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Cover:
In the Ketelmeer, The Netherlands, a new sub-surface dredging technique has been tested for deepening a navigation channel by dredging under the contaminated upper level (see page 11).

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Contents

2 Editorial

3 Pipe Size Effect on Hydraulic Transport of Jumoonjin Sand — Experiments in a Dredging Test Loop
  M.S. Lee, V. Matousek, C.K. Chung and Y.N. Lee
  Recent experiments on the effect of pipe diameter on slurry flow behaviour add to improving the efficiency of slurry transportation.

11 TechNote: Sub-Surface Dredging: An Economic and Environmentally Friendly Technique for Lowering Ground Levels
  Peter van der Linde, Dick Bodegom and Brigit Janssen-Stelder
  A new “keyhole” method shows how to deepen or construct navigation channels by dredging under unmarketable or contaminated upper levels.

  Patrizia Bernardini and Jan Dirk van Duijvenbode
  An old solution, man-made mounds, may serve a dual purpose of creating protection against flooding and finding a use for dredged sediment.

22 15 Years Experience with Fluid Mud: Definitions of the Nautical Bottom with Rheological Parameters
  Rewert Wurpts
  The Outer Harbour of Emden, Germany, has been kept in natural balance in situ by a specially developed dredging system.

33 Books/Periodicals Reviewed
  CANALS, is a fascinating historical study of the importance of America’s inland waterways published by the US Library of Congress. Also just out: IDR’s 2005 Directory of Dredge Owners.

34 Seminars/Conferences/Events
  Gearing up for the WEDA XXV in June, the EADA in October, and CEDA Dredging Days in November, and more.
The dredging industry has long recognised that environmental concerns are an integral part of dredging management and operations. Dredging and the environment are irrevocably intertwined and, in fact, dredging often offers remedies for ecological problems. To those of us in the industry it is evident that the challenge of keeping our harbours, ports and rivers at a navigable depth and simultaneously maintaining an ecological balance requires innovative approaches.

The articles in *Terra* this month make that clear: Research and development are intensive, ongoing, and cover a wide range of dredging technologies. In-house R&D departments as well as other scientists are striving to find techniques to make dredging more efficient and cost-effective, be it improving the design of a slurry pipeline, or developing a new technique such as the BeauDredge®, or utilising a new dredging system such as that employed at the Port of Emden, Germany. In addition to technological research, the need to increase public awareness and find beneficial uses for dredged material remains of paramount importance, as is witnessed by the efforts of the Dutch Department of Water Management to build mounds of dredged material as protection against flooding and for new residential and recreational space.

The techniques described here represent the cooperation amongst dredging companies, universities and government. Together they seek to meet the needs of the world’s expanding population, intensified global trade and environmental consciousness. Working as partners, the private sector, academia and the government are continually re-inventing themselves and finding new ways to do a difficult job better.

This spring and fall, at a variety of conferences, the latest “state of the dredging art” is being presented: at the 50th anniversary IAPH Conference, which took place in May in Shanghai; at the 25th anniversary WEDA Conference in New Orleans in mid June; and at the CEDA Dredging Days in Rotterdam in November, which due to popular demand has been extended to two and a half days. It seems that 2005 is a jubilee year for many organisations – not in the least our own. So in that context, IADC is happy to announce a special edition of *Terra* which will be published in September to celebrate both the IADC’s 40th anniversary, as well as the 100th issue of *Terra et Aqua*.

Robert van Gelder
President, IADC Board of Directors
Abstract
The diameter of a slurry pipeline is an important factor in a design and an operation of a pipeline and pump system connected with a dredger. However, the effect of pipe diameter on the slurry flow behaviour (frictional head losses, specific energy consumption, deposition limit velocity) is not well understood. Moreover, there is a lack of experimental data that could be used to study the pipe size effect on slurry flow behavior and thus on efficiency of slurry transport operation. Recently, tests were carried out in the dredging test loop of Hyundai Institute of Construction Technology with an aim to collect information on the effect of pipe size on pipeline characteristics (I-V curves and specific energy curves) for aqueous slurries of the Jumoonjin sand (a medium to coarse sand with $d_{50} = 0.54$ mm). The measurements were carried out in straight horizontal pipelines of three different diameters – 155 mm, 204 mm, 305 mm. The article describes and analyses results of these tests. It is reprinted from the WODCON 2004 Proceedings in Hamburg, Germany, with permission.

Introduction
The diameter of a slurry pipeline is an important factor in a design and an operation of a pipeline and pump system connected with a dredger. However, the effect of pipe diameter on the slurry flow behaviour (frictional head losses, specific energy consumption, deposition limit velocity) is not well understood. Moreover, there is a lack of experimental data that could be used to study the pipe size effect on slurry flow behavior and thus on the efficiency of a slurry transport operation.

Hyundai Dredging Test Loop
The Hyundai Dredging Test Loop was completed in 2001 with an objective to investigate both the effect of a pipe size and the effect of pipe bends on slurry flow properties in pipelines. The test loop is a part of the Civil Laboratory of Hyundai Institute of Construction Technology in Yongin-city near Seoul in Korea. Basically, the dredging test loop consists of the engine connected with the centrifugal slurry pump, the pipe circuit with parallel pipe sections and the measuring system.

Circuit
Figure 1 shows a schematic diagram of the dredging test loop. The entire circuit is 160 metre long and it is composed of a vertical U-bend, horizontal pipelines, 45° and 90° bends, a cyclone tank and 12 main control valves. The vertical U-bend is 13 m long and positioned downwards from the level of the pump station. The steel pipe of the U bend has a diameter 204 mm. Horizontal sections of the circuit are equipped with
parallel pipes of different diameters: 155 mm, 204 mm, 305 mm (circular steel pipes with nominal diameters 150, 200 and 300 mm) and 200 mm (rectangular steel pipe).

Each horizontal circular pipe has a 80-cm long perspex section for visual observations and taking photos (see Figure 1). There are 45° bends and 90° bends mounted to the circuit at the end of the horizontal pipes. Using the bends and the ball valves the flow is directed to one of the parallel horizontal pipes. The entire circuit contains 49 taps and sedimentation pots at every pressure measuring point.

A cyclone tank is used to introduce solids in the circuit and collect the solids after a test. The cyclone has the diameter 2 metre and the height 3 metre. Inside the cyclone is a wire mesh screen that helps sand to settle down. The cyclone is equipped with 5 control valves and a 15 cm long perspex tube beneath the ball valve at the cyclone outlet. This helps to observe whether the inflow of sand to the circuit is steady.

The centrifugal pump used in the test loop is the JOOHOB dredging slurry pump with the 4-blade impeller of the diameter 0.45 metre and the diameters of pump inlet and outlet 0.3 metre and 0.25 metre, respectively. The pump is driven by a HMC 255kW diesel engine equipped with BOSCH governor and turbocharger. The engine is connected with the centrifugal slurry pump by V belts. The speed of the pump can be controlled within the range of 530 to 2,000 r.p.m. Figure 2 shows the pump performance curve when clean water was transported.

**Measuring system**

The dredging test loop is equipped with 17 measuring devices. The measuring system contains tachometers, flow meters, density meter, absolute pressure and differential pressure transducers and manometers.

The flow rate of slurry through the circuit is measured using two instruments both mounted to the descending pipe of the vertical U-bend. One instrument is the ABB magnetic flow meter and the other the CONTROLTRON ultrasonic spectra flow meter. The density of the flowing slurry is determined using the BERTHOLD radiometric (Cs137) density meter mounted in the ascending pipe of the vertical U-bend (Figure 3).

The absolute pressures at both the inlet and the outlet of the pump and in several points along the circuit are measured by the WYKEHAM-FARRANCE pressure transducers and the GDS pressure controllers and simultaneously by the absolute-pressure manometers. The pressure drops over the 2-metre long measuring sections in both vertical and horizontal pipes are measured using the SENSOTEC 1-psi capacity differential pressure transducers and differential manometers. Two AUTONICS tachometers and...
proximity sensors on the pulley of V-belts sense the speed of both the pump and the engine.

The data acquisition system is composed of two WYKEHAM-FARRANCE data loggers and a noise filter to store simultaneously electric signals from all transducers and to convert the electric signals into digital data collected in data files of the ASCII format. Figure 4 shows the booth with the remote-controlled data acquisition system.

Experiments

Tested solids
The material tested was the Jumoonjin sand that is the Korea Standard Sand. Three tonnes of the Jumoonjin sand were used in this study has the specific gravity (Gs) 2.65. Figure 3 shows the particle size distribution and Figure 4 shows the Jumoonjin sand photography from a scanning electric microscope (SEM).

Test methodology
Before each test run, all sensors were checked on calibration and if necessary recalibrated so that the measurement was as accurate as possible. During a test run the slurry flow rate was controlled by variation of the pump speed. The slurry density was controlled by the ball valve at the outlet of the cyclone tank. Once the required concentration of solids in the circuit was reached the valve was closed.

The flow of solids through the circuit was steady. There was no significant variation in density along the circuit.
One test run contained measurements of slurry flow parameters at different chosen mean slurry velocities from low mean velocity to high. During the measurement at one velocity the material circulated approximately 30 times through the circuit. When the entire run (one concentration, various velocities) was finished, more sand could be added to get higher slurry density and continue with the next test run. During the measurements photos of the flow patterns were taken by a digital video camera in the perspex tube mounted in the horizontal pipe section. At the end of the test runs the sand was collected in the cyclone tank again so that the circuit remained sand free.

**Summary of test runs**

In the 204-mm pipe the mean velocity of slurry was maintained between 1.68 m/s to 5.47 m/s, only velocities higher than the deposition limit velocity occurred in the pipe. The test runs were carried out for the volumetric concentrations of sand within the range 3.3% to 25.8%. The pump speed varied from 530 to 1,433 r.p.m., the r.p.m. increment per step (installing a new value of the mean velocity of slurry in the circuit) was about 100 r.p.m.

For the 155-mm pipe the test runs were carried out for the sand volumetric concentrations of 7.3% and 21.8% and for the mean velocity between 2.91 m/s to 8.82 m/s. Four volumetric concentrations of sand from 3.3% to 19.8% were tested within the range of the mean flow velocities from 1.2 m/s to 3.6 m/s in the 305 mm pipe. The Table I summarised all test runs discussed in this article.

**Table I. Summary of test runs.**

<table>
<thead>
<tr>
<th>Size of pipe</th>
<th>Fluid</th>
<th>$\gamma$ (t/m$^2$)</th>
<th>$C_{vd}$ (%)</th>
<th>Pump speed [r.p.m.]</th>
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<tr>
<td></td>
<td>Mixtures</td>
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<td>7.3</td>
<td>531 637 733 836 925 1028 1127 1229 – –</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.36</td>
<td>21.8</td>
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</tr>
<tr>
<td>204 mm</td>
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<td>0</td>
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</tr>
<tr>
<td></td>
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<td>3.2</td>
<td>529 623 728 829 931 1036 1132 – – –</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.12</td>
<td>7.2</td>
<td>531 637 733 836 925 1028 1127 1229 – –</td>
</tr>
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<td></td>
<td>1.36</td>
<td>21.8</td>
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</tr>
<tr>
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<td></td>
<td>1.43</td>
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<td>– – 725 828 929 1035 1126 1228 1325 –</td>
</tr>
<tr>
<td>305 mm</td>
<td>Water</td>
<td>0.998</td>
<td>0</td>
<td>529 629 734 830 924 1034 1136 1228 1330 1429</td>
</tr>
<tr>
<td></td>
<td>Mixtures</td>
<td>1.06</td>
<td>3.3</td>
<td>– – 726 829 927 1027 1128 1230 1329 1430</td>
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<td></td>
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<td>1.12</td>
<td>7.2</td>
<td>– – 726 829 928 1031 1133 1228 1326 1433</td>
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<td></td>
<td>1.20</td>
<td>12.4</td>
<td>– – – 928 1030 1126 1228 1329 1425</td>
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<td></td>
<td>1.33</td>
<td>19.8</td>
<td>– – – – 1029 1129 1233 1335 1425</td>
</tr>
</tbody>
</table>
**Test Results and Discussion**

**Pressure drop as a result of friction in the horizontal pipes**

The pressure drop measurements were carried out for flow of water only. The reason was to determine the wall roughness of all three pipes. The water test results and their comparison with theoretical curves are in Figure 5. The water test revealed that both the 155-mm pipe and 204-mm pipe are smooth. Thus the friction coefficient is determined using the Blasius equation \( f = 0.316/Re^{0.25} \), in which \( Re \) is the Reynolds number of the water flow in the pipe. The 305-mm pipe is considerably rougher. The friction coefficient is determined using the universal friction-coefficient equation (Churchill, 1977) for the pipe-wall roughness \( k = 250 \) micron.

The slurry tests covered different ranges of mean slurry velocities and thus also different flow patterns in the pipes of different diameters. A visual observation of the slurry flow pattern was possible only in the 204-mm pipe. The observation showed that the deposition limit velocity tended to vary with solids concentration in the flow and its value varied between approximately 1.7 m/s for the lowest concentration (3%) and 2.1 m/s for the highest concentration (26%). The pressure drops were measured for the range of mean velocities in the supercritical flow regime, in which a flow is free of a stationary bed. The flow was partially stratified. A portion of particles occupied the granular bed that slid over the bottom of the pipe. The flow patterns in the smaller pipe (155 mm) and in the larger pipe (305 mm) must be estimated according to the trends predicted by a suitable model. In the 155-mm pipe, the range of the tested velocities was broad and the flow was free of the stationary bed at all velocities.

Presumably, there was no sliding bed at the highest velocities. The tests in the 305-mm pipe covered only a narrow range of mean slurry velocities, presumably below the deposition limit velocity. Thus there was always a stationary bed at the bottom of the pipe. Figures 6 through 8 show the plots of the hydraulic gradient data measured for flows of different velocities and concentrations in the three pipes of the laboratory circuit.

**Effect of pipe size**

A comparison of the pressure drop data from the Hyundai test circuit with the data and model by Clift et al. (1982) on Figure 9 shows very different behaviors. At the low slurry velocities (up to approximately 4 m/s) the values of the relative solid effect \((I_m-I_w)/(S_m-S_w)\) and of the hydraulic gradient \(I_m\) of the Jumoonjin sand slurry in the Hyundai test circuit tend to be smaller than those measured and predicted by Clift et al. At the lowest velocities near the deposition limit velocity the \( I_m \) values are extremely low.

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![Figure 5. Hydraulic gradients of water transport by using the dredging test loop.](image-url)
A possible explanation of this phenomenon is that the top of the (stationary or sliding) bed in the Hyundai test circuit was sheared off more than it was the case in the Georgia Iron Works pipes during the tests published in Clift et al. (1982). A partially stratified flow with a thinner bed obeys lower friction and thus exhibits lower pressure drops (hydraulic gradients). The $I_m$ values for high velocities in the 155-mm pipe tend to be higher than the Clift’s data and predictions.

In Figures 10a and 10b the measured hydraulic gradients versus the Froude number $N_{Fr} = V_{m}^2/(gD)$ are compared for the three different pipes. Interestingly enough the pressure drops in the 305-mm pipe seemed to be higher than in the 204-mm pipe for the flow of the same value of the Froude number and for a similar value of the solids concentration. It is assumed that this effect is associated with the different flow patterns that occur in the flows of the same Froude number in the pipes of the different sizes.

Since the flow in all three pipes is partially stratified (at least for velocities up to approximately 4-5 m/s), it is useful to compare the measured pressure drops with predictions using a two layer model. Basically, the two-layer model predicts the pressure drops for fully or partially stratified flows with a sliding bed at the bottom of a horizontal pipe. The model, which is used for the comparison, was modified and calibrated for flows of various sand slurries in the 150-mm pipe (Matousek, 1997) and recently extended for the use in pipes of different sizes (Matousek et al., 2004).
For the pipes of the diameter 155 mm and 204 mm, the model predicts higher hydraulic gradient values than measured (Figures 11a and 11b) at the velocities with the partially stratified flow pattern. Unfortunately, the tests did not provide concentration profiles across the pipes and thus the degree of flow stratification predicted by the model could not be compared with the real situation in the pipes. The measurements of the concentration profiles would indicate whether the extensive shearing of the top of the bed takes place and what are the sources of the extensive shearing-off.

For the 305-mm pipe (Figure 11c) the direct comparison of the data and predictions is not possible (the available data are from the sub critical regime only and the model predicts only super-critical flows of a settling slurry).

**Specific energy consumption in the pipes**

Figure 12 compares the specific energy consumption (SEC), obtained as $2.7l_i/(G_s C_{vd})$, versus solids throughput for the three pipes. In general, the low concentrated slurries (solids concentration of about 7%) exhibit high SEC values for all three pipes.

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**Figure 10. Comparisons of the hydraulic gradient for two different size pipes (Fr-Froude number curve).**

(a) 155mm and 204mm

(b) 204mm and 305mm

**Figure 11. Two-layer model predictions and measurement results.**

Legend: (-) two-layer model; (- -) theoretical water; (o) slurry flow

(a) the 155-mm pipe.

(b) the 204-mm pipe.

(c) the 305-mm pipe
The trends of the curves indicate that at velocities near the deposition limit velocity the SEC would be very similar for flows in all three pipes. The same effect holds for the higher concentrated slurries (solids concentration 22%). The SEC values are very similar in all three pipes at velocities near the deposition limit. However, these values are lower than those for the low concentrated slurry.

The larger is the pipe the smaller is the change in the SEC with the increasing solids throughput. According to the observed trend, an operation at velocities far above the deposition limit velocity could be more efficient in a pipe of a larger diameter than in a smaller pipe. However, the larger pipe requires the higher transport power. The size of the transport pipe has to be optimised considering both the power of the transport facility and the type of the transported soil.

**Conclusions**

The measurements of the Jumoonjin sand ($d_{50} = 0.54$ mm) in laboratory pipes of three different diameters (155, 204 and 305 mm) showed that a flow pattern has a profound effect on the frictional pressure losses in slurry pipes.

Very low frictional losses have been observed at velocities near and below the deposition limit velocity in all three pipes. Further investigation is required on the internal structure (distribution of solids concentrations) of the flows to find out the reason for the low pressure drops. It is assumed that this is a result of the shearing of the top of the stationary/sliding bed at the low velocities. More detailed tests are required to find the source of the shearing process.

The test results indicate that the specific energy consumption at velocities near the deposition limit velocity is not very sensitive to the pipe size. However, the difference among the pipes of different sizes tends to increase with the increasing velocity in the pipes. For the selection of a pipe diameter in practice, it is necessary to look not only at the specific energy consumption, but also at the required power of the transport facility and other requirements of a dredging project.

**References**


TechNote

Sub-Surface Dredging: An Economic and Environmentally Friendly Technique for Lowering Ground Levels

Peter van der Linde, Dick Bodegom and Brigit Janssen-Stelder

Abstract

A new technique in soil treatment has recently been introduced. Following the successful development of the BeauDrain® vacuum consolidation system, Boskalis has now developed another new dredging technique called BeauDredge®. Clean sand is extracted from underneath the (unmarketable) top layer and consequently the existing ground level is lowered more or less undisturbed. A pilot project at the Ketelmeer (The Netherlands) has demonstrated that the technique is highly suitable for deepening or constructing navigation channels by dredging under (contaminated) upper layers. The technique can also be used for various other “soil jobs” in hydraulic engineering.

Introduction

An entirely fresh approach has been chosen for developing the new “keyhole” dredging technique. In The Netherlands, many of the dredging related problems concern nautical soil. In other words, navigation channels need to be dredged to enable vessels to pass. But often the bottom consists of contaminated or unmarketable sediment that needs to be removed and treated or disposed of.

“Try to lower the ground level by extracting useable sand without spreading deposits”. With this instruction in mind a team of experts set to work. They conceived a technique to lower ground levels and deepen channels by dredging sand under (contaminated) upper layers, so preserving the properties and composition of that layer. A prerequisite in developing this innovation was that it had to be practical to implement and competitive with respect to state-of-the-art dredging techniques.

While this technique was being developed, a case study was also conducted into the economic feasibility. Calculations were made for both a short-term scenario (small-scale deployment) and a long-term scenario (large-scale deployment). The calculations also included the economic value of the extracted sand. When it was found that sub-surface dredging was both technically and economically feasible, the decision was made to test the innovation in practice.

Prototype Testing

The BeauDredge® system was tested for the first time in 2003 on the banks of the sand borrow pit Engelenmeer in Vlijmen (Noord-Brabant). With a newly built prototype extensive ground level lowering trials were carried out on land. Subsequently, in the spring of 2004, a ground level lowering trial was carried out in Herfterwetering (Figure 1). Under contract from the Groot Salland district water board, the ground level with a surface area of approximately 2 hectares was lowered by 0.5 m. The area was subsequently used for water retention and nature development purposes. The sand produced by the sub-surface dredging was used elsewhere. An advantage of sub-surface dredging is that the properties of the upper layer are maintained and the “bed remains bed” principle is preserved. Following the encouraging results, the dredger GunfleetSand was refitted for this purpose for the application of BeauDredge® on water.

Ketelmeer Dredging Trial

In collaboration with The Netherlands Directorate-General for Transport, Public Works and Water Management (RWS), IJsselmeer Department, Boskalis implemented a pilot project to investigate whether the projected Hanzerak-West deepened navigation channel could be constructed at the Ketelmeer in a polluted bed, with the extremely expensive remedial dredging being postponed or even omitted. A mutual aim was that both parties, initiator and partner, should be able...
to gain insight into the background of the technique. They opted for a joint monitoring contract. This saves costs and ensures involvement from both sides. The anticipated result of the pilot project (product) was to lower a part of the navigation channel at the Ketelmeer to the required depth. The following preconditions were specified beforehand in a soil removal permit:

• bed lowering depth tolerance approximately 1.5 m;
• overflow during sub-surface dredging (discharging water-sand mixture) was not permitted; and
• clean extracted sand has economic value and is to be used as fill material (constructing a nature conservation island).

IMPLEMENTATION

RWS made a 60 x 160 m section of the navigation channel at the Ketelmeer available for the pilot project (Figures 2, 3 and 4). Geologically the IJssel Delta is an interesting area. In the Pleistocene Period, the IJssel was a fast flowing river, which brought in coarse sand that settled in the Ketelmeer. In the later Holocene Period, the river started to meander and the flow velocity declined resulting in less and finer sand and later clay with peat formation being introduced. The unusable upper layer of clay and peat is approximately 3 m thick. The sand was extracted at a depth of approximately 6 m below bottom level (approximately 10 m below the Amsterdam Ordnance Datum). This depth lies roughly on the transition of coarse and fine sand. The grain size of the dredged sand has a $D_{50}$ of 191-335 µm. According to the requirements of Standard RAW 2000 this sand is suitable as drainage sand (partially) and fill material.

Since overflowing was not permitted during the pilot project, the total water-sand mixture was discharged into hopper barges of approximately 800 m$^3$. In order to prevent overflow at all the barge was filled to approximately 600 m$^3$ (150 m$^3$ sand and 450 m$^3$ water). The barge was then transported to the discharging location in the mouth of the River IJssel approximately 5 km away from the dredging site. Here the water was pumped into a settling basin and the sand was used to construct a nature conservancy island.

MONITORING

A comprehensive monitoring programme was drawn up to help evaluate the trial properly. Any direct and indirect effects on the environment were examined. The following parameters were established before, during and after the trial:

• soil structure and quality;
• water depth;
• suspended sediment (quality and quantity);
• water quality;
• groundwater level and quality (including salinity);
• ecology of the water bed.

The measurements were carried out according to a monitoring and measurement plan drawn up jointly (by initiator and partner). External quality control was supervised by the Deventer engineering consulting firm of Witteveen en Bos.

Besides the environmental effects, several process parameters of the dredging process were measured including:

• flow rates of the dredging system;
• grain-size distribution of the extracted sand;
• density of the water-sand mixture.
The provisional results show that the trial is running according to expectations. One of the provisional conclusions is that BeauDredge® causes negligible turbidity and that the groundwater level in the surrounding polders is not affected. Moreover, it was found that the (remaining) soil layers do not mix. The dredged sand is used in a project for the construction of a nature conservancy island (creating “work with work”). During the process, as much experience as possible is being gained with different process variations so that on evaluation, the possibilities of the new sub-surface dredging technique become obvious.

Conclusions

A number of application potentials of BeauDredge® have been identified. To date, the keyhole dredging technique has been used for constructing a retention basin and deepening a navigation channel. In the future, projects could also be carried out for profile widening in the context of the “Room for the River” project (a governmental plan to invest 2 billion Euros to protect parts of the Rhine and Maas against flooding and other
consequences of high water levels) and for improving water quality. To this end, sand below the eutrophied (food-rich) waterbed is dredged and the fine fraction used as cover for that same waterbed. This is possible by allowing the overflow to settle in a controlled method or by using an advanced distribution method.

The technique can be further used for selectively extracting high quality sand (such as sand for industrial purposes), below silt that purposely has been discharged into deserted sand borrow pits or below natural silt deposits.

There are other good opportunities for this technique as well. In areas where for example sea grass or other vulnerable bed vegetation occurs, it is possible to dredge without causing appreciable damage to the flora and fauna. BeauDredge® facilitates a number of new hydraulic engineering jobs that were previously technically impossible and economically unfeasible.

Application of the BeauDredge® Technique

The new technique, which is called keyhole dredging or BeauDredge®, has been developed in-house in cooperation with various departments at Boskalis. Existing sub-surface techniques have been upgraded, resulting in a method where clean sand is extracted from under an upper layer without any mixing or spreading the upper layer. During this process, the upper layer settles in a controlled manner, while its character and properties remain intact (“bed remains bed”). As a result, bed lowering can in many cases be achieved without remedial dredging being necessary, while the extracted sand can be used as construction material.

In order to gain insight into the geological make-up, soil investigation and soundings are carried out beforehand. This data is indispensable when preparing a dredging plan. Based on the type of sand, the density, and so on, the area to be lowered is gridded and the information saved to a central computer. In the different process stages operators can view the information on their own monitors. DGPS is used for positioning.

In order to reach deeper sand layers, a displacement drilling method is used to drill the dredging tool – of which the suction mouth is closed during this phase – through the upper bed layer. A standard vertical drilling rig is used of the type used for constructing foundation piles. Once the target depth has been reached, a horizontal (or other required angle) jet is used to erode the sand. From the parameters set (such as pressure and flow rate) it is possible to determine when the optimum horizontal penetration depth has been reached. The dredging tool is then rotated slowly until the circular layer of sand around the tool has been extracted (Figure 5).

During the dredging process the flows of jet water and the extracted water-sand mixture are kept equal. This prevents a blow-out or collapse.

Following dredging, gravity allows the upper layer to settle gradually without changing the character and properties or mixing the soil layers. A full cycle takes approximately 35 minutes. Indicative production is 150 m³ sand per hour.

During the dredging operation, regular measurements are taken: soundings, sub-bottom profiling, and so on. The results are used for the process control and quality control of the dredging process. In addition, the data is saved to a database to build up a knowledge base with process parameters for the different sorts of sand extracted by means of keyhole dredging.

Figure 5. Steps 1 through 3 show the extraction of clean sand in circles from the layer underneath.
Environment

Introduction

How is it possible to contribute to the beneficial use of contaminated sediment and at the same time offer better protection against flooding? The building of mounds of contaminated dredged material appears to be a promising partial solution. Since 2004 a project team of WINN, the water innovation programme of Rijkswaterstaat, the Dutch Directorate for Public Works and Water Management, has been working with market players with the intention of accomplishing these two things simultaneously by creating new high-lying land in lowland areas.

To this end, they have organised “competitions for the best ideas” amongst market players (e.g. landscape architects), as well as secondary school students. The result is a number of interesting and innovative ideas which merit further investigation. To turn words into actions, Rijkswaterstaat is looking for a location for a pilot mound of at least 25,000 m$^3$ of dredged material.

The Mound Is Back

For centuries high-lying land has been the ideal protection against flooding. In the event of an emergency caused by high water, damage is limited and there are no casualties. Dyke rings in The Netherlands consist primarily of flood defences – designed to withstand floods with an exceedance probability of 1:1250 to 1:10,000 per year – and high-lying land. Climate change, the rising sea level and tectonic subsidence of the land mean that dry feet can no longer be taken for granted (Figure 1).

Abstract

The Dutch Department of Water Management (Rijkswaterstaat) is developing an innovative concept: building mounds (terpen) of dredged material. Terpen or mounds were common in Holland centuries ago: man-made mounds a few metres high that were placed as a protection against the sea.

Climate change, rising sea levels, and falling land levels mean that The Netherlands is still challenged to keep the country safe and dry. In addition modern water management and water safety must ensure that waterways are deep enough to keep the functionality (shipping, discharge of rain water) of the water systems intact. Maintenance through the removal of dredged sediment from ports, canals, and rivers is an ongoing necessity, with millions of cubic metres of often contaminated dredged sediment being removed annually.

For this reason, the traditional “mound solution” may be ready to make a come back. Modern mounds made of (contaminated) dredged material create a beneficial use: on the one hand, mounds offer protection against flooding and, on the other, they provide a final destination for dredged material which allows dredging to be continued.

At the initiative of the Dutch Department of Water Management several activities are in progress to involve stakeholders, and competitions have been organised to find possible placement sights for the mounds. The article describes the competitions conducted and the studies which have been done to develop the concept.
The re-introduction of mounds could provide a means to reduce the risk of flooding. Mounds can be made from clean and contaminated dredged material from waterways and flood plains. Since The Netherlands, like many other countries, is battling against a shortage of destinations, in particular, for contaminated dredging material, the new mounds could solve two problems at one time.

Solutions for contaminated dredged material arouse a great deal of NIMBY (not in my back yard) feelings. The building of mounds by local dredging is a good way of getting rid of sludge in the local area in an economic and lasting manner. In addition, mounds offer the local council a large number of interesting possibilities. In principle, living, working and recreation on the top of a mound are all possible. But the use of contaminated dredged material as a building material demands a revolution in thinking.

What is required is a change of attitude from NIMBY to PIMBY (please in my back yard).

**The WINN Project “Mounds of Dredged Material”**

The “Mounds of dredged material” project is managed by WINN, an innovative programme of Rijkswaterstaat. Within WINN (www.waterinnovationbron.nl), Rijkswaterstaat (RWS) together with the public in general, is looking for ingenious, long-term solutions for the optimal use of water and the Dutch water-based infrastructure. This innovative programme aims to give impulse to new land use, while at the same time guaranteeing the safety of waterway systems.

Dialogue and co-operation are sought with external partners, such as waterway users, lobbying organisations, market players, experts, architects, people in the advertising and art world, and secondary school and university students. The working method of the programme involves consideration of concrete test projects and demonstrations on the basis of long-term perspectives. Apart from offering the chance for technical innovations, this also provides an opportunity to discuss how RWS is to carry out its functions in the future.

**Feasibility of Mounds of Dredged Material**

In an in-house preliminary study RWS examined the technical, environmental and legal consequences of building mounds of dredged material. An exploratory investigation was also carried out into the perceptions and opinions of citizens and organisations in the Gelderland (a province of The Netherlands) river area.
Alternatives
A number of technical alternatives have been investigated and selected based on defined stipulations. These stipulations are divided into “must have” requirements, with which every alternative has to comply, and “desirable” aspects, for which the alternative concepts can win extra points to variable degrees. The “must have” requirements and other desirable aspects are listed below.

Requirements:
- The mound must be realised within 1 year.
- The mound must have a recreational function within 3 years after construction.
- The mound must have a living function within 5 years after construction.
- The mound must be constructed with wet contaminated (class III as minimum) dredged material.
- The costs must be less than Euro 30 per tonne dry material. This amount is a reference amount based on cost estimation where dredging, transport, engineering, and construction costs, including VAT, of a mound of 150,000 m³ are included; real estate costs are excluded.
- The mound must be safe with respect to flooding and to the contaminated dredged material.

Desirable aspects:
- It should be possible to construct the mound with all types of material, i.e. a specific fixed degree of sand content or degree of contamination should not be fixed.
- The mound should be construct in one go, wet material should be processed in the mound in one step.

All alternatives are based on the assumption of a mound with a net volume of 150,000 m³.

The technical investigations demonstrated that the so-called filled hill or mound (omputterp) was the best alternative by far.

The central thought is that the (relatively solid) material from the flood plains can be built up into a mound in one go. This material can be heaped up easily to a height above that of a dyke and therefore contribute to safety conditions (probability of flood: 1/100,000 per year) and also be used for the function of housing immediately. The "hole" in the flood plain will be not deeper than 10 metre, according to Dutch legislation (Ontgrondingwet) and not wider than the stability of the summer and winter dykes allow. The "hole" is filled with material from the river. This material is wet and, depending on the intended spatial quality and nature, should be built up in varying heights to ground level.

In Figure 2, the filled mound (omputterp) is drawn adjacent to the winter dyke.

The second alternative is “Concentric Sedimentation Basins”. Sand, silt and water deposits are formed into concentric rings. Wet sludge is pumped into the heart of the mound and the sand (the coarse fraction) is deposited in the inner ring. The coarse fraction
consolidates fast and quickly reaches the bearing power for functions as living and recreation. Next to the improvement of the physical quality, an improvement of the chemical quality occurs as well, because the contaminated material sticks more to fine than to coarse parts. Via the drainage points in the sand dump the sludge moves into the next ring where it can sink and consolidate. Here, the consolidation process is longer because the silt contains water binding parts (see Figure 3).

The dewatering process can be accelerated by means of plants. By aeration and plantation, the organic contamination can break down. The anorganic pollutants (heavy metals) stick to the fine parts (clay minerals), as a result of that the emission in the ground decreases. The process water flows over into the provisional outermost ring and can be purified with helofytes. The water, then, will be pumped out the ring and deposited into the surface water. For the process to work well a sand fraction of 50% is required.

This alternative can be optimised depending on the quality of the material. For example, if the dredged material is rich in silt then the silt ring can be divided in two or three zones (rings). Per zone, the thickness of the layer and the planting can be decided based on the specific requirements: how fine the silt, how thin the layer.

The investment costs of these two types of mound (in Figures 2 and 3) are comparable with the cost of a traditional mound built with primary material such as sand and clay. The benefits of both alternatives are:
- non-use of primary materials;
- no transport and dumping costs of dredged materials; and
- the possibility of subsidies.

Another innovative alternative which was considered is a mound of geotextile tubes. A series of tubes in layers are filled with dredged material (see Figure 4).

During filling, the geotextile tube is pressurised with the soil-water mixture, allowing discharge of the liquid through the fabric pores but retaining the solid particles. The result is a "soil sausage" with lower water content and correspondingly higher percent solids. Succeeding layers of geotextile tubes are placed parallel to the lower layer. The upper layer geotextile tubes can be placed along the gap of the lower layer in a brick-laying pattern or a pyramid pattern. This results in a solid compartmented volume of dredged material.

During the filling, bacteria can be added to the dredged material to break down the organic pollutions. This alternative, although very interesting, cannot compete with the above described two other alternatives because of its higher costs.
Although the introduction of the categorisation of dredged material by class has proven to be very useful in the development of water soil management, at present the relation between classes and the order of destinations needs to be revised.

Dredged materials have been categorised based on toxic aspects but the characteristics of the ground and the environmental conditions influence the behaviour of substances. With present-day knowledge, a risk approach should be found based on toxicity in relation to function: in other words look at the absolute measured contents of the dredged material and add other characteristics such as the percentage of sand, the level of acidity and the redox potential of the system. A similar approach (dynamic approach) allows bottlenecks to be removed at a policy level.

**ROADSOCIAL DISCUSSION THROUGH “BEST IDEAS” COMPETITION**

In order to use the creativity and inventiveness of the marketplace in the development of the concept of mounds of dredged material, RWS organised a “best ideas” competition. The competition attracted some 38 entries. Participants included engineering companies, architects, landscape architects and private individuals. An external commission was formed consisting of experts from outside RWS and representing the most relevant disciplines such as engineering, landscape architecture, architecture and civil administration. The external commission chose the three best entries from ten entries selected by an internal commission. Prizes were awarded in the categories of most technically innovative, the most promising with respect to future expectations and finally the one with the highest PIMBY content. The latter stood for aspects that made the mound attractive and desirable with respect to environmental impact, good integration into the landscape and functionality of the mound.

**THREE WINNERS OF THE COMPETITION**

**Watertight**

The prize for the idea with the most technically innova-
The idea, which was found to be intellectually innovative, includes the adaptation of layered compartmentalised embankments in areas likely to be flooded such as flood plains. These embankments are partially made from dredged material from flood plains and ditches. The embankments have a useful function in that flooding can be better controlled and the river area will fill up more slowly. On these embankments houses or a recreational area can be built. According to the commission the idea would contribute to making the inhabitants more aware of the flood risk in The Netherlands.

“Werk met werk in het kwadraat” (Work with work squared)
The commission found that the most promising entry for the future was ‘Werk met werk in het kwadraat’ by Grontmij Nederland BV. This idea comprises the construction of a village on a mound where it would integrate easily into the Groningen (eastern Netherlands) landscape. The idea was found attractive most of all because it could be fully adapted as a solution for the high water problem. This plan changed the concept of “living in an area protected by dykes” to “living safely high on a mound and be less dependent on the height of the dyke”. In view of the agreement made with local parties in the province of Groningen the idea has considerable promise. It offers the opportunity for a concrete project to act as an example for other areas of The Netherlands.

“Spaarkaart”
“Spaarkaart” (Savings card) by Arcadis, Attika, Attika & Park was the winning entry in the PIMBY category. The idea was appealing because it contained two complementary concepts – living mounds and a multifunctional mound landscape – which differ according to scale and time horizon. The living mound concerns the implementation of earth-wall homes with a back garden in which the function of nature is central. An existing dyke is widened into a mound that is filled with local sludge in phases. The mound with housing is developed over a period of three to ten years. There is room for approximately 85,000 m$^3$ sludge.

For the development of a multifunctional mound landscape 30 years is required. The sludge is required for the construction of an arbitrary area, whether it is deep polders or water-rich landscapes with mounds. The focus is directed towards areas where flooding is unavoidable. In 20 years new use of space will be created with about 1,000,000 m$^3$ sludge. In the opinion of the commission the idea would fit in very well with a project such as “Room for the River”, which is a project directed towards finding new approaches to give rivers the space they need to handle larger volumes of water while improving surrounding land areas. Instead of continuing to raise and strengthen dykes the project is
YOUTH AND OPPORTUNITIES FOR MOUNDS

In order to involve tomorrow’s citizens in a public discussion about dredged sediment as a new building material, RWS organised a competition for 15 and 16 year old high school pupils. They were asked to act as project developers and design their own PIMBY mounds from contaminated dredged material. Before their participation in the school competition to design a mound made of dredged material, the majority of pupils reacted with “No way”.

Thirteen school classes took part in the RWS competition. The pupils concentrated on thinking about the functions of the mounds such as a shopping mall, ski slope and a children’s farm. The competition generated publicity that contributed to the discussion about mounds made from dredged material. In addition the participants increased their knowledge about mounds. Opinion was divided about how they expected social support to be created for the mounds of dredged material. It ranged from consideration of the necessity to give local sludge a useful application to secrecy about the use of the sludge.

Further information about both these “best ideas” competitions can be found on the web site of WINN, the water innovation programme of Rijkswaterstaat: www.waterinnovatiebron.nl or by contacting the authors [p.bernardini@bwd.rws.minvenw.nl] and [j.d.vduijvenbode@bwd.rws.minvenw.nl]

2005/2006 PILOT MOUND

As a follow-up to these competitions for generating new ideas, RWS now needs to get practical experience with the construction of dredged material mounds. This includes adapting the ideas derived from the marketplaces competition into building a pilot mound and by investigating all sorts of technical aspects such as working with wet sludge. RWS is therefore looking for suitable locations. There is currently a list of potential locations where both aspects of the PIMBY mound could be implemented. This would mean a solution to possible flooding as well as the use of locally dredged material as building material for the mound. Recently RWS signed a letter of intent with Zeeland to start implementation of a pilot project in 2005/2006. Other locations are also being sought.

Conclusions

An exploratory investigation was carried out amongst the public and organisations in the Gelderland river area, in which the idea of mounds of dredged material was proposed. This included competitions for new ideas of how to build mounds from dredged materials. In view of the limited scope and restricted area of the study it is difficult to come to firm conclusions. However, since mounds have been a feature of the Dutch landscape for a long time, the idea of building mounds in general was well received by the population. The location, size, height and the use of the mound must be precisely defined. Some respondents thought that living on a mound would afford them a good view over the land. Local councils and the water authority expect a great deal of opposition from the population, based amongst other things on the fear of contamination.

The effort of RWS to find solutions to the continuing problem of disposal of contaminated dredged materials is a significant step in the right direction. Given the new EU Water Frame Directive, similar problems exist throughout Europe. The public relations efforts of RWS to involve the population, engineers and others in related disciplines, as well as the youth, to find future solutions should set an example for other nations facing similar disposal situations, where maintenance dredging through the removal of sediment from ports, canals, and rivers is an ongoing necessity.
Rewert Wurpts graduated in 1967 as a hydraulic engineer from the Technical University of Hannover, Germany. He then joined the dredging division of Ph. Holzmann, working on dredging projects worldwide. In 1986 he went to work at the State Government of Niedersachsen, where he is responsible for R&D, specifically for dredging and surveying for the port of Emden. He has been President of the Central Dredging Association since 2000.

15 Years Experience with Fluid Mud: Definition of the Nautical Bottom with Rheological Parameters

Abstract

In the contract of 1954 between the German Federal Waterways Administration and the newly formed Water and Land Federation Emden-Riepe, the Federation relinquished agricultural land within the Emden-Riepe Lowland to the Association of Port Operators to accommodate sediment from the Port of Emden which at that time was still classified as mud.

This policy continued through the 1980s. During the privatisation of maintenance dredging in 1986, first concepts to reduce the, at that time, considerable amounts of sediment were drawn up. The costs of maintaining the nautical depths in the Port of Emden were significant, and in 1990 the provincial government issued an order to stop flushing in Riepe. Since 1990 the layer in the Outer Harbour of Emden has been kept in its natural balance in situ, by using a dredging system that was specially developed in Emden. The question of whether the technique developed in Emden can be adapted for other harbours with a higher sand content has triggered a series of tests which are also discussed.

Introduction

Since 1954 wetlands within the Emden-Riepe Lowland were used to accommodate sediment from the Port of Emden which at that time was still classified as mud. In the following years the Emden Port Operators demanded an average area of approx. 200 ha of lowland per year. On average about 120 ha of this area were flushed, dried, drained and recultivated. Some 80 ha were returned to agricultural use after about five years. Until the end of the 1980s the average amount of flushed mud was 4.0 million m$^3$/a. About 1.5 million m$^3$ were taken from the Inner Harbour and about 2.5 million m$^3$ were taken from the Outer Harbour of Emden.

In the course of privatisation of maintenance dredging in 1986, first concepts to reduce the, at that time, considerable amounts of sediment were drawn up. Although the flushed areas were ecologically valuable lowlands, the costs of maintaining the nautical depths in the Port of Emden were significant. Therefore, in 1990, the provincial government issued an order to stop flushing in Riepe.

Origin of the Emden Sediment

The location of the area to be maintained can be seen in Figure 1. By investigating the microbial strain (fresh water formations) in the sediment it became evident that the upper course of the River Ems is the source of the suspended particles in the harbour [6]. Like the
River Weser [1], the Ems transports a significant sand fraction of about 20% as a result of the high tractive force on the Ems bottom. In contrast, the tractive force on the bottom of the Emden Outer Harbour is negligible; a measurable sand influx into the Outer Harbour could not be traced up to now.

The River Ems carries an average suspended load of about 900 mg/l in the water column. During certain tidal phases the concentration can reach up to 1600 mg/l and more. Because of the density difference this suspended material has the nature of quickly entering so-called calm zones. Situated on the Lower Ems, the Harbour of Emden is the largest retention zone for these formations of suspended material; since the turbid zone of the River Ems has moved upstream towards Papenburg in the past years, the harbours of Papenburg, Weener, Leer and Jemgum have also become affected by sediments from the tidal Ems. By this, one can presume that the adjoining harbours are also part of the Ems equilibrium.

These interrelations are especially clear in the Outer Harbour of Emden (Figure 2). The top horizon is recorded with a high frequency (210 kHz) and the bottom one with a low frequency (15 kHz). The green line represents the required nautical depth for Emden at 8.5 m below chart datum. The volume between these two frequencies is about 418,000 m$^3$ and has hardly changed since it was first measured in 1989.

This layer of suspended material is in a state of equilibrium. Quantities excavated from this layer by dredging operations returned after a few days time. Both echo horizons move closer together towards the Ems because high current forces prevent the formation of a detectable layer of the finest particles. The detectable distance between the horizons, which is about 3 metres in the Outer Harbour, decreases to 60 cm in the Ems. This shows the impact of the current and tide effects in the Ems. Within the Outer Harbour, tide and current have no effect; here it is solely the density effect that influences the suspended material.

This explains the rapid refilling after dredging operations because the cut dredged into the suspended material was directly replenished by the density effect – the local material deficit was balanced with re-flow from the surrounding area. This leads to the conclusion that there is a constant exchange between the fluid mud layer in the Outer Harbour and the sediment pool in the Ems.

The magnitude of the layer in the Outer Harbour results from the equilibrium between the influx of suspended material during flood and the discharge of suspended material into the Ems near the bottom during ebb. Since 1990 the layer in the Outer Harbour of Emden has been kept in its natural balance in situ and, owing to its outstanding parameter characteristics, it is still navigable by using a dredging system that was specially developed in Emden.

**The yield point**

Leaving such a layer in situ does not permit a definition of the nautical depth with conventional criteria. For this reason the definition of the nautical depth was made depending on only one parameter: The yield point. Even a physical density up to 1.25 t/m$^3$ allows ships to manoeuvre without difficulty in the Harbour of Emden. Only the firm clay layer on the bottom has values
between 1.28 and 1.36 t/m³ and is therefore not navigable.

By 1994 the dredging strategy developed for the Harbour of Emden focussed on not extracting from these in-situ layers but keeping the equilibrium and even increasing the density of suspended material in all harbour basins in order to prevent a density gradient from the Ems to the harbour thus decreasing the density current towards the harbour.

For this reason about 418 000 m³ and 192 300 m³ in the Outer Harbours as well as 584 000 m³ in the New Inner Harbour, that is in total 1.196 mil. m³, are kept as an in-situ layer on purpose in order to maintain the equilibrium. This is the volume of suspended material between the 210 kHz and 15 kHz echo. This formation of suspended material consists of pure fluid mud.

**Definition of Fluid Mud**

Fluid mud clearly belongs to the Hyperconcentrated Flows (HF) formation. These are high concentrated suspensions of solid material together with a low density that have only a slight tendency to consolidate. The close spatial contact between the single particles is filled with microbial slime. Therefore these particles can stay in suspension over a long period of time because this slime is significantly lighter than clear water and hence provides buoyancy. These microbial slimes are generated by the attached bacteria; a fluid-mud layer must therefore be in an aerobic state so that the bacterial cultures have the continuing ability to produce this slime. Although the generated slime fills the gaps between the particles, it significantly reduces the internal friction and causes them to stay in suspension longer. Holding out and “treating” a fluid-mud layer primarily means conserving a microbial budget, i.e. to ensure the production of slime. For this reason it is very important that the aerobic state is kept up. Fluid mud is a pre-stage to mud or silt with which it must not be confused.

This slime has another advantage: The low friction between the particles allows for seagoing vessels to pass through because fluid mud consists mainly of water. Both the high rate of cross-linking of the solid particles and the low shear stress resisting binding strength of the bacterial slime are the reason for the flow capability of fluid mud [6, 12]. As paradoxical as it may sound, it just this high concentration of solid particles that prevents the formation of extensive sediment accumulations that become impassable for ships; it is the high biogenous fraction that delays or even prevents these solid particles from settling.

**Flow behaviour**

After a five-month stop of all activity in the fluid-mud layer in the Outer Harbour, there was no significant change in the flow behaviour; as soon the aerobic substance has been decomposed and a long-term compression takes place then there is talk of a biogenous consolidation. In practice, the transition from fluid mud to mud is defined by the change from an aerobic to an anaerobic state where large amounts of gas are produced, primarily methane. How older mud formations can be revived to a certain extent and brought into suspension will be presented below.

The most important parameter while dealing with these fluid-mud layers technically in respect of the navigability is the organic content which is 22% on average in the tidal Ems as well as in the Harbour of Emden. The existing insitu layers are naturally not to be classified in terms of Newton, neither can they be regarded as soil for which the laws of soil mechanics apply. The insitu layers mentioned above are rather to be regarded as classic fluid-mud formations. The relevant differences are shown in Figure 3.

**Flow Capability**

The good flow capability of the fluid mud on the bottom of the Outer Harbour of Emden was discovered for the first time when the cutter suction dredger pumped the slurries that were not considered navigable (approx. 0.5 mil. m³ per year until 2001) onto the disposal. It has turned out, that fluid mud flows to deeper areas, provided the flow conditions are laminar with a constant gradient towards the deeper areas as well as a suction device over there. Regarding the constantly high output performance of the cutter, it must be assumed that the fluid mud flows towards the point of excavation with a remarkable velocity. On the basis of this experience, an underwater suction system was installed in the
Harbour of Leer towards which the fluid mud will flow along both of the 1000 m long harbour basins at a gradient of 1:1000.

This phenomenon is known from dam operation [18]. A density current of this kind is also a laminar flow of stratified liquids. This flow process is significantly influenced by density differences between the layers and the so-called density current on the bottom is induced by higher density of the bottom layer than that of the liquid above it. This problem plays a particular role when it comes to taking countermeasures against silting up of reservoirs [16, 17], as well as in tide influenced river estuaries. The current conditions for steady density currents can be reliably described if one presumes that the density liquids are homogenous and the current is laminar. It can be taken from literature that a gradient of 0.0001 and less is sufficient to permit a density current. It is known from the Sanmenxia Reservoir in China that slurries can travel an amazing distance of over 40 km at a bottom gradient of 1:100000 [4].

**Physical Preconditions**

From a hydrological point of view, suspended load, as a pre-stage of fluid mud, stands between the law of Newton (100% classical fluid) and the law of Hooke (classical soil mechanics) as shown in Figure 3. Fluid mud cannot be rated as a liquid nor can it be classed as soil; it represents a medium, consisting of a fluid (represented by the damper in the Maxwell model) and of an elastic mud (spring in the Maxwell model). The yield point that has to be overcome is described by the energy in a spring (elastic part) while the attached damper model describes the following Newtonian behaviour (viscous part). Therefore fluid mud represents a viscoelastic material.

To get an estimation for a yield curve for the Emden fluid-mud, yield curves with increasing concentration were generated in long test series carried out with a rheometer. The results are shown in Figure 4 [8]. This approach resembles the Herschel-Bulkley curve power approach after Ostwald-de Waele (Figure 3) [10]. Tests carried out by Dasch [9] with kaoline suspensions and Thomas [10] with limestone as well as Migniot [2] with reservoir sediments gave similar results. Unlike Bingham fluids, these are curves with constantly changing viscosity. They are equivalent to the yield curves of Hyperconcentrated Benthic Layers (HBL) formations [5]. The gradient of the Herschel-Bulkley curve is referred to as the apparent viscosity in the respective points; it changes with each new velocity gradient.

Long-term test series prove how the Herschel-Bulkley curve diverges from the traditional Bingham behaviour.
chosen to define the nautical bottom; assessing the depth using viscosities was eliminated, because viscosity is subject to permanent change under increasing shear rates. This apparent viscosity therefore can never be a parameter for determination of a nautical depth.

Also the parameter density is only a static dimension anyway, that cannot be taken into consideration as a parameter for ship movement. Accordingly, it is not suitable to determine the resistance against a moving ship. Measurements have shown that the critical density of 1.2 t/m$^3$ defined by PIANC is exceeded considerably in most cases. The density dimension in the Port of Rotterdam is similar (Figure 5); they are closer to 1.3 t/m$^3$ than to 1.2 t/m$^3$.

**Thixotropy**

By definition, a thixotropic substance must not only fluidise depending on the shear duration, it must also regain its firmness after a rest period typical for that substance. Examples for thixotropic substances are paints, cosmetics, pastes and fluid mud. Figure 6 proves the typical thixotropical behaviour of a fluid-mud sample: The yield point of the upward curve is at 17.54 Pa with a maximum viscosity at approx. 1600 Pa*s. The downward curve, however, shows a viscosity of only 80 Pa*s. A new upward curve would reach even less yield and viscosity values. Apart from the shear thinning, it is also the thixotropical behaviour that significantly facilitates the treatment of substances. The fact that the downward curve does not end at the origin of the upward curve demonstrates the decrease of viscosity.

Owing to this decrease of viscosity over time, less effort is needed for, e.g. pumping or traversing through the substance, than would be required for the first “force attack”. This explains the phenomenon that is known amongst practitioners that fluid-mud formations can be transported in a pipe over greater distances than clear water with relatively little effort. This is because the mud is homogenous and flows under strictly laminar conditions. This again is influenced by the slime resulting from to the high organic content accounting for the low inner friction.

Shear thinning and thixotropy are completely different rheological properties that must not be confused. Classic fluid mud has both of these rheological properties, as in all other shear thinning substances the viscosity values decrease with increasing shear rates. Contrary to these, the viscosity of shear thickening substances increases with rising shear rates. Examples for these substances are, e.g. sand-water mixtures such as current ripples with an extremely high sand content. Their shear behaviour in the rheometrical experiment shows that the viscosity rises significantly
with increasing velocity gradient. Formations of this kind are therefore real obstructions for ship movement that have to be removed. In contrast, the density currents, as long as they have a high-suspended load, as in the case of fluid mud, belong clearly to the visco-elastic fluids.

Preserving a high grade of organic content within a fluid-mud layer demonstrates the following advantages when minimising dredging effort:

1. The more thixotropic properties increase the higher the organic content in the fluid mud.
2. In the region of low velocity gradients (where dredging takes place) the flow process does not behave like a Bingham fluid, instead it is like a Herschel-Bulkley fluid with highly variable viscosity.
3. A high organic content results in a lower yield point. The yield point of an anorganic sample with a concentration of 4.0 mass-% is at about 1000 Pa, whereas the yield point of an organic sample with the same concentration lies only at about 30 Pa [8].
4. Thus a high organic content also leads to a lower viscosity: When using the same samples the viscosity \( \eta \) decreases from 0.3 kPa*s (anorganic) to 0.08 kPa*s (organic) [8].

**Controlling the Nautical Depth**

Depth survey in Emden is done with 210 kHz and 15 kHz parallel. For port operations the 15 kHz echo is therefore still the most important frequency, but it too does not accurately describe the existence of the nautical bottom. The 33 kHz echo is definitely not suitable as it lies “on the safe side” compared to the 15 kHz echo; the difference between these two frequencies in the Outer Harbour in Emden is about 0.4 m, which causes 20% higher costs.

Long-lasting test series gave a correspondence between the 15 kHz echo and the yield point at 70 Pa, which defines the nautical bottom in Emden. As a result of still very low yield points, the navigability was increased to 100 Pa to be measured with 12 kHz only, as from 2005.

A different measuring technique called rheometry has to be applied when handling rheological parameters for determining the nautical depth:

1. Shearing is only allowed when conditions are laminar.
2. The examined substance should be from homogenous substance. In this connection it is worth mentioning that, when judging the navigability, it is not necessary for the sample to be undisturbed. Results from long test series with disturbed and undisturbed samples taken from the fluid-mud layer have shown that the difference is about 5%, which is negligible.

These two basic conditions are applicable for fluid mud.

**The Yield/Stress Curve**

Important for the navigability is solely the resistance that is put up against the ship’s movement. The resistance of “muddy” sediment is generally shear stress dependant. It shows variable viscosities and cannot be determined with a “static” material property such as density. For this reason the shear strength of dredged sediment has to be determined rheometrically in order to distinguish between non-navigable mud and fluid mud which can still be navigable.

An example for the evaluation principle of such a yield curve for fluid mud from the Emden Harbour is explained in Figure 7: The blue curve shows the shear stress depending on the different shear rates. The red viscosity curve is the first derivation of the blue curve and shows its variable viscosity values. The viscosity reaches is maximum of 1400 Pa*s already at a shear stress value of 11 Pa. Starting from this point the viscosity decreases, i.e. it liquefies.

If the well-known PIANC threshold of 1.2 t/m³ were applied for this sample, it would not pass this criterion for navigability.

Up to now about 90% of the samples taken from the Harbour of Emden to check navigability have had densities of more than 1.22 t/m³ and yield points that were under 30 Pa. The dredging method that is applied here has clearly confirmed that the material is navigable up to a yield point of 70 Pa [12]. After further test series, the yield point was raised to 100 Pa in 2005.

Measuring methods, like tuning fork systems that use constant respectively fixed viscosity values, do not give clear values and therefore make it difficult to assess the navigability, because the viscosity according to the Herschel-Bulkley curve remains variable and has its maximum around the yield point at very low shear rates [11].

**The Creep/Recovery Test**

The creep test is a quick and simple method to make statements about the visco-elastic properties. This test differentiates exactly between the viscous and elastic fraction of the substance. When shear stress is applied to fluid mud it shows properties of elastic as well as viscous deformation (Figure 8). Retraction takes place around the elastic fraction. The viscous deformation \( \gamma_v \) remains.

This difference is very important when judging a dredging strategy: The \( \gamma_v \)-fraction – the viscous fraction of retraction – gives important information about the percentage of a Newtonian fluid in a fluid-mud layer. This fraction does not have to be dredged and removed. The elastic fraction \( \gamma_e \), as can be seen in the creep/
recovery graph, is the fraction of retraction that can build up a resistance when it comes into contact with a ship. The Newtonian fraction in the Maxwell model (damper fraction) (Figure 3) remains irreversibly shifted after load, i.e. it does not retract. Retraction is only caused by the energy fraction in the spring load and this fraction only has to be dredged or conditioned or removed.

Just like the null-viscosity this dimension is a material property and expresses the yield property of a substance. The higher the rate of yield is the more fluid mud can be deformed under a certain load. The creep test is therefore a simple and quick method to get statements about the visco-elastic properties, split up exactly into viscous (water) and elastic fractions (fluid mud) by percentage.

In practice "conditioning" the elastic fraction of the layer – the percentage has been determined graphically – by applying a special dredging technique that will be explained later has proven successful. Since the beginning of consequent evaluation of these measurements the running time of the hopper suction dredger was reduced from 2000 hours/year (1998) to 900 hours/year (2004). In the same period the ratio between the "treated" mass in the hold of the dredge and the in situ mass has also reduced from 3.49 (1998) to 1.44 (2004).

**Dredging Technique**

The present dredging contract was awarded first in 1988 and extended step by step after negotiation up to end of June 2008 as a flat-rate with wage and material rise-and-fall clause. The following equipment is on site:

- 1 hopper dredger with a hold of 1150 m³;
- 1 cutter-suction dredger with 1400 hp pump capacity;
- 1 bed leveller.

At the beginning of the in-1990-developed dredging strategy the cutter-suction dredger had 90% of the work of flushing onto land while the remaining 10% was done by the self-propelled hopper dredger that brought the sediment to the cutter-suction dredger. The bed leveller was used in corners of the harbour that are inaccessible for the larger machines.

Meanwhile until 2004 90% of dredging was carried out by the hopper dredger and from 2002 until July 2003 it was 100%; since 2002 no sediment has been flushed onto the fields of Wybelsum. This complies with the aim of a 100% in situ conditioning of sediment without deposition on land.

In the past 15 years numerous modifications were carried out on the hopper dredger. Especially beneficial was the installation of an underwater pump fitted onto the suction head. This has the advantage that the pump is directly loaded with the water column above and not with a water/fluid mud mixture as is the case with inboard pumps mounted at the water line.

With the underwater pump and degassing methane gas, it is possible to reach a higher density in the hopper than the density at the suction head.

Figure 9 shows how three different extraction methods can be implemented with such a mechanical concept:

- The hold is filled from the bottom with fluid mud (line 0). The underwater pump presses the mixture into the ship at the bottom of the hold; the overflow takes place over the upper edge of the hold. The mixture circulates back through a closed piping system and exits just above the suction head.
- Ultrasonic measurements have shown that ventilated and re-circulated formations remain in suspension above the suction head [11]; the in situ density is thus reduced. This method causes no turbidity.
- The sediment is pumped to the surface of the sediment in the hold; this material is disposed via a transom latch over the whole length of the hold.
The method (3) is not used in Emden as the sand content is almost zero. Methods (1) and (2) are regularly used to bring the sediment in contact with air and to improve its aerobic condition and therefore its organic content before it is put back on the bottom. Fluid mud that is collected in an area of 5 to 6 m\(^2\) around the suction head is distributed over an area of 600 m\(^2\) on the surface of the hold and brought into contact with air. Oxygen consumption has not been observed by this method; methane gas was not detectable and by constantly "conditioning" respective harbour areas the fluid mud is kept as a bacterial culture friendly environment. Different tests have shown also that consolidated, not-navigable mud with 8 to 10% gas content can be made navigable with simple a re-circulation process by reducing the gas content to less than 3%.

In a "normal" sedimentation process the deeper layers are quickly cut off from the oxygen supply in the water. Larger quantities of organic material in the mud can...
only be broken down partially by bacteria; biogas is produced. Reduced ferrous, manganese or sulphuric compounds give the mud a black colouring. The treatment method that is put into practice in Emden supplies the deeper layers with oxygen in regular intervals with the following positive effect on the water quality:

- Prevention of biogas; no oxygen deficit in the bottom water layers.
- Complete reduction (mineralisation) of all organic nutrients.
- Increased reduction of organic pollutants, e.g. hydrocarbon (remains of diesel fuel) and TBT.

The permanent lack of nutrients (owing to ideal conditions) leads to increased excretion of slime as well as bonding iron and manganese hydroxides, all of which have a high volume and low density. This gives a higher buoyancy.

This dredging method complies with all known environmental demands. It must not be confused with harrowing or water injection dredging. The latter works by injecting jet water into the bottom that generates a mixture which, provided there is a sufficient slope, induces a density current that moves down the slope.

In Emden no jet water is used, and thus no density current generated because a density current is not possible towards the Emn as the harbour is much deeper than the Ems. A full scale test with an injection dredge that was carried out in 1993 confirmed this: A light outward flow of suspended load towards the Ems was registered in the upper third of the water column, but at the bottom a brisk inward current of water with a high sediment load was generated, because the water injection reduced the density at the bottom.

The fluid-mud bodies in the Outer Harbours are 418 000 m$^3$ and 192 300 m$^3$, i.e. there is constantly a total of 610 300 m$^3$ of detectable fluid mud that varies by about ± 5000 m$^3$ with the tide whether or not the dredger is in action in the Outer Harbour. The total volume roughly remains constant independent of tidal variation, different river discharge, dredging activity on the Ems or opening or closing the Ems Barrier [15].

In the BMBF (German Ministry of Education and Research) project 03 KIS 019 the turbidity and current conditions between the Ems and the Harbour of Emden were investigated by the Institut für Wasserbau (IWA) of the University of Applied Sciences Bremen [14]. The results from the 10/06/2002 and 04/11/2002 will be taken as examples.

The flood measurements from the 10/06/2002 show the remarkable effect of outward current reaching as far as the Ems fairway in lesser depths while simultaneously there is an inward current in higher depths (Figure 10). During the ebb tide on the 04/11/2002 there is an inward current on the surface and an outward current on the bottom (Figure 11).

During this field campaign ADCP measurements were carried out on several days. The high-suspended load found in the Ems raise problems when measuring with high frequencies (600 kHz). Yet it was possible to verify the density currents into and out of the harbour even during high river discharge periods.

The distinct density effect in the Harbour of Emden around low water is documented in [14]. The density eddy has a clear horizontal axis and it is superimposed on the clockwise ebb current eddy with a vertical axis. Both effects raise the water exchange rate between harbour and Ems.

The reversed effect during flood tide was also recorded. The currents on the bottom are amplified by the incoming salt water from the Ems. Consequently the less salty water is transported out of the harbour in the upper water layers. ADCP measurements have shown that during various neap and spring tides on the 30/10/2002 and 05/11/2002 as well as 04/11/2002 both the in- and outward currents are approximately equal. The fluid-mud layer in the Port of Emden therefore remains in a 100% equilibrrial status.

For the interpretation of the results it is irrelevant whether the hopper dredger was in action in the Outer Harbour or not. There is no sign of a continuous backflow of sediment from the Outer Harbour into the Ems.

**Practicability in Other Harbours**

The question of whether the technique developed in Emden can be adapted for other harbours with a higher sand content has triggered off a series of tests in which rheological profiles for different sand contents and grain sizes were compiled. The results are widely scattered, depending not only on the sand content, but even more on the grain size. It is however certain that if medium sand is added to pure fluid mud this mixture reacts shear thickening at an earlier stage of the shearing process, i.e. the shear stress increases with increasing velocity gradient. The measuring instrument fails with larger grain sizes because of the slit between the viscosimeter and rotation piston. From literature [2] it can be taken that shear thinning and thixotropical properties can be found up to a sand content of 30%.

The grain diameter of the sand was uniformly 250 µm and it became apparent that although the density increased the yield point remained almost unchanged up to a sand content of 30% and decreases the higher the sand content. This is a reasonable result as the silt content, which is the cause for the viscous behaviour, is very low. Measurements made in the Mississippi
Harbour in Rotterdam gave similar results. However, compared to the results from Migniot [2] they were lower by a factor of 5. The reason could be that the sand in the Mississippi Harbour is much finer than in [2].

According to the author’s experience these results are of little practical use. The grain sizes of the sand fractions found in dredged sediment from the most estuaries cover a wider spectrum which makes it difficult to make statements about the rheological parameters. Practical experience has shown that a sand content of up to 10% with grain sizes between 60 and 200 µm can be accepted without worry. With higher sand contents it is recommended to filter the sand with the dredging method described above (line 3 in Figure 9) before bringing it back to the bottom.

The organic content is significantly lower when there is a higher sand content. This degrades the rheological properties, i.e. the yield point and the viscosity go up. Also the higher sand content is responsible for a significant derivation from the Herschel-Bulkley curve in the region of low shear rates. The dredging method used in Emden can very well be used in other harbours as seen in Figure 12 where the results of 103 mud samples are shown. The viscosity bandwidth is relatively low, but this is because these are the values “after” having reached the maximum viscosity (Figure 7). However, the tendency is more than clear. The yield values from 50 to 90 Pa are from Central America / Guyana (approx. 60 Pa) and Indonesia (70 to 100 Pa). The maximum sand content of these samples was 10%. The middle group contains results from IJmuiden, Vlissingen, Delfzijl, from the Ems and from different harbours along the Schelde (30 to 60 Pa). The results from Bristol, Liverpool, Rotterdam, Brunsbüttel, Harwich, Leer and Emden are scattered between 5 and 30 Pa. Especially in this zone of low yield points the values are close together [10].

The Emden method is applicable in the latter harbours and, depending on the “treatment” technique (Figure 9), also in all of the other harbours with a sand content of less than 10% in the mud. As soon sand content exceeds 10% extraction of this sand before conditioning of the remaining fluid mud is recommended (see line 3 in Figure 9).

Results and Outlook

Significant improvements were attained with this new dredging method. Judging the navigability with rheological parameters has finally led to the decision to leave the fluid mud in situ and to keep it navigable by “conditioning” it regularly.

Since 1989 The NHED has spent a total of about 400 000 Euro for hard- and software, which is relatively little compared to expensive civil works, e.g. CDW-constructions, for changing the current direction in the entrance of the Emden Harbour. It is also notable that the dredging method developed in Emden has fulfilled all the ecological demands up to this day.

Technically speaking the dredging technique in Emden should not to be regarded as injection dredging, as the fluid mud sinks to the harbour bottom by gravity rather than being pumped. Likewise this method must not be confused with harrowing. Furthermore this method has no negative consequences on the oxygen content. An oft-raised question as to whether the sediment flows back into the Ems was clarified by extensive investigations carried out by the University of Applied Sciences Bremen, Institut fuer Wasserbau [14, 15]. The constant fluid mud volume of 618 000 m$^3$ in the Outer Harbours clearly shows the existing balanced condition.

Conclusions

The following conclusions can be drawn from the past 15 years of experience with fluid mud in the Harbour of Emden:

1. Exploiting the local specific equilibrium reduces the amount of dredged sediment.
2. The use of rheological parameters allows for selective dredging.
3. Common soundings with 12- 5 kHz come closest to nautical bottom defined with rheological parameters.
4. Soundings with 210 kHz are not suitable.
5. Soundings with 33 kHz are not suitable, as they would result in a much higher dredging effort.
6. The yield point is at 70 Pa that will be increased to 100 Pa.
7. Payment is lump-sum with incentive, not on a m$^3$ basis.
8. The method of treatment keeps the mud layer in a good ecological condition.
9. The good quality of the harbour water is ensured.
An optimal cost minimisation has been reached: 90% of the cost are hire charges for the dredging equipment. The remaining 10% are costs for labour, material and survey boat. The annual costs have decreased from €13.5 mio in 1988 down to €1.2 mio in 2004.

Still more effort has to be put into further minimisation (minimisation bid):

1. Taking bed samples and determining the rheological parameters in the laboratory is time consuming; a wide-area ultrasonic investigation of sediments with lines of equal yields (Isoyields) has given some promising results [11]. This will be reported in due course.

2. The aim is to reduce the present “treatment factor” between in-situ volume and hopper volume of 1.44 even more in the future with increased selective dredging.

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Structure of thixothropic suspensions in shear flow: I. Mechanical properties.

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Omgaan met vloeibare sliblagen in de haven van Emden ter vermindering van de hoeveelheid baggerwerk; Lecture held at Rijkswaterstaat, Rijksinstituut voor Kust en Zee, Den Haag (unpublished).

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In Situ Messungen in Brackwasserhäfen: Vorabzug aus dem BMBF- Forschungsvorhaben 03KIS020: Sedimentation in brackwasserbeeinflussten Vorhafen, unpublished.

Monitoring zum Neubau der Empier -Erstbaggerung- Untersuchungen im Auftrage des Niedersächsischen Hafenamtes Ems Dollar, unpublished.


Entlandung von Stauräumen; 1. Entwurf, Stand 15.05.2003

Transport characteristics of suspensions, laminar flow properties of flocculated suspensions. American Institute of Chemical Engineers.
As a historical perspective of the importance of inland waterways and their role in the growth of a nation, this book is exceptional. Covering the history of America’s first transportation network, the book describes the heyday of American canals, their development, and the varied structures they engendered. This includes locks, lock houses, aqueducts, bridges, dams and tunnels as well as the engineering and construction of these structures, life on and alongside the waterways, and the equipment involved in the operations. For those wishing to explore canals today and for professionals engaged in the preservation and rehabilitation of canals, this is a fascinating source of information.

The book is the product of an ambitious project of the Center for Architectural, Design and Engineering of the United States Library of Congress. The Center’s mission is to support the preservation of the Library’s enormously rich collections in the subject areas. Profusely illustrated, the book is drawn from the collections of the nation’s oldest federal cultural institution and one of the largest libraries in the world.

The introduction presents an overview of the development and types of inland waterway routes that served to define the nature and growth of the United States and its people. The period covered is the classical era of American canals extending from 1785-1860 and includes a concise tour of more than three dozen canals that by 1835 made up the over 2,500 miles of canals throughout the United States, stretching from New England to the South and from the East Coast to the Midwest. It provides a visual journey along the two most famous canals, the Morris Canal (largely lost to development) and the Chesapeake and Ohio which is now a national park worthy of a visit.

Over 800 illustrations are found throughout, with all them also available as screen resolution TIFF format images on the included CD-ROM which can be viewed by PC and MacIntosh operating systems. Each of the figures in the book are captioned identifying subject, location, date, creator’s of the image and the Library of Congress call numbers, which can be used to find the images online. The link to the Library of Congress and its searchable catalogues and image files is found on the CD.

In terms of typography, images and binding the book is outstanding. It is divided into the introduction, four chapters and four appendices. The table of contents is of use to the reader in appreciating the subject categories:

- Introduction: American Canals
- Canals Across America
- Canal Structures
- Morris Canal
- Chesapeake & Ohio Canal
- Bibliography, Glossary, Index, About the CD-ROM

Continued on page 36
Seminars/Conferences/Events

WEDA XXV and TAMU 37
Astor Crown Plaza Hotel, New Orleans, Louisiana, USA
June 19-22, 2005

The twenty-fifth Western Dredging Association (WEDA XXV Annual Conference and membership meeting) and the Thirty-seventh Texas A&M Dredging Seminar (TAMU 37) will be held in New Orleans, Louisiana in the French Quarters. Technical sessions will be presented June 20-22, 2005. The theme for the conference is “Dredging for Sustainability”, and will be a unique forum for discussion amongst dredging contractors, port authorities, government agencies, environmentalists, consultants, academicians, and civil and marine engineers who work in the fields of dredging, navigation, habitat restoration, environmental remediation, and marine engineering and construction.

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e-mail: r-randall@tamu.edu

International Conference on Port-Maritime Development and Innovation
World Trade Center, Rotterdam, The Netherlands September 5-7 2005

The conference is the first jointly organised by the Maritime and Port Authority of Singapore and the Port of Rotterdam. It is a follow up on the conferences Port and Maritime R&D and Technology held in Singapore in 2001 and 2003. The objective is “to stimulate innovation in port and maritime management, operations and development through the presentation and exchange of the results of applied research and technologies”.

Themes include Port Planning and Design, Port and Marine Environment, Port Related Maritime Operations, Port Security and Port Related Transport, Handling and Logistics. The conference is aimed at port authorities, government agencies, the shipping community, port consultants and contractors, and academic and research institutions. A pre-registration form can be found on www.portofrotterdam.com.

For further information contact:
Port of Rotterdam, Mrs Deibel
PO Box 6622, 3002 Rotterdam, The Netherlands
tel. +31 10 252 1311, fax +31 10 252 1020
e-mail: secretary-tc@portofrotterdam.com

Offshore Europe 2005
Exhibition and Conference Centre
Aberdeen, Scotland September 6-9 2005

OE 2005, the oil and gas exhibition and conference, is one of the most innovative oil and gas events on the industry calendar. The conference theme is “Managing Mature Production: A Global Challenge”, with the Chairman and CEO of Schlumberger, Andrew Gould, as Chairman.

A new development at Offshore Europe 2003 was the hugely successful launch of the Real Time Zone. The RTZ was a ‘show within a show’ dedicated to the technologies that facilitate the continued march towards the web-enabled Digital Oilfield. For 2005, the RTZ has been re-branded as the Digital Energy Zone and looks set to give exhibition and conference goers a chance to immerse themselves in an online showcase for the next generation oil field.

For further information contact:
Noel Armstrong
Spearhead Exhibitions
tel: +44 (0)20 8439 8855
e-mail: noel.armstrong@spearhead.co.uk
www.oe2005.co.uk
Enquiries on the exhibition can be addressed to:
PDA Trade Fairs, tel: +91 80 2554 7434,
fax : +91 80 2554 2258,
email: pdaexpo@vsnl.com
Visit the CEDA website (www.dredging.org) for updates.

Europort 2005

Ahoy’ Conference Centre
Rotterdam, The Netherlands
November 1-5 2005

Owing to changing market conditions, the organisers of Europort (Amsterdam RAI) and Rotterdam Maritime (Ahoy’ exhibition, congress event management) have decided to merge these two international maritime trade exhibitions. The combined Europort and Rotterdam Maritime trade exhibition for the inland shipping, short sea shipping, ocean shipping, fishing, dredging and port equipment industries will be held for the first time in November 2005 in Ahoy’ Rotterdam and thereafter in odd years.

It will also feature the Marine Equipment Trade Show (METS) as well as various maritime trade association meetings including CEDA Dredging Days. Europort, which takes place every two years, is one of the premier events for all aspects of the maritime industry both nationally and internationally.

For further information contact:
Amsterdam RAI, PO Box 7777
NL-1070 MS Amsterdam, The Netherlands
tel. +31 20 549 1212, fax +31 20 644 5059
www.europort2005.com

CEDA Dredging Days 2005

Ahoy’ Conference Centre
Rotterdam, The Netherlands
November 2-4 2005

The theme of this year’s CEDA Dredging Days is "Dredging: The Extremes" and will look at how the industry responds to extreme requirements, whether physical or regulatory, and how it produces extraordinary results in creating new land, valuable habitats and in dredging to allow ports to accommodate ever larger ships. The new challenges that our society presents to the dredging industry forces the industry to look for novel, innovative approaches in equipment and techniques. Please note that as a result of the enthusiasm and quality of the response to the Call for Papers, the conference has been extended to two and half days, beginning with the technical visit taking place on Wednesday afternoon, November 2nd.

The IADC will present its award to the best paper of the conference by an author under 35 years of age. The prize includes a monetary reward as well as publication in
Call for Papers

Second Port & Terminal Technology 2005

Hamburg, Germany
October 25-26 2005

The second Port & Terminal Technology 2005 Conference & Exhibition is being planned for October 2005 in Germany. The event provides an international forum for discussion for Port Authorities, Terminal Operators, Consulting Engineers, Government Bodies, Software companies, Consultants, Universities, Laboratories, companies involved in Port Construction & Dredging and manufacturers and suppliers of cargo handling equipment.

Suggested topics include: Increasing capacity, Port operations, Fender systems, Terminal security, Breakwater design, Ports & the environment, Maintenance, Quay design, Dredging, Port planning, New technology in cargo equipment, Simulation, Port & terminal automation, Terminal design, and Impact of large ships on port infrastructure.

Interested authors should send a brief abstract to the organisers MCI as soon as possible. Technical papers will be reviewed and selected on the basis of technical quality, relevance and their potential to generate discussion. The work reported in the papers must be original and should not have been published or offered for publication elsewhere. Purely promotional text will not be accepted.

For further information and registration contact: Millennium Conferences International Ltd, Chantry House, 156 Bath Road, Maidenhead, Berkshire SL6 4LB, United Kingdom tel: +44 1628 580 246, fax: +44 1628 580 346 email: PTT2005@millenniumconferences.com www.millenniumconferences.com

Books/Periodicals Reviewed

Continued from page 33

Certainly, this book should be of interest to historians and engineers and it gives an appreciation of the importance of engineering and water transportation in the growth and development of the United States. There are some clear parallels to the waterway systems elsewhere in the world, but few can compare to the sheer length, breadth and scope of the system and their impact on so many aspect of national history. The thesis underscores the importance of waterway transportation, and the multitude of activities required to design, construct, operate and maintain complex waterway systems.

It leaves the reader wanting to get more information about other volumes in this series, entitled, Norton/Library of Congress Visual Sourcebooks in Architecture, Design & Engineering. The author, Robert J. Kapsch was the chief of the Historic American Buildings Survey/Historic American Engineering Record for fifteen years. He is currently the U.S. National Park Service senior scholar in historic architecture and historic engineering.

The book may be ordered directly from the publisher: W. W. Norton & Company, Inc. 500 Fifth Avenue New York, New York 10110 USA or W. W. Norton & Company Ltd., Castle House 71/76 Wells Street London, WIT 3QT, United Kingdom, or Online at: http://www.wwnorton.com/npb/rnparch/730883.html

IDR 2005 Directory of Dredge Owners & Operators; Dredging Industry Buyer’s Guide


The new annual updated directory from IDR is now available. It contains information on over 1000 dredge owners and suppliers and includes specifications on over 2000 individual dredges. The Buyer’s Guide is divided into 94 equipment and categories. The print edition is sorted by country, state and company name. The online and CD editions can be searched by company, location, name of dredge, type of dredge, size, horsepower and manufacturer. A free preview can be seen online by visiting www.dredgemag.com/dir. It can also be ordered from IDR emailing: editor@dredgemag.com, or phone: +1 970 568 0833.

Terra et Aqua. A special Academic Hour will be featured for young professionals and university students.

For the first time Dredging Days will include a small dredging exhibition adjacent to the technical session room. Space is limited and will be assigned on a first come first served basis. The conference will be held in conjunction with the Europort Maritime exhibition (November 1-5 2005, see above).

For further information contact: Anna Csiti, CEDA Secretariat tel. +31 15 268 2575, fax +31 15 268 2576 email: ceda@dredging.org or www.dredging.org

Certainly, this book should be of interest to historians and engineers and it gives an appreciation of the importance of engineering and water transportation in the growth and development of the United States. There are some clear parallels to the waterway systems elsewhere in the world, but few can compare to the sheer length, breadth and scope of the system and their impact on so many aspect of national history. The thesis underscores the importance of waterway transportation, and the multitude of activities required to design, construct, operate and maintain complex waterway systems.

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Through their regional branches or through representatives, members of IADC operate directly at all locations worldwide.

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- Van Oord Nigeria Ltd, Ikeja-Lagos, Nigeria

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- Ballast Ham Dredging do Brasil Ltda, Rio de Janeiro, Brazil
- Dragmex SA de CV, Coatzaacoalcos, Mexico
- Van Oord ACZ bv, Buenos Aires, Argentina
- Van Oord CuraVao nv, Willemsstad, CuraVao

**Asia**
- Ballast Ham Dredging India Private Ltd., Mumbai, India
- Ballast Ham Dredging bv Singapore Branche, Singapore
- Ballast Ham Dredging Philippines Branch, Manilla, Philippines
- BHD Korea office, Busan, Republic of Korea
- Dredging International Asia Pacific (Pte) Ltd, Singapore
- Far East Dredging Ltd. Hong Kong, China
- Hyundai Engineering & Construction Co. Ltd., Seoul, Korea
- Jan De Nul (Singapore) Pte. Ltd., Singapore
- Penta-Ocean, Tokyo, Japan
- Toa Corporation, Tokyo, Japan
- Van Oord ACZ Marine Contractors bv, Shanghai, China
- Van Oord Hong Kong Branch, Hong Kong, China
- Van Oord (Malaysia) Sdn Bhd, Selangor, Malaysia

**Australia**
- Dredeco Pty. Ltd., Brisbane, QLD, Australia
- Van Oord Australia Pty Ltd., Brisbane, QLD, Australia

**Middle East**
- Boskalis Westminster M.E. Ltd., Abu Dhabi, UAE
- Gulf Cobia (Limited Liability Company), Dubai, UAE
- Jan De Nul Dredging, Abu Dhabi, UAE
- Jan De Nul Dredging Ltd. (Dubai Branch), Dubai, UAE
- Van Oord ACZ Marine Contractors Gulf FZE, Dubai, UAE

**Europe**
- Aanemingsbedrijf L. Paans & Zonen bv, Gorinchem, Netherlands
- Atlantique Dragage S.A., Nanterre, France
- Baggerwarenhandelijks Rotterdam B.V., Rotterdam, Netherlands
- Baltic Marine Contractors SIA, Riga, Latvia
- Boskalis B.V., Rotterdam, Netherlands
- Boskalis International B.V., Papendrecht, Netherlands
- Boskalis Westminster Dredging & Contracting Ltd., Cyprus
- Brewhaha Wasserbaugesellschaft Bremen mbH, Bremen, Germany
- C.E.I. Construct nv, Zele, Belgium
- DRACE, Madrid, Spain
- Dravo S.A. – Italia, Amelia (TR), Italy
- Dravo S.A., Lisbon, Portugal
- Dravo S.A., Madrid, Spain
- Dredging International N.V., Zwijndrecht, Belgium
- Dredging International (UK) Ltd., Weybridge, UK
- Heinrich Hirdes G.m.b.H., Hamburg, Germany
- Jan De Nul Dredging nv, Aalst, Belgium
- Jan De Nul nv, Aalst, Belgium
- Jan De Nul (U.K.) Ltd, Ascot, UK
- Mijnzand- en grinthandel bv, Gorinchem, Netherlands
- N.V. Baggerwerken DeCloeidt & Zoon, Oostende, Belgium
- Sociedad Española de Dragados S.A., Madrid, Spain
- Sodranord SARL, Le Blanc-Mesnil Cédez, France
- Terramare Oy, Helsinki, Finland
- Tideway B.V., Breda, Netherlands
- TOA (LUX) S.A., Luxembourg, Luxembourg

Van Oord Ireland Ltd., Cork, Ireland
Van Oord Nederland bv, Gorinchem, Netherlands
Van Oord nv, Rotterdam, Netherlands
Van Oord Offshore bv, Gorinchem, Netherlands
Van Oord UK Ltd., Newbury, UK
Westminster Dredging Co. Ltd., Fareham, UK