Owner.

This paper presents general aspects on the organization and coordination of the design work in the different phases being administrated by the Contractor. The conditions of the different types of contracts between the Contractor and his Design Consultants are also discussed.

### 1. Design phases

*Pre-tender phase.* In order to reach the primary goal (to win the contract) the Contractor and his tender project group should handle the tasks mentioned below at this stage. Even if the particulars of the project requirements are still unknown, getting familiar with the project is essential. The core of the future competitive design team is created here and introduced to the project.

Important tasks in this phase are to

- Collect as much information as possible of the future project
- Identify critical parts or areas, where special competence or experience will be needed
- Allocate best possible design and engineering resources (individuals) to the group
- Organize brainstorming meetings where alternative approaches and solutions are invented and scrutinized
- Select alternatives for detailed evaluation
- Prepare for a possible prequalification together with the chosen internal and external design consultants
- Estimate the need for design resources in the following phases (quality and quantity).

*Prequalification phase.* Prequalification of the Contractor together with his consultants is made based on the experiences from the pre-tender phase. Conditions of cooperation and



possible exclusivity for the tender phase is discussed, with regard to confidentiality or strategy.

*Tender phase.* The tender phase will to some extent contain the same activities as the pre-tender phase. Based on the knowledge of the Owner's requirements some alternatives can now be excluded from further investigation, while some might be added. The design resources are split up in different sub-project groups, each group working according to a time schedule. Sufficient time and resources for evaluation of new ideas and concepts popping up during the course of the work must be available.

In order to maintain the intentions given by the Owner special attention should be given to the esthetical appearance of the structures as well as to environmental issues and of course to matters related to quality, durability and maintenance.

Design work performed at this stage should aim at providing a winning concept to the Contractor. It should of course arrive at the correct quantities, to be maintained in the construction phase. Likewise important is that calculations and other documentation are prepared for immediate continuation in the construction phase.

At the end of this phase the conditions of the future design contracts should be negotiated with the different design consultants.

*Basic and Detailed design (Construction phase).* Based on the Contract with the Owner and the time schedule, as defined in the Contract, the Basic design and the Detailed design is performed in parallel with the construction work. Careful planning and cost control (follow-up on quantities of construction material as well as design costs) of the design activities are crucial to avoid delays as well as excessive construction and design costs. A considerable design effort has normally to be laid down in this phase in connection with change orders from the Owner and from the Contractor's engineering teams.

## **2. Design Contracts**

The design contracts are normally concluded separately for the tender phase and the construction phase. The following types of agreements are discussed in the paper

- Fixed fee agreements
- Variable fee agreements based on specified costs
- Incitement and bonus agreements

## **3. Design coordination for the Öresund Bridges**

The design organization set up by the Contractor (Sundlink) for design of the Öresund Bridges is described and some experiences of the actual design work are briefly given in the paper.



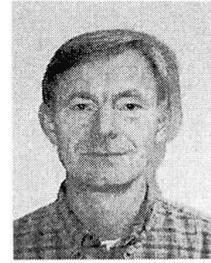
## The Öresund Bridge, Erection of the Cable-Stayed Main Span

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Sundlink Contractors HB  
Sweden



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Engineering  
Employed by Monberg &  
Thorsen A/S since 1981

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### Abstract

The Öresund bridge consists of two approach bridges and a cable-stayed central bridge 1092 meters long. The main span is 490 meters which is a world record for cable-stayed bridges carrying both highway traffic and trains. The navigation clearance is 57 meters. The bridge girder is a composite structure with a steel truss and a concrete deck carrying four lanes of highway traffic on top. Inside the truss girder a steel railway deck carrying two railway tracks is installed.

### Prefabrication of the Girders

The construction of the Öresund bridge is to a very high degree based on prefabrication of large elements on-shore - 8 girders with lengths 120 or 140 meters and weights up to 6200 tonnes are used for the cable-stayed bridge. The steel part of the girders for the high bridge are prefabricated in Karlskrona in Sweden and transported by barge to Malmö where they are unloaded at the girder reloading station and the concrete deck is cast.





## Erection of the Girders

The main span of the bridge is erected using an innovative method. The girders are placed by the floating crane Svanen on temporary support towers placed on the seabed.

The joints are welded and the stay-cables are erected before the support towers are moved to a new position at the other pylon. The main advantage of this method is that the off-shore activities are cut down to a minimum which leads to time and cost savings compared to the normal cantilever method.

The girders for the high bridge are during erection connected to the previously erected girders. For this purpose a girder connection device has been developed. The girder connection device uses the short diagonal in the truss as a support element. The short diagonal is temporarily hinged at both ends to enable node rotations when the girder weight is transferred from the Svanen to the support arrangement. As the short diagonal is inclined a tension connection with hydraulic jacks is used in the upper chord to take the horizontal drift force.

## Connection of the two cantilevers

When all the girders and the stays are erected the two cantilevers are joined at the centre of the main span. While the connection operation takes place the joint is exposed to environmental loads resulting in bending moments and forces at the joint. Therefore a cantilever connection arrangement has been developed to overcome these solicitations during the welding operation. The connection arrangement consist of two vertical and one horizontal lattice triangle which enable the transfer of shear forces and torsion at the joint. Bending moments from wind load on the bridge girder is taken by strong push pull connectors installed at the chords. The system is designed to enable rapid connection of the cantilevers to obtain a quick and safe transfer from the two free cantilevers to one main bridge span.

## Erection of the Stay Cables

The main span of the bridge will be carried by stay-cables. 160 stays each consisting of approx. 70 strands will be used. The 7-wire strands are individually corrosion protected and anchored by wedges at the ends. A PEHD casing keeps the bundle of strands in position and reduces the drag coefficient of the stay-cable.

In order to prevent rain/wind induced vibration the casing is equipped with a double helical 2 mm thick spiral.

The stay-cables are erected strand by strand. The first strand to be erected in each stay is the reference strand which is stressed to the correct length. The first strand is equipped with a load cell and the following strands are all stressed until the load in the reference strand is reached.

## Conclusions

The erection of the superstructure for the Öresund bridge is a challenging task involving development of erection techniques for girders weighing up to 6900 tonnes.

The erection of the superstructure for the cable-stayed bridge was commenced by the erection of the first girder in June 1998 and completion of the erection of girders and stays is scheduled for the summer 1999.