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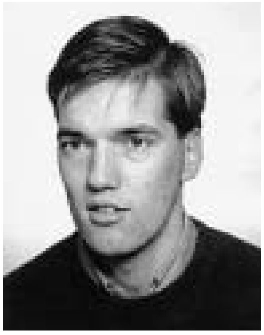
The Øresund Fixed Link: Dredging Reclamation



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Maurice de Kok graduated in 1989 from the Technical University Delft, The Netherlands with a MSc in Civil Engineering. He was employed by Hoek Engineering bv and Ballast Nedam Engineering bv for work on the West Bridge of the Storaebelt Project in Denmark. Since 1991 he has been a Project Organiser, Production and Planning Manager, and Project Engineer for Ballast Nedam.

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Abstract

The Øresund Fix Link project will be a 16 km long bridge-tunnel link connecting Kastrup, Denmark with Lernacken, Sweden.
The project has been divided into three contracts: No. 1, the Tunnel Contract; No. 2, the Dredging and Reclamation Contract; and No. 3, the Bridge Contract.

The dredging work encompasses the excavation of a 3500 m long tunnel trench in which the tunnel sections will be placed. Then, using the dredged material, a 4000 m long artificial island complex is being reclaimed to form the connection between the tunnel and the bridge. Work also includes the deepening of two canals and shore protection.

The dredging and reclamation contract (No. 2) has been awarded to the Øresund Marine Joint Venture (ØMJV) and this article describes some aspects of Contract No. 2, Dredging and Reclamation.

The article is presented in three sections dealing with the hydraulic dredging and reclamation activities: a general introduction defining the scope of the works, environment, design, tolerance and survey and planning, written by Maurice de Kok; the soil conditions and dredgeability written by Wouter Dirks; and the wear of pipelines, written by Rienk Hessels.

Introduction

The European Council has identified the Øresund Fixed Link as one amongst 14 priority project in the Trans European Network programme. The fixed motorway and railway link across the Øresund will connect Kastrup on the Danish coast with Lernacken on the Swedish coast.

The link will consist of the following elements:
– an artificial peninsula extending 430 m from the Danish coast at Kastrup
– an immersed tunnel 3510 m long under the Drogden Navigation Channel

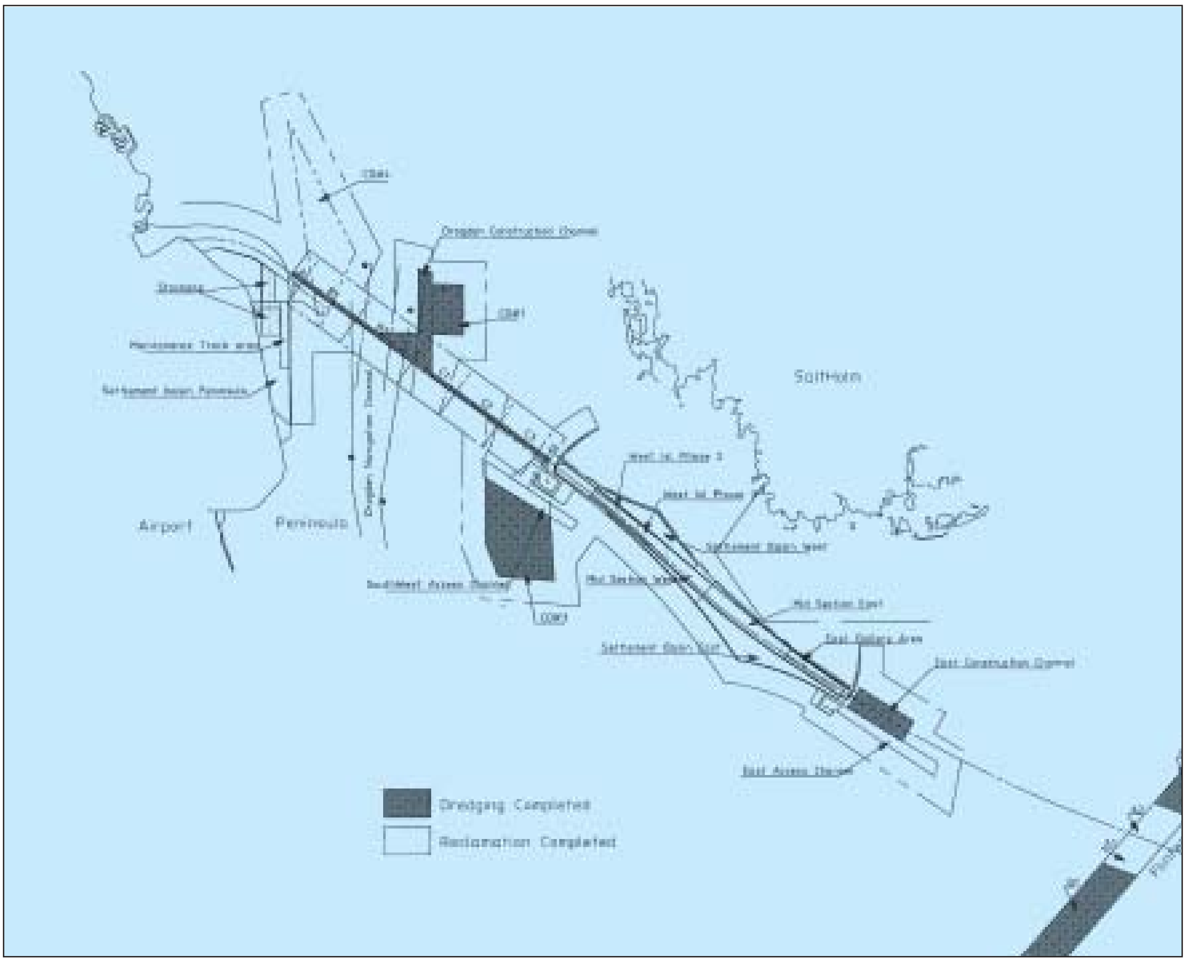


Figure 1. An overview of the site boundaries for the dredging and reclamation contract.

- an artificial island 4055 m long south of Saltholm
- a western approach bridge 3014 m long between the island and the high bridge
- a cable-stayed high bridge 1092 m long across the Flinte navigation channel
- an eastern approach bridge 3739 m long from the high bridge to the Swedish coast at Lernacken
- a terminal area with toll station and Link Control Center located on the Swedish coast at Lernacken.

Three contracts have been awarded to build the Fixed Link: No 1. the Tunnel Contract; No 2. the Dredging and Reclamation Contract; and No 3. the Bridge Contract.

The Contractor that won the dredging and reclamation contract is the Øresund Marine Joint Venture (ØMJV) consisting of: Per Aarsleff from Denmark; Great Lakes Dredge & Dock Company from the USA; and Ballast Nedam Dredging from The Netherlands.

Scope of the Works

The dredging and reclamation contract comprises:

- construction of bunds for the peninsula and island; and
- construction of a motorway and railway at the island; and dredging of:
- work harbours and access channels at the peninsula and island 1,300,000 m^3
- trench for installation of the tunnel 2,300,000 m^3
- relocation and deepening of the Flinte Channel 1,300,000 m^3
- compensation dredging to achieve zero blocking of water flow. 1,800,000 m^3

Figure 1 gives an overview of the site boundaries for the dredging and reclamation contract and indicates hydraulic dredging upon completion later in 1977.

The artificial peninsula will serve to reunite the passenger track from the underground station at the airport terminal with the freight track running north of the airport. The motorway along the northern edge of the peninsula joins the railway at the entrance to the Drogden tunnel portal. Furthermore, the peninsula will accommodate a track leading to a train maintenance work area.

The artificial island south of Saltholm will form the transition between the tunnel and the western approach bridge, including a 750 m long level and

Figure 2. Progress of the works at 12 July 1996 (photo: Jan Kofod Winther).

straight section for railway crossovers. From the tunnel portal on the western end of the island the motorway runs alongside the railway to the north until the eastern end, where it is led over the tracks on a viaduct to enter the upper level of the bridge. Figure 2 shows the progress of the works at 12 July 1996.

Environment

Strict environmental requirements are in force governing both the construction of the Link and the impact of the completed Link on the surrounding environment.
A main requirement is that the Fixed Link must not block the water flow in the Øresund. Through the execution of compensation area dredging, the blocking effect will be reduced to zero.
A second requirement is that spillage from dredging in the seabed and from the reclamation areas may not exceed 5 per cent on average.

The Contractor has developed a system to monitor or estimate at all times every spill source during dredging operations in the construction area. There will be transport of sediment in connection with dredging, transport and reclamation operations, partly as suspended sediment transport, partly as bottom transport.

On the basis of daily surveys the daily spill and dredged quantities are made up for the spill monitoring and dredging control authorities. The quantities are controlled and corrected weekly by means of surveys of the seabed, accurate production estimates and reevaluation of the discharge and turbidity measurements.

All dredged seabed material is reused in the reclaimed areas, which include sedimentation basins. This entails the following advantages with respect to environmental impact:
– minimal sediment spillage;
– need for dumping sites; and
– reduced need for import of sand and gravel from borrow areas.

Hydraulic Dredging and Reclamation

To carry out the dredging works the Contractor has deployed large equipment; one of the world's largest dipper dredgers *Chicago*, bucket capacity 21 m^3 and cutter suction dredger (CSD) *Castor*, cutting power 5000 hp and pumping power 10,000 hp.

From an early stage of the project, the ØMJV had to dredge large quantities of hard material. The main job of the hydraulic dredging work consists of dredging a quantity of approximately 2,400,000 m^3 to a maximum depth of 23 m in the Tunnel Trench. Figure 3 gives a cross-section of the Tunnel Trench with the various types of soil to be dredged.
The cutter suction dredger *Castor* has been substantially modified to be fully prepared for the dredging works in the Øresund. The main parts of the cutter suction dredger are:
– *Cutter:* the tool with which the soil, is being loosened. The cutting power on the *Castor* was upgraded in The Netherlands during 1996 from 1,700 kW to 3,600 kW in order to be able to cut through the hard material the Contractor expects in the Tunnel Trench. The cutter is supported by the ladder and the ladder provides breaking power through its weight of 650 tons combined with the pulling forces to both anchors.
– *Pumping system:* which causes vertical and horizontal transportation to the required deposition area. The total installed pumping power of the dredge is 10,000 hp and it is possible to increase this capacity by adding up to two booster stations, called *Malmö* and *Kopenhagen* of 5000 hp each to increase pumping capacity.
– *Control room at the bridge:* the nerve centre from where the whole dredging operation is monitored and controlled.
– *Spud carrier:* the spud fixes the position of the dredger to the ground.
– *Gravity anchors* to create holding force for the side wires that makes the dredger swing from portside to

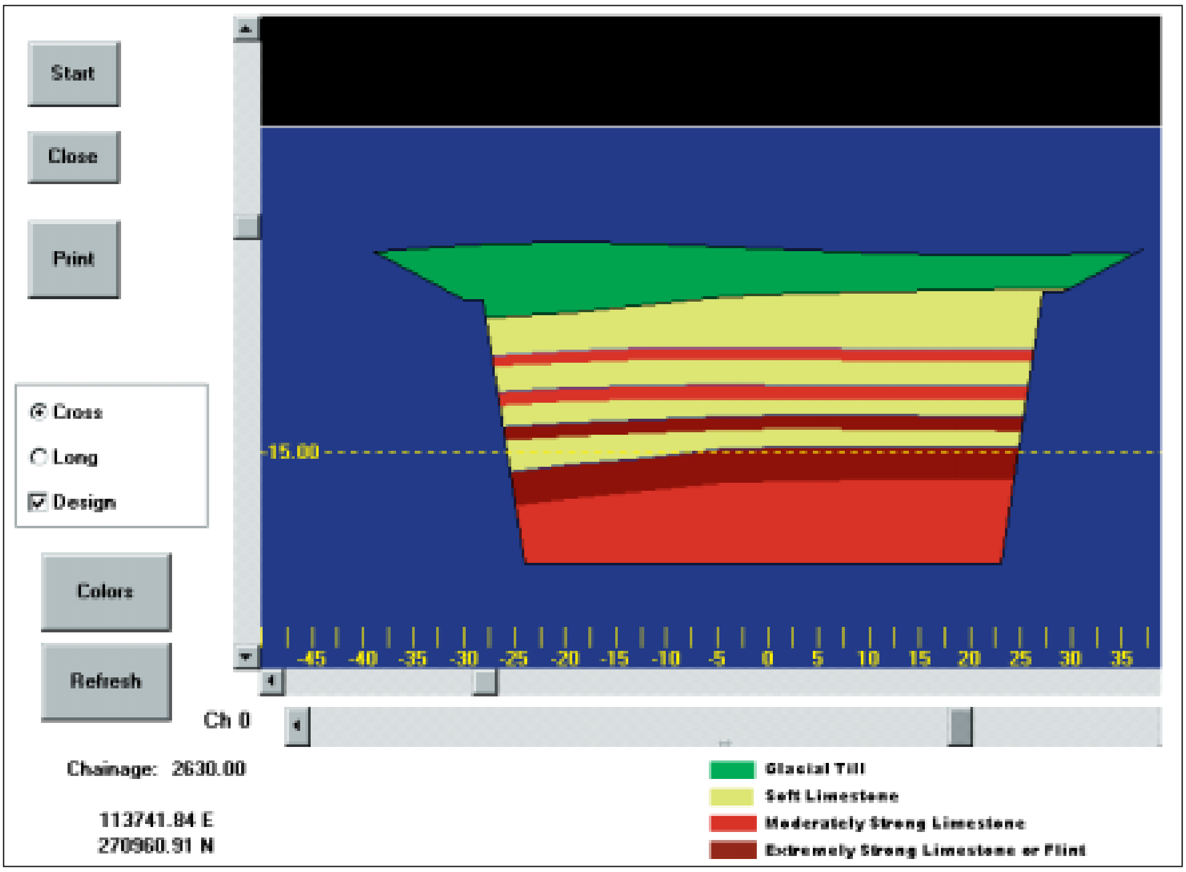


Figure 3. Cross-section of the Tunnel Trench at chainage 2630 with the various types of soil to be dredged.

starboard and vice versa. Figure 4 shows the cutter dredger *Castor* and gravity anchors in the Øresund.

Design, Tolerance and Survey

Strict tolerances on the design apply in the Tunnel Trench as shown in Figure 5. The Contractor has installed a Real Time Kinetic (RTK) on-the-fly (OTF) Differential Global Positioning System (DGPS) positioning system, this three-dimensional system will give the height of the DGPS antenna on board of the vessel above datum (dredger or survey vessel).

Surveys are conducted using a 210 kHz, 33 kHz echo sounder as well as a multi beam echo sounder together with the RTK/OTF DGPS positioning system. In the tunnel trench the survey vessel runs survey lines every 10 metres perpendicular to the alignment of the channel, starting and ending each line 60 metres outside of the work area.

The multi-beam echo sounder is calibrated before and after each survey. The echo sounder is interfaced with a heave compensator in order to reduce the effect of seas on the soundings. The accuracy of the DGPS position is monitored by a separate DGPS receiver on shore.

The height of the DGPS antenna above the ship's reference point is exactly known, together with the ship's heave, roll, pitch, trim, list and draught measurements the actual tide level with reference to DKS will be calculated. The survey data is post-processed to remove any erroneous fixes or depths, and then com-

Figure 4. Cutter dredger Castor and gravity anchors in the Øresund (photo: Jan Kofod Winther).

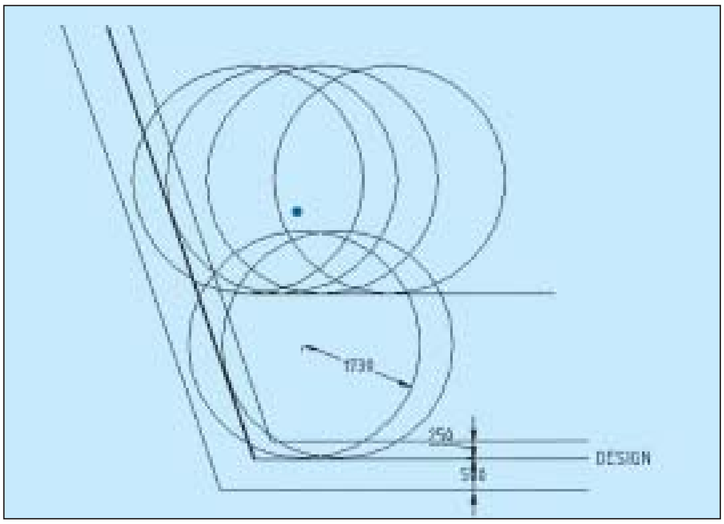


Figure 5. Strict tolerances on the design apply to the Tunnel Trench.

pared to previous surveys to verify the accuracy of the survey.

The information generated by the sophisticated survey equipment will guarantee the required accuracy whilst dredging the Tunnel Trench by cutter suction dredger *Castor.*

Planning

The dredging and reclamation works were started in October 1995 and completion of the dredging works is presently scheduled for August 1997. Immersing of Tunnel Elements will start in the spring of 1997 and is scheduled to finish in the autumn of 1998. Reclamation works will take up to 1999 whilst completion of the works is scheduled for April 2000.

The dredging and reclamation project is extremely complicated in terms of planning. ØMJV has to optimise its planning within a tight scheme of completion milestones for the different dredging and reclamation areas. Within ØMJV an internal scheme of milestones has to be maintained to control the hand-over of work between partners.

Due to spill and contractual spill limitations, detailed planning is difficult. The actual spill is very much effected by seasonal and weather changes. The cold Scandinavian winters can delay operations for weeks or even months. The uncertainty in soil conditions and consequent production rates as well as wear of dredging equipment has a significant effect on required contingencies. Down hours, which were caused by unexpected pipeline failures, are now being avoided by an accurate monitoring system. More details on OMJV's methods and research activities to handle these uncertainities are provided below.

Planning and progress is monitored closely within ØMJV and reported internally through a system of progress meetings and progress reports. A similar system is maintained between Øresundskonsortiet and ØMJV.
All relevant construction programmes of the contractors are linked through the comprehensively implemented planning programme, Primavera.

Soil Conditions and Dredgeability

At the project location two types of materials have to be dredged and used for reclamation of the artificial Island. These two types of materials are Limestone and Glacial Deposits both having varying but typical properties.

Glacial Deposits

The youngest and at seabed occurring material is the "Glacial Till" and consists of Clay, Silt, Sand, Gravel, Stones and Boulders deposited by Glaciers during the latest Ice Age. The Till is overlying the Copenhagen Limestone in about 50% of the project area.

In the Till all grain sizes are present but the grain size distribution varies dramatically. The Till may be a very clayey silt in one place and almost a slightly silty gravel in other places. Big boulders with diameters up to a few metres are present throughout the Glacial Till.
The Till is very much overconsolidated with high Unit Weights (up to 24 kN/m^3) and Shear Strength values (up to 1 MPa) due to the high overburden pressures of the Ice Cap present during the latest Ice Age.

Worldwide experience has been gained dredging similar glacial materials, as well as closer to home when these identical materials in the Great Belt for the Storebælt project were dredged.
Large back-hoe dredges, dipper dredges and cutter dredges are capable of dredging these materials.
The presence of boulders can cause serious production delays or additional costs if they become too large to be handled by the equipment used.

CSD *Castor* has successfully been dredging Till in the Øresund Project area though a number of big boulders had to be removed separately by a large grab dredge.

Copenhagen Limestone

The "Copenhagen Limestone" is directly exposed at sea bed or overlain by Glacial Deposits. The Copenhagen Limestone has been deposited early in the Palaeocene about 60 million years ago.
The Limestone in the Øresund Project Area consists of a succession of Limestone Units which are the Lower, Middle and Upper Copenhagen Limestone. Each of these units consists of layers of Limestone and Flint. Flint, being micro-crystalline Quartz, occurs both dis-

Figure 6. One of six cutterheads available at the project prior to being installed to dredge the extremely hard layers of Copenhagen Limestone in the tunnel trench.

persed in the Limestone matrix and as nodules, bands or even rather frequent as solid layers.
The layers, in which strength properties are relatively constant, vary in thickness between typically 5 mm and 500 mm. The strength of layers varies between 1 MPa for slightly lithified limestone and 350 MPa for Flint layers.

The Rock Mass is folded with an amplitude of not more than 5 metre. Locally faulting occurs with minor displacements of not more than 1.5 m. The Rock Mass can be described as fissured with vertical joint spacing varying between 2 mm and 500 mm with an average RQD value of 29%.

The Rock Mass is very fissured and sometimes even crushed in the top 1 to 4 metre. In this part of the Limestone the action of ice has caused significant disturbance and fracturing and sometimes even mixing with the glacial materials.

The Copenhagen Limestone has very varying properties in the vertical direction but the lateral continuity of properties makes correlation of mechanical properties between boreholes possible.

The Middle Copenhagen Limestone is the "softest" unit with the lowest UCS and RQD values. The Lower Copenhagen Limestone has extremely well defined thick flint layers and the Upper Copenhagen Limestone has the most intact Rock Mass and hence highest RQD values.

The Tunnel Trench to be dredged as part of the Øresund Project represents a volume of 2.2 million m^3 of which 1.9 million is Upper, Middle and Lower Copenhagen Limestone. The depth of the tunnel trench is in places up to 12 metre into the Limestone formations.

From a dredgeability point of view the Copenhagen Limestone is at the borderline of what can be dredged by a cutter suction dredge. Any other type of equipment cannot be used to dig the hardest layers within the Copenhagen Limestone without the use of explosives to break the rock.

Evaluation of the available data indicated that although rock strength values are often sometimes high to extremely high, the fracturing and layer thickness favour the use of a cutter dredge.

Additional investigations to verify the properties of the Copenhagen Limestone revealed increased percentages of high strength limestone and flint. Also the Rock Mass properties showed to be better than the tender information indicated.

So far CSD *Castor* has removed 1 million m^3 from the tunnel trench of which a considerable volume was in the parts which were envisaged to be extremely diffi-

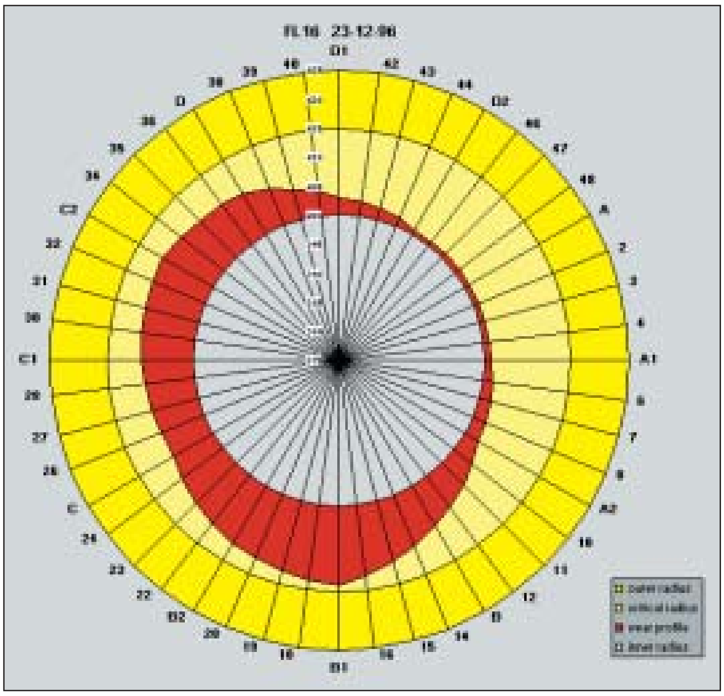


Figure 7. The results of the measurements are stored in a database and presented in the form of "status circles" to the project staff and instructions to turn or replace a pipeline can be derived from these circles.

cult and it can be concluded that CSD *Castor* will be able to dig all the material in the tunnel trench.

The productions of the CSD *Castor* have been optimised by adjusting the cut design for the extremely hard layers in the Copenhagen Limestone (Figure 6). A true 3-D model was established using the boring information in combination with advanced geo-physical borehole logging and seismic interpretation.

Figure 3 gives a cross-section through the tunnel trench chainage 2630. The different colours indicate layers with different dredgeability classification.

Wear and Tear of Pipelines

Before the start of this project, little experience had been gained with the wear of pipelines when dredging Flint and Limestone. It has been anticipated in the tender stage that severe wear of the pipeline system could be expected. In practice the wear at the bottom of a pipeline is varying from 1 mm steel per 20,000 m^3 to 100,000 m^3. This means that to avoid delays a pipe has to be turned or a pipeline replaced in a timely fashion.

Economical Justification

The pipeline system of the cutter suction dredger consists of floating pipeline, sinkerpipelines and landlines. Riser pipelines are used to connect floating pipeline, sinkerpipeline and landline. In total there are some 10 kilometres of pipeline (submerged and floating pipeline diameter 850/800 mm and landline 840/800 mm) on site, with an installed value of approximately NLG 10 million.

The breakdown of, in particular, sinker/submerged pipelines can result in delays of days or even weeks of the dredging process. The strongly varying sea conditions, in particular the currents, in the Øresund disable planning of activities on the water and therefore can cause long delays. It was therefore decided to monitor the wear of the pipeline system closely.

Representative Measurements

Measurements are done by using a Krautkramer Branson DM4 DL acoustic thickness measurement device. A number of measuring points have been defined and prepared, corrosion is removed, and they are covered by grease to enable accurate measurements.

The measurement points are chosen on the wall, since the measurements are most easily taken here.

From the measurements a wear rate per day is derived. This is used to estimate the status of the rest of the pipeline, which cannot be measured at any time.

The estimates of the pipeline status are checked ad-hoc when the pipes are available for measurement. Pipes are both measured from the outside and from the inside. The results of the measurements are stored in a database and presented in the form of "status circles" to the project staff and instructions to turn or replace a pipeline can be derived from these circles (Figure 7).

Pipeline Management System

The pipeline configuration changes frequently: land pipes are being shifted and extended, floating pipelines are installed and removed as required. Therefore it is essential, for a good estimation of the status of pipelines, to know how many and which cubic metres have been pumped through each of the pipeline sections.

This information is stored in the computer database. The database is built up in such a way that per day a list of pipelines can be presented, including bends and special pipes, e.g. to connect a booster station in the pipeline system (see Figure 8). Furthermore the database can be used to look at the number of cubic metres that were pumped through the pipeline, for every turn of the pipeline. This, together with the calculation of a daily wear rate, is used to estimate the status of the pipeline.

Wearbed and Economical Use of Pipes

Figure 9 shows the result of measurement of a floating pipeline. The wear is concentrated at the bottom 40 cm of the inside diameter of pipeline and is most severe 1 m to 3.5 m behind a balljoint. This is caused by the turbulence behind the joints of the floating pipeline. Based on the wear bed it has been decided to turn the

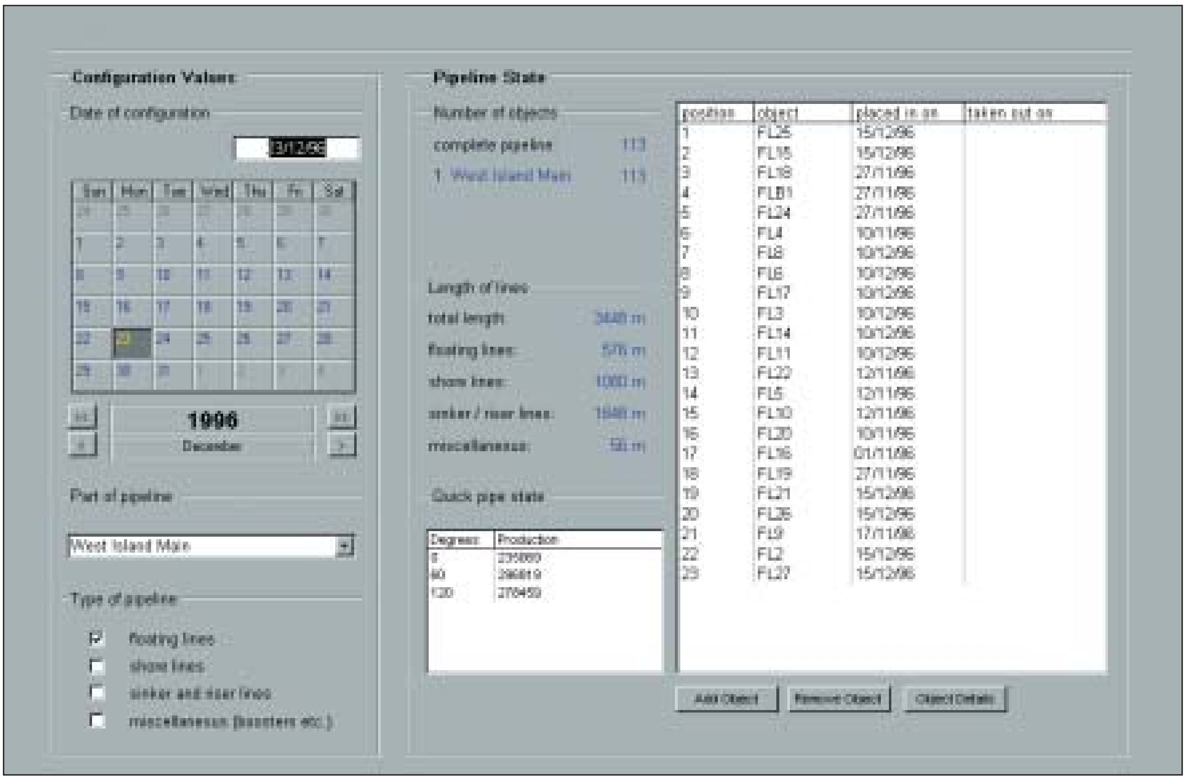
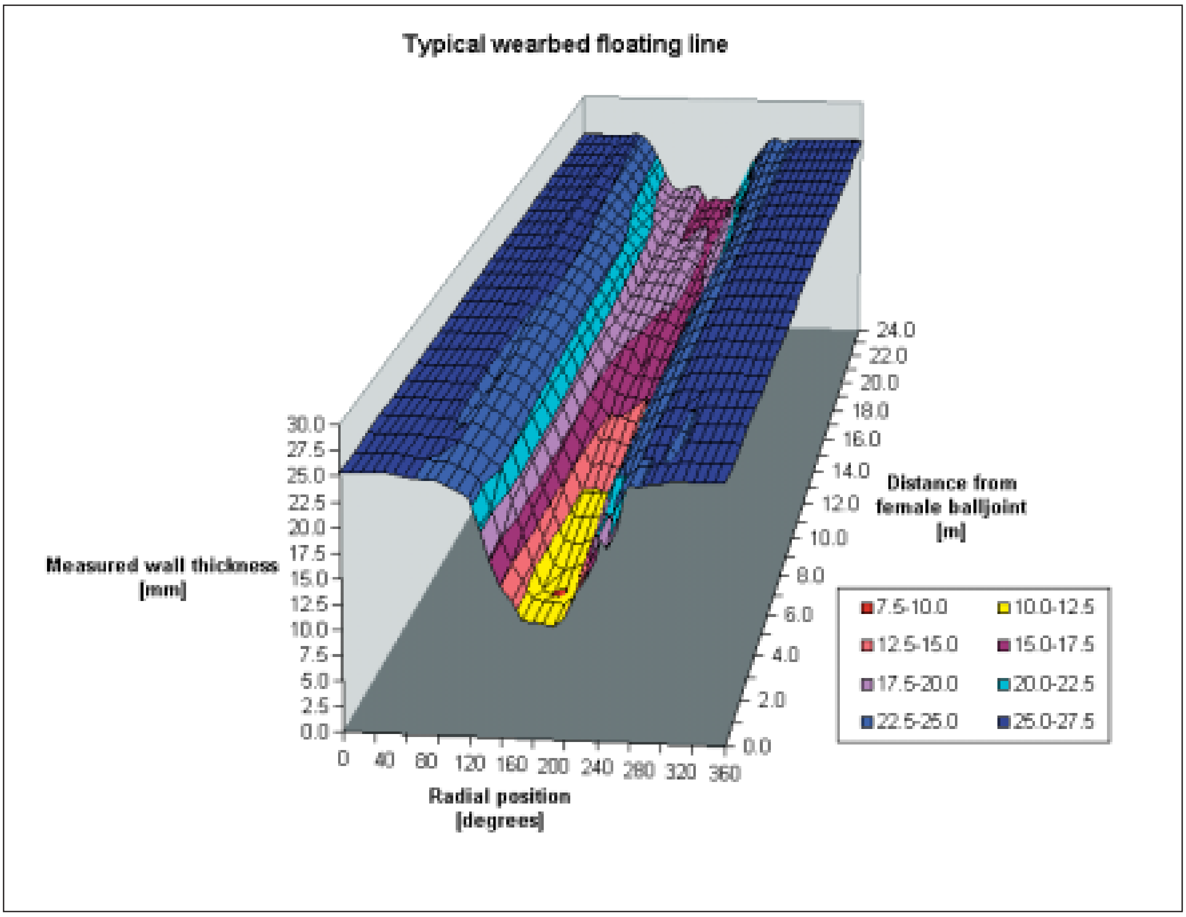


Figure 8. The database is built up in such a way that per day a list of pipelines can be presented, including bends and special pipes, e.g. to connect a booster station in the pipeline system.

Figure 9. The result of measurement of a floating pipeline.



pipeline over 60 degrees, when the bottom side is critical (approximately 10 mm wall thickness). This applies both to the land lines and the floating pipelines. The submerged pipelines are typically turned over 180 degrees or 90 degrees, because of the difficulties to control the position when lowering the pipeline to the seabed.

Prediction of Wear, Velocity and Flint %

Existing wear prediction formulas shows that the wear of pipelines is correlated to the type of material, the density of material which is pumped through the pipe and to a large degree by the velocity of the material in the pipeline. The velocity is therefore set, as low as practical, between 4.5 and 5.5 m/s, by an automated velocity control system which is installed at the CSD *Castor* and the booster stations *Kopenhagen* and *Malmö.*

The density of the pumped material is low and varies little and is approximately 1.10 ton/m^3, for the dredging of limestone and flint. Since the velocity and the density are relatively constant, the type of material is causing the differences in wear. Notably the percentage of flint, which is harder then steel, in the material is the determining factor. To be able to predict the status of pipelines and to plan the turning and replacing of pipeline sections, the rest of the dredging of works have been divided in parts of 5000 m^3. For each 5000 m^3 an estimate of the flint percentages were derived from the 3-D ground model and a prediction of the wear and consequential activities have been made for each section.

Conclusion

The dredging and reclamation work for the Øresund Fixed Link must be considered technically as a very complicated dredging project. ØMJV is dealing with strict environmental restrictions, design tolerances and completion milestones, and has to manage considerable risks in terms of delays caused by soil conditions, wear of pipelines, and difficult weather conditions.

So far, CSD *Castor* has been able to excavate the hard layers in the Copenhagen limestone and is expected to complete the tunnel trench dredging in the summer of 1997. By then the *Castor* will have completed a piece of work that must be considered as "high performance" when related to the type of material dredged, allowable spill, and the acceptable design tolerances.

Down hours, which were caused by unexpected pipeline failures, are now being avoided by an accurate monitoring system which enables an economical use of the pipelines exposed to the extremely abrasive slurry pumped by the *Castor.*