Presentation session 2: barriers (continued)

Objekttyp: **Group**

Zeitschrift: **IABSE reports = Rapports AIPC = IVBH Berichte**

Band (Jahr): **63 (1991)**

PDF erstellt am: **27.08.2024**

SESSION 2

Barriers (continued)

Leere Seite
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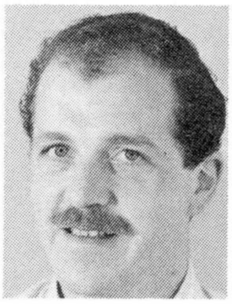
Evaluation of the Management of the Eastern Scheldt Barrier
Evaluation de l'exploitation du barrage sur l'Escaut oriental
Einschätzung des Managements der Osterscheldebarriere

Cees-Jan van WESTEN
Eng.
Rijkswaterstaat
Middelburg, The Netherlands



Cees-Jan van Westen, born in 1954, studied at the Agricultural Univ. of Wageningen. Since 1983 he has been involved in studies into the management of the Eastern Scheldt Barrier. He is also involved in policy preparation for state-administered waters throughout the Netherlands.

SUMMARY

Recognition of the ecological value of the Eastern Scheldt has resulted in the construction of a storm-surge barrier instead of a solid dam to provide protection against flooding. The desire to safeguard the ecological features of the area played an important part during the implementation of the Eastern Scheldt project. Efforts have also been made to strike a balance between safety, ecology and the wishes of sections of the public and industry in the management of the area and the storm-surge barrier. A study is currently being carried out to evaluate whether adjustment of the management plans is necessary or desirable in the light of the current situation.

Evaluation de l'exploitation du barrage sur l'Escaut oriental

Résumé

La reconnaissance de la valeur écologique de l'Escaut oriental a eu pour conséquence la construction d'un barrage contre les raz-de-marée au lieu d'une digue solide en vue d'une protection contre les inondations. Le désir de garder les caractéristiques écologiques de la région a joué un rôle important durant l'étude du projet. Des efforts ont été réalisés pour obtenir un équilibre entre la sécurité, l'écologie et les désirs de l'opinion publique et de l'industrie. Une étude est actuellement en cours pour évaluer si une adaptation des plans d'exploitation est nécessaire ou désirable à la lumière de la situation actuelle.

Einschätzung des Managements der Osterscheldebarriere

Zusammenfassung

Aus der Erkenntnis des ökologischen Wertes der Osterschelde hat sich die Konstruktion einer Sturmflutbarriere anstatt eines soliden Damms ergeben, um Schutz vor Ueberschwemmung zu bieten. Der Wunsch, die ökologischen Merkmale des Gebietes zu sichern, spielte eine wichtige Rolle während der Studie des Osterscheldeprojekts. Es wurden auch Anstrengungen gemacht, ein Gleichgewicht zwischen Sicherheit, Oekologie und Wünschen der Oeffentlichkeit und der Industrie in der Bewirtschaftung des Gebietes und der Sturmflutbariere zu treffen. Kürzlich wurde eine Studie angefertigt, um abzuschätzen, ob eine Regelung des Bewirtschaftungsplans im Lichte der laufenden Situation notwendig oder wünschenswert ist.

1. INTRODUCTION

The aim of the Delta Project was to safeguard the southwestern Netherlands against flooding by damming a number of estuaries. At the end of the 1960s, the importance of the rich ecological diversity of these areas began to be recognised and there were increasing calls for this factor to be taken into account in the further implementation of the Delta Project. Attention focused mainly on the Eastern Scheldt, since the other estuaries had either already been dammed or were to be dammed in the near future. As a result of the strong lobbying by nature conservationists and fishermen and on the basis of extensive studies of the technical options and their ecological consequences, the Government decided in 1976 to build a storm-surge barrier in the Eastern Scheldt and to construct two secondary dams in the east (Fig.1). This decision led to fresh insights into the management of both the Eastern Scheldt and the storm-surge barrier itself. The contribution by environmentalists was essential. During the implementation of the Eastern Scheldt project, too, consistent efforts were made to strike a balance between technically feasible, environmentally desirable and socially acceptable solutions to the many problems associated with carrying out a hydraulic engineering project on such a scale.

It was recognised that following the completion of the project, many unforeseen changes would occur in the Eastern Scheldt. This is why the management plans for the area and for the barrier itself include procedures allowing the plans to be modified and adjusted; studies are also being carried out to ensure that any changes are identified promptly and their policy implications indicated.

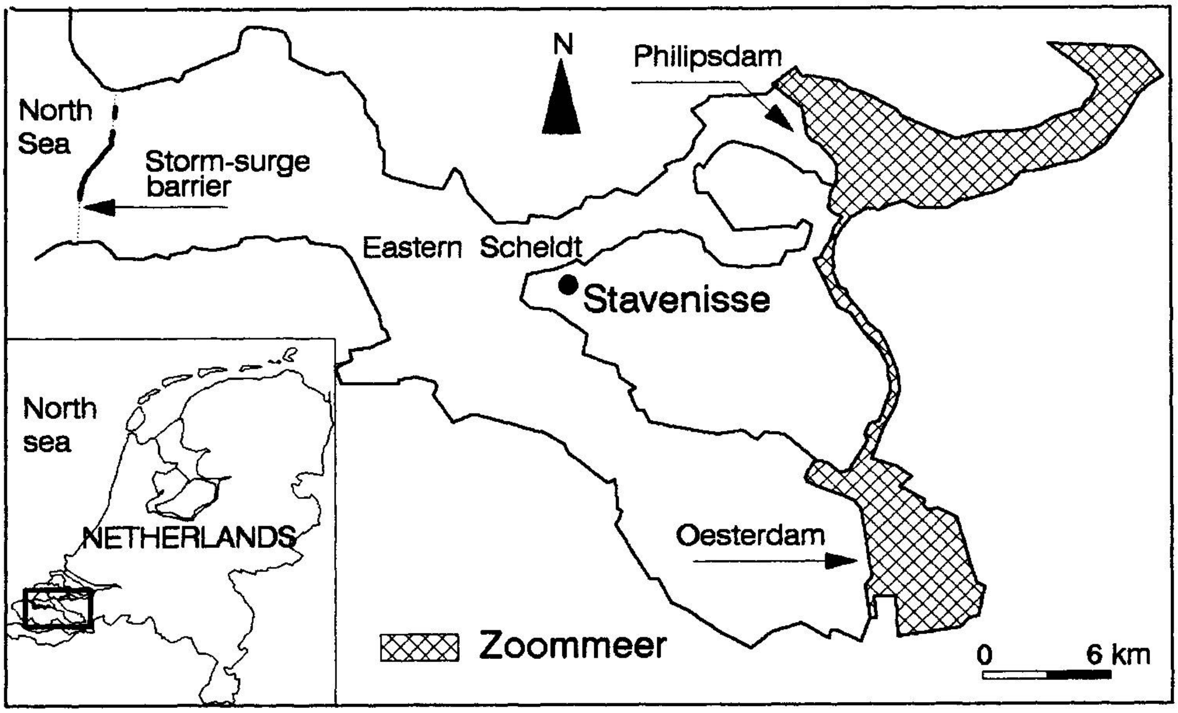


Fig. 1 The Eastern Scheldt Area

2. THE EASTERN SCHELDT PROJECT

2.1. The Eastern Scheldt Barrier

In April 1987 the Eastern Scheldt Project [1] was completed. The main parts of this project were the construction of the storm-surge barrier in the mouth and two secondary compartment dams, the Oester dam and the Philips dam, in the eastern part of the Eastern Scheldt.

The storm-surge barrier was constructed at the mouth of the Eastern Scheldt to safeguard the surrounding region against flooding while preserving the unique saltwater tidal environment that existed in this area. A total of 65 piers were positioned in the three tidal channels known as the Hammen, Schaar and Roompot. Gates were installed between the piers, which are normally kept open but which are lowered if there is a threat of dangerous storm surges. The construction of the storm surge barrier resulted in the opening at the mouth of the Eastern Scheldt being reduced from 80,000 m^2 to about 18,000 m^2.
The Philips dam and Oester dam are intended to guarantee a sufficient difference between low and high water when the storm-surge barrier is open, despite the fact that the mouth of the Eastern Scheldt estuary has been reduced in size. The area behind the dams has now become non-tidal, which complies with the requirements of the Dutch-Belgian Treaty concerning the shipping route between the two countries. In order to improve water supplies for agricultural purposes, a freshwater lake - Zoommeer - was created at this location.

2.2. A Policy Plan for the Eastern Scheldt

After the change of mind regarding the way in which the Eastern Scheldt should be closed it was very soon recognized that a coherent plan would be needed for the management and the development of the area. Various sectors of government policy are involved, and the relevant powers are shared among the three tiers of government (central, provincial and municipal). In order to produce a joint policy for the Eastern Scheldt a broadly constituted steering group was established (the Eastern Scheldt Steering Group), which formulated the following objective for the development and management of the estuary: "the conservation and if possible strengthening of the existing natural features and functions of the area, with due regard to the public and economic interests - notably including fishing - concerned". The pursuit of this objective must not be allowed to have any adverse effects on the primary objective of the Delta Project: the safety of the people living in the area. All the administrative levels supported the policy plan, and it thus became binding. This means that the Steering Group has to be consulted before new activities can be undertaken or existing ones can expand.
Now that the storm-surge barrier has been completed, many environmental changes will occur which cannot be predicted with certainty; this is an important aspect in any consideration of the estuary's potential. Due to these uncertainties the policy plan for the Eastern Scheldt has a flexible nature and can be adjusted if ecological evaluations or changes in public and economic interests require it. As provided for by the policy plan for the Eastern Scheldt this amendment procedure is a system of yearly progress or evaluation reports. These reports include the following elements:

1. a survey of the developments which have taken place in the year;
2. the research results relevant to the policy plan;
3. a summary of the necessary changes or adjustments to policy which are needed in the light of points 1 and 2.

The policy plan that was finalized in 1982 sets out the broad outlines of the policy to be followed regarding the various potential uses of the estuary and the possible means of effecting them. Of particular importance is the management of the storm-surge barrier itself. The various closure strategies needed to be evaluated in the light of their potential impact on the environment, so that a management plan could be prepared which meets the requirements of both safety and conservation. Before such a management plan could be drawn up, it was necessary to have a proper understanding of the nature and functioning of the ecosystem of the Eastern Scheldt.

2.3 Environmental Research

The decision to construct a storm-surge barrier in the mouth of the Eastern Scheldt was intended not only to guarantee safety but also to preserve the natural features and fishing interests of the area. This naturally meant that environmentalists would be involved in the project's implementation, especially since many decisions still had to be taken concerning, for example, the size of the wet cross-section of the storm-surge barrier, the location of the compartmentation dams, the date on which these dams should be completed and the manner in which this should be done. Since the necessary environmental knowledge was almost entirely lacking, an extensive research programme was set up by the Rijkswaterstaat and a number of scientific institutes.

Hydraulic studies in particular were carried out to support the project's implementation. In addition, a programme was drawn up for the periodic approval and adjustment of the policy plan, comprising the following elements:
a. the new basic situation which will arise as a result of the construction of the storm-surge barrier and the compartmentation dams;
b. the potential for the development of the fishing industry;
c. the development of the recreational use of the area;
d. the impact of human activities on the environment;
e. possible and desirable management measures and their effects.

Research was also conducted to facilitate the management of the Eastern Scheldt Barrier, concentrating on the effects of the barrier's closure on dykes and salt marshes in relation to the length of time it is closed and the water levels in the estuary.

The above-mentioned studies were more or less specific project studies and were based on general research into the various types of environment in the Eastern Scheldt and the changes which would occur in them after the completion of the storm-surge barrier. The principal research aspects were the morphology of channels and shallow areas, the impact of changes in the duration of flooding on the salt marshes, the basic food chain and organic communities, such as those living on the hard substratum.

3. MANAGEMENT AND MONITORING

3.1 Interim Management Policy for the Eastern Scheldt Barrier

During the completing stage of the project, from July 1985 to April 1987, the reduction of the tidal motion has been much stronger than the present final reduction [2]. The reasons for this extra reduction were:
1. the secondary dams were closed after completion of the storm-surge barrier;
2. during the completion stage of the barrier and the final stage of construction of the secondary dams the tide was reduced by the completed parts of the storm-surge barrier; the tidal reduction during the final stages of the closure operations of the dams, allowed the remaining closure gaps to be completely filled in with sand, which yielded a saving of 80 million guilders.

During the planning stage for the construction work several different options were considered, although the degree of freedom was limited among other things by the following agreed principles:
1. the lowering of a number of gates in the storm-surge barrier during the period from November 1985 to October 1986 would be permitted, to allow certain work to be completed;
2. the storm-surge barrier was to be used to reduce the flow velocities during completion the Oester dam and Philips dam;
3. the Philips dam could not be completed before the Oester dam, for hydraulic

engineering reasons, since this would have resulted in excessive flow velocities in the Scheldt-Rhine Canal;
4. the completion of the Oester dam and Philips dam had to be carried out in different years to allow a better phasing of the capital expenditure on the project.

A number of boundary conditions were subsequently formulated based on a detailed understanding of the environment in the Eastern Scheldt, which were intended to minimise the potential damage the construction work might cause:
1. the mean tidal range at Stavenisse was not allowed to drop below 2.30 m, which meant that up to about 4,200 m^2 of the open area of the barrier could be closed, except during the final phase of the construction work, when the entire barrier was closed for short periods;
2. during the final phase of the dam's construction, the barrier was not to be completely closed for longer than two days.

After extensive discussions it was agreed that spring or autumn would be the most acceptable periods for the completion of the Oester dam, and the Philips dam, both from an environmental point of view and in the interests of the fishing industry in the area.
Although extensive investigations had been carried out prior to the hydraulic engineering work in the Eastern Scheldt and assessments had been made of the environmental implications of such operations, it was not possible to give firm guarantees that permanent damage could be avoided. The major uncertainties concerned the weather and the possibility of setbacks occurring in the engineering work. This meant that the situation had to be reconsidered at each a stage of the project. A close watch was therefore kept on developments in the estuary to ensure a ready supply of up-to-the-minute information for making the necessary decisions.

During the change-over phase from the original to the new tidal situation, a large number of parameters were carefully monitored. This monitoring exercise was primarily intended to serve as an early warning system. More detailed investigations were instituted if it was discovered that readings from the field lay outside the natural variations in the original conditions.
Observations and measurements were taken on a more or less continuous basis during the final stages of the construction of the compartmentation dams. The information that was collected was processed and interpreted at once, so as to allow immediate corrective action to be taken if necessary. The way in which the storm-surge barrier was used was modified several times as a result of these observations. For instance, during a later construction phase, a severe storm took place which coincided with the completion of the Oester dam in October 1986. As a result delays were encountered at a time when the tide had already been greatly reduced. It was observed that birds were no longer foraging in the extremely inclement and cold weather conditions, while at the same time the size of the feeding grounds had been severely restricted. Under these circumstances, a significant increase in the mortality rate among the birds was anticipated. It was therefore decided to deviate from the original planning and temporarily reduce the water level in the Eastern Scheldt before starting work on the final stage of the dam's construction. This greatly increased the availability of foraging areas with an adequate supply of food and led to the birds making effective use of the opportunity presented.

The fact that the secondary dams were completed later than the storm-surge barrier caused only a few adverse effects on the environment. Parts of the salt marshes in the Eastern Scheldt suffered some damage as a result of dehydration in the summer of 1986. Changes in the soil structure due to drying-out and settling were reported in some places.

3.2. Management of the Storm-Surge Barrier

Under normal circumstances the storm-surge barrier remains open to allow water to flow in and out freely. The barrier is closed only if the expected water level exceeds a predetermined "predicted critical level" [3]. In such a situation the actual water level in the North Sea will continue to rise until the storm surge has reached its peak. Meanwhile the water in the Eastern Scheldt will become virtually semi-stagnant. It has been decided to adopt a predicted critical level of Mean Sea Level (MSL) + 3 m for a period of several years, in order to evaluate the system. During this period there will be an opportunity to gain some experience in operating the barrier.

The decision to close the barrier will be based on a predicted water level. This will allow the authorities to fix the desired water level in the Eastern Scheldt by choosing the appropriate moment to close the barrier. In the case of storm-surges that peak more than once, the water level in the Eastern Scheldt could remain stagnant during the whole period of the storm if the barrier is kept closed. It is also possible to open the storm-surge barrier after the first and second high water peaks and to close the barrier again before the next high water occurs, thereby fixing a new water level in the Eastern Scheldt. The various management strategies based on these options have been examined in detail with regard to safety. Some of the strategies did not comply with the required safety level specified for this region. A final choice between the remaining options that satisfied the required safety criterion was made on the basis of environmental concerns and of the likely impact on fishing in the area.

After analyzing the various strategies, it was concluded that the alternating mode of operation offered significant advantages in terms of the environment and the preservation of fishing interests, as compared with other strategies based on the maintenance of fixed levels. This led to the 1-2-1 alternating strategy (1st peak: inner level MSL + 1 m; 2nd peak MSL + 2 m; 3rd peak: MSL + 1 m) being adopted as the basis on which the system would be operated. It was anticipated that this mode of operation would prevent serious erosion occurring in the intertidal area, since such phenomena are mainly associated with water levels close to MSL. Furthermore, this strategy should limit the amount of disruption caused to the environment by parts of the salt marshes being washed away.

It is also possible to close the Eastern Scheldt Barrier for reasons other than safety, as was done during the completion of the Philips dam and Oester dam. Following a thorough analysis of these reasons, it was decided to pursue a very restrained policy in this regard, mainly in view of the provisions of the policy plan. The Eastern Scheldt Barrier will be closed entirely or partially only to prevent disasters, e.g. following dyke subsidence or serious storm damage.

4. EVALUATING THE NEW SITUATION

During the period April 1987 to April 1991 an assessment is being made of the effects of operating the storm-surge barrier and the presence of a new infrastructure. The aim of this evaluation is to consider the main aspects of water management and safety in relation to the original forecasts.

The safety evaluation is concentrating on the strenghth of the barrier and the dykes, and the wave forces acting on them during the period of closure for flood protection. In the period from 1 May 1987 to 1 December 1990 the Eastern Scheldt Barrier was closed (Table 1.) several times to prevent excessive water levels in the estuary (Fig. 2).

date	expected waterlevel sea side	highest waterlevel sea side	highest waterlevel Stavenisse	maximum duration of stagnancy
861218	MSL + 2.85 m *	MSL + 2.73 m	MSL + 1.03 m	6 hours
861219	MSL + 2.85 m *	MSL + 2.71 m	MSL + 0.97 m	5.2 hours
890214	>MSL + 3 m	MSL + 3.17 m	MSL + 1.60 m **	5.5 hours
900227	MSL + 2.98 m	MSL + 3.17 m	MSL + 1.02 m	6.5 hours
900227	MSL + 3.40 m	MSL + 3.69 m	MSL + 2.06 m	3.2 hours
900228	MSL + 3.14 m	MSL + 3.25 m	MSL + 1.06 m	6 hours
900301	MSL + 3.00 m	MSL + 3.25 m	MSL + 1.07 m	6 hours

* predicted critical level of MSL + 2.75 m
** prediction was not available in time

Table 1 Closures of the Eastern Scheldt Barrier during storm surges

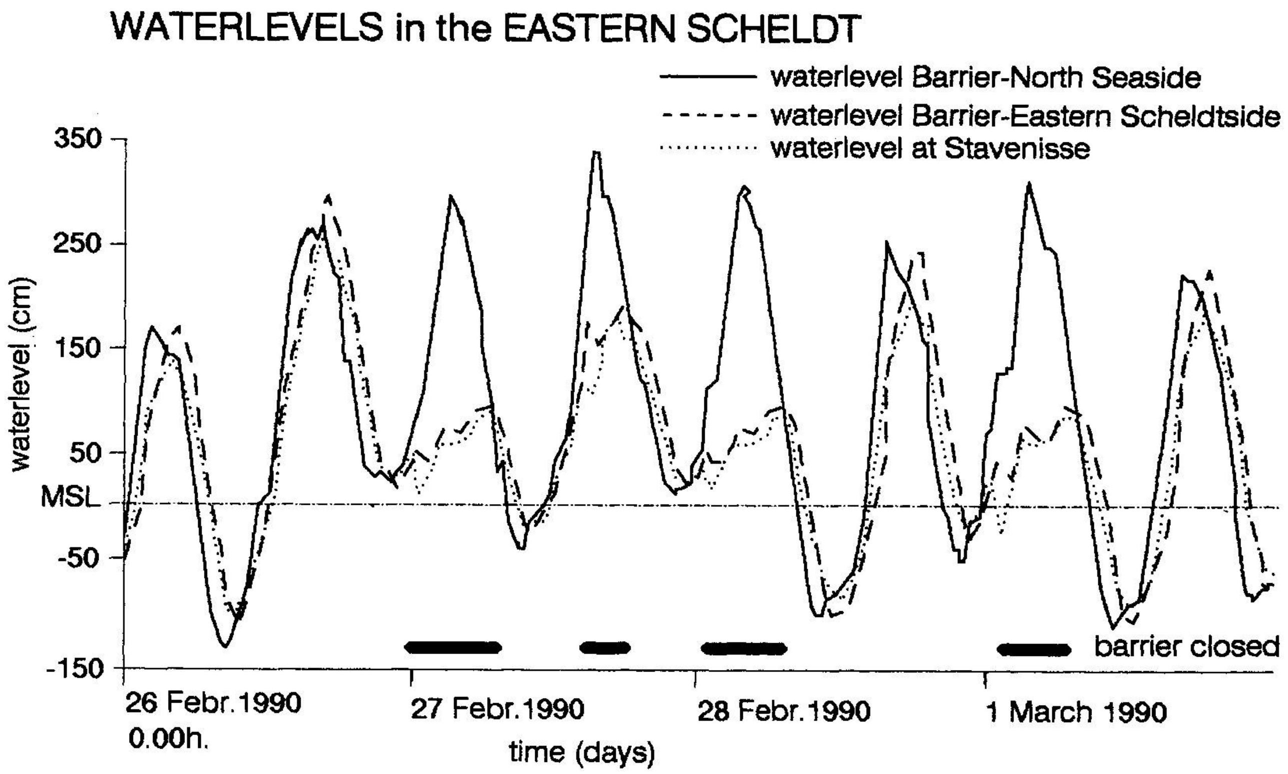


Fig.2 Water Levels in the Eastern Scheldt during storm-surges.

Following each period in which the storm-surge barrier was closed, civil engineers and environmentalists carried out observations to ascertain whether dykes, intertidal areas and fishing areas had sustained greater damage than they would have done if the barrier had not been closed. So far there is no evidence that this is the case. These observations form part of an extensive monitoring programme, which carefully follows the development of the ecosytem towards a new state of equilibrium. Research is aimed at verifying earlier predictons (Table 2) and at adjusting earlier models. The physical circumstances which are evaluated are changes in water movement, salinity and the bed.

aspect	before 1987	expected	measured after 87
total area (km^2)	452	351	351
waterarea at MSL (km^2)	362	304	304
intertidal areas (km^2)	183	109	118
salt marches (km^2)	17.2	6.4	6.4
cross-section of mouth of Eastern Scheldt (m^2)	80,000	16,500	17,600
average tidal range at Stavenisse (m)	3.7	3.1	3.28
maximum flow velocity (m/s)	1.5	-	1.0
residence time (days)	5-50	10-100	10-150
average tidal volume (m^3*10^6)	1230	880	880
freshwater discharges (m^3/s)	70	40	10
salinity (g Cl^-/l)	15.5-17.5	-	16-18

Table 2 Changes in the Eastern Scheldt

The monitoring programme also focuses on the biological components of the ecosystem. The results largely correspond to predictions. It should be noted, however, that the evalution period is fairly short; changes such as the adaptation of channels to the new hydraulic situation and related developments in intertidal areas and salt marshes proceed very slowly. Many consequences for the biological component of the ecosystem will only become visible in the longer term. Constant monitoring therefore remains a necessity. On the basis of the evaluation which is now almost complete, recommendations will be formulated as to how the Eastern Scheldt Barrier should be used, the type of policy needed to develop specific functions in the area and the requirements for future monitoring of the water system.

5. CONCLUSIONS

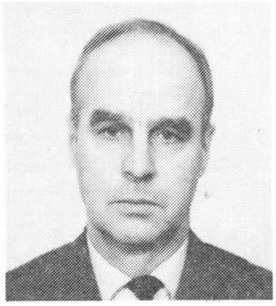
The decision to construct the Eastern Scheldt Barrier has led to greater knowledge about the area and the storm-surge barrier itself. Ecological features played a prominent role in the decisions made on this matter. During the change-over from the old to the new tidal regime no large-scale damage occurred to the environment or the fishing industry, despite the fact that the storm-surge barrier was used to modify the water movements in the estuary so as to facilitate part of the construction work. Use of the barrier for this purpose led to considerable savings in time and money. Detailed understanding of the ecology of the Eastern Scheldt together with effective environmental safeguards allowed the risks to the environment and fishing industry to be reduced to acceptable proportions. In this way, long-term ecological research can be seen as having yielded direct benefits for society since it enabled work to be carried out more cheaply without harming the environment. Studies need to be conducted to enable management plans for the area or the Eastern Scheldt Barrier to be modified, should the situation require it.

6. REFERENCES

1. KNOESTER, M., J. VISSER, B.A. BANNINK, C.J. COLIJN and W.P.A. BROEDERS, The Eastern Scheldt Project. Wat. Sci. Tech. Vol. 16, Rotterdam, 1984.
2. WESTEN, C.J. VAN and J. LEENTVAAR, Ecological Impacts During the Completion of the Eastern Scheldt Project. In: Pollution of the North Sea. An Assessment. Springer Verlag, Heidelberg, 1988.
3. WESTEN, C.J. VAN, T. PIETERS and L.D. BOOM, The Management of the Eastern Scheldt Barrier. Proceedings 16th Congress ICOLD, San Francisco, 1988.

Leningrad Flood Protection
Protection contre les inondations à Léningrad
Leningrader Flutschutz

Yuri SEVENARD
Dir.
Lengidroenergospetsstroy
Leningrad, USSR



Yuri Sevenard, born 1935, received his degree in hydraulic engineering at the Institute of Civil Engineers in Moscow. For 32 years he was involved in hydraulic construction works in the USSR and in Egypt. Yuri Sevenard is now in charge of the construction of the Leningrad storm surge barrier.

SUMMARY
The Leningrad flood protection system was designed and has been accomplished in such a way that its negative impact on the environment should be excluded. However, due to the poor publicity and under the influence of mass media and the false information constantly being circulated by the opponents of the construction, a considerable part of the population of Leningrad is prejudiced and therefore against the storm surge barrier. In this connection, an objective evaluation of the project by the international scientific public might be of paramount importance.

Protection contre les inondations à Léningrad

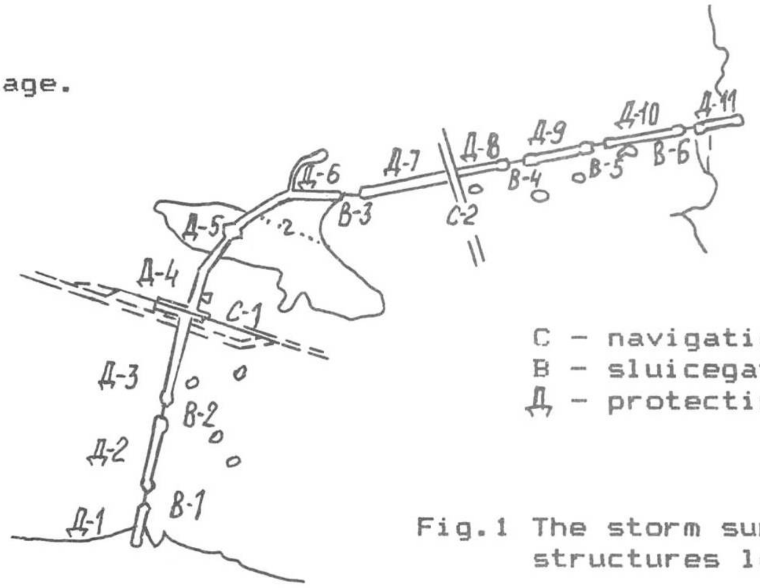
Résumé
Le système de protection contre les inondations à Léningrad a été conçu et réalisé de sorte que l'influence négative sur l'environnement soit réduite à zéro. Cependant, sous l'influence d'une mauvaise publicité de la part des mass media et de mauvaises informations circulant en permanence chez les opposants à la construction, une partie importante de la population de Léningrad est opposée à la construction du barrage contre les raz-de-marée. En ce sens, une évaluation objective du projet par la communauté scientifique internationale pourrait s'avérer décisive.

Leningrader Flutschutz

Zusammenfassung
Das Leningrader Flutschutzsystem wurde entworfen und in der Weise ausgeführt, dass ein negativer Einfluss auf die Umwelt ausgeschlossen sein sollte. Infolge schlechter Oeffentlichkeits-arbeit und unter dem Einfluss der Massenmedien und der ständig zirkulierenden Falschinformationen aus Kreisen der Baugegner ist ein beträchtlicher Teil der Leningrader Bevölkerung jedoch gegenüber der Sturmflutbarriere voreingenommen. In dieser Hinsicht könnte eine objektive Bewertung des Projektes durch die internationale wissenschaftliche Oeffentlichkeit von höchster Bedeutung sein.

Leningrad is a large industrial, scientific and cultural centre of the USSR. It is one of the most beautiful cities of the world. Stately historical sites of Leningrad belong to the whole mankind.
From the early years of the city history its location in the vicinity of the sea as well as the abundance of wetlands predetermined the dangerous nature of relationship between the city and the waters. Practically every year Leningrad is subject to the sea pile up floods that cause considerable and very often unrecoverable damage to the central part of the city and to the towns of Petrodvorets, Lomonosov and Kronshtadt also.
Under the influence of the integrated meteorological and hydrodynamic processes the balance of the water bulk in the Baltic Sea and the Gulf of Finland has been disturbed and a so-called long wave has been formed which increases due to lowering the shores and reaches the Neva Bay and the delta of the Neva. In combination with the wind pile up and other warer level variations (i.e. seiche-type and tidal) the long wave causes brisk and short-term wateter elevation in the eastern part of the Gulf of Finland and in the delta of the Neva.
Since 1703 when the city was founded about 300 floods have been registered with the water level elevation of more than 1.6 meters. The calculation show that evev without taking into account the total rise of the sea level floods with water elevation up to 5.4 m may occur in Leningrad being able to submerge 30% of the city area, i.e. in fact the whole central historical part.
Typically the floods in Leningrad are sudden and short-term and are characterized by high intensity of the water build up and fall. A reliable prediction of possible floods can only be made 4-6 days in advance. The duration of a flood usually amounts to several hours and never exceeds twenty four hours. As a rule floods are accompanied by storm winds with the velocities up to 30-40 m/sec. More than once the water elevation was above 3 meters. Some of the floods were really disastrous and caused human losses.
In 1824 a flood with the water level elevation of 4.21 m took place.
Since 1979 along the line of contact between the Neva Bay and the eastern part of the Gulf of Finland, at a distance of about 30 km from the Neva estuary, the Leningrad storm surge barrier has been under construction designated to safely eliminate in future any floods in the protected water area, including the floods with the probability rate of 0.01%.
The Leningrad storm surge barrier is an integrated system of sluicegates and navigation passages connected by earth-fill dykes. The total length of the barrier is 25.4 km (Fig.1).
Along the crest of the barrier a six-row highway is supposed to be constructed. The highway will connect thenorthern coast of the Neva Bay with the southern one and will be the most important component of the future roundabout road encircling the city. This progect is extremely important for Leningrad from the ecological point of view.
Now the construction of the barrier has entered the final

stage.



C – navigation passages
B – sluicegates
Д – protecting dykes

Fig.1 The storm surge barrier structures location

Out of the total length of the barrier only the fraction 0.9 km long remains undeveloped. It is there that the main navigation fairway goes. So far the construction of the main navigation passage has not been completed either. All the six sluicegates provided for by the desin are in operation, the sluices are fitted with 64 big gates and spans 24 meters long(Fig.2).

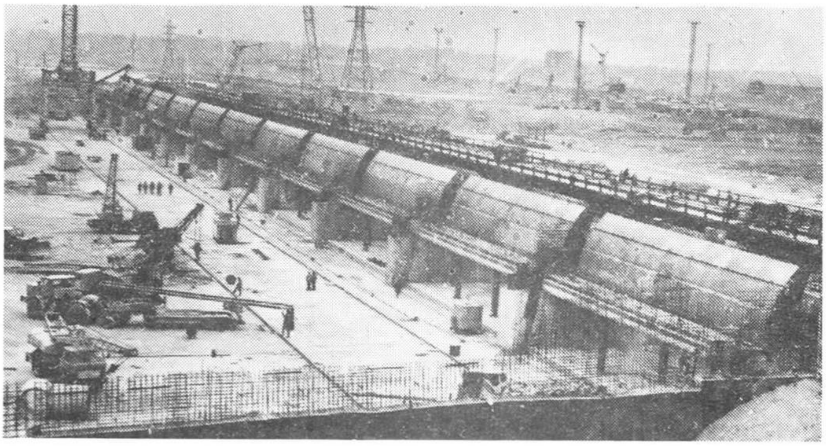


Fig.2 Storm surge barrier

The bulk of the construction include about 40 mln.m3 of earth-fill embankments, 2.5 mln.m3 of reinforced concrete and 45 thous.t of suitable matal structures and equipment. The cost of the whole system is 1 mlrd.rbl.
A lot of new engineering and organizational solutions have been used while constructing the storm surge barrier. One can mention, for example, making use for the first time in the open water area of moraine loams with their pioneering filling up in the water at depths up to 5 m, in any season of the year. To execute engineering works under the water a floating mechanized unit has been formed and now is in successful operation. This unit includes a big floating ex-cavating machine manufactured by the Austrian company "Osvag"(Fig.3).
Of considerable importance is draining at big depths of the foundation for the earth-fill dykes in the southern part of

the barrier. This problem is being solved successfully by means of a high-efficiency draining plant, tailor-made by the Italian company "Trevi-Soilpack"(Fig.4).

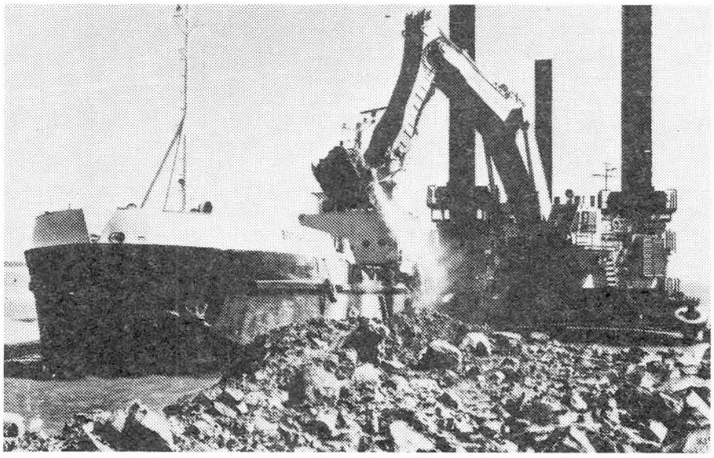


Fig.3 "Osvag"floating excavating machine

To accelerate the construction and to raise its rate of industrialization two sluicegates, i.e. N4 and N2 (the sluicegates are numbered northward) have been constructed making use of large floating units up to 130 m long, 53 m wide and 14 m high. The weight of the units amounted to 30 thous.t. The units bore basically assembled gates(Fig.5).

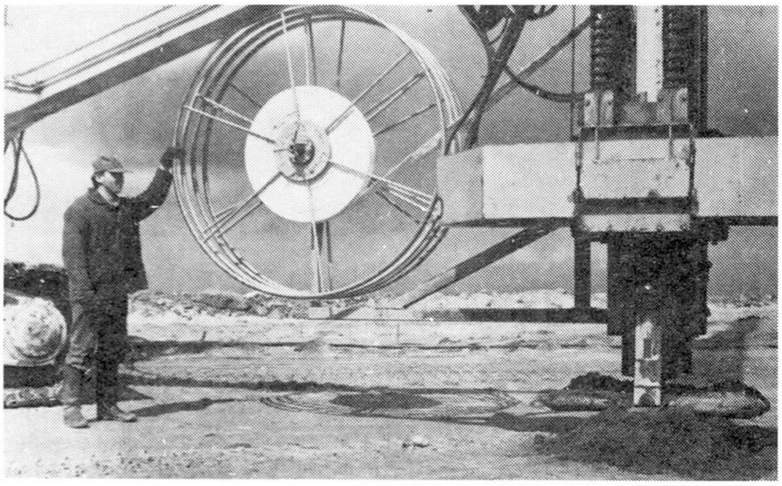


Fig.4 "Trevi-Soilmec"drainage plant

Consequently the threat to the city on the part of the sea may be eliminated in the nearest future. But during the whole period of the city history there existed the threat to the sea on the part of the city, their interaction taking place through the shallow and narrow Neva Bay. This threat was caused by the wrong and light-minded approach of the people considering the self-restoring capacity of the Neva Bay unlimited. With the growth of the city area and the extension of the industries,constantly increasing amounts of different pollutants including toxic ones were being dis charged into the small affluents and arms of the Neva and into the Neva Bay itself, in fact without any treatment.It takes usually 5-8 days for the water to cover the distance between the Neva estuary and the island of Kotlin and to reach the entrance to the Gulf of Finland, that distance amounting to 35 km and the average flow velocity being 6-8 cm/sec. During this time a considerable part of the suspended solids contained in the water are being precipitated and they gradually form the polluted bottom layer. This takes place especially in the coastal areas where the flow velocity is less and amounts to only 2-4 cm/sec.

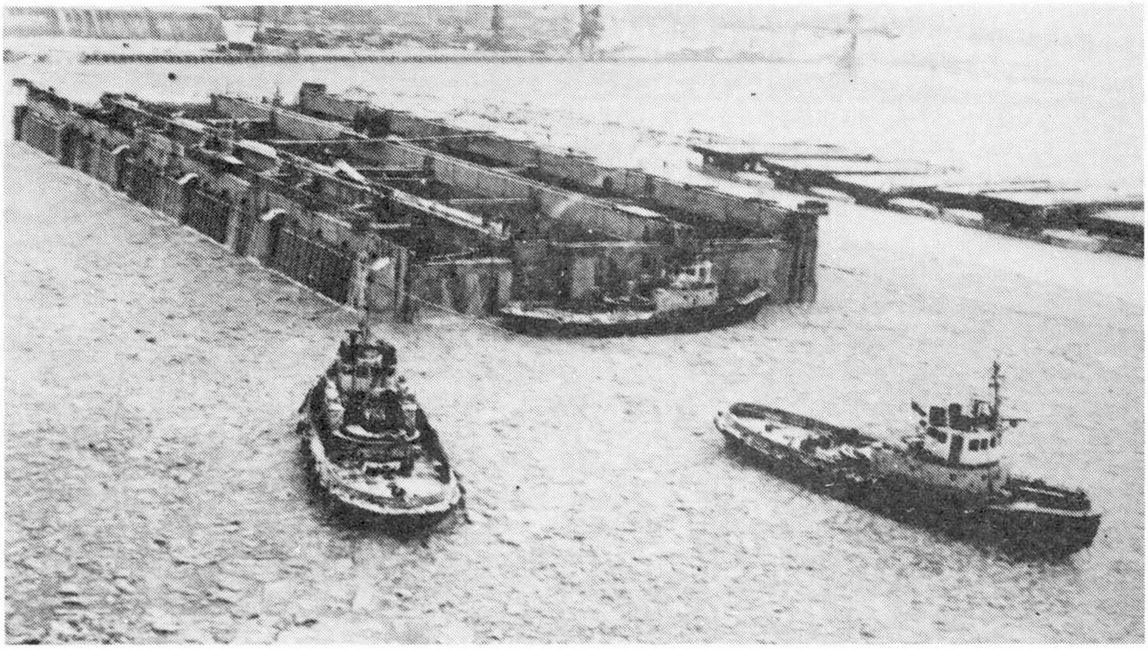


Fig.5 Transporting of floating units for sluicegates

Only after the time when it became evident that continued discharges of the untreated water would inevitably and soon lead to ecological calamity, the construction of huge waste water treatment plants with the capscities of 1.5-2.0 m3/day was started fevereshly in the northern, central and southern parts pof the city. Both domestic and industrial waste waters are being supplied to the treatment plants through the same suers.
At the epoch when the decission concerning the beginning of constructing the stirm surge barrier was taken and the construction itself started in the Soviet Union there exis-ted no unconditional practice of discussing similar projects with the broad public. There was no independent system of information and the public opinion analysis. The public opi-nion was never taken into consideration during the

preparations of projects and on the final stage of decision-making.
However, it did not mean that the projects considered at the time did not take into account the requirements existing at those days on the basis of the standards and scientific predictions both in the Soviet Union and abroad. The design of the storm surge barrier in Leningrad was subjected to a comprehensive analysis to a greater extent than any other hydraulic engineering project in the USSR. In fact, during the whole period of the final decision preparation, i.e. for more than 10 years, two alternative versions have been worked out by scientists and design engineers. There were still other options but they soon lost their competitive ability.
The two versions,i.e. the so-called Eastern version and the Western one, as the saying has it faught dog, faught bear. Of course, it was not the versions themselves that were objectively engaged in the fight. The fight was going on between the authors and adherents of one concept and the authors and adherents of the other one. There was a threat of this fight lasting for an indefinite time since the opposing parties could not find any possible solution and, to be more honest, they did not even try to do so.
In such a situation the necessity of a willed decision inevitably emerges if there are forces capable of making this decision.
The Soviet government controlling the situation at those days and capable of not only making important decisions but also of implementing them considered all the pros and contras and decided to construct the flood protection in Leningrad according to the Western version.
The adherents of the Eastern version being disappointed and angry decided to take their time waiting for a chance to discredit the decision taken, meanwhile giving rise the rumours that coul contribute to this discrediting, also provoking and supporting those rumours. In the time of glasnost and unlimited criticism of all that was implemented or was started in the past there appeared a possibility for "the insulted" to carry on their destructive activities openly being not afraid of responsibility for that.
In the atmosphere of one-sided information or rather false information appearing in the press and on television whish easily catch up sensations and alleged "disclosures" the opponents of the construction managed to mislead the major part of the Leningrad population as well as the broad public in the Soviet Union and throughout the world.
In their fight for power at the meetings and conferences,im the reports published by the press and on television the new-come politicians under the cover of pseudodemocratic slogans took advantage of the artificially created psychological situation in connection with the problem of the flood protection of the city. They announced their strongly negative attitude to the project being under construction and promised that if they were elected people's deputies they will provide for halting the construction works and dismantling the part of the structure already erected. And they were not in the least embarassed by their complete lack of expertise in the problems concerned.

Now that they have become the deputies of the Lensoviet and they are unable to fulfill their promises, namely, to feed and to clothe the people, to eliminate the criminality etc., making use of their majority those people managed to drag in the decision about suspending the construction of the Leningrad storm surge barrier. However, since the decission was taken corporatively, by vote, there is no one at present to bear the responsibility for the consequences.
However, to implement this decision or any other decision in connection with the said problem this decision has to be accepted or approved by the USSR government, since the barrier has been constructed according to the governmental decision and is financed by the state.
Predicting a possible negative development of the situation around the flood protection in Leningrad on the initiative of mr.Marchuk, President of the Academy of science4s of the USSR, supported by the State Committee of the USSR on science and technology, the State Committee of the USSR on nature protection and the Gosplan of the USSR. the USSR Council of Ministers authorized by a special direction carrying out a comprehensive state expert study of this problem involving the work of an international group of experts.
During the second part of 1990 this expert group, where renowned scientists from many countries took part, gave a thourough study to the problem taking into account the world experience, and submitted a convincing material together with conclusions and recomendations which may be summarized as follows:

1.Since the ancient times a certain negative impact on the system Ladoga-Neva has been noticed which may be accounted for by such antropogenic features as:
-Discharge of untreated or of unsufficiently treated domestic and industrial waste waters.
-Reclamation of the marshlands to construct new residential and industrial areas. It influenced considerably the functioning of the Neva Bay as the area of stay of wading birds.
-Extraction of fill-in materials, service dredging of navigation channels, construction of military defense works by dredging the bottom sediments etc.
-Dumping the polluted sediments extracted by the dredgers and the snow from the sity streets into the system Ladoga-Neva.
-The inflow into the system Ladoga-Neva of different pollutants washed out on the whole surface of the Ladoga-Neva catchment including the pollution coming down from the air and caused by agricultural activities.
During the last ten years of the construction of the barrier its impact on the water quality in the Neva Bay has been negligeable as compared to the effects mentioned above.

2.The International commission is of the opinion that the flood protection is necessary. At present there is no economically justified alternative solution to the completion of the barrier construction which has been almost accomplished.

3. Due to the fact that the construction has not been completed yet storm waves and flows may cause considerable damage to the barrier; its repair may cost as much as several tens of millions rubles. Damages to the barrier will influence the environment negatively.

4. The present desighn of the storm surge barrier, as it has been confirmed by the international commission following the inspection, is reliable. The barrier is capable of protecting Leningrad from the floods.

However, at the moment on can not be sure that political manipulations should not lead to new complications and a new threat of halting or suspending the construction in spite of the fact that the jeopardy of strong and disastrous floods objectively grows in connection with the progressing sea level rise and common lack of ecological stability in the world. Similar situations have occured in this country and in other parts of the globe and may occur in future. It should be taken into consideration that solution of such problems is impossible without considerabile money and time expenses. Very often to reconsile opposite interests it is necessary to lower the quality level of the problem under solution, though in the countries with the high culture of the society it should not be like this.

During the international meeting in Venice in 1989 I already put forward my suggestions concerning setting up under the aegis of UNO a permanent international board possessing necessary power functions, to conduct expert studies of large projects of hydraulic engineering in any region of the world. Now I am turning back to this suggestion again since the problem becomes very urgent.

The extending scope of the interaction between the mankind and the water environment requires that the coordination of this interaction on the basis of the hydroecological situation, both locally and globally, should be provided for irrespective of any regional political situation.

Environmental Impact of Offshore Concrete Structures

Influence sur l'environnement des Structures Offshore en Béton

Umwelteinflüsse aus Bau und Betrieb von Offshore-Plattformen

Dag N. JENSSEN
Senior Vice Pres.
Norwegian Contractors a.s.
Stabekk, Norway

Dag N. Jenssen, born 1944, received his Ph.D in Mechanical Engineering at Heriot Watt Univ., Edinburgh. He is now senior Vice President of the Offshore Division. During his years in Norwegian Contractors he has also been involved in projects, platform design and marketing- and business development.

SUMMARY
This paper discusses experience from concrete platform construction in Norway. It deals with building site requirements vs. residential interests, fishing interests inshore, sea water contamination offshore and platform removal.

Influence de l'environnement sur les phases de construction et d'exploitation

Résumé
L'article présente les expériences norvégiennes de construction en mer en béton. Il traite des conditions posées aux sites par opposition aux intérêts privés, des questions de la pêche côtière, de la contamination des eaux de mer au large et de la démolition ultérieure des ouvrages en mer.

Umwelteinflüsse aus Bau und Betrieb von Offshore-Plattformen

Zusammenfassung
Dieser Artikel diskutiert Erfahrungen beim Bau von Betonplattformen in Norwegen. Er handelt von Bauplatzerfordernissen gegenüber Anwohnerinteressen, Küstenfischereiinteressen, Meerwasserverun-reinigungen auf See und dem Entfernen der Plattform.

INTRODUCTION

The design and construction of concrete offshore platforms for the North Sea have been continuous activities in Norway since 1971. There have been a number of technical improvements during this period, related to material strength, analysis methods, slipforming techniques, computer aided design etc; at the same time there have been a growing awareness of the environmental issues that are consequences of concrete platforms. This paper discusses experience from concrete platform construction in Norway concerning:

- building site requirements vs residential interests
- fishing interests inshore
- sea water contamination offshore
- platform removal

BUILDING SITE REQUIREMENTS

The dimensions of concrete platforms make them major undertakings. Data from three ongoing projects are listed below to illustrate the magnitude:

Project Operator	Sleipner Statoil	Draugen Shell	Troll Shell
Concrete volume, m^3	72.000	85.000	225.000
Height, m	112	290	370
Bare area, m^2	11.700	9.300	14.000
Construction period, months	34	35	44
Reinforcement, tons	17.000	22.000	67.000
Installation date	1992	1993	1995

The construction site at Hinna is located right within a residential area and we have therefore had to deal with a number of conflicting issues, some of which are satisfactorily resolved and others that remain to be solved;

- **View.** The site occupies an area of about 30 hectare and there is no way you can hide that. Two drydocks, a multitude of cranes and barges, stores, workshops, cement silos, offices and prefab areas make for a different view than trees and wetland. Personally, I am not so concerned about the view, that can be restored, but the loss of wetland represents an irreversible act.

- **Noise.** The Norwegian State Pollution Board has laid down specific requirements. Initially our attitude was to modify our activities solely to make sure that the requirements were met. Lately we have developed a more active approach where we define our own goals and where we see noise as an element in the much broader concept of work environment, i.e. the interaction between job planning, safety, construction methods, weather protection and working hours. Thus, noise virtually ceases to be an issue if we properly identify the work environment to be the mitigating factor. Status to day is that we have some way to go, although the noise level as such is formally resolved.

* We meet the SFT requirements w.r.t. noise. There are occasional exceptions, but not regular or planned deviations. During daytime (06-18 hrs) the maximum noise level at the nearest residential house should not exceed 55 dB (A), during the evening (18-22 hrs) 50 dB (A), and at night and Sundays 45 dB (A).

  A 4,5 m barrier has been constructed along the site perimeter where there are residential houses.

* Light represents a problem. There are prolonged periods where there is a two shift system and regular periods with around the clock operations. Particularly during the winter months this is a disturbance for the neighbours.

* Traffic is another problem. Roads both inside and outside the site have been upgraded to reduce noise and dust sources, but there will be traffic associated with a busy site. There is also marine traffic, both to unload bulk materials and equipment and to service the inshore construction site in the middle of the fjord. All marine traffic is coordinated with the local harbour boards of Stavanger and Sandnes.

* The main constituents of concrete, cement, water, aggregates, are locally obtained and do not represent major quantities in terms total national supplies. One aspect worth noticing here though is that civil engineers in Norway have hurt a number of salmon rivers by removing river bed aggregates. This is a tragedy considering that our forefathers have harvested salmon for thousands of years from these rivers. This practice is now illegal, but still persists in some areas.

* Building site effluents are tightly controlled and are not considered to be a problem. However, particular attention has to be paid to operations like injection of prestressing cables, epoxy applications and machinery maintenance.

FISHING INTERESTS INSHORE

The inshore constructions sites occupies substantial areas of the fjord when the mooring systems are included. Typically, there are 4 to 5 anchors legs, each having a length of 1.000 m - 1.500 m. This effectively closes the area to commercial fishing. This is alleviated by monetary compensation to the local fishermen's council. The magnitude of this is agreed according to the area covered by the inshore sites and the length of stay. This has been resolved without major conflicts.

SEA WATER CONTAMINATION OFFSHORE

Offshore drilling and production platforms are subject to a host of regulations to minimise the environmental impact. Designers of concrete platforms provide one feature that is not common for other materials - that is the possibility of crude oil storage. To date about 10 North Sea platforms have inbuilt storage facilities. All of these utilize sea water as ballast medium with an interface that continuously moves as oil is produced and/or exported. Measurements show that the ballast water discharge contains 6 - 10 ppm of oil which is well below 25 ppm that is the maximum permitted. However, it must be borne in mind that,

- technically, there is no practical way of reducing the contamination

- 10 ppm represents an annual level of about 100 tons oil spill for a big North Sea platform. In perspective, the same platform will probably have other sources of contamination and leakage that exceeds the ballast water oil, but nevertheless, this is an additional load

For the oil company which operates the platform the issue is to decide whether oil storage is needed or not. If it is, then it is the responsibility of the designer to engineer a storage system with minimum contamination. The two main areas to be addressed are the wet vs. dry system and the piping and instrumentation principles. All systems have so far been wet, but the first dry system, i.e. no ballast water, will be operational offshore Holland in 1992.

PLATFORM REMOVAL

Platform removal is a matter of disconnecting all risers and pipelines, plugging the wells and then reversing the installation procedure. This is, of course, a very simplistic, representation. But as a platform has reached the end of its operational life, the biggest challenge will be disposal, not removal. The topside can certainly be dismantled, lifted ashore and recycled like other industrial scrap, but the concrete structures will have to be dumped, possibly in a deep fjord or the Atlantic trench.

HINNAVÅGEN

1. LABOUR ACCOMODATION
2. STAFF ACCOMODATION
3. CANTINE
4. PARKING AREA
5. RECEPTION
6. OFFICE BUILDING
7. QUAY
8. SAUNA/GYMNASIUM
9. SQUASH COURT
10. FOOTBALL PITCH
11. MECHANICAL WORKSHOP
12. STORE
13. REINFORCEMENT PREFAB. AREA
14. FORMWORK PREFAB. AREA
15. SECURITY
16. NC's LEANING TOWER
17. CHAIN INSPECTION
18. MARITIME STORAGE
19. SAND BLASTING
20. TEMP. STORAGE AND WORKSHOPS
21. DRY DOCK

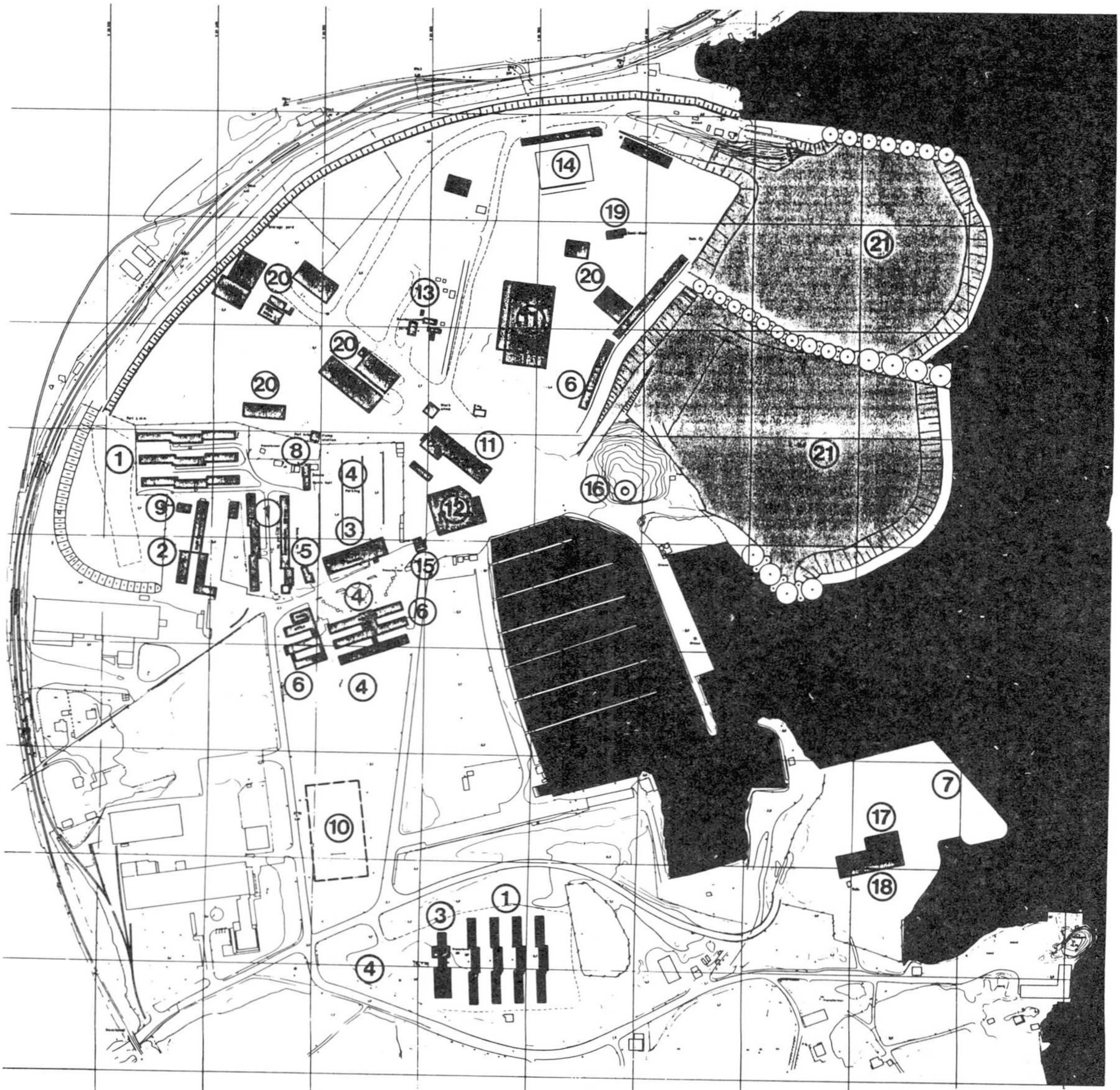


Fig.:

SITE PLAN
HINNAVÅGEN
ST-60D

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Environmental Management for the Great Belt
Gestion de l'environnement pour le projet du Great Belt
Umweltmanagement für den Grossen Belt

Knud Mose POULSEN
Civil Eng.
A/S Storebæltsforbindelsen
Copenhagen, Denmark

Knud Mose Poulsen, born in 1945, received his MSc at the Technical Univ. of Denmark. For 12 years he worked for consulting firms in the fields of pollution and hydraulics. Presently, he is Project Manager for the Environment at A/S Storebæltsforbindelsen.

Jan DIETRICH
MSc, Civil Eng.
Water Consult
Glumsø, Denmark

Jan Dietrich, born 1946, received his civil engineering degree at the Technical Univ. of Denmark. For 13 years he was a research engineer at the Danish Hydraulic Institute. He is now Managing Director for a consulting firm dealing with environmental issues in the Marine Environment.

SUMMARY

The Act of the Danish Parliament for the construction of the fixed link across the Great Belt determines that the link be constructed in sush a way that the water flow through the Belt to the Baltic Sea is unaffected by the presence of the Link. This environmental design requirement is called the "Zero Solution".A conditional hypothetical concept is introduced, meaning that if a hypothesis is confirmed, additional survey is triggered off. The Feedback Programme describes the procedure to be followed when predetermined levels of the impact of the local environment are exceeded. The paper describes the management and organization of the environmental programmes.

Gestion de l'environnement pour le projet du Great Belt

Résumé

L'acte du Parlement danois pour la construction d'une liaison fixe sur le Great Belt précise que la liaison doit être construite de sorte que les courants marins à travers le détroit jusqu'à la Mer Baltique ne soient pas modifiés. Cette condition pour l'environnement est appelée la "solution zéro". Un concept de conditions hypothétiques est introduit, précisant que si une hypothèse est confirmée des études supplémentaires doivent être déclenchées. Un programme itératif nouveau décrit la procédure à suivre lorsque des niveaux prédéterminés de l'influence sur l'environnement local sont dépassés. L'article décrit la gestion et l'organisation de ces programmes d'environnement.

Umweltmanagement für den Grossen Belt

Zusammenfassung

Der dänische Parlamentsbeschluss über den Bau einer festen Verbindung über den Grossen Belt verlangt, dass die Strömungsverhältnisse durch den Belt in die Ostsee durch die Verbindung nicht beeinträchtigt werde. Diese ökologische Entwurfsbedingung wird die "Null-Effekt-Lösung" genannt. Ein Konzept hypothetischer Bedingungen wurde eingeführt, bei dem das Eintreffen einer Modellannahme automatisch weitere Untersuchungen auslöst. Ein Feedback-Programm gibt Handlungsanweisungen für den Fall, dass die Umweltauswirkungen festgelegte Schwellenwerte überschreiten. Der Artikel beschreibt das Management und die Organisation dieser Umweltprogrammme.

1. INTRODUCTION

A Master Plan for the protection of the environment around the Great Belt Link is being implemented.

The Master Plan comprehends all studies and investigations which A/S Storebæltsforbindelsen has already initiated or intends to carry out in order to protect the environment. The Plan was set off with initial studies in 1987-88 of the Zero Solution Concept for the Baltic Sea and the impact on the near field environment on which the approval in October 1988 of the overall design of the fixed link was based. It will be concluded with the final environmental documentation in 1997.

The Master Plan was designed on the basis of two overall environmental criteria and on an overall environmental link optimization made by the Danish Government in 1987/88.

2. OVERALL DESIGN CRITERIA

The overall environmental design criteria set up by the Government was divided into:

- The Zero Solution Concept for the Baltic (far-field).
- Minimization of the impact on the local environment.

The Zero Solution Design Concept is described in § 5 of the Act of Parliament of 26 May 1987 (Law No. 380) concerning the link across the Great Belt, which reads as follows:

> "*The two stages of the work are to be carried out separately in such a way that the water flow through the Great Belt shall remain unchanged after the completion of the work for the sake of the marine environment in the Baltic.*"

3. LINK DESIGN - ENVIRONMENTAL OPTIMIZATION

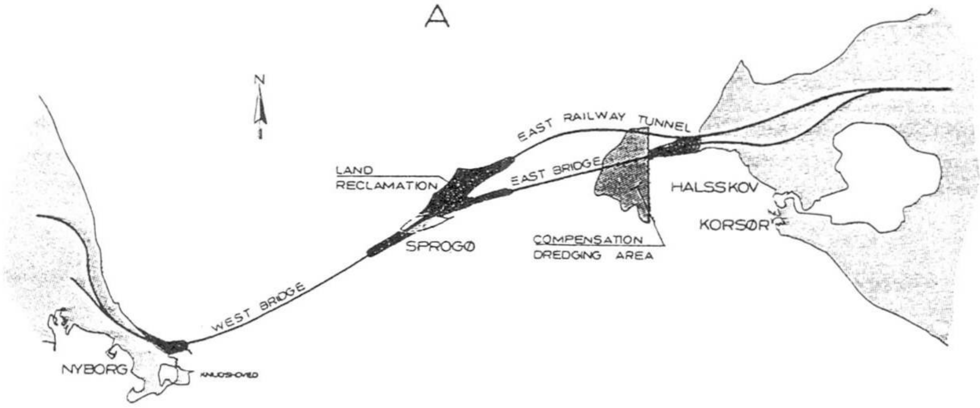
The preliminary purely economic optimization of the link design resulted in a combined bridge - ramp - tunnel layout as shown in Figure 1.

This layout involved large marine earth works for construction of ramps and the execution of the necessary extensive compensatory dredging. As the major impact on the environment originates from the spillage of sediments and nutrients during the handling of earth volumes, the following projects were decided upon during the "environmental optimization", see Figure 1.

- The size of Sprogø island and the length of the ramps were reduced considerably.

- The ramp at Halsskov was removed.
- The bridge piers and anchor blocks were hydraulically shaped.

A



B

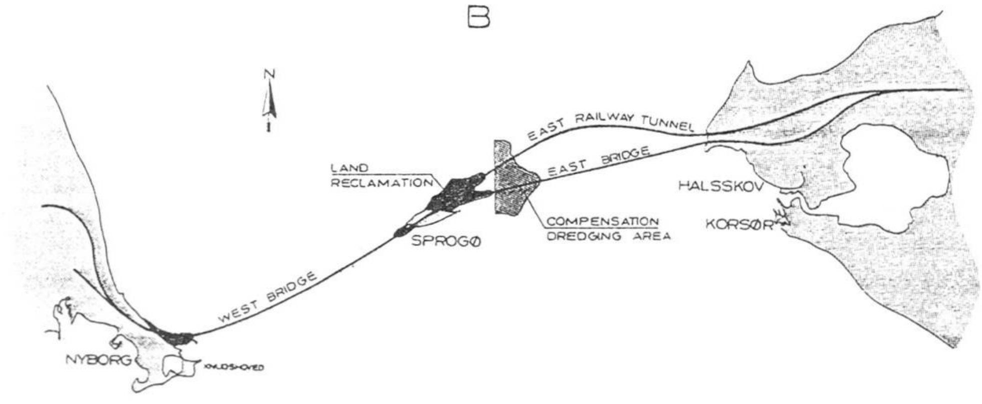


Figure 1 A: Economically optimized link design
B: Environmentally optimized link design

It became apparent that this link design had a very small blocking effect against the flow to the Baltic, in the order of .5%.

In order to further reduce the spillage to the Great Belt, it was decided to deposit all excavated marine material, that contained more than 5% organic matter, in special sedimentation basins at Sprogø, see Figure 2.

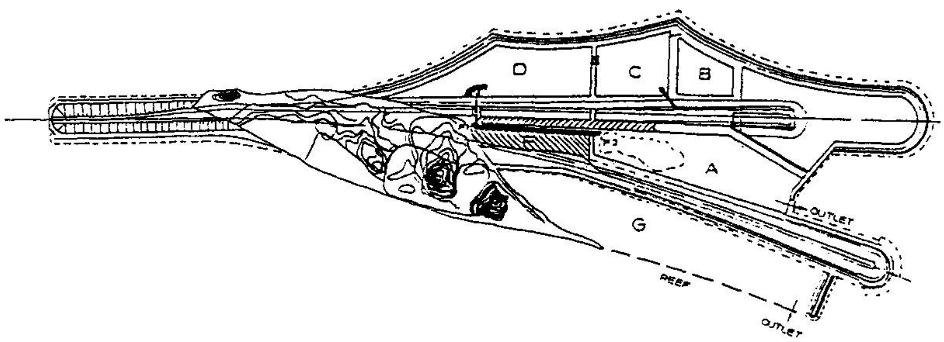


Figure 2 Sedimentation basins at Sprogø

Finally, it was decided that the loss of material from the sedimentation basins and from the reclamation at Sprogø should be less than 3% and at Knudshoved should be less than 5%.

The environmental benefits of the optimization were thus:

- Considerable reduction of the absolute uncertainties on the achievement of the Zero Solution.
- 50% reduction of the total spillage of sediment and nutrient to the Great Belt from the reduced amount of marine earth works and the inclusion of sedimentation basins.
- Particularly, a considerable reduction of the spillage at the reefs of Sprogø and Halsskov.

The costs of the environmental minimization were estimated at: DKK .5 billion for the compensatory dredging, DKK .15 billion for the execution of the environmental Monitoring Programme, and DKK 1 billion for the changes of the overall The total cost of these benefits were thus estimated at DKK 1.65 billion, corresponding to nearly 10% of the total link construction budget.

4. THE ZERO SOLUTION

The legal design requirements were technically interpreted into the following requirements to the link:

- The water flow through the Great Belt must not be changed by the link.
- The salt balance in the Baltic Sea must not be changed by the link.

Hereby the environmental design requirements for the far field were reformulated into a purely hydraulic requirements.

The technical hydraulic requirements to the link involve:

- that the hydraulic flow resistance in the Great Belt be unchanged.

- that the mixing between the surface layer and the bottom layer in the Great Belt be unchanged.

- that the frequency of the supercritical two-layer flow be unchanged.

The hydraulic design criteria is met by compensating for the blocking of the flow by the bridge piers and the ramps with a corresponding enlargement of the flow cross section.

The compensatory dredging is carried out at Sprogø East Reef and comprises the excavation of a total amount of 6 - 8 million m^3 sand, stone and moraine clay, see Figure 1.

An advanced, mathematical two-layer hydraulic model was developed for the calculation of the extent and amount of dredging.

A series of physical model tests were performed in order to improve the capability of the model to reproduce the various hydraulic features in the Great Belt and blocking effects of the various link elements.

The model was calibrated and verified against a comprehensive hydraulic monitoring programme, see Figure 3.

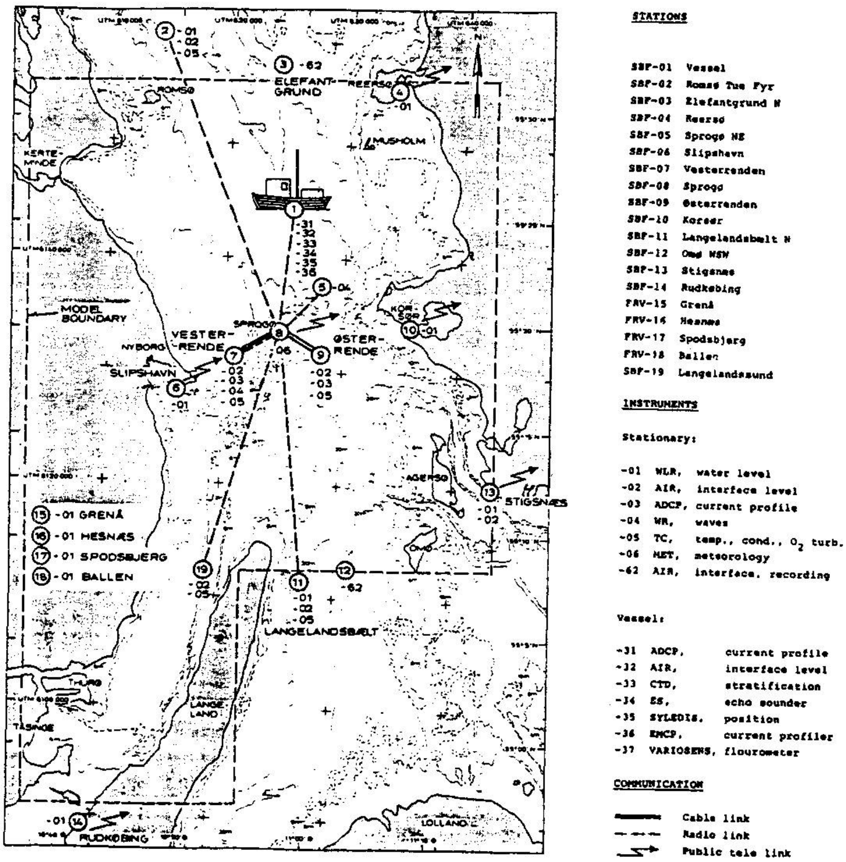


Figure 3 Hydraulic Monitoring Programme

The design of the compensatory dredging takes place during the execution of the actual dredging operations. The predicted hydraulic effects of the excavation are verified against field data from the area. If required, the model will be adjusted and the dredging amounts consequently revised. This process will be repeated immediately before completion of the entire dredging operation and final design will be performed.

5. NEAR FIELD

It appears that the Zero Solution Design Concept only deals with the far field. The environmental effects cannot be completely avoided during construction and by the permanent link. In the near field the bridge abutments, tunnel construction works, causeway and artificial island will create certain disturbances in the environment compared to the situation today.

In order to meet the design criteria of "minimizing" the impact on the near field, a comprehensive monitoring of a series of physical and biological variables are performed throughout the entire construction period.

Four concepts were developed and formed the basis for the outline of the Monitoring Programme:

- Conditional Hypothetical Concept
- Feed Back Concept
- Contingency Concept
- Sediment Source and Spreading Concept

Conditional Hypothetical Concept

The key biological variables which are included in this concept were selected on the basis that they are significant ecological components of the Great Belt marine ecosystems and that the effects of the construction activities can be quantified reliably.

The key biological variables are:

- Eelgrass: north of Sprogø, at Vresen and at Halsskov
- Kelp: south of Sprogø and north of Sprogø
- Mussels: around Sprogø, at Vresen, and at Halsskov
- Soft bottom fauna.

A number of hypotheses was formulated on the basis of expected responses. Some of these are conditional, and will only be investigated if a significant effect is found in the first hypothesis.

Hypothesis 1: That due to increased sedimentation (and thereby reduced light) reductions in growth of eelgrass (Zostera marina) and kelp (Laminaria spp.) will occur.

Hypothesis 2: (conditional)	That reduced growth may lead to reduced areas of eelgrass and kelp beds.
Hypothesis 3:	That increased sedimentation will lead to reduced growth rates of mussels (Mytilus edulis).
Hypothesis 4: (conditional)	That reductions in growth rate lead to reduced areas of mussel beds around Sprogø.
Hypothesis 5:	That due to increased sedimentation and/or reduced oxygen concentration, changes in species composition of the soft bottom communities will occur.
Hypothesis 6: (conditional)	That due to increased nutrient discharge there will be an increased growth of epiphytes on eelgrass (Zostera marina).

A large-scale monitoring of the involved variables was designed with the objective of confirming or rejecting the established hypotheses.

If the hyphoteses are confirmed, the Monitoring Programme is to be extended and construction methods more favourable to the environment should be adopted.

Feed Back Concept

Biological monitoring with feed back possibilities is a totally new concept. The basic idea is that unacceptable changes in the environment caused by construction activities can be defined in terms of biological variables, and that exceeding of the prefixed limit should lead to changes in the construction activities which mitigate the adverse effect.

Three biological events have been chosen as important elements for the feed back monitoring:

- Wintering eider ducks
- Spring spawning herring
- Phytoplankton blooms

These variables were chosen for the reason that they may be affected by the construction activities at distances beyond the near field area.

The prefixed limits and the possible feed back actions were discussed with the authorities and the monitoring programme outlined for each of the variables.

If the prefixed limits are exceeded, alternative construction methods should be analyzed with respect to:

- reducing the spillage
- reducing the disturbances of the environment
- reducing impact during the sensitive seasons of the environment

Contingency Concept

Particular attention was put on the development of oxygen depletion and the development of a sudden algae bloom from the activities in the Great Belt.

A special Contingency Programme has been set up to follow the risk of occurrence of such events.

A weekly routine profiling of the oxygen contents and the flourescens were performed in the Eastern Channel in the period 01 May - 31 September 1990. If the oxygen content fell below 4 mg/l or the content of flourescens exceeded 10 mg/l, the Programme would be extended to cover a larger area and to include a number of water samples.

The authorities were to be notified if the oxygen content came below 4 mg/l or if a toxic algae bloom developed in the Great Belt.

If the oxygen depletion and the algae bloom were caused by the activities of the Great Belt company, steps should be taken to reduce spillage from on-going operations.

Sediment Source and Spreading Concept

As previously mentioned, the major impact on the local environment originates from the spillage of sediments and nutrients during the execution of the compensatory dredging, the sand winning in the Great Belt, and the reclamation works.

The objective of this concept is to evaluate the actual physical and chemical conditions affecting the flora and fauna.

This concept comprehends the follow main variables:

- Source Emission Monitoring
- Plume Emission Monitoring
- Plume Modelling
- Data base for all earth volumes handled during the construction phase

The spillage is measured for all marine earth work operations contributing significantly to the total spill budget in the Great Belt.

The major plumes are traced with respect to:

- Sediment content
- Nutrients
- Oxygen
- Phytoplankton

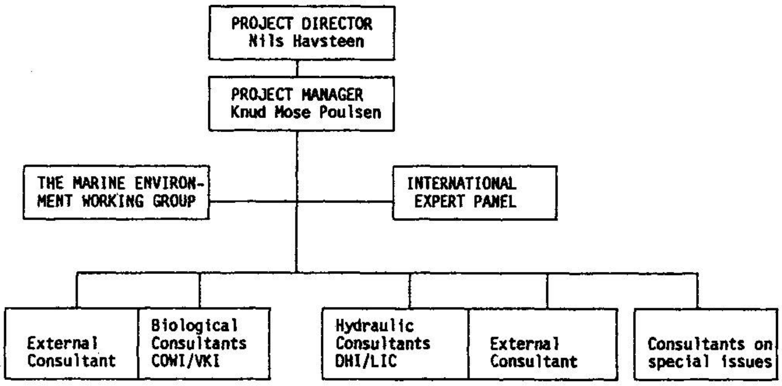
The plume model is calibrated on the basis of the plume tracing.

The results of the modelling are used for the interpretation of the results of the monitoring of the biological variables and the subsequent assessment of the impact on the local environment.

The plume modelling also contributes to the detailed planning of the monitoring of the biological variables.

6. MANAGEMENT

The organization set up for the implementation of the Environmental Master Plan is as follows:



COWI/VKI: COWIconsult and Water Quality Institute Joint Venture
DHI/LIC: Danish Hydraulic Institute and LIC Engineering Joint Venture

The open door policy is the guideline for the organization and management of the Environmental Master Plan.

The contact with the environmental authorities is coordinated through a working group "The Marine Environment". All relevant local and central authorities are represented in the working group.

The planning, execution and results of all the environmental studies and investigations are discussed in the working group on a current basis.

In order to ensure a high technical and scientific level of the Master Plan, an International Expert Panel composed of ten internationally esteemed scientists was appointed. The expert panel follows the implementation of the Master Plan and reviews the results of all the main activities of the plan at an annual review session.

The implementation of the Master Plan is carried out by two consultant groups, COWI/VKI Joint Venture and DHI/LIC Joint Venture.

The consultant groups carry out the biological and hydraulic investigations with the assistance of two internationally esteemed experts (External Consultants) Professor Flemming Bo Pedersen, The Technical University of Denmark, and Professor John S. Gray, Oslo University.

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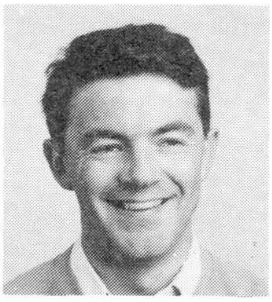
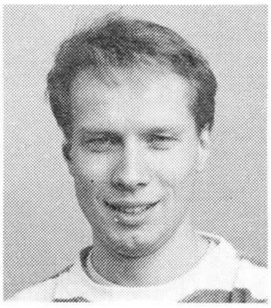
The Great Belt Link: Zero Environmental Impact on the Baltic Sea
Impact "zéro" du Great Belt sur l'environnement de la Mer Baltique
Die Grosse-Belt-Verbindung: Umweltneutrale Verwirklichung für die Ostsee

Jacob Steen MØLLER
Head of Div.
Danish Hydraulic Institute
Hørsholm, Denmark



Jacob Steen Møller, born 1954, received his Ph.D. in environmental hydraulics at the Technical Univ. of Denmark(1984). Since then he has been Research Engineer in environmental and coastal engineering at Danish Hydraulic Institute. In 1989 he was appointed Head of Coastal and Environmental Division.

Henning Smith NIELSEN
Hydraulic Eng.
Danish Hydraulic Institute
Hørsholm, Denmark



Henning Smith Nielsen, born 1964, received his M.Sc. at the Univ. of Aalborg. Since 1989 he has been employed in the Coastal and Environmental Division at Danish Hydraulic Institute. As a research engineer he has been investigating environmental aspects related to the Great Belt Link.

SUMMARY
The Great Belt Link is located in the main outlet from the Baltic Sea, and the changes in the flow conditions caused by the Link may influence the environment of the Baltic Sea. This paper shows how these possible effects are avoided by the design of compensation dredging. The design work has involved comprehensive use of a numerical hydrodynamic two layer model, the model and the design method being described as well as some special problems related to the stratification of the Great Belt waters highlighted.

Impact "zéro" du Great Belt sur l'environnement de la Mer Baltique

Résumé
La liaison du Great Belt se trouve au débouché principal de la Mer Baltique. Des changements importants dans les courants causés par la liaison pourraient influencer l'environnement de la Mer Baltique. L'article montre comment de tels effets peuvent être évités par un dragage de compensation. L'étude comprend une application extensive d'un modèle hydrodynamique numérique à deux couches. Le modèle et la méthode de projet sont décrits et quelques problèmes particuliers liés à la stratification des eaux du Great Belt sont présentés.

Die Grosse-Belt-Verbindung: Umweltneutrale Verwirklichung für die Ostsee

Zusammenfassung
Die Verbindung über den Grossen Belt liegt im wichtigsten Wasserdurchlass der Ostsee. Ihre Lage verursacht Veränderungen der Strömungsbedingungen, die die Oekologie der Ostsee beeinflussen könnten. Dieser Artikel zeigt, wie diese möglichen Nebenwirkungen durch den Entwurf von Ausgleichsbaggerungen vermieden werden. Die Entwurfsarbeit bediente sich in grossem Umfang eines numerischen hydrodynamischen Zwei-Schichten-Modells. Modell und Entwurfsmethode werden zusammen mit einigen speziellen Problemen der Wasserschichtung des Grossen Belts beschrieben.

1. INTRODUCTION

The Great Belt is the main outlet from the Baltic Sea. At the site of the Link the small island of Sprogø divides the Belt into an eastern and a western channel. The Link will consist of a combined road and rail bridge across the western channel. On Sprogø the traffic is divided and the road traffic continues to Zealand on an elevated bridge, whereas the rail traffic will continue in a bored tunnel beneath the 70 m deep eastern channel.

Since the Great Belt is forming the transition between the saline North Sea and the brackish Baltic Sea, the Belt can be considered the "Gibraltar Strait" of the Baltic Sea. Because of this delicate location changes in the flow conditions of the Great Belt due to the Link will influence the hydrography and hence the aquatic environment of the Baltic Sea.

The potential effects of restricting the flow through the belt by building causeways and bridge piers have raised concern for the environment of the Baltic Sea. This concern has lead to a new and very strict approach to the environmental impact design criteria: the so-called zero effect solution or the "zero solution" which is included as §5 in the Act of Parliament concerning the Great Belt.

§5 can be translated into English as:

"The work is to be carried out ... in such a way that the water flow through the Great Belt shall remain unchanged ... for the sake of the marine environment of the Baltic Sea".

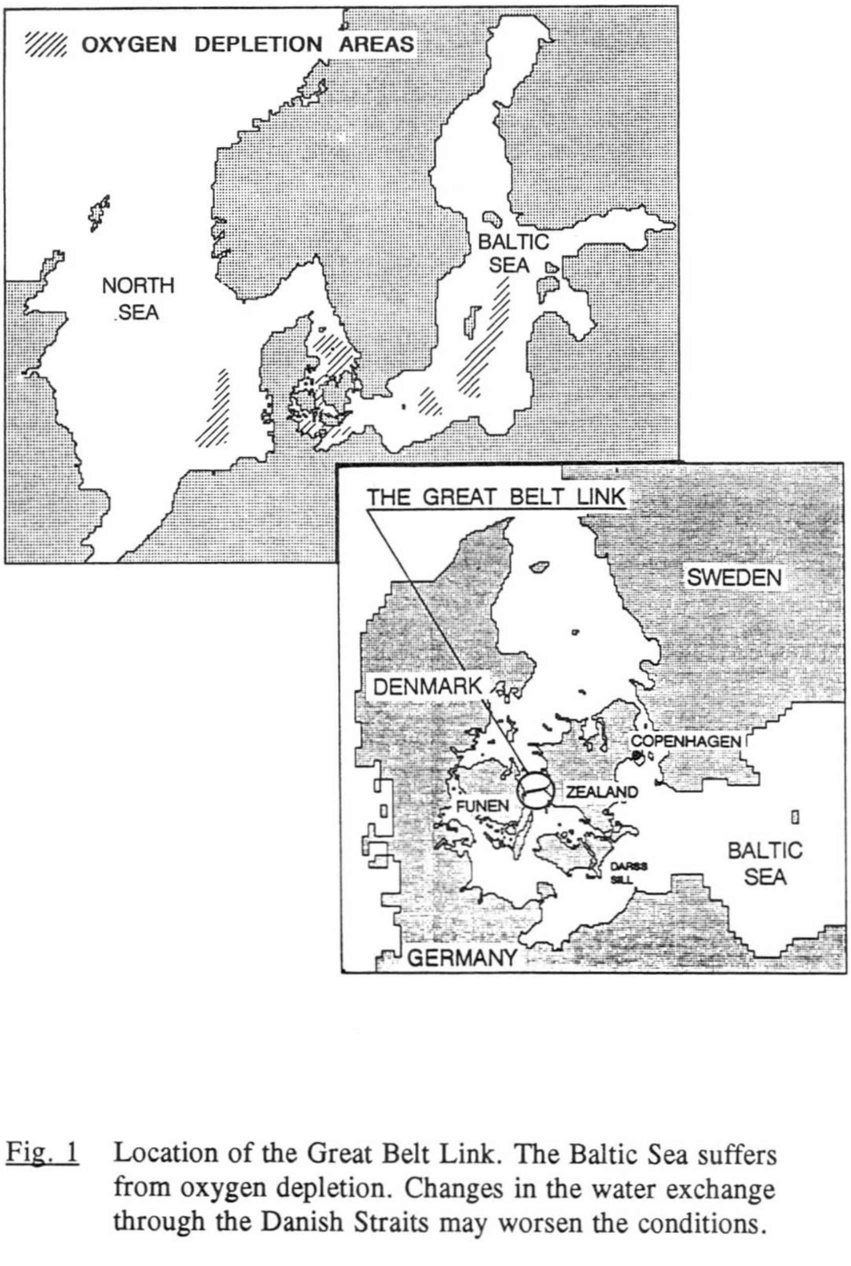


Fig. 1 Location of the Great Belt Link. The Baltic Sea suffers from oxygen depletion. Changes in the water exchange through the Danish Straits may worsen the conditions.

The legal requirement is interpreted into the following requirements to the design of the Link:

1. The water flow through the Great Belt must not be changed by the Link.
2. The salt balance for the Baltic Sea must not be changed by the Link.

The basic idea of the zero solution is to keep the hydrography of the Great Belt and hence the Baltic Sea unchanged by the Link. This is achieved by compensating the flow resistance and mixing due to the piers and causeways by dredging.

2. ZERO SOLUTION CONCEPT

During construction of the Great Belt Link efforts have been made to reduce the flow resistance of the construction elements:

- The tunnel is bored below the sea bed.
- The embankments have been shortened.
- The bridge piers have been streamlined.

The remaining blocking has to be compensated. This is done by executing compensation dredgings on mainly the East Reef of Sprogø, see Fig. 2. Approach channels on the West Reef for manoeuvring the vessel employed for construction of the West Bridge and realignment of the navigation channel (Route T) are also causing a minor compensating effect.

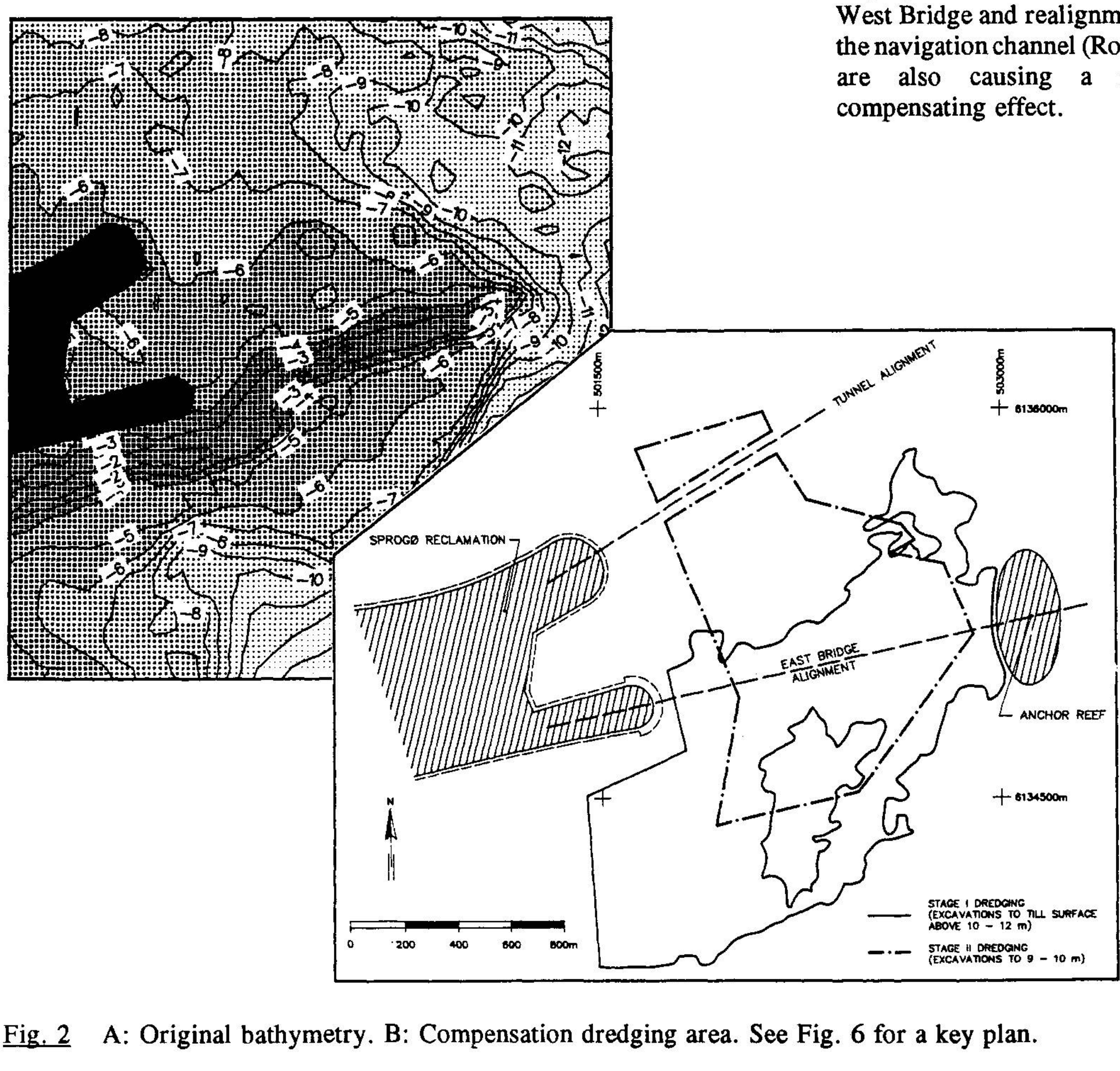


Fig. 2 A: Original bathymetry. B: Compensation dredging area. See Fig. 6 for a key plan.

The problem now arises, how to determine the size and location of the compensation dredging. This engineering design work is carried out according to the following principle.

Given the boundary condition for the flow through the Great Belt the surface current is calculated as it was without the Link, and as it will be with the Link. By calculating the deviation in surface water flow, we have defined a measure of deviation from the zero solution. This measure will depend on the geometry of the Link: large piers and long cause-ways will increase the deviation.

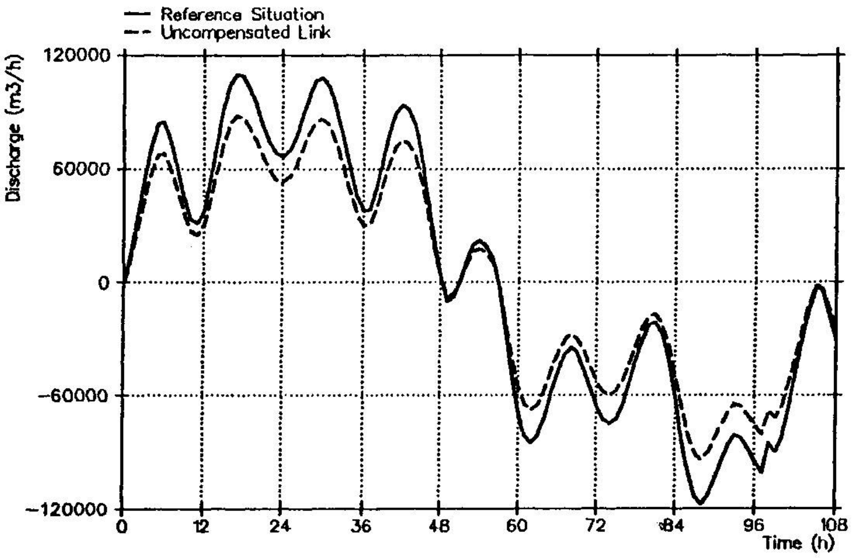


Fig. 3 Sketch showing effect of the Link on the flow. (Principle).

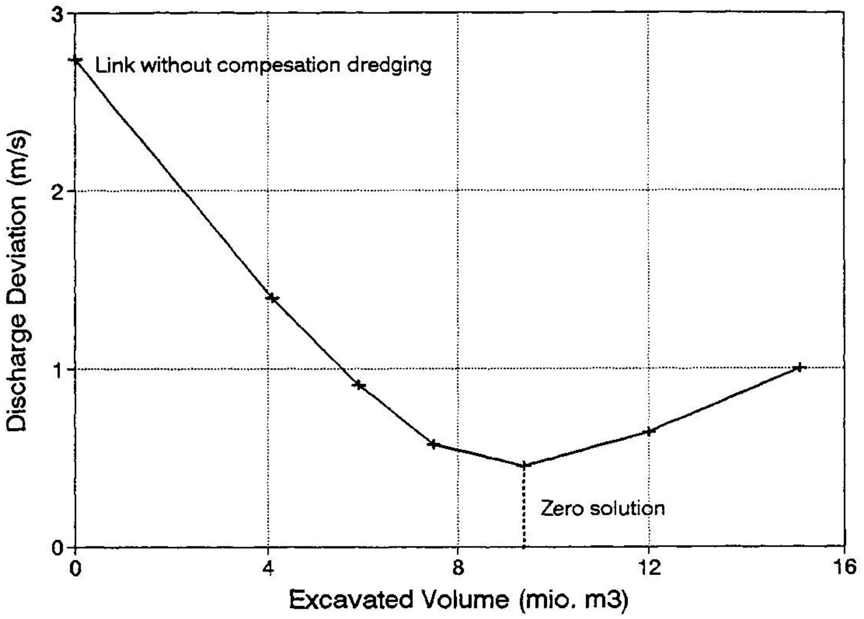


Fig. 4 Discharge deviation as function of the excavated volume. (Principle).

The flux for a combination of bridge design and compensation dredging design is compared to the reference situation, see Fig. 3. The area between the curves is representing the deviation of the flux. The deviation Δq_i is expressed by

$$\Delta q_i = \frac{\int_T |Q_i - Q_{ref}|\, dt}{\int_T |Q_{ref}|\, dt}$$

Q is the flux through the link section. Index "ref" is denoting refererence situation and "i" design i.

Now for a given design of the Link we can introduce a dredging scheme and calculate the resulting deviation caused by the combined Link and dredging. By repeating the calculation of deviation for different dredging volumes the deviation is minimized. Zero solution is reached for minimum deviation, see Fig. 4.

As demonstrated below not only the water flow but also the mixing must be kept unchanged by the Link. This is ensured by the use of a verified two layer numerical model.

3. HYDROGRAPHY OF THE GREAT BELT

To perform reliable numerical modelling it is necessary to understand the hydrographic conditions. The water exchange through the Great Belt is governed by the following mechanisms:

1. Tidal forces.
2. Fresh water surplus from the Baltic Sea.
3. Meteorological forces.

The tidal forces are generating an oscillating current of well known periods. The fresh water surplus is generating a current varying over the year, the mean flow being 9,5 · 10^3 m^3/s, Belt Project (1980). The meterological forces are less predictable. These forces are generating an oscillating current with varying period and amplitude. It is thus concluded that the flow is more complicated than just a monotone flow of brackish water from the Baltic Sea into the North Sea.

When the current is north bound brackish water from the Baltic Sea is flowing across the Darss Sill (Fig. 1). Since the brackish water is buoyant compared to the saline water from the North Sea, a stratified flow is generated in the Great Belt. The upper layer of brackish water moving towards north tends to increase its salinity due to turbulent mixing with the saline bottom water.

When the flow is south bound the now saline upper layer is moved across the Darss Sill. Even more saline water from the bottom layer is also being pulled over the sill. These saline water masses plunges down the slopes of the Darss Sill and eventually feeds the bottom water of the Baltic with salt and oxygen.

Modelling the stratified flow of the Great Belt requires in principle a three-dimensional hydrodynamic model. Such a model suitable for engineering purposes does not exist. It was therefore decided to analyse the flow further in order to investigate if it was possible to use a 2-layer model for documentation of the compensation dredging design. When stratified flow is simplified and assumed two layered, one has to distinguish three flow regimes:

- Subcritical two-layer flow •
- Supercritical two-layer flow
- Well mixed flow

Subcritical flow exist when the stratification together with the dynamic condition (the speeds of the layers) is stable and long internal waves in the interface between the brackish upper layer and the saline bottom layer can move freely in all directions.

Supercritical flow exist when the long interval waves are arrested by the mean current, the waves cannot move freely against the current.

Well mixed (or continously stratified) flow exist when the two-layer assumption is unstable and internal waves break. In this last case the two-layer assumption is invalid.

Based on the theory of dynamic stability outlined in Abbot and Torbe (1963) field data from Storebælt (DHI/LIC, 1990) have been analysed and a histogram of the frequency of the flow regimes is shown in Fig. 5. It is seen that the most frequent flow regime is the subcritical regime. This supports the choise of a two-layer model as an appropriate design tool.

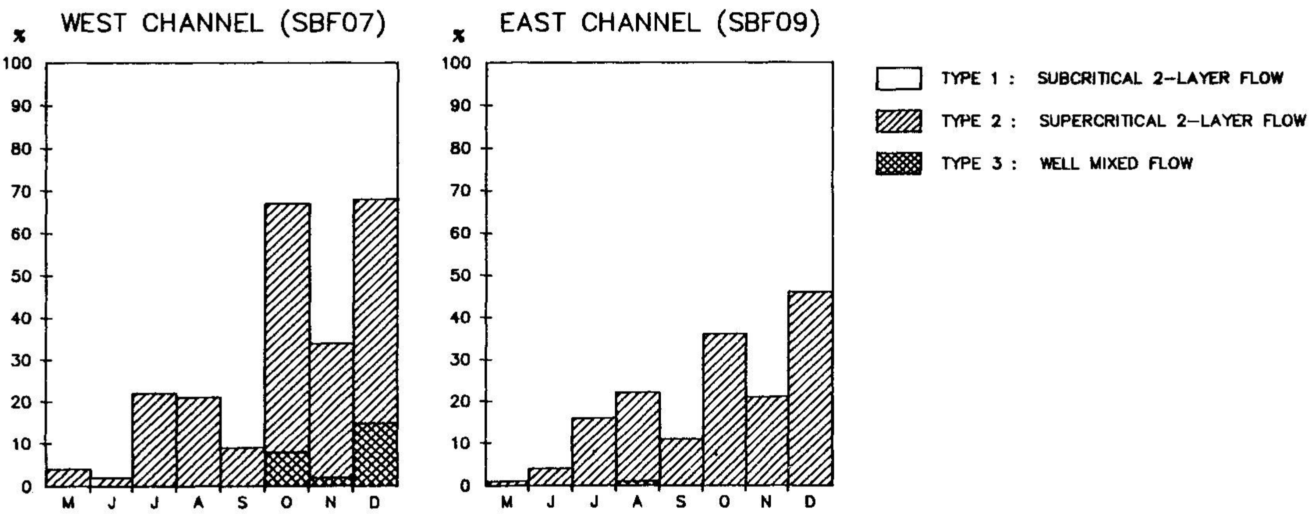


Fig. 5 Frequency of flow regimes in the Great Belt based on measurements from West Channel (SBF07) and East Channel (SBF09) see Fig. 7. Data from the period May to December 1989 are included.

4. NUMERICAL MODELLING

From the hydrographic description it is seen that a layered model should be chosen. Also the model must be able to calculate the effect of bridge piers and causeways on the flow.

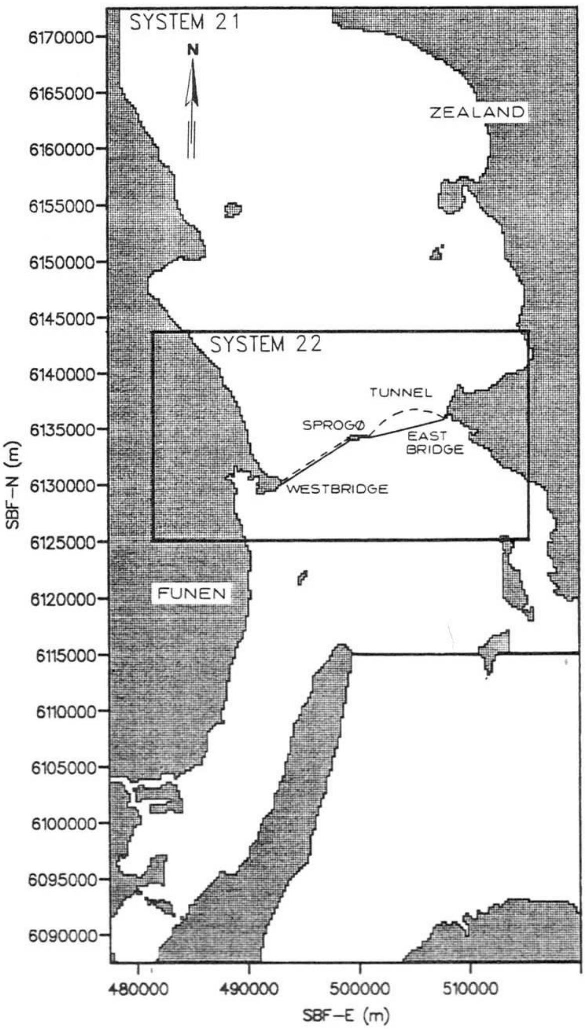


Fig. 6 Model Area.

The model requirements are:
- Two-layer model
- Subcritical and supercritical flow regime
- Flow resistance of bridge piers
- Flow resistance of causeways
- Turbulence description (mixing between layers)

Also it is required that the model is verified by field measurements, see below.

The task of setting up a numerical model for producing multiple simulations is a compromise between model performance and the limits due to computer capacity. For the determination of the zero solution an approach including two models was chosen.

A main model was set up for a large area of 43 · 85 km². Inside this area a submodel of 34 · 19 km² was employed on basis of boundary data calculated by the main model. The grid size was chosen to be 250 x 250 m².

The main model is an one-layer model set up in the DHI modelling system 21. The submodel is a two-layer model set up in the DHI modelling system 22. See Fig. 6.

The surface elevation along the submodel boundary is extracted from the main model results. The level of the interface is found on the basis of measurements carried out on a few locations corresponding to the model boundary.

The tilt of the interface along the boundaries is found from surface elevations considering hydrostatic pressure distributions.

The models are based on the coupled equation for conservation of mass and momentum in two directions. By solving this set of equations numerically the elevation and two velocity components are found for each grid point and each layer.

In the equations of momentum the following terms are included:

- non linear convective and cross momentum,
- coriolis force,
- turbulent momentum dispersion,
- wind shear stress, and bottom shear stress,

and for the two-layer model:

- interface shear stress.

To model the bridge piers properly a subgrid module has been developed. The drag forces on the piers are calculated and equivalent drag forces are added to the momentum equations.

The calculations are performed using a design period representative for the varying current conditions in the Belt. The final compensation dredging is controlled by a sensitivity analysis in which design period and model parameters are varied within a physically reasonable range. Sensitivity tests show that the uncertainty of the method is comparable to the practical uncertainty of dredging.

5. VERIFICATION

The verification of the model includes comparison of measured and model simulated parameters such as water level, interface position and current. The measurement programme is described in Mogensen (1991). An outline of the measurement programme is shown in Fig. 7.

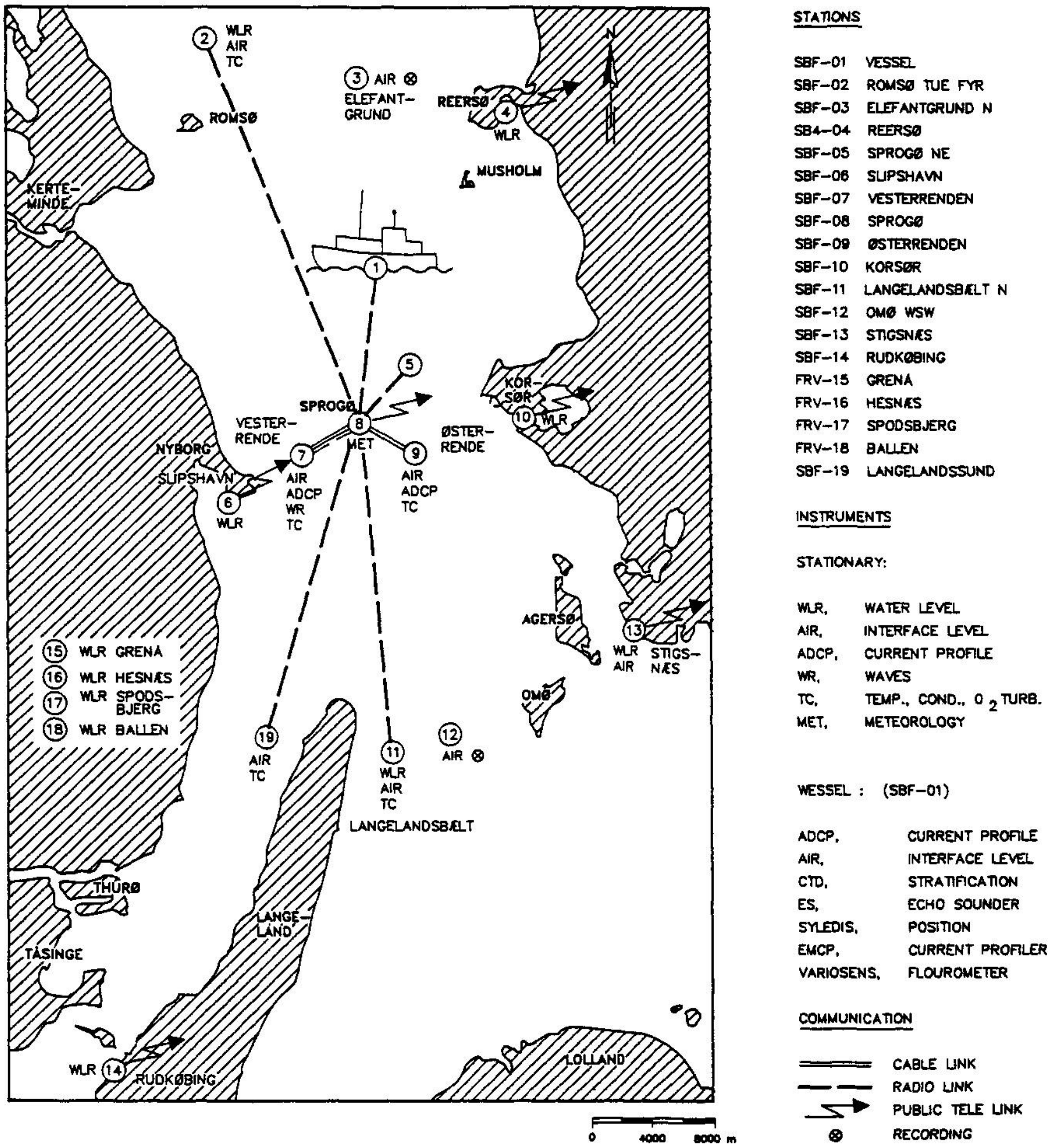


Fig. 7 The Great Belt Link Monitoring Programme.

Model verification was carried out for all three flow regimes and the overall conclusion is that the model verification was successful and that the model is a suitable tool for the compensation dredging design.

Examples from the verification period 2. to 8. September 1989 are shown in the figures. The flow regime of the period is mainly subcritical, except at the end of the period where the flow becomes supercritical.

In Fig. 8 is shown the measured and calculated time series of the current in station SBF07 and SBF09.

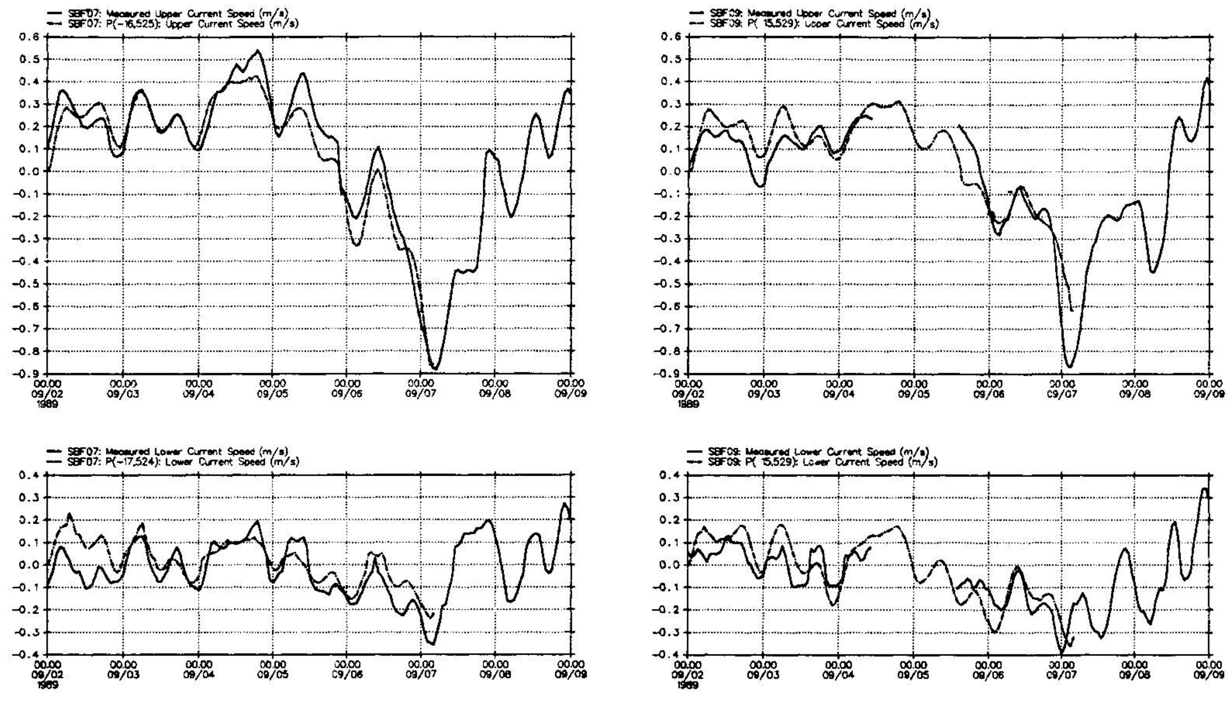


Fig. 8 Current time series. Measured and calculated (SYSTEM 22) for upper and lower layer in SBF07 and SBF09.

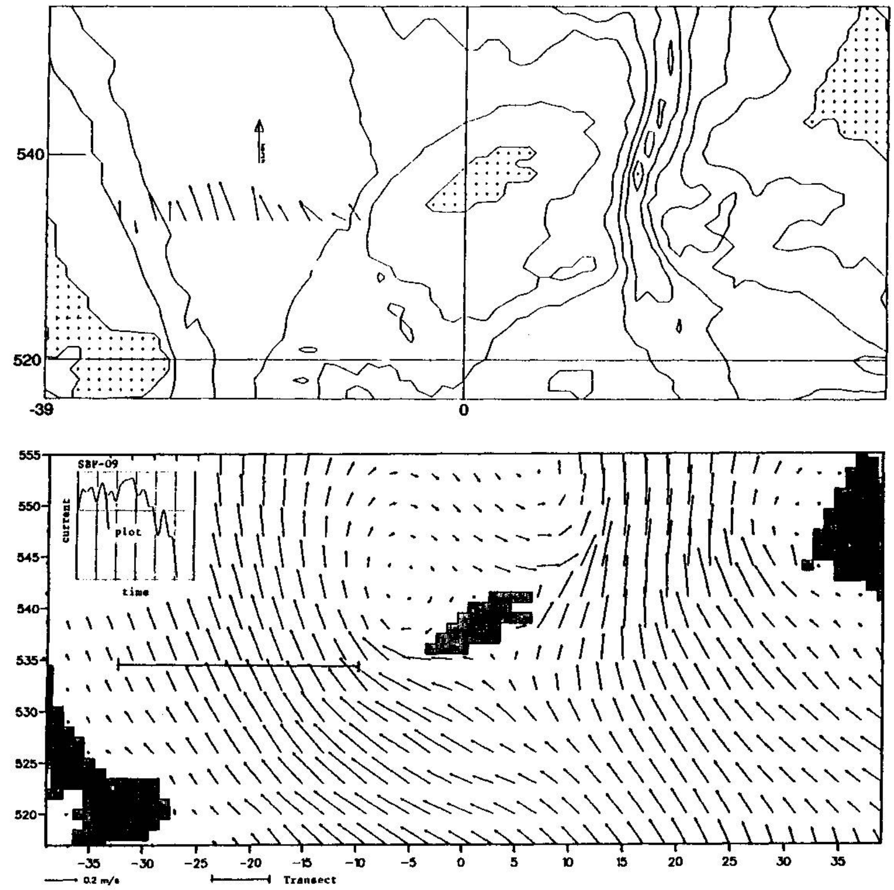


Fig. 9 Example of measured (vessel mounted ADCP current meter) and calculated (SYSTEM 22) current vectors, upper layer. (03/09/89, 10:00)

Good agreement is obtained for both upper and lower layer. Some discrepancies are observed for SBF09 when the flow is strong towards south. SBF09 is located at the transition between the jet and the lee water whereas the current signal is unstable.

An example of synoptic plots of measured and calculated current vectors are shown in fig. 9. When the vector plots are inspected it should be noted that calculated vectors only are plotted for every second grid point in the east-west direction, and for every third grid point in the north-south direction.

In Fig. 10 is shown the measured and calculated time series of water levels. The water levels show very good agreement between measured and calculated values.

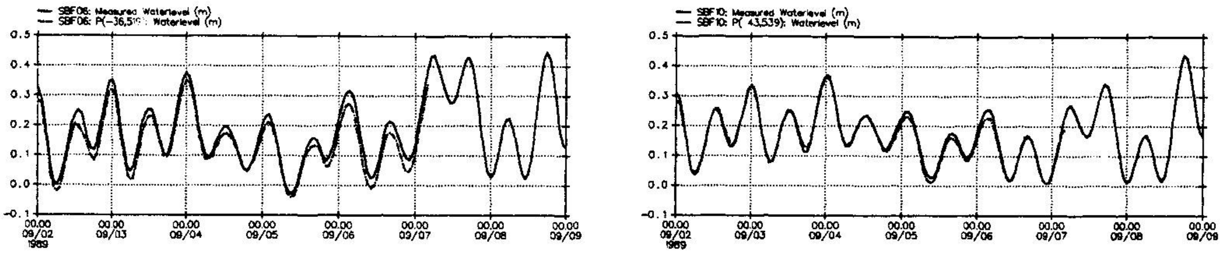


Fig. 10 Measured and calculated water levels for SBF07 and SBF09.

In Fig. 11 is shown the measured and calculated time series of interface levels. It is seen that in SBF07 the agreement is good considering the uncertainty in measurement of the interface. It is nice that the sharp change in level on 5 September is simulated by the model. The same trend is seen in the comparison for the SBF09. An example of synoptic plot of interface level is shown in fig. 12.

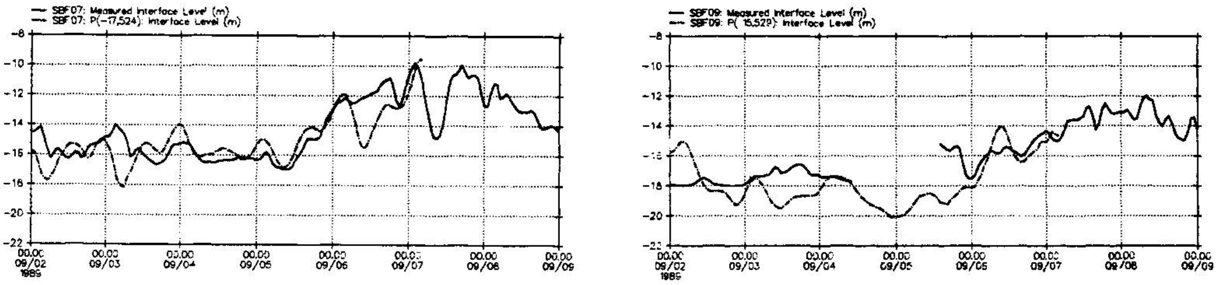


Fig. 11 Measured (TC-chain) and calculated interface level (SYSTEM 22) for SBF07 and SBF09.

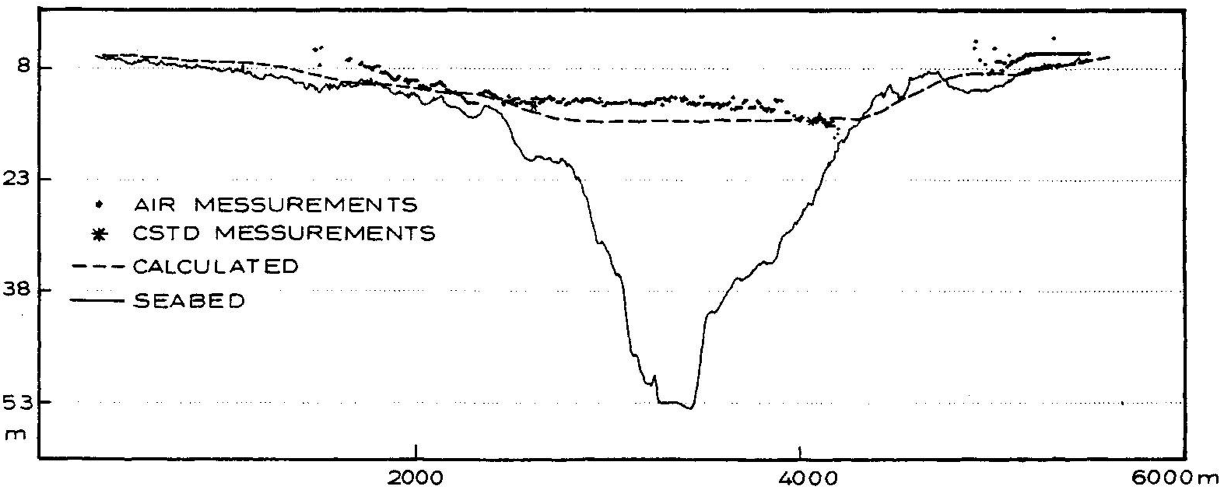


Fig. 12 Measured (vessel mounted AIR and CSTD) and calculated (SYSTEM 22) interface. (06/09/89, 10:00). Section across East channel.

A measure of the flow regime is the densimetric Fronde number number G^2, Pedersen (1986). G^2 is defined by:

$$G^2 = \frac{V_1^2}{\Delta g y_1} + \frac{V_2^2}{\Delta g y_2}$$

Where V is speeds, y is layer depth, Δ is $(\rho_2-\rho_1)/\rho_2$, (ρ is density) and g is accelleration of gravity. Index 1 and 2 is denoting upper and lower layer. In fig. 13 is shown the calculated densimetric Fronde number. It is seen that in the vicinity of the link, the flow can become supercritical. Outside the supercritical area the flow gradually adjust to the subcritical flow regime. This flow adjustment was observed by measurements carried out during the verification period.

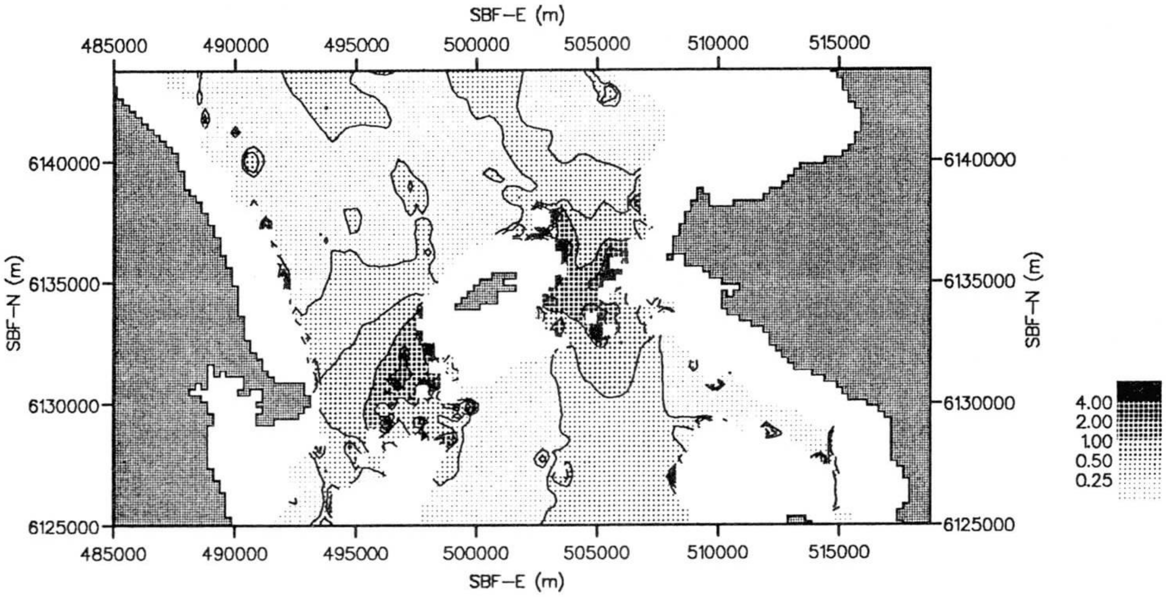


Fig. 13 Contour plot of Fronde number (07/09/89, 02:00). In blank areas one layer flow is present due to shallow water depth.

The verification is considered successful and the model is accepted as the design tool when compensation volumes are calculated.

6. COMPENSATION DREDGING

The final compensation dredging is shown in fig. 2. The dredging is described in Ottesen-Hansen (1991). The total volume is $6 \cdot 10^6$ m^3 on the East Reef of Sprogø. The major part of the dredged material is used in the ramps and anchor block construction.

The dredging influences the near field because of significant sediment spill to the environment. The near field effects are described in Randløv and Jensen (1991).

7. ACKNOWLEDGEMENTS

The authors appreciate the support of Storbælt A/S. Also the cooperation with Niels Erik Ottesen-Hansen, LICeng. A/S. with respect to the development of the zero solution concept - is greatly appreciated.

8. REFERENCES

/1/ Abbott, M.B. and Torbe, I. 1963: "On flows and Fronts in a Stratified Fluid", Proc. of the Royal Soc. A. Vol 273.

/2/ Belt project 1980: "Sea Water exchange of the Baltic, Measurements and Methods" for The National Agency of environmental protection.

/3/ DHI/LIC 1990: "Environmental Programme, Model Verification with Field Data for A/S Storebælts-forbindelsen, October.

/4/ Mogensen, B et al. 1991: "Environmental Monitoring Instrumentation and Data Flow Techniques, IABSE Colloquium, Nyborg, Denmark.

/5/ Ottesen-Hansen, N.E. 1991: "Environmental impacts of Bridges and Causeways". IABSE Colloquium, Nyborg, Denmark.

/6/ Pedersen, F.B. 1986: "Environmental Hydraulics: Stratified Flows", Springer-Verlag, 1986.

/7/ Randløv, A. and Jensen, K. 1991: "Environmental Impacts of Great Belt Link: IABSE Colloquium, Nyborg, Denmark.

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Design and Results of a Biological Feedback Monitoring Programme

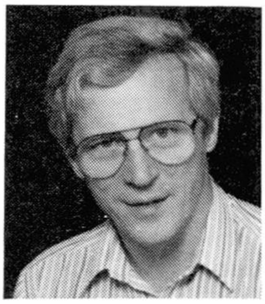
Concept et résultat d'enregistrement de données biologiques

Entwurf und Ergebnisse eines biologischen Rückkopplungsüberwachungsprogramme

Anders RANDLØV
Marine Biologist
COWIconsult
Copenhagen, Denmark

Anders Randløv, born 1949, cand.scient from the Univ. of Copenhagen, Research Biologist at the Marine Pollution Lab. of the National Agency of Environmental Protection and the Institute of Marine and Fisheries Research. Since 1982 with COWIconsult, from 1987 as Head of Department of ecology and environmental chemistry.

Kurt JENSEN
Marine Biologist
Water Quality Institute
Copenhagen, Denmark



Kurt Jensen, born 1944, cand.scient. from Univ. of Copenhagen 1970. Lecturer at Univ. of Copenhagen, Roskilde and Odense, Consulting Biologist, Research Biologist at the Marine Pollution Laboratory of the National Agency of Environmental Protection, since 1989 Head of Department of aquatic ecology at The Water Quality Institute.

SUMMARY

An Environmental Impact Assessment of the construction of the Great Belt Link (Denmark) showed that construction activities might have adverse impact on the marine environment. Therefore, a monitoring programme designed to quantify and control these effects was started in 1989. The programme comprises a new feedback principle implying mitigating actions to be taken by contractors if the biological effects exceed limits stipulated in the Environmental Impact Assessment. The design of the programme was based on the recommendations made by an international panel of environmental experts. The paper presents the results and discusses the relevance of the feedback principle.

Concept et résultat d'enregistrement de données biologiques

Résumé

L'étude de l'impact sur l'environnement de la liaison du Great Belt a montré que les activités de construction pourraient avoir un effet négatif sur l'environnement marin. Un programme d'enregistrement destiné à quantifier et à contrôler ces effets a débuté en 1989. Le programme comprend un nouveau principe d'enregistrement entraînant des mesures à prendre par les entrepreneurs si les effets biologiques dépassent certaines limites fixées. Le programme a été réalisé sur la base de recommandations d'un groupe d'experts internationaux de l'environnement. Les résultats sont passés en revue et le principe de rétroaction est discuté.

Entwurf und Ergebnisse eines biologischen Rückkopplungsüberwachungs-programms

Zusammenfassung

Eine Abschätzung der Umweltfolgen der Konstruktion der Grossen-Belt-Verbindung zeigte, dass Bautätigkeiten einen Einfluss auf die Meeresökologie haben könnten. Deswegen wurde 1989 ein Ueberwachungsprogramm gestartet, das entworfen wurde, um die Wirkungen zu quantifizieren und zu kontrollieren. Das Programmm umfasst ein neues Rückkopplungsprinzip, das Abhilfemassnahmen seitens der Baufirmen vorsieht, wenn die biologischen Auswirkungen die in der Umweltverträglichkeitsprüfung gesetzten Grenzen überschreiten. Der Programmentwurf gründete auf den Empfehlungen eines internationalen Fachkreises von Umweltexperten. Der Artikel präsentiert die Ergebnisse und diskutiert die Bedeutung des Rückkoppelungsprinzips.

1 INTRODUCTION

Specific requirement regarding the marine environment were stipulated by the act on the Great Belt link. To comply with these requirements A/S Storebæltsforbindelsen (the company to which has been established to construct and run the link) has established a comprehensive environmental programme [1].

To *neutralize* a potential impact on the *Baltic Sea* - as required by the act - the design has been greatly modified and mitigating actions have been taken in accordance with the result of hydrographic modelling [2].

To *minimize* environmental impact in the *near field,* ecological mapping, environmental impact assessments, baseline investigations and biological monitoring have been carried out. This paper describes the handling of the near field environment with emphasis on the biological monitoring programme.

2 INTERACTIONS BETWEEN ENVIRONMENTAL AND ENGINEERING ACTIVITIES

The construction work and the monitoring of possible associated effects on the marine environment in the near-field of the constructions site in Storebælt were initiated in 1989.

The monitoring programme is the last in a series of activities which are necessary for the successful handling of the biological effects in the near-by marine environment. The scheme shown in Fig. 1 emphasize the close interaction between the traditional engineering activities and the environmental activities.

It is the *general* experience from the Great Belt link project that environmental issues should be addressed early in the planning process. The possibilities for mitigating actions are progressively reduced as the planning and the construction process proceeds.

In *particular,* it is important to define and include the environmental requirements to the construction work in the tender documents in order to minimize the impact from the construction phase.

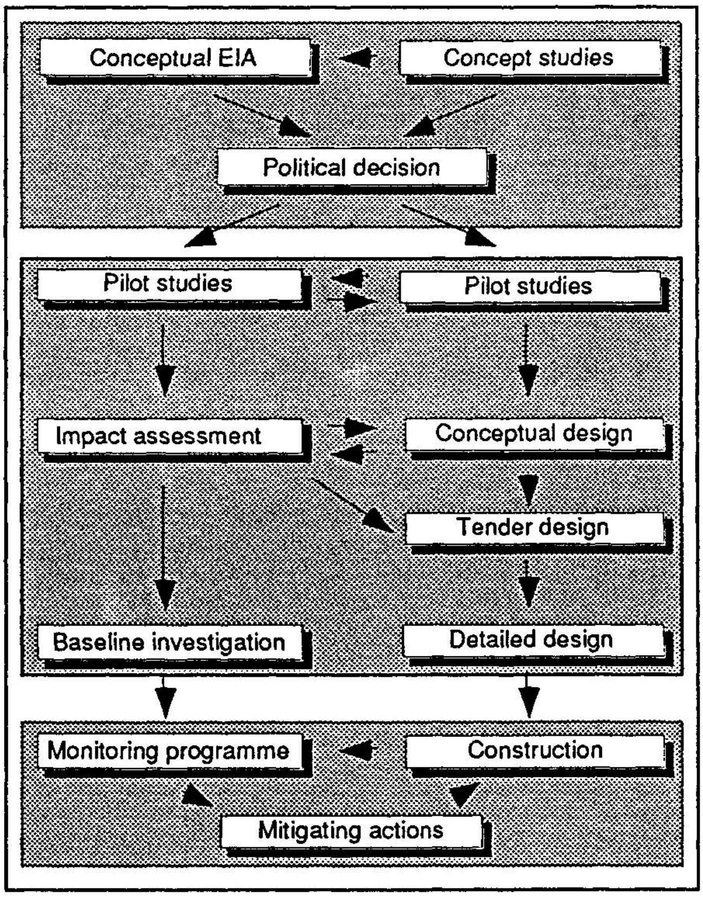


Fig. 1 Interaction between environmental and engineering activities.

3 DEFINITION OF MONITORING PROGRAMME

3.1 Objectives

The objectives of the biological monitoring programme are:

- to assess biological effects which can be used to initiate *feed back* loops whereby the construction process may be altered to mitigate environmental damage;
- to assess the extent and character of other possible adverse environmental effects arisen from the activities;
- to provide adequate environmental information to respond to public interest and settle possible issues.

3.2 Feedback Monitoring

Biological monitoring with feedback possibilities is a totally new concept, which has not previously been demonstrated to function in practise. The basic idea is that unacceptable changes in the environment caused by construction activities can be defined in terms of biological variables, and that the exceeding of the prefixed limit can lead to changes in construction activities which mitigate the adverse effects.

Three biological events have been chosen as important elements for the feedback monitoring:

- wintering eider ducks,
- spring spawning herring, and
- phytoplankton blooms.

These elements have been chosen for the reason that they may be affected by the construction activities at distances beyond the near-field area.

3.3 Key Biological Variables

In addition to the feedback parameters a number of other key biological variables have been selected on the basis that these are significant ecological components of the Great Belt marine ecosystems, and that effects of construction can be quantified reliably. The key biological variables are:

- eelgrass,
- kelp,
- mussels, and
- soft bottom fauna.

The use of key biological variables illustrates two other important principles of the monitoring programme:

- All parameters can be quantified;
- Falsifiable hypotheses have been established; some of these are conditional and will only be investigated when finding a significant effect in the first hypothesis.

4 ENVIRONMENTAL EFFECTS OF THE CONSTRUCTION ACTIVITIES

4.1 Ecological Mapping

As a basis for the Environmental Impact Assessment (EIA) and the definition of the monitoring programme the marine ecology of the Great Belt has been mapped prior to the start of the construction work (Fig. 2). The mapping was performed using diver operated video equipment, sediment and bottom fauna sampling equipment and fishing gear.

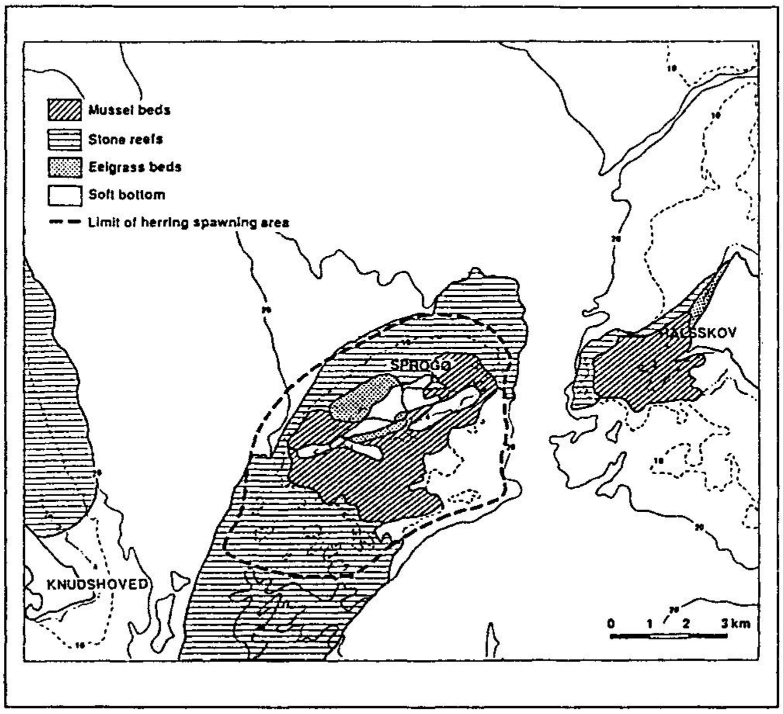


Fig. 2 Marine biotopes in the Great Belt

The area accommodates several areas of high ecological interest:

- *Herring spawning:* The area around Sprogø is used as spawning area for spring spawning herring.
- *Eiders/Mussel:* The area around Sprogø holds large flocks of wintering eider ducks gathering from great parts of northern Europe. The number of birds may in some winters reach figures of around 100,000. The eiders feed on the rich mussel beds in the area. The eiders are the main reason for the area being declared an EEC bird protection area.
- *Stone reefs:* Stone reefs are rich biotopes which are important as fish spawning and nursery areas and as feeding grounds for adult fish.

4.2 Environmental Impact Assessment

The conceptual EIA performed in 1988 [3] was upgraded in 1990 to a full EIA in 1989 [4]. A revised EIA [5] has since been prepared in order to allow for much higher dredging spill rates than anticipated in the first EIA.

The main environmental effects are related to the reclamation and dredging activities. The major part of the dredging activities concerns the dredging of reefs with the purpose of facilitating the flow of water to and from the Baltic Sea. This illustrates the dilemma between mitigating environmental effects in the far field (the Baltic Sea) and the near field (the Great Belt): The greater the effort to achieve the "zero solution" [2] for the Baltic Sea, the greater the environmental damage in the Great Belt.

In addition to direct destruction of habitats by dredging and reclamation the effects are related to the release and sedimentation of particles during dredging; the calculated sedimentation shown in Fig. 3 gives an indication of the intensity of this impact.

The main environmental effects predicted by the EIA and now partly verified by the monitoring programme (see later) listed below.

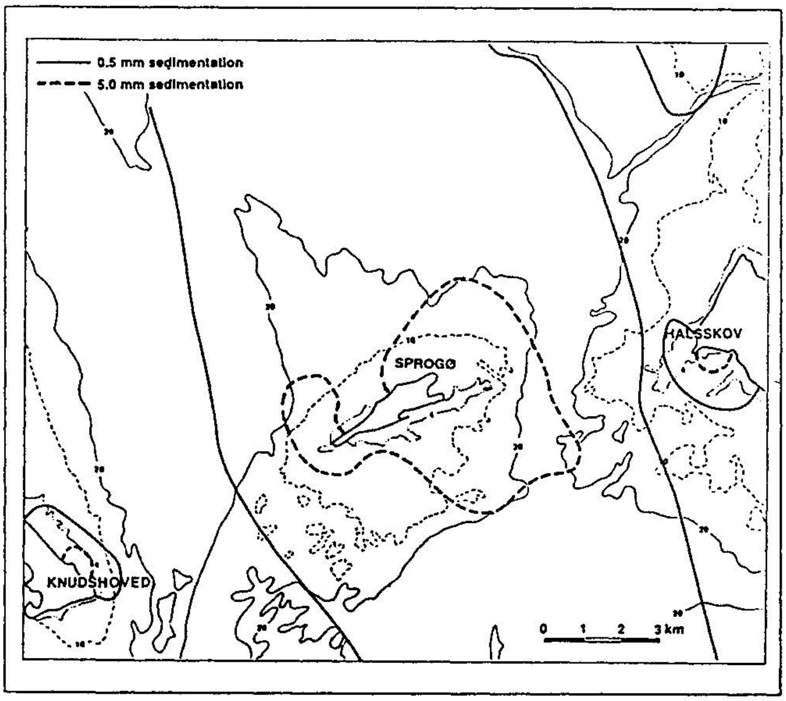


Fig. 3 Predicted sedimentation from dredging activities.

Short term effects (<10 years):

- Reduction of *mussel biomass* by x% due to reclamation, lee effects and smothering. It is estimated that the carrying capacity of the mussel beds as feed for *eider ducks* is reduced correspondingly.
- Decrease in macro *vegetation* on stone reefs by 30-40%.
- Decrease in area used as *herring spawning areas* by 20%.
- Change in composition of local *soft bottom fauna* communities due to smothering and anoxic conditions.

Long term effects (10+ years):

- A possible decrease in population size of wintering eiders and other diving ducks which feed on mussels;
- An increase in the area of eelgrass beds due to lee effects;
- A possible reduction of the area of herring spawning grounds;
- An incomplete recovery of perennial species of algae at stone reefs and eelgrass beds.

5 RESULTS OF MONITORING PROGRAMME

5.1 Overview

The biological monitoring programme was initiated in 1989 and it is now possible to assert some of the short term effects. Some effects are insignificant in relation to the regional ecology, e.g. the release of nutrients from suspended sediment material and the release of oxygen consuming substances.

Other effects may prove to have serious consequences, e.g. the effects of suspended sediment material on mussel beds and - ultimately - on the eider duck population as described below.

5.2 Effects on Mussel Beds and Eider Ducks

The monitoring of the conditions of the mussels beds along the alignment have shown a dramatic decrease in the population density (individuals/m^2) around Sprogø (i.e. close to the dredging activities); at other stations at greater distance (Halskov rev) a similar decrease could not be observed [6] (Fig. 4). Analysis of the development of the size distribution of the remaining individuals at the affected stations indicate that the decrease is caused by unsuccessful recruitment of young individuals. (Young individuals are recruited from swimming larvae which settle on the bottom; the larvae and newly settled juveniles are more susceptible to damages from smothering).

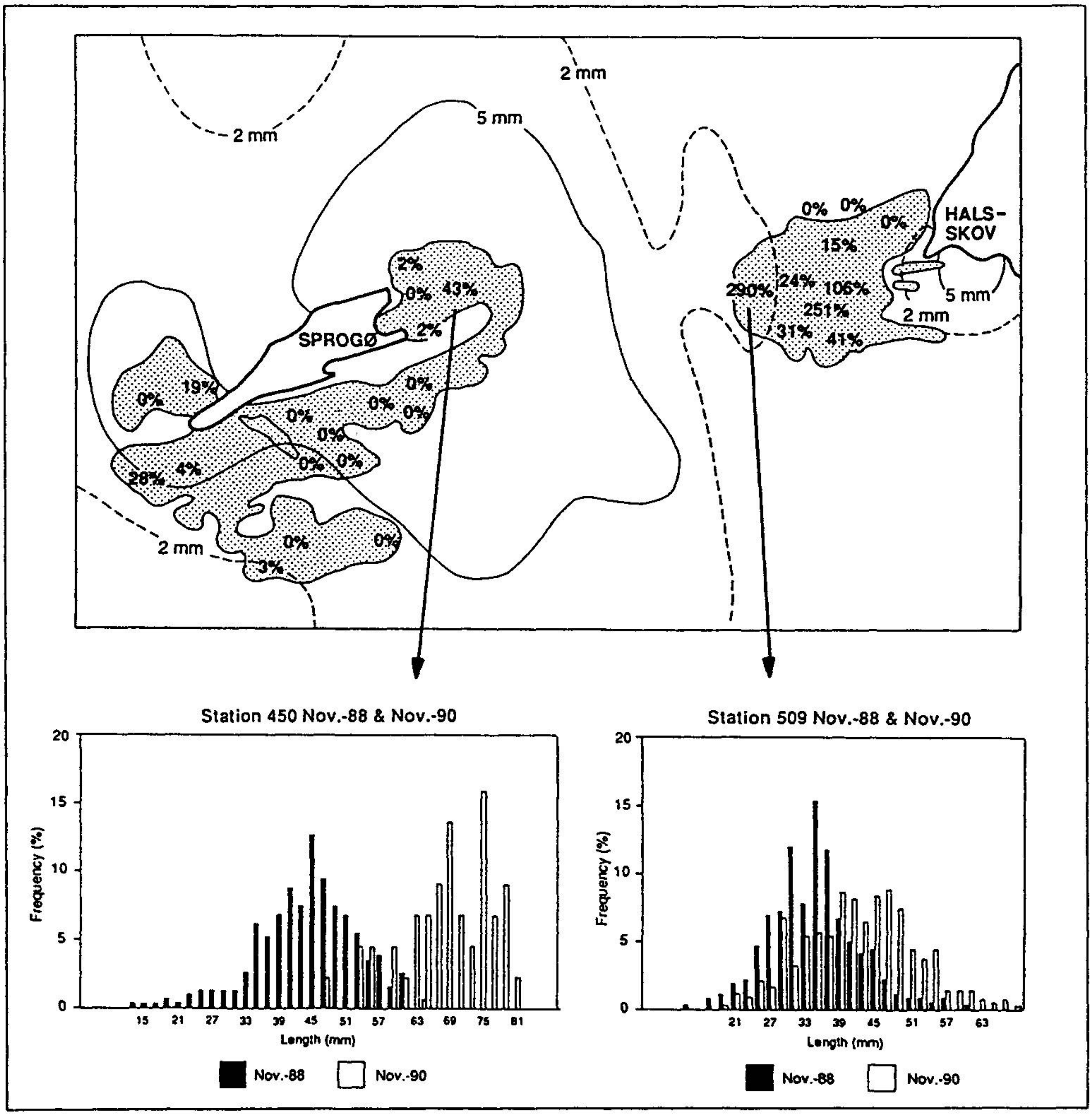


Fig. 4 Reduction in mussel population density and recruitment. *Above:* Population density in November 1990 relative to November 1988 in %. *Bottom left:* Typical shift in size distribution at station with decrease in population density. *Bottom right:* Typical size distribution from *Halskov rev* stations where little or no impact has been assessed.

The monitoring programme has also shown that the predators (mainly eiders and sea stars) during winter consume mussels corresponding to the production of one year [7]. It may therefore be assumed that the carrying capacity of the area for eiders has been reduced and that part of the eider population will be forced to find other wintering areas. Preliminary results from the winter 90/91 strongly suggest that this is the case: the number of eider around Sprogø have been drastic reduced and seemingly the eiders have moved to other locations in the Danish waters where an increase in numbers has been recorded [8].

6 CONCLUSION

The results and the experience from the biological monitoring programme so far have indicated that it is possible to assess the environmental impact from such projects, and to some extent limit the effects by mitigating actions.

However, some points are crucial for the possible applicability of the feedback principle:

- The monitoring programme must be based on a comprehensive baseline study and an impact assessment which enable the definition of precise and realistic limits relevant to the environment in question, which can release mitigating actions;
- Environmental considerations which ensure that a precautionary principle is introduced must be involved prior to the planning of the construction and the elaboration of tender material;
- All involved parties must have commitment to following the precautionary principle, be it (client, contractor, authorities, etc.);
- The monitoring programme must include a sufficiently fine grid - in time and space - in order precisely enough to demonstrate the transgression of feedback limits;
- The results of the monitoring programme must appear at intervals much shorter than and the time steps in the planning and progression of the construction work.

The present results of the biological monitoring programme in connection with the construction of the Great Belt Link indicate that a monitoring programme based on such principle may be drawn up, but so far none of the above critical items have been fully achieved.

ACKNOWLEDGEMENT

The biological monitoring programme is undertaken by a joint venture between COWIconsult and Water Quality Institute in cooperation with Prof. John Gray, University of Oslo. Client: A/S Storebæltsforbindelsen.

REFERENCES

1 POULSEN, KNUD MOSE, *<paper in these proceedings>*

2 MØLLER, JACOB STEEN, *<paper in these proceedings>*

3 COWIconsult, Environmental Investigations, Status Report no. 2: Biological Mapping, Impact Assessment. Main report, June 1988.

4 Danish Hydraulic Institute and LIC Engineering in cooperation with COWI/VKI-Joint Venture, Environmental Impact Caused by Dredging Operations, Compensation Dredging and Dredging for Bridge Piers - Fixed Link across Storebælt, January 1990.

5 COWI/VKI-Joint Venture and Danish Hydraulic Institute/LIC Engineering, Storebælt Environmental Programme, Environmental Impacts Caused by Dredging, Reclamation and Disposal Operations, Including Lee Effects around Sprogø, October 1990.

6 COWI/VKI-Joint Venture, The conditions of the Mussel Beds in the Central Part of the Great Belt in November/December 1990, January 1990 (1. draft).

7 COWI/VKI-Joint Venture, Predation on Mussel Beds by Eiders in the Central Great Belt, November 1989.

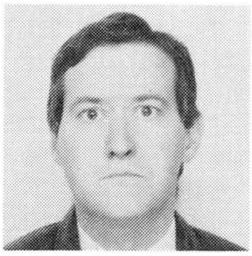
8 POULSEN, KNUD MOSE, *Pers. comm.*

Environmental Demands and their Effects on Design

Exigences de l'environnement et conséquences sur le projet

Umweltanforderungen und ihre Auswirkung auf den Entwurf

N. - E. Ottesen HANSEN
Dr.
LICengineering A/S
Copenhagen, Denmark



N. - E. Ottesen Hansen, born in 1947, graduated from the Technical Univ. of Denmark with a degree in Structural Engineering and Ph.D in Hydrodynamics. He has been working in Offshore and Hydrodynamic Engineering for 20 years. He is presently a director.

Knud LARSEN
Civil Engineer
Hostrup-Schultz & Sorensen A/S
Copenhagen, Denmark

Knud Larsen, born in 1931, graduated from the Technical Univ. of Denmark, 1957, with a degree in Civil Engineering. He has been working as a consulting engineer for 34 years with Coastal EngineeringandHarbourStructural Problems. He is presently Vice President and partner in Hostrup-Schultz & Sorensen A/S.

SUMMARY

The paper describes how careful engineering in the Great Belt Link project has reconciled environmental criteria for the earthworks with purely constructional demands. The dredging materials have been re-used in ramps, causeways, and dikes, instead of being dumped, even if they were classified in-situ as unsuitable for construction purposes. The unsuitable materials have been converted to acceptable fill by grain sorting, the production of suitable fill from the unsuitable materials being explained in detail. Finally, the type of earth structures built and the special quality control are described.

Exigences de l'environnement et conséquences sur le projet

Résumé

Une étude d'ingénierie soignée pour la liaison du Great Belt a permis de réconcilier des critères de l'environnement pour les travaux de terrassement avec des exigences purement constructives. Les matériaux dragués ont été réutilisés pour des remblais de routes et de digues au lieu d'être jetés à la mer, même si ils étaient inutilisables pour la construction. Les matériaux non appropriés ont été améliorés par filtrage et séparation des agrégats. La méthode utilisée est expliquée dans le détail. Les types de structures en terre construites et les différents contrôles de qualité sont décrits.

Umweltanforderungen und ihre Auswirkung auf den Entwurf

Zusammenfassung

Der Artikel beschreibt, wie sorgfältig Ingenieurarbeit beim Grossen Belt Projekt die Umweltkriterien für die Erdarbeiten mit den Anforderungen seitens der Bauausführung in Einklang brachte. Das ausgebaggerte Material wurde bei Rampen, Dämmmen und Deichen wiederverwendet, anstatt es zu deponieren, und zwar sogar dann, wenn es als für konstruktive Zwecke unbrauchbar eingestuft wurde. Wie im Detail erklärt, wurden die unbrauchbaren Materialien durch Kornfraktionierung in brauchbares Auffüllmaterial umgewandelt. Schliesslich werden die Arten der Erdbauwerke und die spezielle Qualitätskontrolle beschrieben.

1. INTRODUCTION

This paper presents some of the effects of environmental demands on the design and construction of the Great Belt Link in Denmark. The sensitive environment of the Baltic has dictated that the water exchange through the Great Belt to the Baltic shall remain unchanged in spite of the constrictions imposed by the causeways and bridge piers of the link. This is achieved by increasing the constricted flow cross section of the link by dredging.

Since the 17 km link for part of the length consists of causeways and earth ramps (up to 25 m high) it was obvious that the dredged materials should be reused in the earth works, thus achieving a perfect soil balance completely as when building railroads where soil dug out in the hills is used as fill in the embankment. Thus the environmental demands become completely reconciled with the constructional demands. Some local environmental effects were of course foreseen due to the dredging but they were completely immaterial compared with the greater issue of maintaining the environment of the Baltic.

Because of the above considerations the earthworks and causeways were put out for tender under the constraint that they should be built of the dredged materials. The causeways and ramps midway at the link (Sprogoe) are shown in Fig. 1.

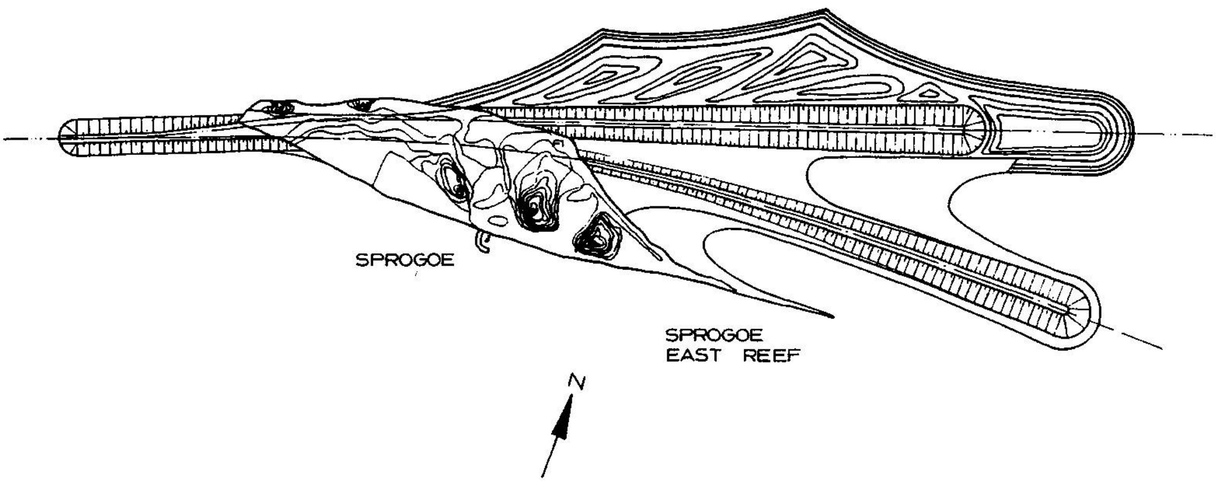


Fig. 1 Final earthworks in the middle part of the Great Belt Link (Sprogoe).

The materials to be dredged are for the smaller part late and post glacial materials and for the greater part hard glacial materials (moraine till) with typical in-situ shear strength between 100 kN/m2 and 400 kN/m2. Due to the large content of hard clay it turned out that the tenderers did not believe that the work could be made by reusing the dredged materials. As one Contractor put it during a pretender meeting "Do you really yourself believe that 25 m high ramps can be built in the Danish winter with dredged moraine clay"? Well, the Great Belt Link Company and the authors believed it and this paper describes how the work was successfully executed completely as intended.

Part of the soils to dredge were excellent fill materials and were of course directly used in the filling of the causeways and the ramps. These soils was dredged by the hopper suction dredger and directly pumped into the ramps and dikes of the islands in the middle of the Great Belt (Sprogoe).

Another part of the soils to dredge were soft organic materials which could not be used for construction. On the other hand if they were dumped in the sea they might have enhanced the lack of oxygen in the lower strata of the Great Belt. Therefore these soils were deposited in sedimentation basins placed within the confines of the island Sprogoe, Fig. 2. Besides being storage basins

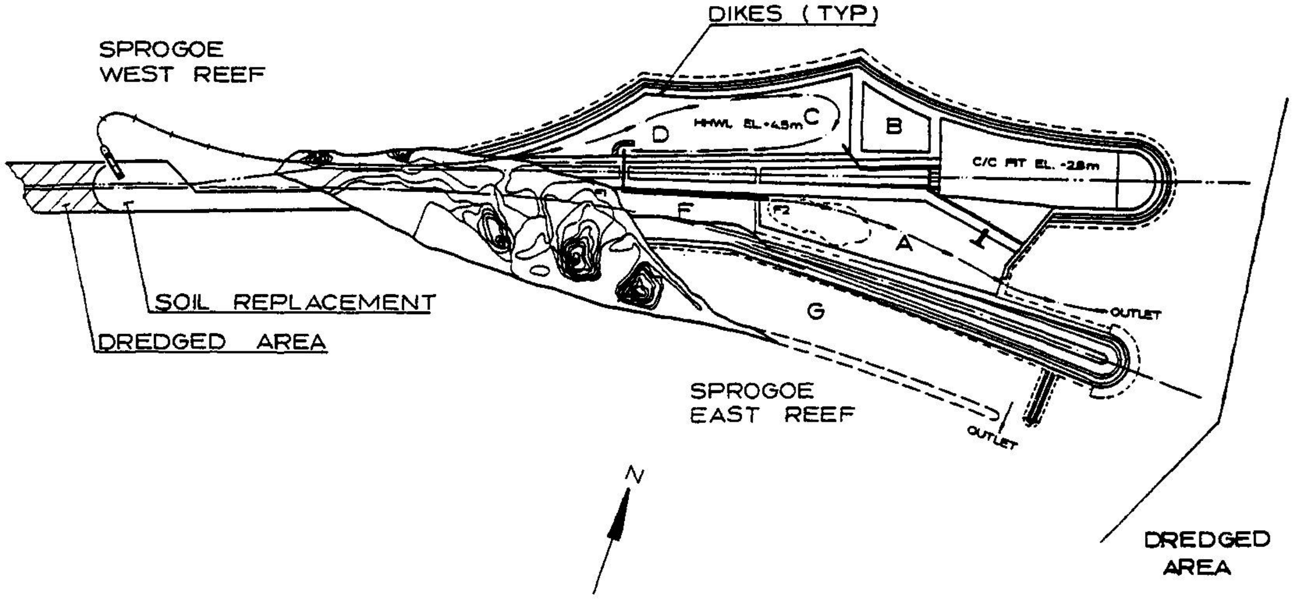


Fig. 2 Sedimentation basins at Sprogoe.

the completed basins, when filled with materials and regulated to final shape, would serve as barriers against water intrusion into the tunnel ramps. The soft organic materials were dredged by means of cutter suction dredger and the materials were pumped in slurry to the basins. Even though the materials had some cohesion they were broken down in the flow through the pipeline into clay balls, gytje balls, stones, gravel, sand, silt and clay. At the outlet the broken down materials were separated such that the coarser fraction was deposited close to the pipe outlet, whereas the finer particles were carried away with the flow and deposited in the center of the basins. The coarser fractions were in fact excellent material and were used to increase the height of the dikes around the sedimentation basins and for filling in the dike structures. In fact the sorting mechanism was so effective that in certain areas the material became coarse sand and gravel which was used as frost upheaval ballast for the expressway.

The greater part of the fill materials were used in the high ramps. The dredge materials available for this fill were sand and moraine clay. These materials were dredged with cutter suction dredger and pumped in slurry into the ramps and the areas to be reclaimed. In the flow through the pipeline the materials were broken down in clay balls, stones, gravel, sand, silt and clay. By regulating the retention times in the reclamation and ramp basins the fill could be produced exactly to specifications. The spill water with dredgeate was let out into a secondary sedimentation basin (G or A in Fig. 2) for final clearing of spill water before being let out into the Great Belt.

The produced material was called engineered fill and was used for the construction of the 25 m high ramps In fact the materials were directly jetted in up to elevations above +20 m.

2. PREVIOUS WORK

A large number of projects have been executed in the past where clayey or silty materials have been dredged and used for fill in structures. Examples are the Logan Airport in Boston, Roberts Bank Offshore Island, Johansen and Birkland (1980) or Halmstad in Sweden in 1978, Hartlen and Ingers (1987). The reclamation of the Roberts Bank Offshore Island expansion in Vancouver, BC, Canada, was made with cutter suction dredger pumping in-situ silt into the main reclamation at the outlet. The dredgeate was either let directly to sea or carried to deeper areas by a pipeline. The similar work made in Halmstad, Sweden, was a forerunner of the reclamation of Sprogoe dredging moraine clay by cutter suction dredger and jetting it into a reclaimed area.

The novel feature of the present project is that the material is directly used in the well defined structures such as 25 m high ramps with steep slopes (1:2) and in water retaining dikes and not just in reclamations of diked areas.

3. THE FIRST STEPS

3.1 Introduction

The first steps for reusing the materials were made due to the demand for storage volume in the sedimentation basins midway on Sprogoe Island . Since the perimeter was already built the only possibility was to increase the height of the dikes around the basins. The operation was not without risk because the water level in the basins had to be raised to El. +4.5 m at the same time as the adjacent cut and cover tunnel was built in a dry pit at El. -28 m.

3.2 The Material

The suitable material which were used are presented in Table 1. It demonstrates the separation of the materials, originally being gytje and clay, into an artificial sand material, the Engineered Fill.

The large contents of silt and clay in the samples presented in Fig. 1 are deceptive, because the clay and the silt and even the gytje occur in clumps in the otherwise quite coarse material. These clumps are quite hard and behave as stones in a mix and consequently the material behaves as sand. It is seen that the material is very heterogeneous.

Sample No.	d50 mm	d60/d10	0.074 mm	16 mm	32 mm	Organic content
In-situ	0.01	70	92%	100%	100%	5.0%
In-situ	0.10	18	35%	100%	100%	3.0%
1	0.50	60	18%	97%	100%	4.6%
2	0.5	8.75	10%	95%	98%	3.0%
3	0.35	3.5	5%	100%	100%	3.5%
4	0.22	3.75	8%	98%	100%	2.8%
5	0.17	3.0	11%	100%	100%	3.0%
6	0.35	2.7	3%	95%	98%	2.7%
7	0.15		17%	100%	100%	2.5%
8	0.42	3.33	3%	99%	100%	3.0%
9	0.15		15%	99%	100%	3.6%
Mean	0.31	>9.4	10%	98%	100%	

Table 1 Soil samples taken from the Sprogoe West Reef and from the coarse part of materials jetted into basin D (1-9).

3.3 Construction of the Dikes, Principles

The construction of the dikes was made by excavating the materials in the basins, transporting them out, and placing them with dumpers. Bulldozers were used for final shaping. In certain areas the dikes were built directly on deposited unconsolidated sludge which was displaced currently by the overburden.

The dikes built in these rather miscellaneous materials were supposed to sustain a water level of 3 m. The inhomogenity was too large to introduce rigorous quality control by inspection. Instead the dikes were built as prescribed but with a certain tilt of the downstream slope. A tilt of 1:2 was chosen because in case of heavy load the first area to slide was the foot of the slope. This sliding was therefore the indicator of the weak spots. When the sliding started there was a safety of 1.8 against complete dam break. Hence during the rising of the water levels and the depositing of the materials the downstream slope was monitored and every time a slide at the foot of the dike was observed a doubling of the dike width was made in the particular areas. This was far more economical and easier in execution than introducing all kinds of geotechnical tests. All compaction was made by the work traffic of the construction vehicles. By this a SP value of 92% was reached.

It turned out that only three times it was necessary to repair the dikes and that these repairs were only a matter of a few hours.

4. TEST WITH PRODUCING OF ENGINEERED FILL FOR RAMPS

4.1 General

The fine results with dikes built by Engineered Fill led of course to the consideration that the method could be used for the ramp construction of the 25 m high ramps. In order to test whether it was possible a number of field tests were made with dredged moraine clay or with a dredged mix of sand and moraine clay. The ratio between sand and moraine clay was highly varying. The basic problem was that the content of silt and clay in the moraine clay is between 50% and 60% and has to be washed out and reduced to below 15% in order to be sufficiently draining for stability and work purposes.

4.2 Execution of Tests

The tests were simply executed by pumping the materials into a corner of an already completed reclamation. Initially the elevation of the outlet was low, approx. 2 m above the ambient water level. Part of the deposited fill was satisfactory i.e. rapidly draining material, but in a corner a dead area with very fine and swampy material was formed. There could be two reasons for that - first that the dredged material was very clayey, or second, there was too small momentum in the flow in the reclamation basin. It turned out that the latter reason was the reason. Elevating the outflow to El. +4.0 m creating a steep incline for the flowing water raised the sediment carrying capacity of the run-off such that the fines effectively were washed out and a good stable material was deposited.

The steep incline was the key to control the wash out of the fines because when th flow became supercritical (wavy surface) then the transport capacity for the suspended sediment was very high. Therefore if the clay and silt fraction in a dredged material is high then the run-off incline shall be steep.

The strong moraine till dredged resulted in a rather high percentage of stones, gravel, and clay balls which settled in the immediate vicinity of the outfall of the pipeline and quickly created heaps in front of the pipeline. Some of the clay balls were transported further downstream in the reclamation basin and created local heaps which could trap some clay and silt in dead zones. In order to release these silt and clay pockets the deposited material was regularly plowed with bulldozers. However, especially for the engineered fill it turned out that this plowing operation should be kept at a minimum, because the load of the bulldozer tracks tend to smash and remould the clayballs after repeated crossings, hereby creating a more silty - and thereby less draining material. In the end a suitable compromise with respect to plowing was reached.

The heaps of clay balls creating in front of the outlet had to be removed. Using bulldozers the clay balls were kneaded and the material dozed aside became muddy with a behaviour like fresh concrete with high water content. Settling and draining of the rehandled material took rather long time when placed with an almost horizontal surface but it was possible to heap up the material and thereby improve the draining conditions. Alternatively a backhoe was used to remove the clay balls. Hereby a heaping up of the material was easily achieved. When the heaped material was drained it formed an excellent material especially when there was sufficient sand materials to fill the voids between the clay balls.

When pumping operations stopped excavation in the run off area could easily be performed and the settled material was used to create bunds to guide and concentrate the run off to avoid settlement of fines. The settled material was very densely compacted by the strong vertical downwards seepage through the fill. Here again the advantage of jetting in the fill on a steep incline showed up, because the incline produced large hydraulic gradients for this seepage.

The seepage could of course disturb the stability of the bund by creating quicksand at the downstream slope and thereby generate slides. This was solved by building the ramps in terraces with bunds of 4-6 m height and then use the quicksand formation of the foot of the bunds at the terraces as indicators for dam break as described in section 3.3.

From time to time some quicksand and well formations were formed and the water started to run. However, here the gravel content of the fill of 3-5% helped in sealing up the small gorges made by the wells thus making them stable.

By such operations of pumping and excavation it was possible to construct the Eastern Ramp almost completely by means of hydraulic filling up to level +20 m without any damaging slip failure of the outer slopes.

When the hydraulic filling was completed compaction tests were made which proved that very high density was achieved and that there was no need for further compaction for fulfillment of the requirements. It appeared that even deposits of coarse silt (80-85% passing the 0.078 mm sieve) were compacted to more than 100% Standard Proctor by means of the accretion in streaming water. The deposits could without further compaction function as substructure for the motorway and railway of the Great Belt Link.

As can be understood there was no on-line testing of the material and its compaction because the execution method itself did the work. This kept the work simple which was essential when the filling in rate was 1600 m3/h (cutter suction dredger, Leonardo da Vinci). Only the compaction in the upper 2 m layer was documented.

5. CLASSIFICATION OF FILL, QUALITY CONTROL

5.1 Classification of Soil

Reverting to Table 1 the materials deposited in the basins could be classified as sand, but with a relatively large content of clay and silt. A large part of the clay and silt, however, were trapped in the clay balls which have maintained their original shear strength of 100-400 kN/m3. For some part of the soft deposits even gytje balls had survived the transport. A more realistic classification of the material was therefore to take the clay and gyttje balls out (as stones) and then put the rest of the material through a sieve analysis. The problem was of course then to define when the balls of clay, gytje and silt should be classified as stones and when they should be classified as loose material.

The problem was solved by executing the sieve analysis in the following way:

1. The material was disintegrated with finger rubbing. Finger forces were used to crush the different clumps, but no more. If the clumps (>16 mm) did not disintegrate they were classified as stones and taken out of the sample together with the stones. These clumps were then referred to as clay balls. No mechanical milling or grinding of any of the clay/ silt/gytje clumps took place.

2. The material <16 mm was dried at 60 degrees C.

3. The above material was sieved (without washing) and the grain size distribution was determined.

5.2 Compaction

Standard Proctor tests of the above material proved to be meaningless, because of the large inhomogenities in the material. Therefore the final documentation of compaction was based on:

1. Water content
2. Dry weight of material (of samples spanning the clay balls).

The water content was kept below 14% and the dry weight of the material should be either above 18 kN/m3 or 19 kN/m3 depending on the compaction specification.

The problem was to measure the dry weight. Taking up a volume and drying it was easy enough, but the volume had to be large (400x400x400 mm3). The in-situ volume determination would on the other hand have been very inaccurate. The method was therefore not considered viable. Therefore the only method left was the isotope method (Troxler). This method, however, had to be modified because the instrument was close to being too small for the inhomogenities in the material.

ACKNOWLEDGEMENTS

A number of persons have contributed decisively to the developments of th concept. These persons are:

Christian Tolstrup: The Project Director in the Great Belt Link for the Dredging and Reclamation work without whose ability to cut the red tape and whose unwavering support, even in spite of sometimes unsuccessful tests, no project would have materialized.

Claus Iversen: The acting head of Site Supervision, (Mother company, The Danish Hydraulic Institute) whose enthusiasm during the tests ensured that all possibilities were tried out.

Ole Milvang Nielsen; Statens Vejlaboratorium, who defined the test procedures to identify the Engineered Fill.

Carlos Johansen, Delcan, who first defined the properties of engineered fill.

Wilbert van Bolderick from the Contractor CD-Joint venture. He was instrumental in defining the mix between sand and moraine clay for optimizing the fill in the ramps.

REFERENCES

HARTLEN J. and C. INGERS, Use of Dredged Clay for Land Reclamation. Proceedings Baltic Conference on Design, Construction and Maintenance of Harbour Structures. Norrkoeping, Sweden, Sept. 24-25, 1987.

JOHANSEN, C. and O. BIRKELAND, Expansion Plans for the Roberts Bank Offshore Island Port Facilities, World Dredging Conference, 1980.