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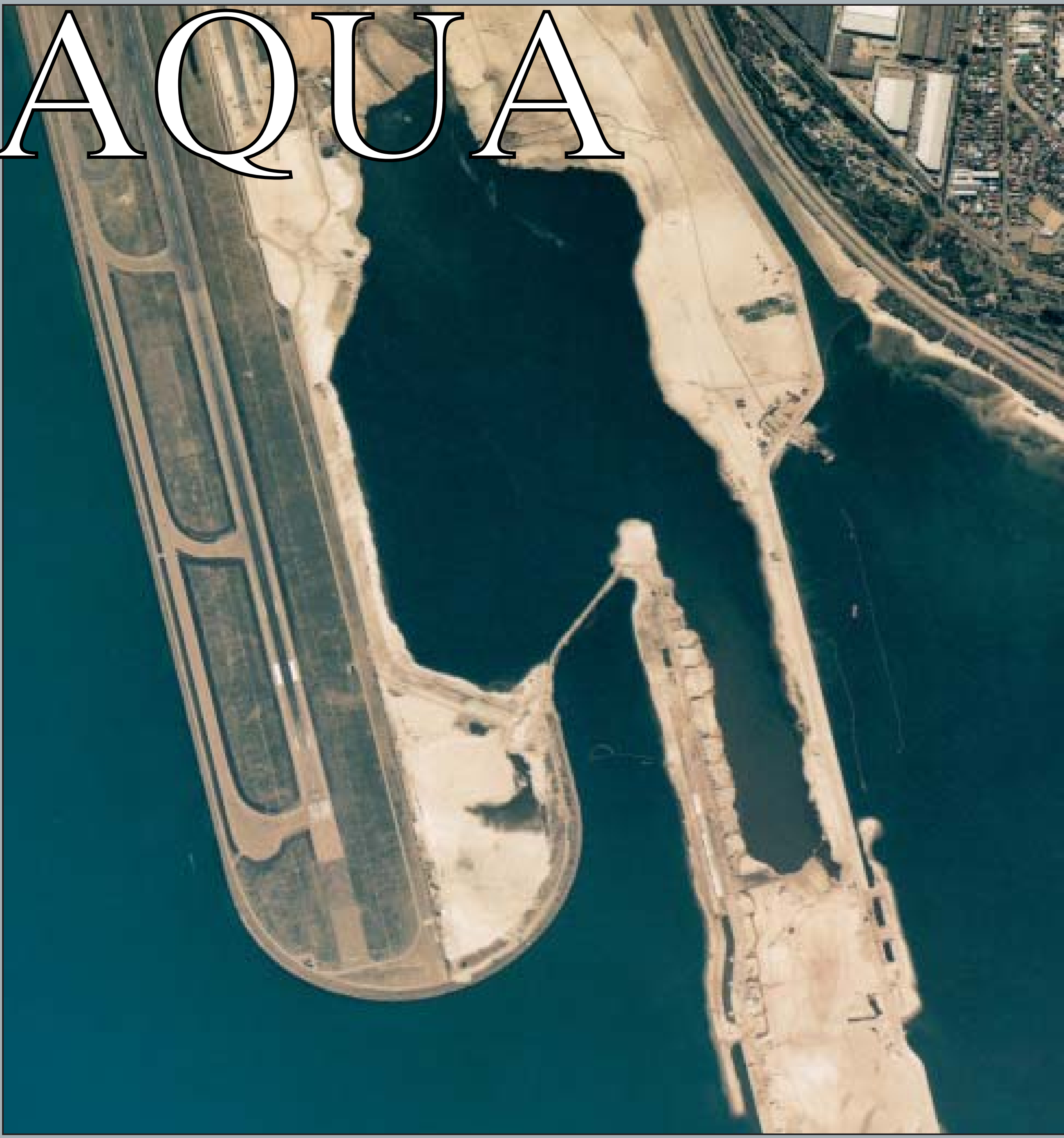

INTERNATIONAL ASSOCIATION OF DREDGING COMPANIES

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Front cover:
Dredging sand from Botany Bay (Australia) for use as bulk filling for Sydney Airport's new parallel runway proved to be environmentally sound and cost efficient as well. The choice of sand helped contractors finish the project six months ahead of the anticipated completion date. Pictured here, dredging activities in August 1993 (see page 12).

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International Association of Dredging Companies

CONTENTS

TERRA
ET AQUA

EDITORIAL

Continuing the trend of recent years, the beneficial uses of dredging and related environmental issues continue to be important focal points for the industry in 1996. The amount of research conducted which relates to environmentally sound processes continues to grow and this can be witnessed by the present issue of *Terra.* Two articles are reprinted from the XIV WODCON proceedings, *Dredging Benefits:* One on the new parallel runway at Australia's Sydney Airport, and the other by Vaclav Matousek which received the IADC Award for 1995, for the best paper presented at a conference by a younger author.

In addition, a scientific examination of the difficulties of dredging polluted matter is presented and sensible control options and measures are proposed.

The industry is clearly concerned with the environment and dredging in a responsible, beneficial manner. This is no where more evident than in the new database, "DEBBY", developed by a group of dredging organisations (IADC, IAPH, PIANC, CEDA, WEDA and EADA) to create a comprehensive bibliography of dredging literature, reports and data. Originally responding to a need identified by the London Convention of 1972, this new computer software, with updates, offers the public current, accurate otherwise difficult to obtain information. It is available through the IADC.

Though the dredging industry is highly competitive, and rightly so, it remains remarkable to see how well various agencies cooperate to the benefit of the industry as a whole. Coming up in 1996 are the first volumes in a series entitled Environmental Aspects of Dredging. This "joint venture" between IADC, CEDA and others will be a welcome addition to dredging literature. We will keep you posted as the books progress.

Marsha R. Cohen
Editor

Vaclav Matousek

Solids Transportation in a Long Pipeline Connected with a Dredge

Abstract

Extensive field measurements on a dredging installation with a pipeline that is approximately 10 km long and has three booster stations in series, have shown that, contrary to expectations, density fluctuations in slurry flow generated in a system inlet are not flattened. Whilst passing along the pipeline with pumps in series, they are transformed into long density waves with high amplitude.

This phenomenon is typical for dredging operations because it is effective only in long pipelines with slurry flow of continuously fluctuating density. Only on-line measurements at several measuring sites along the whole conveying system can detect the phenomenon. For this reason it has not been explicitly observed and analysed yet.

A mechanism for material aggregation and the development of an internal structure of slurry flow in a long pipeline are analysed under a condition of continuously fluctuating slurry density. Data are interpreted by using the physical two-layer model to verify factors arising from the analysis of a process of material aggregation. To enable a simulation of the phenomena observed in the slurry pipeline connected with a dredge, a recommendation for a physical model configuration is submitted.

The data interpretation issues are verified experimentally in a laboratory circuit. MeaVli data are published with permission of Royal Boskalis Westminster N.V. This paper was first published in the proceedings of the WODCON, *Dredging Benefits,* Volume 1, pp. 55-73. It is reprinted here with permission in a revised version which includes verification by laboratory tests.

Introduction

An unsteady state of solids flow has interesting effects on the internal structure of mixture flow in a long conveying pipeline. From these a process of material aggregation along a long pipeline and the behaviour of solid particles settled at the bottom of a pipeline are of a major interest. An aggregation process may have an influence on the efficiency and safety of the system

Winner of the IADC Award, Mr Vaclac Matousek, is pictured here (right) with Mr Peter Hamburger, Secretary General of the IADC, at the IADC booth at the Europort Exhibition which ran simultaneously with the World Dredging Congress.

IADC Award 1995

Presented during the XIVth World Dredging Congress and Exhibition, Amsterdam, The Netherlands November 14-17 1995

At the XIVth WODCON held in Amsterdam in November 1995, Mr Vaclav Matousek was presented the IADC Award by Dutch Minister of Transport Mrs. A. Jorritsma who officially opened the WODCON. Mr Matousek received his MSc from Czech Technical University in Prague in 1986. After working at the Czech Academy of Sciences, in 1992 he came to Delft University of Technology where he joined the Faculty of Mechanical Engineering and Maritime Technology as a PhD student in Dredging Technology.

Each year at a selected conference the IADC grants an award to a paper written by a young author. The Paper Committee of the conference is asked to recommend an author who must be under 35 years of age, and whose paper makes a significant contribution to the literature on dredging and related fields. The purpose of the award is “to stimulate the promotion of new ideas and encourage younger men and women in the dredging industry”. The IADC Award consists of US$ 1,000, a certificate of recognition and publication in *Terra et Aqua.*

operation. Prediction of the aggregation process together with an accurate estimate of the critical velocity in a pipeline may lead to a more effective control of the diesel engines and other types of drive used by the drive of a conveying system.

The phenomena characteristic for the development of an internal structure of unsteady solids flow in a long pipeline can be described and simulated in a simplified way by a physical model.

Nomenclature

c_v	local volumetric concentration at some position in pipe cross-section	[1]
C_{cod}	delivered volumetric concentration of solids in contact load	[1]
C_{vd}	delivered volumetric solids concentration in pipe cross-section	[1]
$C_{vp}(C_{vi})$	spatial volumetric solids concentration in pipe cross-section	[1]
C1	volumetric concentration of solids in upper layer	[1]
C2	volumetric concentration of solids in lower layer	[1]
d	particle diameter	[m]
d_s	mean particle diameter	[m]
d_{50}	mass-median particle diameter	[m]
D	internal diameter of a pipe	[m]
I_m	friction loss of slurry flow in a pipe	$[mH_2O/m']$
V_b	solids velocity at the bottom of a pipe	[m/s]
V_m	mean velocity of mixture	[m/s]
V_s	mean velocity of solids	[m/s]
V_s1	mean velocity of solids in upper layer	[m/s]
$V_s2(V_2)$	mean velocity of solids in lower layer	[m/s]
γ	vertical distance defining a position in pipe cross-section	[m]
Y_b	thickness of bed layer	[m]
α	angle defining a position in pipe cross-section	[deg]
ρ_m	density of mixture	$[kg/m^3]$

Abbreviations

DIM	Data Interpretation Model
DTI	Data Transfer and Interpretation
PSD	Particle Size Distribution
SRC	Saskatchewan Research Council
2LM	Two-Layer Model

Meavli Database: Field Measurements on a Long Conveying System

Field measurements on a long conveying system composed of the dredge *Groningen* (Figure 1) and a long slurry pipeline with three booster stations in series *(Zaandam, Jagersplas, Duinjager)* were carried out by the Department of the Technology of Soil Movement of Delft University of Technology and the dredging company Royal Boskalis Westminster N.V. during works on the project “de Vlietlanden”. A database collected in 1981 (rather huge with its almost 2 GB of information in a mainframe storage) has been named MeaVli (Measurements Vlietlanden) database. The purpose of the dredging project was to supply material, dredged from the bottom of the artificial lake Vlietlanden, to the construction of the new highway junction Prins Clausplein near The Hague. A fine to medium sand with a mean particle diameter varying approximately from 150 to 300 μm was conveyed in a long pipeline the major part of which was horizontal and of DN650. The system was fed by the deep-dredger *(Groningen,* Gr) and driven by one water-based *(Zaandam,* Za) and two land-based booster stations *(Jagersplas,* Ja; *Duinjager,* Du). During a twelve-day experimental programme a large set of data, containing measured data of pumps *(Groningen, Jagersplas* and *Duinjager)* and pipeline operational parameters, was collected.

This database is unique experimental material, monitoring the real processes in a full-scale long slurry pipeline with unsteady flow of sand-water mixture. It covers the time-continuous on-line observations of the most important parameters along the entire long conveying system during a dredging operation. The process of field measurements, the measurement techniques and an organisation of a collected database have been described elsewhere (Duizendstra, 1987a,b,c; Matousek, 1994; de Vries, 1981).

Two types of experimental measurements were carried out on a dredging installation and two types of data files were acquired during the field measurements:

- Data files (A): a time continuous on-line measurement of pumps and pipeline operational parameters of the entire system of a dredger, pipeline sections and three booster stations in series (acquired data files have 45 channels)
- Data files (B): a time continuous on-line measurement of solids velocity profiles in the pipeline cross section at one measuring place on the slurry pipeline; in conjunction with basic integral slurry flow parameters in the pipeline (acquired data files have 14 channels).

To evaluate the phenomena observed in a pipeline, both types of acquired data files have to be analysed. Data files (A) detect a phenomenon of a material aggregation in slurry flow when transported in a long pipeline. Data files (B) describe, in a simplified way, an internal structure of solids flow with slurry density fluctuations in the pipeline and they are the basis for an analysis of the phenomenon detected in data files (A). A relationship between the velocity of solid particles at the bottom of the pipeline and slurry density in the pipeline can also be correlated for approximately constant mean slurry velocity from data files (B).

PHENOMENA OBSERVED IN A LONG SLURRY PIPELINE

Two interesting phenomena were observed in the pipeline when MeaVli database had been processed:

- an aggregation of material into long density waves with a high amplitude within a slurry stream in a long pipeline (Figure 2);
- a variation in velocity of solid particles at the bottom of a pipeline as a result of fluctuating slurry density in a pipeline (Matousek, 1995c).

During dredging operations slurry density varies in time and space along the entire long pipeline of a conveying system. The controlled global operational parameters of the system (slurry flow rate through the conveying system, rpm of pumps) are assumed to be maintained at an approximately constant level during the whole operational period of the system. That was also the case during the field measurements of the MeaVli project.
A fluctuating density which enters the system and moves through the pipeline is detected at three measuring sites along the pipeline length by the radioactive density meters and interpreted as the moving density waves in the pipeline. A material aggregation phenomenon, which is observed along the long pipeline, is demonstrated by a transformation of density waves which are moving along the pipeline. From analysis of MeaVli pumps data (torque and rpm measurements at the Gr, Ja, Du pumps) the influence of a pump performance on density waves transformation has been observed to be negligible. An aggregation mechanism is active in the pipeline.
When unsteady solids flow in a long pipeline is modelled by means of basic hydrodynamic equations, including transport and turbulent dispersion effects (Basco, 1977), the fluctuating slurry density entering the system is assumed to be gradually flattened and become almost constant in time and space along the pipeline. This mechanism may be effective in a short time and length scale and may cause a flattening of short-time density fluctuations behind a dredge pump (compare Gr and Ja density signals of Figure 2). Over a longer time and length scale (more suitable for a description of the process in a pipeline which is more than 10 km long, in which each particle needs almost one hour to reach its destination from the bottom of a lake) a mechanism of slip between phases may be prevailing. With respect to the specific flow conditions in a long slurry pipeline connected with a dredge, it is believed that a process of material aggregation is caused by the variable slip in an unsteady solids flow along the long pipeline. It is a product of an instability of solids flow along the pipeline. More detailed analysis of the phenomenon has been published previously (Matousek, 1995a), so only a brief description is given here.

Figure 1. Suction dredger Groningen *at work.*

Slurry density, a major variable parameter of the transport system, produces an unsteady solids flow along the pipeline even when a slurry flow is considered steady. Stability of solids flow in steady slurry flow in a pipeline of constant pipeline diameter is characterised by constant mean solids velocity in pipeline cross section along the whole long pipeline.
Because a relationship between slip and slurry density is expected (different level of mutual particles hindrance), mean solids velocity varies in different pipeline cross-sections throughout the pipeline. This V_s variability along the pipeline causes a relative material transfer among moving density waves, which results in a transformation of density waves. To evaluate an aggregation mechanism the parameters characterising the mean slip in the pipeline cross section must be evaluated. These parameters are V_s and V_m or C_{vd} and C_{vp}. For MeaVli data processing this means a requirement to determine V_s from measured velocity profiles in a pipeline cross section for all flow conditions occurred. Then a ratio V_s / V_m, called slip ratio and considered as a parameter describing a mechanism of a material aggregation in slurry flow in a long pipeline, can be evaluated. To accomplish this, a physical model, described below, is used to process the MeaVli data.

According to particle size distribution (PSD) curves from slurry samples collected during MeaVli measurements the PSD of dredged material is rather wide. A transported material (of particle diameter d_{50} approximately 0.2 mm) contained a portion of sand coarser than 0.6 mm (approx. 10% of the total amount of a transported material) but also a silt finer than 0.075 mm (approx. 12% of a transported material). PSD together with a flow regime causes a certain degree of slurry flow stratification in the pipeline cross-section. The stratification has been observed in the MeaVli pipeline, as it is seen from a shape of measured solids velocity profiles (Figure 3).
The structure of a stratified flow in the pipeline matches the pattern of a physical two-layer model (2LM) developed originally by Wilson. Its physical background has been published (e.g. Wilson, 1988;

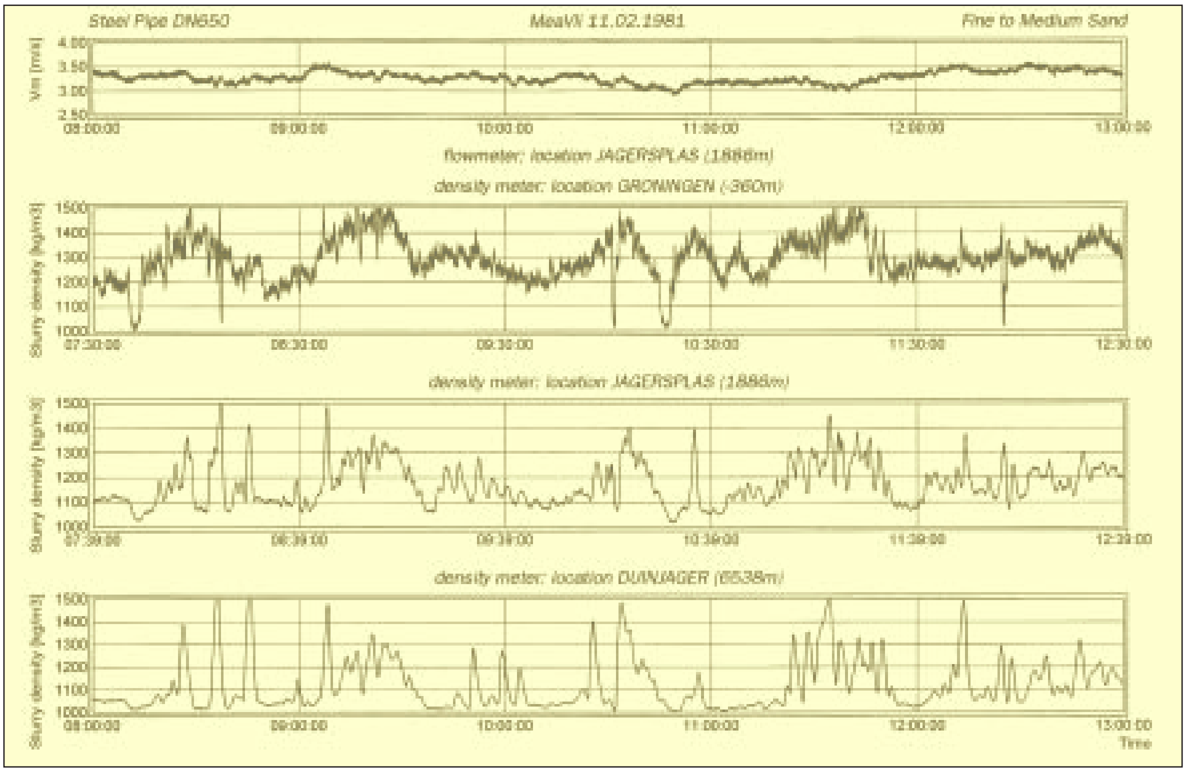


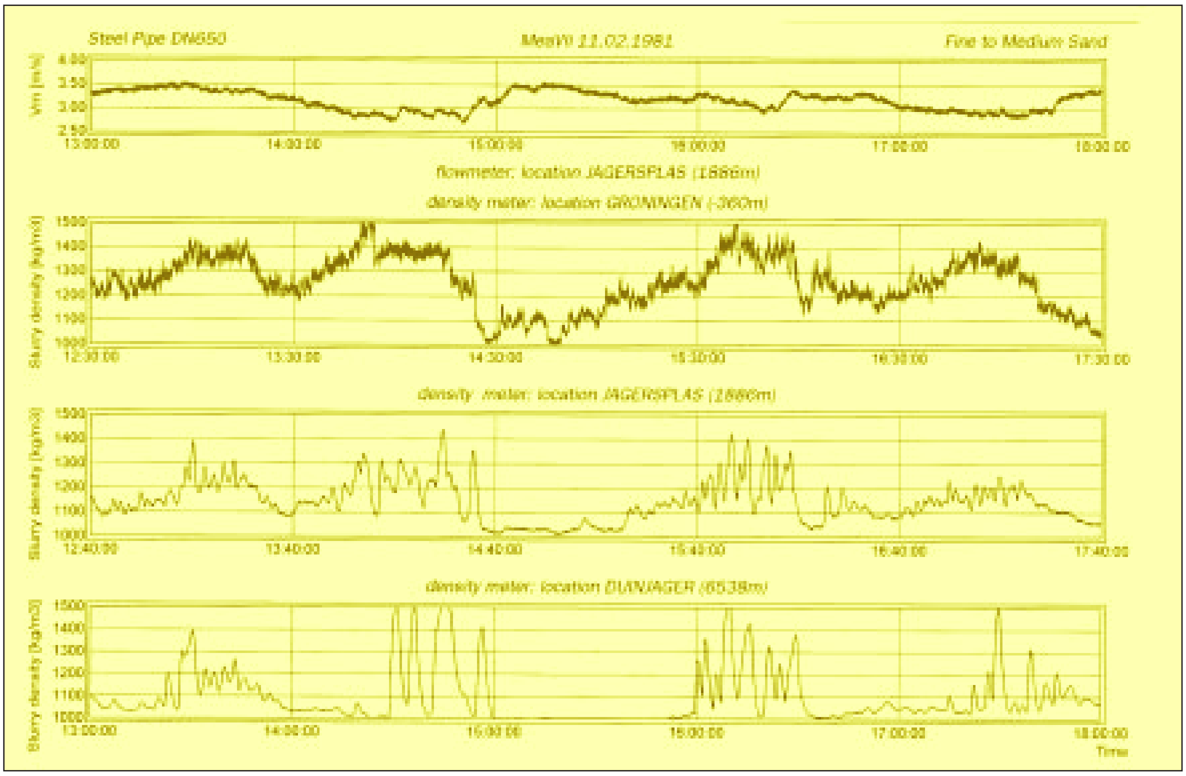
Figure 2. Density waves measure along DN650 pipeline, left, from 8:00 to 13:00 hrs and, right, from 13:00 to 18:00 hrs.

Wilson *et al.,* 1992). When accepting the simplifications of internal structure of solids flow assumed by the two-layer model (constant velocity and concentration distribution within each layer), the model version for heterogeneous flow can be used for an evaluation of the phenomena observed in the MeaVli pipeline. The model operates with a simplified two-layer distribution of velocity and concentration in a pipe cross-section. Bed velocity can be evaluated and slip can be determined by the model in this flow pattern.

DTI AND DIM: EXPERIMENTAL DATA INTERPRETATION BASED ON A TWO-LAYER MODEL

A relation between slip and slurry density which would verify an assumption that material aggregation is caused by slip can be accomplished by processing data files (B). These contain solids velocity profiles, mean slurry velocities and related slurry densities passing the pipeline cross-section. The solids velocity profiles were derived from measurements at one measuring site (location Jagersplas) in the pipeline. Profiles are constructed from local solids velocities at α = 0, 20, 30, 40, 60, 90, 135 and 180 deg. measured continuously by acoustic Doppler velocity meters. Slurry density, measured by a radiometric method (γ-ray radiometric density meter with a beam directed to the center of the pipeline cross-section) in a down coming vertical section of the pipeline as a mean value for the pipeline cross-section, provides a value of delivered volumetric concentration C_{vd}. To evaluate V_s from measured velocity profiles, the solids concentration distribution must be known. Since it was not measured this must be reconstructed by an appropriate data interpretation model (DIM) to which the physical two-layer model is implemented. DIM is a module of a data processing programme Data Transfer and Interpretation (DTI) which executes all operations required for an interpretation of data from an experimental database. A procedure of the data interpretation has been described elsewhere (Matousek, 1995c).

A set of 3 mass balance equations of the two-layer model are used to get C1, C_{vp} and V_s from measured parameters transformed to the two-layer pattern. Then the slip ratio is calculated (V_s / V_m or C_{vd}/C_{vp}). The rule for a split of solids flow into two layers is examined by DTI. It is expressed as the stratification ratio C_{cod}/C_{vd}. C_{cod} is determined from 2LM parameters.
All interpreted data plotted in Figures 4 and 5 have been processed by DIM based on the two-layer flow composition. Data files (A) and (B) contain measurements from different measuring days, so density waves presented in Figure 2 were measured at other times than velocity profiles and integral parameters from which slip values were processed. But since the operation conditions (properties of transported material, mean velocities and slurry densities, pumps revolutions) of the dredging installation were maintained at an approximately constant level during all measuring days, the same processes are supposed to occur in slurry flow in the pipeline in each particular measuring day.



Description of the Observed Phenomena by the Interpreted Data

Slip Ratio in a Pipe Cross-Section

Results of data interpretation (Figure 4) verify the existence of the relationship between the slip and slurry density in a pipe cross section and support the hypothesis that there is a slip effect on the material aggregation along the long pipeline characterised by density wave transformation. While V_m is considered constant in time, V_s varies according to slurry density in various pipeline cross sections along the long pipeline of the constant diameter.

An Explanation of a Variable Slip in a Pipe Cross-Section: Variable Mutual Force Interaction Between Two Layers

Slip was evaluated by 2LM, therefore constant velocity and no slip is expected within each layer. Different slip is caused by different mutual shift between two layers in a pipeline. This shift is a product of a force interaction between contact (bed) layer and suspended layer in a pipeline.

A relation between V_s2 and ρ_m processed by DTI and plotted (Figure 4) explains why the slip ratio has been found to increase with slurry density. There is an effect of density variation on solids velocity at the bottom of a dredging pipeline. When mean slurry velocity is approximately constant, measured velocity profiles show that particles at the bottom of the pipeline (in a contact layer) are sliding faster in a mixture of higher density than in that of lower density (Figure 3). This can be explained by a mechanism of force balance within a two-layer flow structure. A higher driving force acts on the bed layer and promotes its sliding in a mixture of higher density in the pipeline. Increasing slurry density has following impact on the acting forces in a pipeline section with stratified flow. A denser suspended flow (higher C1) in upper layer produces higher shear stress at the interface between two layers and so the higher driving force acting via the interface to the bed. The finest portion of the transported material (approx. d_s<75 µm) contributes directly to the fluid and increases carrier (water + finest particles) density. An increase in carrier density has an effect of increasing buoyancy on the solid particles. The increased buoyancy reduces the submerged weight of the bed load which is in mechanical contact with pipeline wall and therefore decreases the bed resistance by mechanical friction between particles in bed and a pipe wall. The effect of the contribution of the finest particles to the carrier on slurry flow behaviour has been measured and published, see e.g. SRC experiments with sand + clay in DN315 pipeline (Shook, 1988).

The magnitude of the forces and their mutual relation is dependent on the position of the interface between two layers in a pipe cross-section. Processing of the profiles shows that a variation in Y_b is confined to the lowest part of a large pipeline, even for very different slurry density in the pipeline cross-section. For most of the profiles (especially when V_m does not drop below 2.9 m/s) it is maintained at approximately constant value. The assumption of a relatively small variation of Y_b with slurry density is supported by a wide PSD of transported material. Only the coarsest portion of

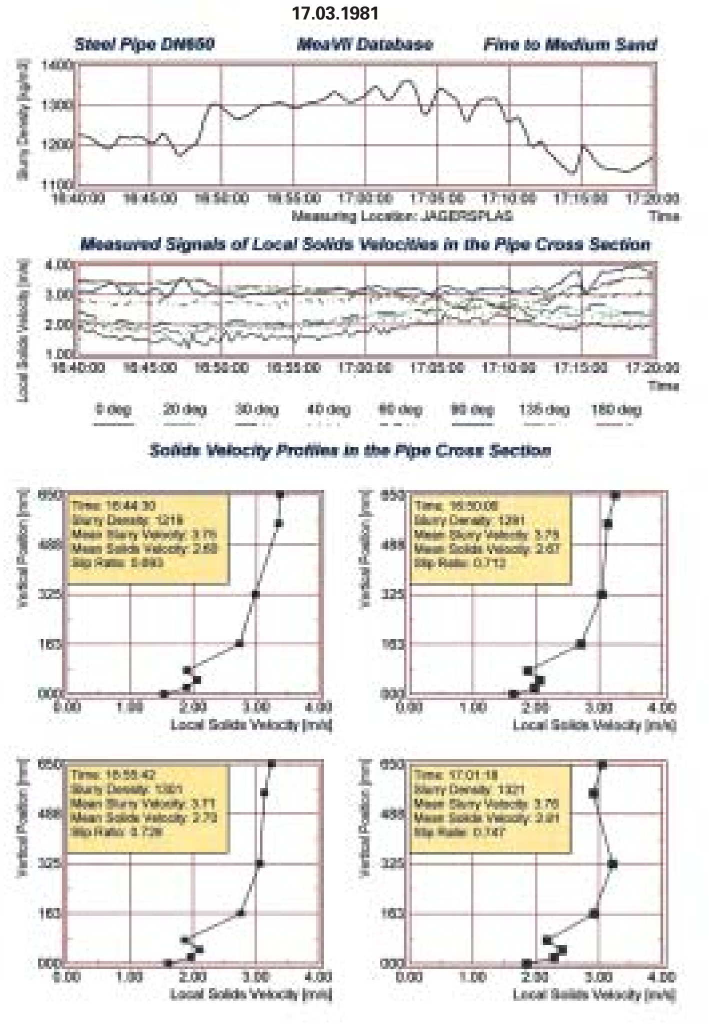


Figure 3. Solids velocity distribution in non-stationary solids flow in the DN650 pipe.

transported material contributes to the contact load and the rest remains suspended above the bed or (in case of the finest material) contributes directly to the carrier. With some degree of idealisation it can be predicted that flow is separated into two layers immediately at the beginning of the entire horizontal pipeline and a stable flow pattern is maintained along the whole pipeline length; coarser particles are transported within the bed of approximately constant concentration and thickness. The bed is sliding slowly (with a variable velocity) at the bottom of the pipeline and it is continuously passed by faster upper layer containing suspended solids in a variable concentration. Slurry density variation in pipe cross section is realised exclusively within the upper layer and it is expressed by C1 variation. A material aggregation effect is realised within the lower layer where accelerated bed within denser slurry flow gradually accumulates the material from slower bed before the forehead of the high density wave.

The computer analysis of 2LM parameters, as V_s1, V_s2 and slip ratio, reconstructed from MeaVli database has been done for both Y_b=const. ($Y_b/D=0.117$) and variable Y_b determined by DTI from the shape of measured velocity profiles. The results obtained do not differ significantly and both show the same sort of a relationship between parameters, as described here. Determined by DIM, the stratification ratio appears to be weakly dependent on the slurry density in the pipeline cross-section for C_{vd} higher than approx. 9% (Matousek, 1995c). This parameter is decisive for a correct prediction of slip and bed velocity in a pipeline by the two-layer model. Over-estimation of the layer of the contact load in a dense mixture flow gives too high Y_b and diminishes V_s2, expressing velocity of solid particles at the bottom of a pipe in 2LM.

A SIMULATION OF THE OBSERVED PHENOMENA USING TWO-LATER MODEL

To interpret the MeaVli data by 2LM for a concentration and velocity distribution and a slip determination, only the mass balance equations of 2LM are taken into account in DIM module. *To predict* slip ratio and bed velocity (and friction loss per unit length) in a pipe cross-section under various conditions, the two-layer model has to be calculated as a complete set of the balance equations, i.e. a force balance equation for each layer must be included together with a rule for a material division into two layers.
A physical two-layer model was found to be an appropriate model for the analysis of the phenomena monitored in a long pipeline and for the interpretation of MeaVli data. A simulation of the phenomena observed in a pipeline connected with a dredge could be achieved by a two-layer model with reasonable accuracy, if the model could be successfully configured for a heterogeneous (partially-stratified) flow regime. A rule for a determination of a slurry flow distribution into two layers is necessary. A slurry flow distribution is represented by:

a. the geometry of the layers (Y_b)
b. the concentration of suspended and contact layer (C_{cod} transformed to C1, C2).

Consideration of the processed MeaVli database leads to the following recommendation. To configure the model for application to unsteady solids flow of sand in a long dredging pipeline of a large pipeline diameter, the following aspects must be taken into account:

a. thickness of a contact layer does not vary significantly, even for very varying slurry densities; this is caused by rather wide PSD of a dredged material and therefore a sharp flow stratification in a large pipeline; this relatively weak variation in a bed thickness – observed in measured velocity profiles – produces an increase of V_s2 with increasing slurry density as a 2LM output;
b. a stratification ratio is independent of slurry density in the pipe for densities higher than approx. 1150 kg/m^3.

A configured model should provide following outputs for parameters of our interest here:

- V_s2 that increases approximately linearly with slurry density in a pipe cross- section;
- a slip ratio that increases with slurry density in a pipe cross-section.

The validity of a model configuration is tested by an additional measured parameter typical for slurry flow in a pipeline: the friction loss. Friction losses calculated by 2LM are compared with the real losses measured in the MeaVli pipeline. The pressures in the pipeline were measured at the inlet and outlet of Gr, Ja, Du pumps. Therefore friction loss evaluation can be done only for a long pipeline section and only for the mean values of slurry density averaged over the long pipeline section. Values of a friction loss in the Ja-Du pipeline section (4820 m of a pipeline length) is determined as a difference between measured pressure signals when minor losses in the pipeline section and a difference in geodetic heights of the pumps are subtracted. Values of friction losses are predicted by 2LM for model parameters reconstructed from measured velocity profiles. The predicted values match reasonably those acquired from Ja-Du pressure signals (Figure 5).

The non-increasing friction loss with mean slurry density observed in the MeaVli pipeline (in the density range 1080-1270 kg/m^3) is explained by the principles of two-layer model for the flow conditions described above. The contact load contributes predominantly to the slurry flow resistance. When the thickness of the contact layer does not vary significantly with slurry density in a pipe section also the friction loss does not significantly vary.

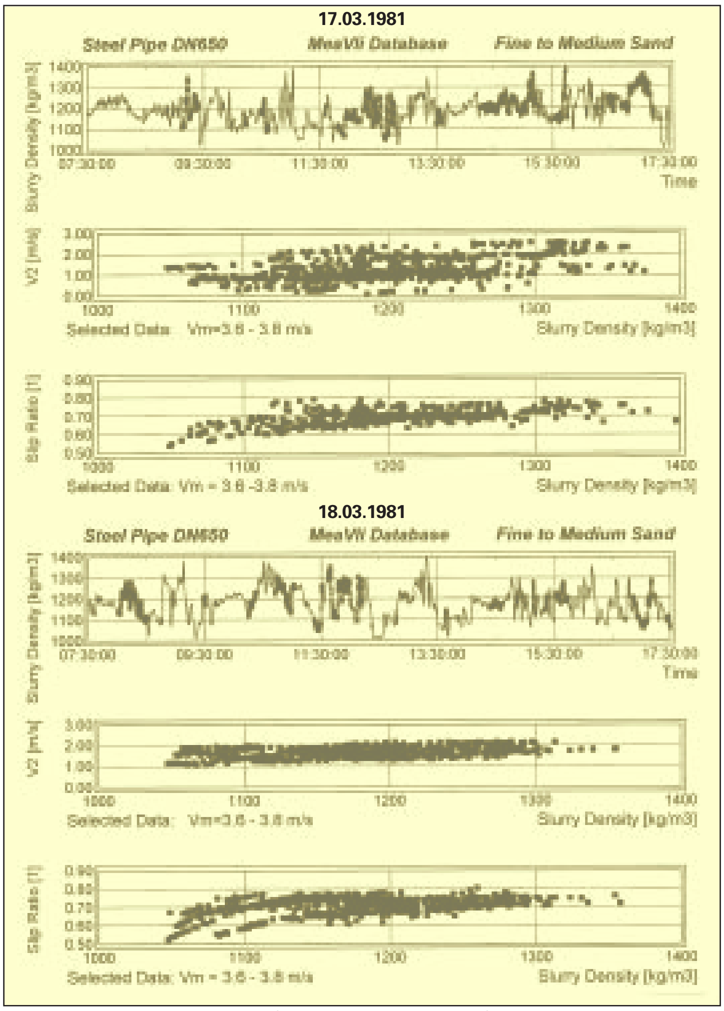
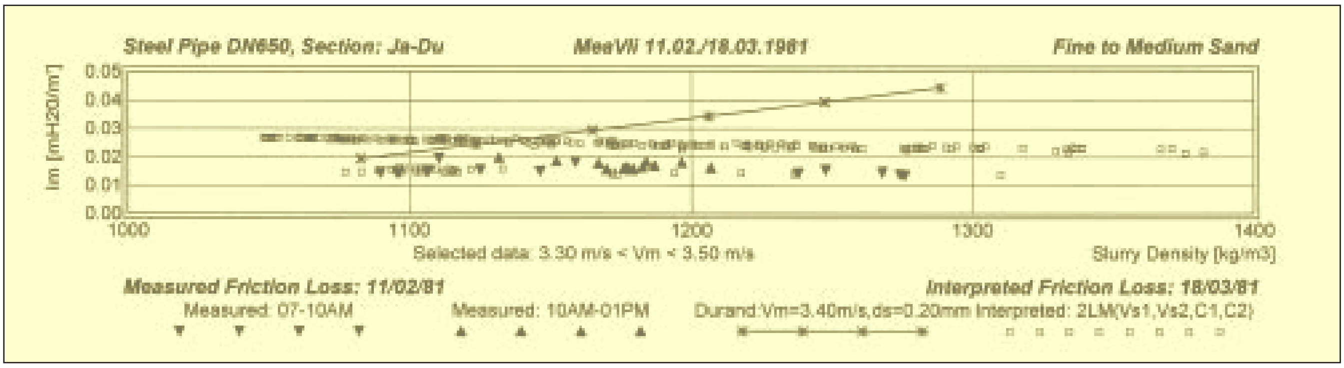


Figure 4. 2LM interpretation of measured velocity profiles in the DN650 pipe.

Verification by Laboratory Tests

A development of slip ratio in a pipe and of solids velocity at the bottom of a pipe in slurry flow of different densities was investigated in a laboratory circuit. The laboratory facility has been described elsewhere (Matousek, 1995b). Steady solids flow in DN150 pipe was monitored during a set of test runs for slurries of constant delivered concentrations from a range C_{vd} = 0.09 to C_{vd} = 0.30. Tested solid material was similar to that in MeaVli pipeline, only this was less broad-graded (quartz sand 0.2-0.5 mm). The slip was determined from the parallel measurements of concentration profiles and C_{vd} in the pipe. Integration of concentration profile $c_v(y)$ provided C_{vp}, so slip ratio C_{vd}/C_{vp} was directly obtained from measured parameters in the pipe cross-section. Also local solids velocity at the bottom of a pipe was measured during test runs. Laboratory tests show that:

Figure 5. Friction loss in DN 150 pipeline. Comparison of measured, interpreted and predicted friction losses.



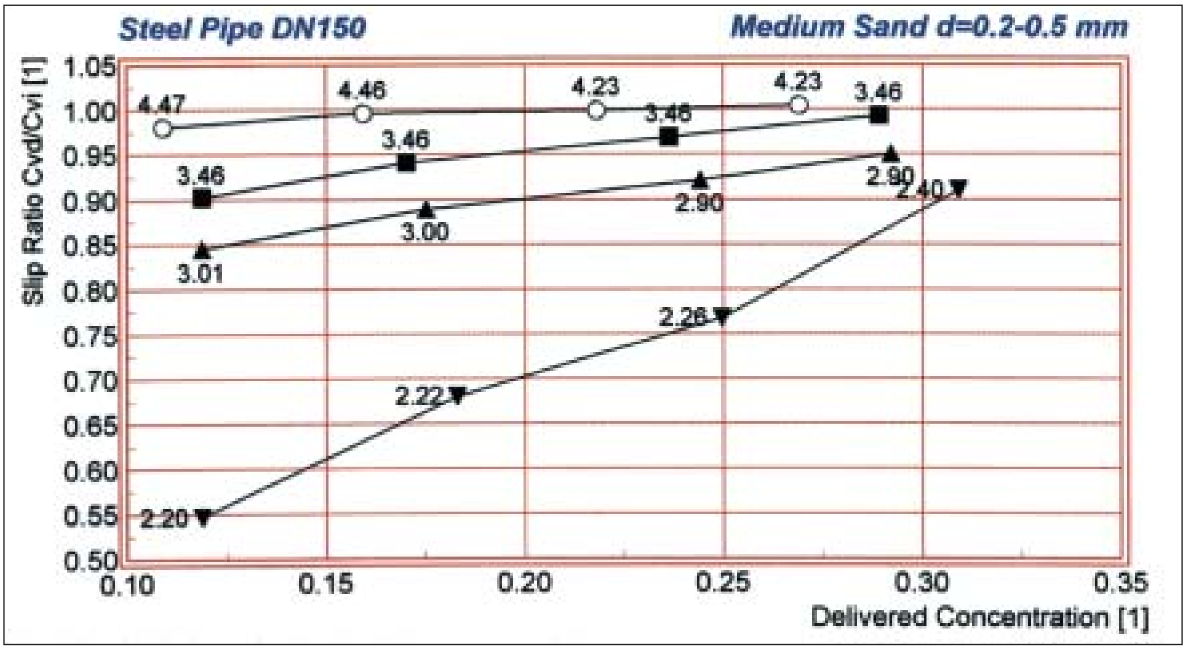
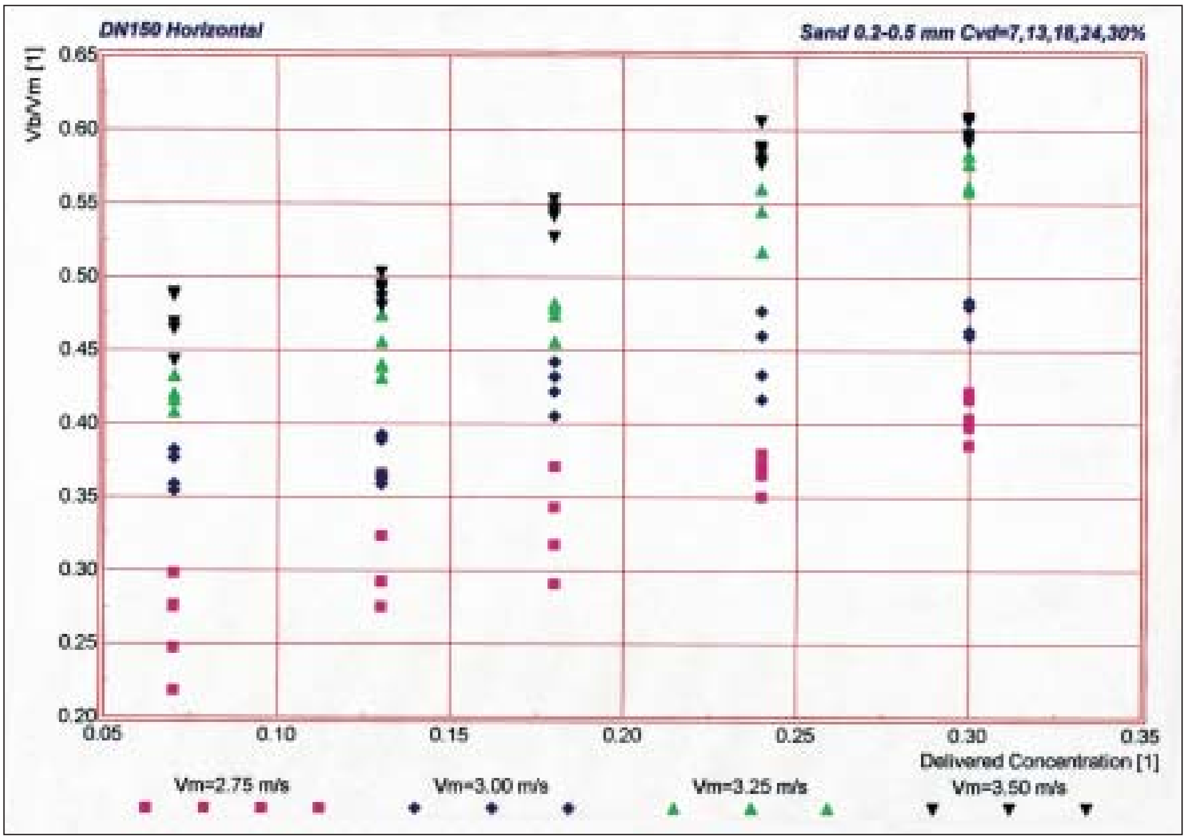


Figure 6. Slip ration measured in the DN 150 pipe (V_m as a label).

- slip ratio increases with increasing slurry density in the pipe for all V_m at which slip ratio has been measured (Figure 6);
- solids velocity at the bottom of the pipe increases with increasing slurry density for all V_m at which solids velocity has been measured (Figure 7).

Laboratory tests verify a trend in a relation between slip ratio and slurry density identified in the dredging pipeline by MeaVli data interpretation. The tests also confirm a trend in a relation between solids velocity at the bottom of a pipe and slurry density measured in the dredging pipeline. This gives an indication that the

Figure 7. Solids velocity at the bottom of the DN 150 pipe.



same processes occur in partially-stratified flow in the dredging pipe and laboratory pipe. The simplifications chosen for the MeaVli interpretation model do not misinterpret a description of a behaviour of slurry flow in the dredging pipeline.

Conclusions

A process of material aggregation has been detected in a slurry pipeline during a dredging operation. Material aggregation occurs as an effect of unsteady solids flow caused by fluctuating slurry density in a long pipeline. Transported material is gradually accumulated into highly concentrated density waves along the pipeline. This effect is a product of variable slip in different pipeline cross-sections along the slurry pipeline. Slip in pipeline cross-section is related to slurry density just passing the cross-section. The slip ratio V_s/V_m increases with increasing slurry density in pipeline cross-section. The variable slip ratio in partially-stratified flow is caused by variable mutual shift between suspended layer and contact layer in pipeline. The material aggregation effect occurs predominantly in the contact layer.

Velocity of solid particles at the bottom of a slurry pipeline varies with fluctuating slurry density in pipeline cross-section. Particles at the bottom of the pipeline are accelerated within a denser mixture when solids of wide PSD are transported. This is caused by the higher impelling force exerted on a bed load by a denser mixture stream and by a buoyancy effect reducing the submerged weight of bed.
Friction loss in a dredging pipeline may be weakly influenced by variable slurry density when broad-graded solids are transported. The thickness of the contact layer does not vary significantly with slurry density along a pipeline so friction loss, caused predominantly by mechanical friction between contact layer and pipe wall, does not vary significantly as well.

A simulation of the phenomena discussed can be achieved by physical two-layer model when the model is suitably configured. A comparison of trends in parameters obtained from the two-layer model with those measured both in the dredging pipeline and laboratory circuit shows a good agreement and confirms the applicability of the two-layer model to describe and simulate processes occurring in stratified flow in a long pipeline connected with a dredge.

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Christopher Herbert, Jean-Louis Betbeder Matibet, and Jean De Wilde

Sydney Airport's Parallel Runway: The Beneficial Use of Sand Dredged in Botany Bay


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Abstract

The construction of Sydney (Kingsford Smith) Airport's new parallel runway involved the reclamation of some 170 hectares of Botany Bay using approximately 15 million m^3 of sand dredged from within the bay.
The sand filling is retained by 7 km of vertical sea wall constructed from precast concrete panels using the reinforced earth principle. Due to a number of noteworthy innovations on the project, construction was completed ahead of schedule.

This paper looks at the alternative materials considered for use as bulk filling and the reasons for the selection of sand. It also discusses the advantages that this choice of fill offered the consortium of contractors awarded the AUS$ 210 million (US$ 150 million) contract, which helped the consortium to finish construction six months ahead of the anticipated project completion date.

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Introduction

Sydney (Kingsford Smith) Airport is the hub of the national domestic airline network and Australia's principal gateway for international travel (Figure 1). To meet the projected increases in air traffic into the 21st century the Federal Airports Corporation (FAC), the authority established in 1988 by the Australian Government to administer and develop the country's major airports, decided to construct a third runway parallel to the existing north-south runway.

Under Australian law a project such as the parallel runway cannot proceed until specified environmental

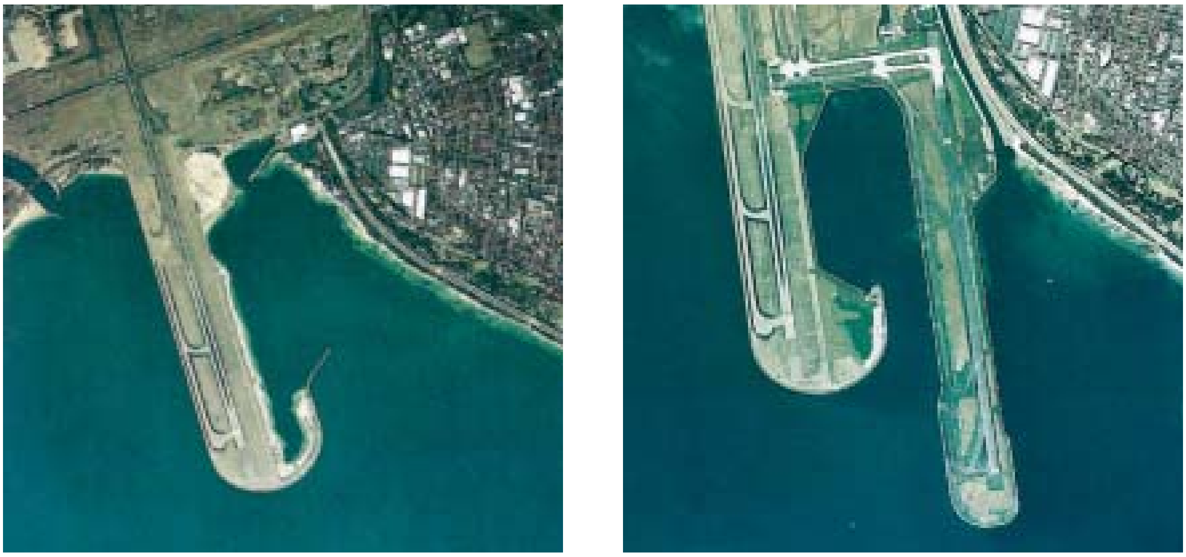


Figure 1. Left, Sydney Airport, Australia in September 1992, and right, with the new parallel runway.

impact assessment processes have been satisfactorily completed.

The first stage in this process was the preparation by FAC, as the proponent of the project, of a Draft Environmental Impact Statement (EIS). Following the publication of the Draft EIS, in September 1990, a period of three months was allowed for public review and the submission of written comments by any interested parties. For the parallel runway, which was already the subject of considerable public interest and debate, a total of 1897 written submissions were received. The FAC was then required to analyse all the public submissions and respond to every separate issue raised. This was achieved by the issue of a Supplement to the Draft EIS which was submitted to the relevant government department in September 1991. Government approval to proceed with the project was conditional on the preparation and implementation of an environmental management plan to manage the impacts arising from the construction and the operation of the parallel runway.

The 130 week contract for approximately AUS$ 210 million (US$ 150 million) for the design and construction of the new runway was awarded to a consortium consisting of Baulderstone Hornibrook Engineering Pty Ltd, Dredeco Pty Ltd., Dredging International N.V. and N.V. Baggerwerken Decloedt & Zoon. Dredeco is the Australian subsidiary of Dredging International N.V. a member of Dredging, Environmental and Marine Engineering N.V. (DEME).

The project involved the reclamation of approximately 170 hectares of Botany Bay, using sand fill dredged from the Bay and pumped to the site directly from the cutter suction dredge via a floating pipeline. Some 15 million m^3 were placed over a period of 12 months.

Alternative Locations for the Parallel Runway

Because of its proximity to the city of Sydney and the degree of development already in place in the areas surrounding the Airport, the most practical alternative was to build the runway and its associated taxiways on land reclaimed from Botany Bay. This procedure had already been successfully adopted when the north-south runway was previously extended, once in the 1960s and again in the early 1970s.

In the Draft EIS locations east and west of the existing runway were considered. The preferred option, based on a combination of operational requirements, the physical impact of the runway structure on the surroundings and the cost of construction, was to locate the new runway 1037 metres east of the existing north-south runway and 1250 metres south of the east-west runway (Figure 1).

Construction Methods Considered

For construction of a runway structure in a marine environment, two alternative methods are generally applicable:

- bulk filling retained by either a vertical perimeter wall or a sloping perimeter faced with stone or manufactured units;
- a concrete deck supported on a piled structural steel framework.

Whilst the latter method was technically feasible and was known to have been used on runway extensions outside Australia, for this particular application, it was estimated to be sufficiently more expensive than bulk filling not to warrant further consideration.

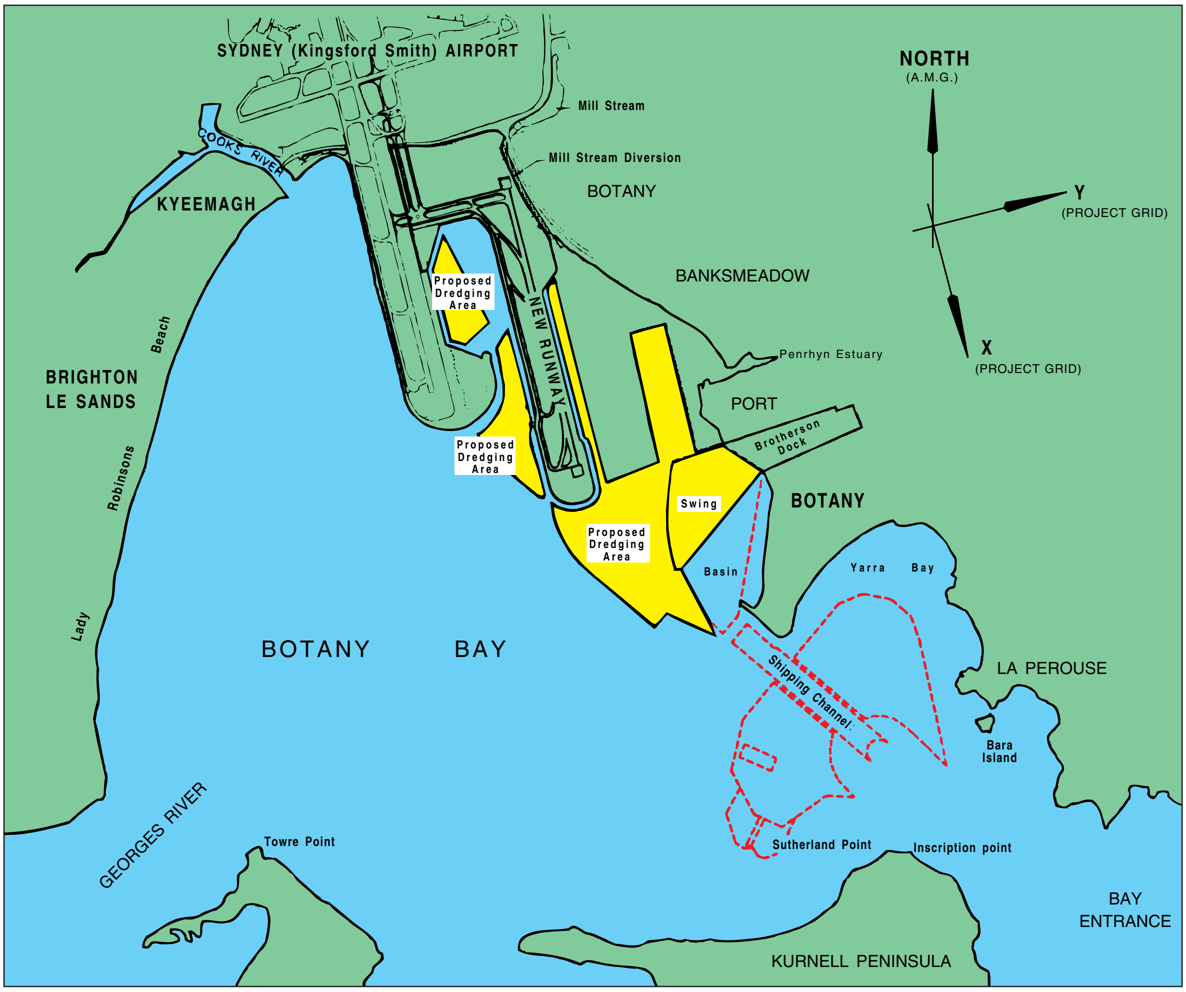


Figure 2. Runway location and proposed dredging areas.

The FAC's tender document called for a vertical steel sheetpile retaining wall with a concrete capping beam, the wall being anchored back into the bulk fill.

ALTERNATIVE SOURCES OF MATERIAL FOR BULK FILLING

The alternative sources of bulk filling listed below were considered as options for the construction of the parallel runway:

1. Reserves of blast furnace slag at Port Kembla south of Sydney
2. Reserves of coal wash residue from collieries located south of Sydney
3. Reserves of overburden from quarries located in the Shoalhaven area south of Sydney
4. Sand from onshore sources in the Sydney region
5. Sand from offshore sources within Botany Bay
6. Sand from offshore sources outside Botany Bay.

Of these options, the use of sand was considered to be the most suitable, as adequate reserves were available close to the site and because of the advantageous characteristics of sand as a medium for filling requiring a high degree of compaction (Figure 2).

ALTERNATIVE METHODS FOR DELIVERY TO THE SITE OF BULK FILL

Three options existed for the delivery of bulk fill for use in the construction of the parallel runway: railway; road transport; and water.

Rail Transport

Although the construction site is close to the New South Wales State Rail Authority's (SRA) line to Port Botany, the existing single line branch would have required extensive refurbishing and upgrading to make it suitable to handle the quantity of filling needed. In addition sidings and other facilities for the unloading and transfer of material to the site would have been required.

Whilst several of the onshore sources were close to the existing rail network, to avoid double handling loading facilities would have to have been constructed at the source. The viability of rail transport was also dependent on the SRA's ability to guarantee that operational restraints would not restrict the delivery of fill to the site.

Road Transport

The Draft Environmental Impact Statement (EIS) for the project estimated that at the time the annual demand for filling sand in the Sydney area, transported by road, was in the order of 3.5 million m^3. Thus the requirement to provide a further 15 million m^3 over a period of approximately 12 months was likely to severely strain the truck resources in the Sydney area.

Furthermore, to transport the quantity of fill needed would require some half a million truck movements, equivalent to one every minute, twenty four hours a day, every day for a year. An increase of heavy vehicles of this magnitude, even if the resources had been available, would have had a severe impact on other road users in the vicinity of the Airport. It would also in all probability have created a significant adverse response from the local residents as well as creating noise pollution, road safety hazards and deterioration of the roads leading to the site.

Although road transport was used without any significant adverse reaction from the local community or the general public for the delivery of fine crushed rock and blast furnace slag for runway pavement construction, in comparison to the volume of bulk filling required, the quantity of material delivered by road (approximately 500,000 tonnes) was relatively small.

Water

Of the land based sources of bulk filling, quarry overburden from the Shoalhaven area could have been delivered to the site by sea using the existing shiploader at Bass Point. However the use of this method of transportation would have required the construction of temporary unloading facilities at the site and their removal at the completion of the project. Sand from offshore locations could be brought to the site by one of two methods:

1. the use of a floating pipeline where the source of sand was located sufficiently close to the site, or
2. the use of barges or trailing suction hopper dredges where the source of sand was too far away to permit direct pumping.

Of all the methods of transportation considered, it was clear that transportation by sea would have the least adverse impact on the existing infrastructure and the areas surrounding the Airport. Of the two options using this medium, direct pumping of dredged sand did not require the construction of temporary wharves or conveyors to get the fill to the reclamation area and therefore offered savings in both time and cost.

Figure 3. The extent of the work carried out in two years.

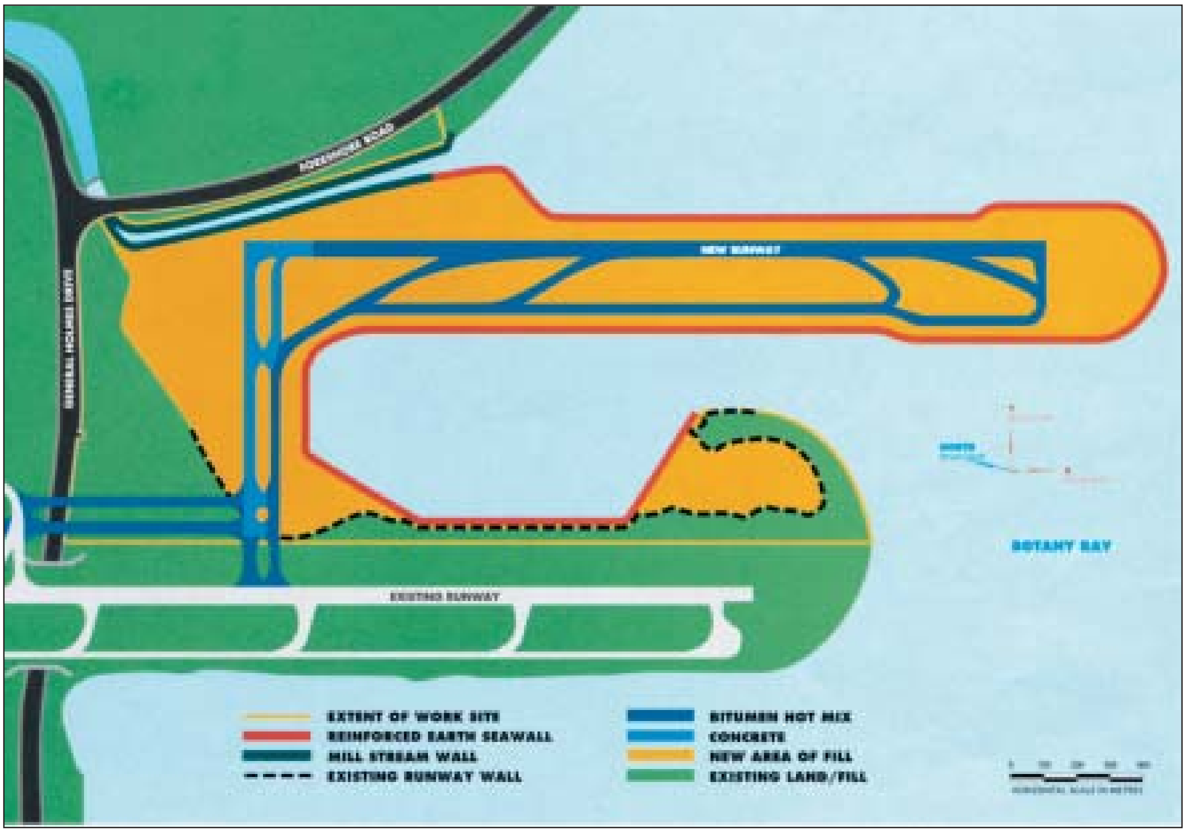


Figure 4. The floating silt curtain anchored to the bottom kept suspended solids (bottom materials disturbed by dredging) from spreading throughout the bay.

AVAILABILITY OF SAND RESERVES FOR BULK FILL

The Draft EIS identified potential sources of sand for bulk fill for the runway both onshore and offshore. Whilst onshore resources were available, the use of such sources to provide the quantity of fill needed would have been a significant extra burden on already depleted reserves. Additionally the onshore reserves with the potential to provide the required quantity were all located a considerable distance from the runway site, further increasing the impact of bulk road haulage.
Suitable offshore sources were identified at Bass Point, some 60 km south of the runway site, and at Broken Bay, a similar distance north of the site. Transportation from those locations would have required the use of barges or trailing suction hopper dredges. Suitable offshore sources were also identified within Botany Bay. These sources had the advantage of being close enough to the site to allow transportation by direct pumping through a submerged/floating pipeline from the dredge to the shore, provided that the environmental safeguards to protect Botany Bay, stipulated in the approval to proceed with the project, could be maintained.
Thus for the reasons outlined above, sand dredged from Botany Bay was selected as the most suitable filling for the construction of the parallel runway (Figure 2). The benefits arising from the use of sand are discussed in the remainder of this paper.

BENEFITS FROM USING RESERVES WITHIN BOTANY BAY

The use of sources within Botany Bay had indirect benefits as well as the direct advantage of being the closest source to the runway site.

Port Development

The parallel runway is located adjacent to Port Botany, Sydney’s principal port facility, which in 1993/94 handled approximately 5.3 million tonnes of containerised cargo (500,000 units), and 870,000 tonnes of bulk liquids.
Development of the ports is the responsibility of the Maritime Services Board of New South Wales (MSB). To cater for the predicted increase in demand for the facilities at Port Botany the MSB intends in the short term (1996) to construct a second bulk liquids terminal, and in the medium term (1998-2005) to construct new 250 metre long multi-purpose berth and an additional 7 hectares of storage.
As part of this work it was necessary to increase the depth of water in the entrance channel and in the swing basin from 15 metres to 20 metres to permit the entry to the port of larger vessels. It was also necessary to dredge the area adjacent to the new multi-purpose berth. These works together amounted to some 5.5 million m^3 of dredging which would, in any event, have been required for MSB’s planned expansion (Figure 3).

Wave Propagation

Because the entrance to Botany Bay faces southeast the bay is exposed to the waves generated by the predominantly southerly winds.
For the construction of the previous extension to the north-south runway in 1969-71, sand was dredged from an area immediately inside the entrance to the bay. As well as deepening the entrance, the excavation created a depression in the sea bed which helped to dissipate the wave energy and deflect it away from the beaches directly opposite the entrance.
Although this excavation had the desired effect, the resulting waves were not normal to the coastline, so that sand migration continued to occur. By careful planning of the areas and profiles to be dredged for the parallel runway filling, the wave direction has been altered and the sand migration has been reduced.

ENVIRONMENTAL MANAGEMENT

Approval from the Australian Government to proceed with the project included the requirement that the construction work was subject to strict environmental management controls, particularly with respect to activities which impacted on the water of Botany Bay.

Base Line Studies

Prior to construction commencing, the FAC commissioned a number of specialist studies to establish base line data for comparison purposes for items such as water quality, the extent and condition of seagrasses, marine sediments and benthic fauna.
An extensive regime of testing was carried out to establish the overall quality of the water in the bay. In addition to recording the physical properties such as

dissolved oxygen, clarity and total suspended solids, samples were also tested to determine the presence of metals, nutrients, organic compounds such as hydrocarbons, and organochlorine pesticides and pcbs.
The study of marine sediments established that within the areas to be dredged there were isolated areas affected by low level contamination from heavy metals such as cadmium, chromium and mercury. The study also established that some areas, although not contaminated, were not suitable for use for filling for structural purposes.

Management During Construction

The contract documents included an environmental specification which required the whole of the work to be undertaken in accordance with quality systems developed by the consortium to the ISO 9000 series of codes. Items to be addressed included noise, air quality, soil conservation, traffic management, bird strike and all the water quality related issues affected by the construction within Botany Bay.

Water Quality Control

Prior to the commencement of dredging operations the consortium was required to establish a water quality monitoring programme, in accordance with the FAC's Environmental Management specification.
Amongst other requirements the specification stipulated the provision of a turbidity barrier to enclose the runway site, with the permissible level of suspended solids outside the containment area limited to 20 milligrams per litre during normal dry weather conditions and 20 milligrams per litre above background after wet weather conditions.
To meet this exceptionally stringent requirement the Contractor installed a silt screen some 4800 metres long, totally enclosing the area being filled with dredged sand from the remainder of Botany Bay. This screen was anchored to the sea bed and contained sufficient slack to allow for the tidal change occurring in Botany Bay (Figure 4).

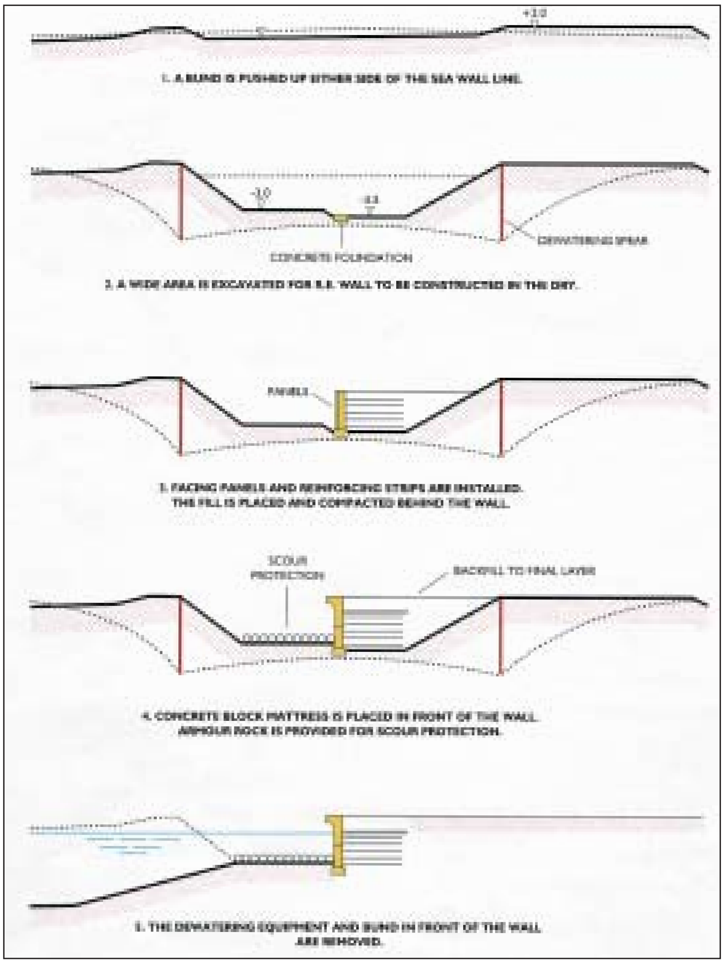
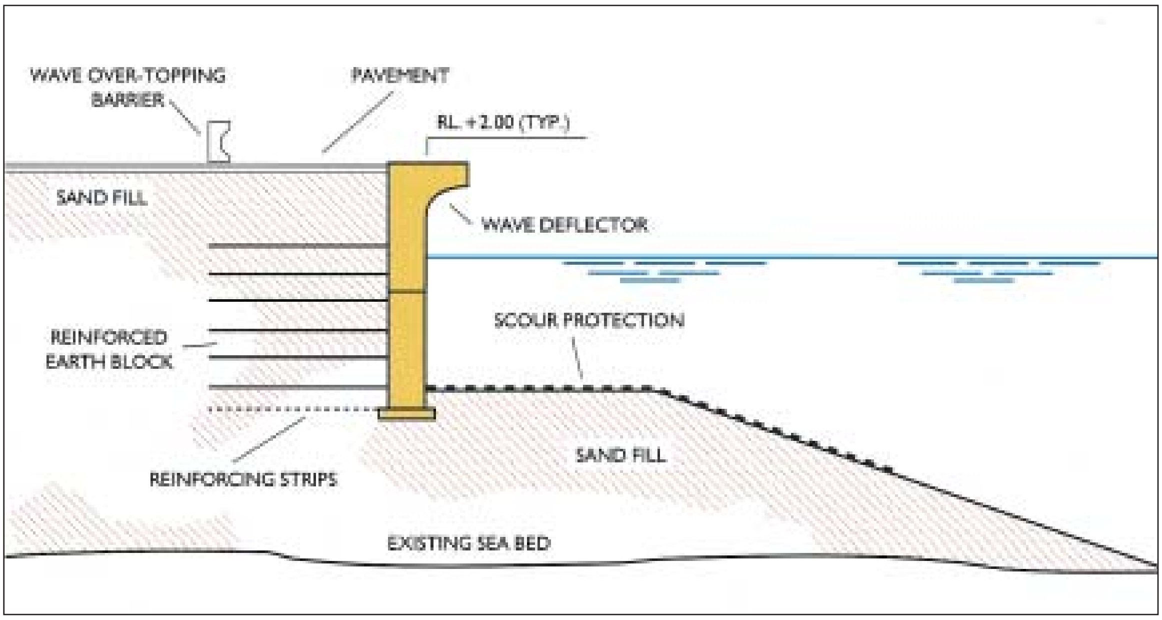


Figure 5. Construction procedure of reinforced earth sea wall.

Figure 6. Typical section of reinforced sea wall.



TENDERING

Based on its previous experience constructing the second extension to the original north-south runway at Sydney Airport, carried out in 1969-71, Dredeco was confident that the sand available by dredging Botany Bay would provide a cost-efficient and practical medium for use as bulk filling for the new parallel runway structure.

The FAC's design was based upon the construction of a steel sheetpile wall with a concrete capping beam, tied back to deadman piles driven into the fill. From the consortium's point of view this was neither the most practicable nor economic solution. Driving almost 9 km of steel sheetpiles (7 km sea wall and 1.9 km Millstream Diversion) was likely to be a slow operation. Furthermore, the noise limitations in the environmental specification were such that it was probable that the hours available for this work would be restricted.
The use of sheetpiling also incorporated a substantial component of imported material into the tender price.

The consortium identified significant cost savings of at least AUS$ 25 million and a potential acceleration of six months on the overall programme by utilising an alternative design maximising the usage of the available sand. This was achieved by founding the sea wall on a sand berm approximately 4 m in depth placed on the existing seabed. Ultimately this berm would be protected using proprietary systems to prevent scouring (flexmat and foreshore protection). The alternative design also contemplated using the dredged sand as granular material for the bulk of the "reinforced earth" block for the sea wall, to be built in the dry on top of the foundation berm (Figures 5 and 6).

The innovative features of this alternative design were instrumental in the consortium's successful bid leading to the award of the contract by FAC in August 1992.

CONSTRUCTION

It would not be an exaggeration to say that the maximisation of the use of dredged sand filling in the construction of the parallel runway was one of the most important factors in the successful completion of the project six months ahead of the 130 weeks construction period (Figure 3).
To carry out the dredging works, worth AUS $83 million, the consortium shipped one of its largest cutter suction dredges, *Vlaanderen XI* (13400 HP) from Singapore. To save time and eliminate the risks involved in towing the dredge some 6500 kilometres Dredeco elected to transport the vessel to Australia using a semi-submersible transport ship.
To carry out detail work Dredeco used two smaller cutter suction dredges, *Bilba* (1566 HP) and *Mudsnapper* (690 HP), both of which were already located in Australia.

Figure 7. The sea wall structure consists of concrete panels which are built at a rate of 25 to 30 metres per day, thus keeping pace with dredging.

The method of construction for the sea wall was to form a bund of dredged sand along the line of the wall to the finished height of the bulk fill. A trench was then excavated in the centre of the bund and dewatering spears installed along each side to allow excavation to the required foundation level of the wall, three metres below low water level.

Excavation was straightforward, using draglines and large excavators. The outer portion of the bund was used as a cofferdam which was sufficient to withstand the moderate wave action prevailing in the bay.
The excavated trench was made wide enough to permit the placement, "in the dry", of the 15 metre wide scour protection mats (Figures 5 and 6). This was of considerable advantage to the consortium in terms of ease of construction to obtain the required quality of finish, and cost and time savings. The sand cofferdam was ultimately pumped into the reclamation area using the two smaller cutter suction dredges, *Bilba* and *Mudsnapper*.

A similar technique was used to construct in the dry a 1 km long channel extending the outlet of the Millstream along the eastern side of the runway.
Because the sand filling was placed using a pipeline direct from the dredge, a high degree of compaction was already attained before rolling commenced. The uniformity of the sand layer was such that the consortium was able to construct the base slab of the sea wall in precast concrete panels, placed in position with a crane. This degree of mechanisation meant that the construction of the sea wall was able to proceed rapidly with all the various activities being carried out simultaneously at different locations along the wall (Figure 7).

Another notable success was the turbidity barrier which totally surrounded the reclamation site and acted as a filter to prevent any solid particles from being dispersed throughout the rest of Botany Bay by the action of the tides. As the footprint of the sea wall extended the silt screen, purchased from Japan at a cost of $5 million, was also extended to a maximum length of almost 5 km. The skirt of the silt screen was anchored to the seabed and the top was attached to flotation cells on the surface of the water. The screen was of sufficient depth to cope with the tidal range experienced in the bay.

During the placing of the bund, water quality testing was carried out daily to verify compliance with the specification. The turbidity barrier was kept in position until the bund for the sea wall was completed.

With the exception of isolated breakages caused as a result of accidental damage, and in one instance vandalism, the screen proved to be totally effective in retaining the turbidity caused by the dredge return water and ensured that the level of suspended solids outside the screen was below the specified maximum of 20 mg/litre.

DISPOSAL OF UNSUITABLE MATERIALS

Material unsuitable for use as filling, totalling approximately 0.5 million m3 was deposited in a pit excavated between the two runways bounded by an underwater bund. The transportation of this unsuitable material was done using one of the smaller cutter suction dredgers. The unsuitable material was placed in the containment area using a specially constructed diffuser to spread the dredged material as closely as possible to the bottom of the pit. After allowing time for the materials to settle, the unsuitable material was covered with a 500 mm blanket of clean sand to seal it off from the waters of the bay.
Water quality testing was increased during this operation but no increase in contamination was detected.

Conclusions

The construction of Sydney (Kingsford Smith) Airport's new parallel runway was completed ahead of schedule and without adverse environmental impacts by utilising approximately 15 million m^3 of sand dredged from within Botany Bay. The successful completion of construction was made possible for a number of reasons:

- the use of sand for bulk filling from adequate reserves close to the construction site in Botany Bay;
- the delivery of sand by sea using direct pumping which had the least adverse environmental impact; and
- the retention of the sand by a 7 km vertical sea wall constructed from precast concrete panels using the reinforced earth principle which improved the speed of construction.

There were also a number of indirect benefits to using sand dredged from Botany Bay:

- in order to further develop the Port Botany, the nearby port facility, dredging would have been necessary in any case to increase the depth of water;
- by careful planning, the dredging for the parallel runway filling was able to alter the wave direction and reduce sand migration in the bay.

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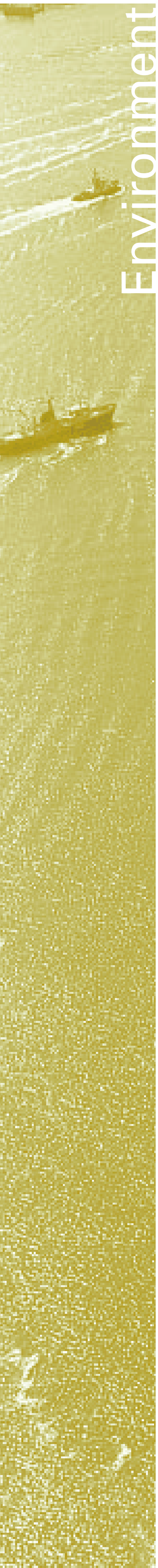

Hans Goossens and John J.G. Zwolsman

An Evaluation of the Behaviour of Pollutants During Dredging Activities

Abstract

The growing environmental concern in the world is also noticeable in the dredging world, especially in relation to dredging polluted sediments. The knowledge obtained during the last decades of the behaviour of pollutants in aquatic systems has been used to manage the environmental quality of aquatic systems. The situation during dredging differs from the regular situation, due to processes with short time scales and very heterogeneous environmental conditions. In this article the risks of dredging polluted sediments are shown to depend on the risk of dispersion and on the mode of occurrence of the pollutants. During dredging, shifts in mode of occurrence may occur which affect the availability for uptake by organisms (the bioavailability) and consequently the toxicity of the pollutant. The toxicity is highest in the free mode of occurrence, i.e. when the pollutant occurs as single molecules dissolved in water.

General descriptions are given of the behaviour of the two main classes of pollutants: heavy metals and organic micropollutants. Evaluating the processes occurring during dredging revealed the conditions and activities causing environmental risks.

As a conclusion, the risks of dredging polluted sediments are related to the uncontrolled dispersion of pollutants, both in dissolved state and in particulate state, and to the incomplete removal of polluted sediment. Shifts in environmental conditions may cause substantial release of pollutants to the water column. Complete removal of the polluted sediment is very important. When the new top layer of the sediment has higher concentrations than the top sediment prior to dredging both heavy metals and organic micropollutants may be mobilised. The liberation mechanisms, however, are different for both classes of pollutants. For heavy metals, iron chemistry may provide a temporary, partial safety belt preventing the dispersion of dissolved heavy metals during the dredging process. On the longer time scale of the after-dredging situation, however, substantial release of heavy metals into the water is expected. Consequently, for heavy metals, temporary mixing with the water column on the short time scale (hours) can be allowable, whereas complete removal of the polluted sediment is important.
For organic micropollutants a substantial amount of Dissolved Organic Matter bound pollutants may enter the water column during dredging. Therefore, mixing with the water column should be avoided as much as possible. The mobilisation of organic micropollutants from resuspended sediment depends on the pollution level of the suspended solids in the water column prior to dredging. When the layer coming to top in the after dredging situation has a higher pollution level than the old top layer, substantial release of pollutants will occur. In that case complete removal of the polluted layer is important.
There is an urgent need for proper data collection during dredging projects to support the results of this evaluation. Based on the available knowledge and the data to be collected, sensible control options and measures can be designed for specific dredging projects in polluted sediments.
This paper has been prepared in cooperation with the partners who together form the CSB (Dredging Research Association): Ballast Nedam; HAM; Royal Boskalis Westminster; Van Oord-ACZ; The Netherlands Public Works Department of the Ministry of Transport and Public Works; Public Works of the City of Rotterdam; Delft Geotechnics; and Delft Hydraulics. The authors wish to express their gratitude to the members of the group and to Nico de Rooij of Delft Hydraulics.

Introduction

Over the last years the dredging world has faced growing public awareness of environmental issues and in many dredging projects ”the environment” requires explicit considerations in the design phase as well as in the operational phase. The point of environmental awareness is very clear when dredging polluted sediments. Projects with the single, dedicated goal of removing pollution, are rare and the market for these projects, though promising, is only at its beginning. Nevertheless, many dredging projects are carried out in

polluted sediments, simply because dredging projects and pollution both have a strong link to populated, industrially developed areas. The problem of dealing with polluted sediments is thus very common.
In the more general context of pollution in the aquatic environment, an overwhelming amount of data on the behaviour of pollutants in aquatic systems has been collected over the last decades. From the 1960s on, the problem of pollution has been recognised and, progressively, measures are being taken to reduce the loads on the waterways, especially in the western world. A substantial reduction of pollution level has been achieved in some cases. These measures have been founded by scientific research on the behaviour of pollutants in aquatic systems. The knowledge obtained has been formalised in numerous computer models, with which rather reliable predictions can be made of the effect of measures and management options on the pollution level of a specific system.

Surprisingly little, however, is known of the behaviour of pollutants *during dredging* (some relevant information can be found in: Calmano *et al.,* 1989; Kersten *et al.,* 1985; Hafferty *et al.,* 1977; Rice and White, 1987). Obviously, this is because environmental conditions during the dredging process are very complex and show a high variability in space and time. Dredging-related turbidity often occurs in “clouds”, indicating steep gradients in suspended sediment concentrations. Steep gradients are also apparent from the relatively small zone of impact around dredging vessels in quiet water (50-100 m, Pennekamp and Quaak, 1990).
The water movements in a dredging area are also very complicated as a result of density currents caused by the different densities in the turbidity clouds in combination with the currents caused by vessel propellers. In addition, the time scale of these processes is very short. Typically, the turbidity generated by the dredging process lasts only several hours (Pennekamp and Quaak, 1990).

This high variability and the short time scale differ substantially from the generalised conditions used in computer models for policy making and management of polluted water systems. These models are therefore not suited to the development of environmental control measures in dredging projects.

Nevertheless, the fundamental knowledge of the behaviour of pollutants in aquatic systems has developed enormously and could be utilised to improve the environmental quality of dredging operations.
Recently, we performed an evaluation of the environmental aspects of the dredging process, based on fundamental, theoretical knowledge of the behaviour of pollutants. The aim of this evaluation was to provide better insight into the behaviour of the pollutants to be expected under dredging conditions. Although the evaluation was theoretical for the greater part, some important conclusions for the practice of dredging were derived. In addition, the insight obtained can help improving the environmental quality control of specific dredging operations on the basis of project-specific information.
In order to expand this knowledge to real dredging projects, there is an urgent need for proper data collection during dredging operations to support the conclusions. The combination of knowledge and collected data will provide a solid basis to design sensible control options of environmental aspects in specific dredging projects.

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Dr Hans Goossens

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John J.G. Zwolsman

THE POLLUTANTS

Anthropogenic substances accumulating in aquatic systems can be distinguished into two groups:
- nutrients (Jones and Lee, 1975); and
- pollutants.

This study is confined to pollutants present in sediments which can be generally classified in two classes:
- heavy metals; and
- organic micropollutants.

This distinction is related to different (chemical) behaviour.

Understanding the potential risks of dredging polluted sediments requires some basic knowledge of the behaviour of both classes of pollutants. In addition, it is necessary to know how pollutants are present in the water and in the sediment (Table I).

Table I. The main forms of pollutants in the aquatic environment.

State	Dissolved (in pore water and water column)	Particulate (in sediment and suspended matter)
Mode of occurrence	– free – complexed	– adsorbed – precipitated

An important distinction is made between dissolved and particulate state. The state affects the potential for dispersion. The "particulate fraction" of a pollutant will be dispersed with particles. Any measure to control the dispersion of particles will also control the dispersion of this pollutant fraction. In the dissolved state, a pollutant is dispersed with the water. This type of dispersion is invisible to the human eye and difficult to control.
Both dissolved and particulate states can be further specified into "modes of occurrence". Mode of occurrence is a general term for "speciation", which is the term chemists use for the different molecules in which a specific pollutant may occur.

The specification of the mode of occurrence is important for the chemical behaviour of the pollutants, especially for the heavy metals. The mode of occurrence is also an important factor in the "toxicity" of pollutants. A much higher toxicity is exerted in the free mode of occurrence than in a different mode as a result of increased "bioavailability", i.e. the availability for uptake by organisms.
Therefore, an evaluation of the risks of dredging polluted sediments should include a study of the possible shifts of states and modes of occurrence as a result of dredging activities, in addition to the possible dispersion of polluted sediment particles.

Heavy metals

Heavy metals occur in different modes in aquatic systems. Figure 1 shows the four basic modes of occurrence and the potential transfers of one mode to another. Central is the free mode of occurrence. In this mode, heavy metal molecules discussed in this paper (Cadmium (Cd), Copper (Cu), Mercury (Hg), Nickel (Ni), Lead (Pb) and Zinc (Zn)) occur as single, positively charged ions in the water. [The metals Arsenic (As) and Chromium (Cr) occur in negatively charged forms; these metals are not discussed here].

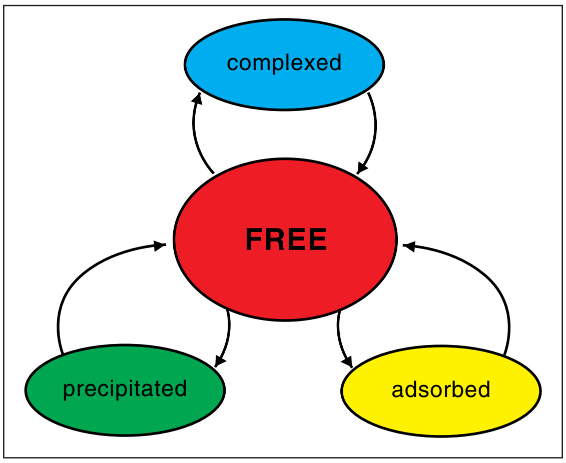

Figure 1. Description of the different forms of presence of pollutants and a schematised view on the possible shifts between modes of occurrence of heavy metals.

In the free mode, metals are transported with the water, are easily taken up by organisms and, generally, exert their highest toxicity.
From the free mode heavy metal molecules can shift to three other modes which differ fundamentally.
The complexed mode indicates a combination of the metal molecule with another molecule. Complexation occurs with so-called Dissolved Organic Matter (DOM), i.e. organic material which is too small to be particulate (i.e. < 0.45 µm) and with negatively charged molecules, e.g. metal-carbonate or metal-chloride. Both in the free mode and in the complexed mode the metal is in dissolved state.

In the particulate state, heavy metals may occur in an adsorbed or a precipitated mode. In the adsorbed mode, the metal molecules are adsorbed to the surface of particles. The bond of the metal to the surface is often the result of opposite electrical charges of the metal molecule (positive) and the surface of the particle (negative). This bond is very susceptible to changes in electrical charge of the surface, e.g. as a result of changes in pH (acidity) of the water.

The precipitated mode of metal ions is the result of precipitation from the water through formation of an insoluble salt with a counter-ion (mostly sulfide, see hereafter). The sulfide form is chemically stable as long as anoxic conditions are preserved.
In the particulate state the metals cannot be taken up directly by organisms (unless by ingestion of particles) and thus the toxicity is reduced as long as the particulate state is preserved.
In sediments only a small fraction of the total amount of heavy metals is dissolved because of a high ratio of sediment to pore water and the tendency of the metals to be bound to the particles. In anoxic pore waters the dissolved part is reduced further by precipitation with sulphide.

Measurements in the sediment of the Western Scheldt, The Netherlands, indicated that <1% of the amount of heavy metal (Cadmium, Copper and Zinc) in the sediment was in the dissolved state (Zwolsman and van Eck, 1993). This is a general phenomenon in anoxic sediments, caused by the very low solubility of heavy metal sulfides (Davies-Colley *et al.,* 1985; Moore *et al.,* 1988).

Figure 2 indicates how heavy metals can behave during dredging, i.e. through possible shifts in mode of occurrence. Clearly, all shifts proceed via the free mode of occurrence. The processes causing the shifts are under control of the environmental conditions. Changes in the redox conditions are very important, because oxidation causes a shift from the precipitated mode (metal-sulfides) to the free mode. The reverse, precipitation from the free mode to the insoluble precipitated mode, occurs under anoxic conditions.

Another important environmental parameter is the pH (acidity). The exchange between the adsorbed and the free mode strongly depends on the pH. A pH decrease may cause a very rapid transfer of a substantial fraction of the adsorbed amount to the free mode.

Organic Micropollutants

The class of organic micropollutants includes an enormous number of compounds. For the dredging world it is relevant that a common characteristic of many of these compounds is that they tend to stick to particles, preferentially to Organic Matter (OM). This behaviour is caused by their "oily" nature, i.e. their inability to dissolve in water.

A second common characteristic is that they are persistent (Poly Aromatic Hydrocarbons, PAHs) (Delaune *et al.,* 1981; Mille *et al.,* 1988) or are degraded very slowly (Poly Chloro Biphenyls, PCBs) in the sediment under natural, i.e. anoxic conditions (Brown *et al.* 1987). Due to the slow degradation rate, only the "exchange process" between water and particles (Organic Matter) is relevant for dredging. The class of organic micropollutants thus differs from the heavy metals, which cannot be degraded at all and show shifts in mode of occurrence mainly as a result of "chemical reactions", driven by redox conditions.

Organic micropollutants occur in only three modes:
- free,
- complexed or
- adsorbed.

The free mode and the adsorbed mode belong to the dissolved and particulate state, respectively. The complexed mode represents pollutants bound to Dissolved Organic Matter (DOM). Substantial amounts of organic micropollutants may adsorb to DOM, forming a complexed fraction which is included in the operationally defined dissolved state (particles <0.45 µm, Table I), although the micropollutants occur in bound form (Figure 3).

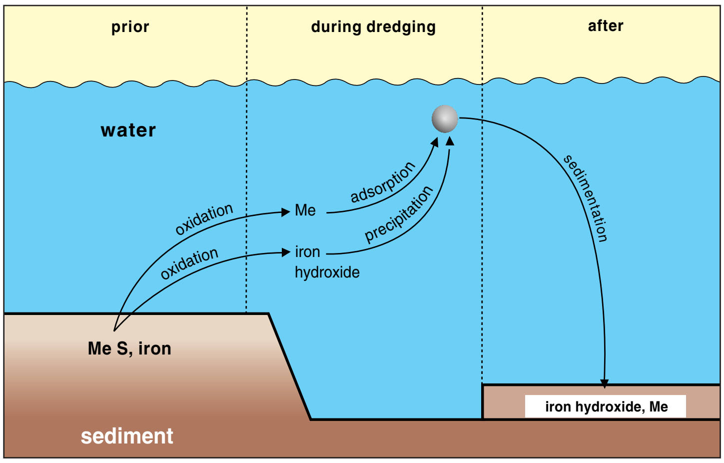

Figure 2. Schematised view on the shifts in mode of occurrence of heavy metals before, during and after dredging activities (Me: heavy metal; S: sulphide).

When looking more closely, there are also important variations in the particulate fraction, as can be concluded from the pollutant exchange characteristics. It is argued that penetration of pollutants into particles is important. Exchange processes are very slow as a result of slow diffusion of a pollutant from the inner side of the particle to the surface where the exchange processes take place (Brusseau *et al.,* 1991). Penetration of pollutants into particles may be caused by diffusion or by coverage of the outside of the particle by (organic) coatings (e.g. iron precipitation, see below).

These considerations are important when exchange processes (mobilisation and immobilisation) have to be quantified. To understand the behaviour of organic micropollutants qualitatively, however, a distinction between dissolved and particulate state is sufficient. The process of exchange between free and adsorbed mode is driven by a compounds potential to dissolve in water, which is determined by its molecular structure. A given total amount of a specific compound shows a distribution over free and adsorbed mode which is determined by its solubility. The distribution reflects a free concentration (in µg/l) in equilibrium with the concentration in the organic matter part of the particles (in µg/g). It is generally assumed that the ratio of these two concentrations is constant for a specific compound. This theory of the distribution is called the partition theory and is widely accepted. It has important consequences for the dredging case, as shown later.

Measuring the truly dissolved fraction of organic micropollutants is very difficult due to the low dissolved concentrations and the adsorption of organic micropollutants to Dissolved Organic Matter (DOM). Some calculations were performed which indicate that the truly dissolved fraction in the pore water is very low and reaches only about 2% of the total present amount for the best solving pollutants (e.g. lindane). The DOM-bound fraction, however, deserves attention because this fraction may contain substantial amounts of pollutants. This fraction will be dispersed with the pore water when entering the water column during dredging operations and behaves independently from the particle fraction.

The description of the behaviour of organic micropollutants during dredging can be limited to the exchange of pollutant between dissolved and particulate states which is described below. Changes in environmental conditions have relatively little influence on this exchange and can be omitted in the analysis.

THE SEDIMENT

For the present evaluation two fractions of the sediment should be distinguished:
– the pore water and
– the solid part.

The pore water might be important because pollutants present in the pore water can mix directly with the overlying water column, thus escaping measures to control particle dispersion.

For the solid part the distribution of particle dimensions could be relevant because these classes might be different, e.g. with respect to concentrations of pollutants, dispersive properties, etc.. There is a general agreement that the greater part of the pollutants is bound to the "fine" fraction (< 63 µm). However, data of pollutants on that level are almost completely lacking. For the present evaluation the solid part is considered homogeneous.

MOBILISATION OF POLLUTANTS DURING DREDGING

The Dredging Process

During dredging, sediment is transferred from its original position to somewhere outside the system (via barges or transport pipe). This transfer has at least two side effects:

- part of the sediment is lost to the water column. This sediment, which is contaminated, can be dispersed into the adjacent environment forming the new top layer (after sedimentation).
- after removal of the dredging layer, the new sediment top layer is exposed to environmental conditions which differ from the situation prior to dredging (e.g. a shift from anoxic to oxic conditions, etc.).

Of course, many more side effects can be identified but, basically, the risks of dredging polluted sediments can be evaluated by considering these two side effects.

The Risks of Dredging Polluted Sediments

To evaluate the ecological risks of dredging polluted sediments both the amounts of pollutants dispersed into the surrounding environment and the toxicity of the pollutants are important.
As shown above, the direct contribution to the amount of dissolved heavy metals from the pore water is negligible while the direct contribution to the amount of dissolved organic micropollutants is low, unless there is a substantial contribution of DOM-bound organic micropollutants (e.g. in case of high DOM concentrations).
When risks would be based on the amounts of the pollutants only, the amount of particulate polluted material entering the water column would be most important. With respect to toxicity, however, the increase in bioavailability which results from a shift from particulate to the free mode, is also very important.
The risks of dredging polluted sediments are primarily related to activities or conditions promoting the shift of pollutants from the particulate state into the dissolved state.

Dispersion of pollutants with the suspended solids

Dispersion of pollutants may occur in both the dissolved and the particulate state. The latter form of dispersion is obvious and is recognised in the dredging world. The measures taken in "environmental dredging" projects are, in general, directed towards minimal dispersion of particles:

- The generation of turbidity can be minimised by using special dredging equipment.
- The dispersion of generated turbidity to the surroundings can be minimised by the utilisation of silt screens.

Measures to reduce the dispersion of particles will also reduce the dispersion of pollutants. However, this is not always sufficient, due to the potential dispersion of pollutants in the dissolved state.

Dispersion of pollutants in the dissolved state

The dispersion of pollutants in the dissolved state is less obvious because this process is invisible for the human eye. Nevertheless, it is clear that pollutants, once desorbed from particles into the dissolved state, will be dispersed with the water and thus escape control by silt screens or by other measures taken to prevent dispersion of particles. The risks of dredging polluted sediments thus include risks of creating situations which provoke desorption.

The dissolved amount of a pollutant in a sediment to be dredged is determined by the pore-water content of the sediment and the concentration of the pollutant in the pore water. Only a (unknown) part of this pore water will be lost into the water column. Depending on the thickness of the layer to be dredged, the porosity of the sediment, the loss percentage of pore water (depending on dredging equipment and operation) and

the depth of the water column, a substantial dilution of the concentration in the pore water occurs upon mixing with the water column.
Simple calculations indicate that the direct pore-water contribution of heavy metals to the water column concentration is (almost) negligible compared to the contribution by particles. This may hold also for organic micropollutants, but depends on the contribution of DOM adsorbed pollutants.

Since sediment particles contribute by far the greatest amount of pollutants to the water column during dredging, desorption from particles is the most important potential source of dissolved pollutants in the water column. Establishing the risk of desorption of pollutants from particles requires an analysis of the behaviour of the pollutants in those circumstances. Due to the different processes causing mobilisation, the behaviour of heavy metals and organic micropollutants is discussed separately.

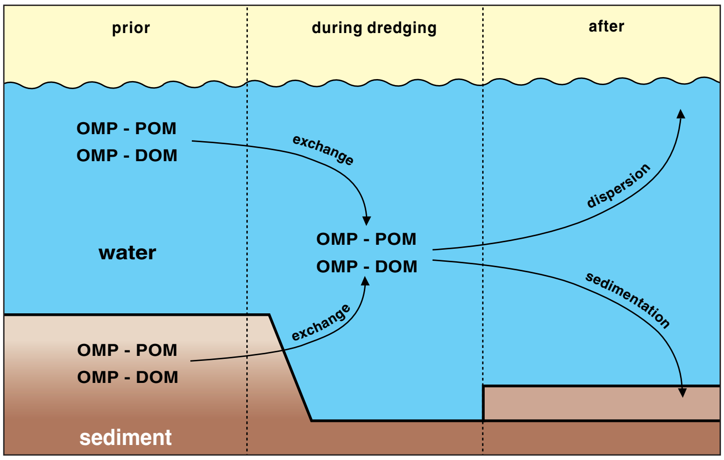

Figure 3. Schematised view on the shifts in mode of occurrence of organic micropollutants before, during and after dredging activities (OMP: Organic Micro Pollutant; POM: Particulate Organic Matter; DOM: Disssolved Organic Matter).

Heavy metals show complex behaviour related to the complicated chemistry of Sulfide, Oxygen and Iron. Generally, polluted sediments are anoxic. The sulfide forming heavy metals are then precipitated as sulfides.

The free concentrations of heavy metals in the pore water are very low because of the very low solubility of these precipitates (Davies-Colley *et al.,* 1985; Moore *et al.,* 1988). Simultaneously, there is a substantial concentration of dissolved iron (Fe^{2+}) in anoxic pore-water, especially in fresh water sediments. Generally, the iron concentration in sediments is in the percentage range, i.e. ca. 100 times the heavy metal concentration in polluted sediments.

When sedimentary material is mixed with column water, it is transferred from anoxic into oxic conditions. Then, two reactions will take place: oxidation of heavy metal sulfides and oxidation of the dissolved iron (to Fe^{3+}). These two processes have counteractive consequences:

- The oxidation of sulfides liberates the heavy metals because the precipitates are degraded;
- The oxidation of iron causes precipitation of iron-(oxo)hydroxides which form a very strong adsorptive surface.

This precipitation process will cover any particle available with a layer of iron-(oxo-)hydroxide. As a result, the heavy metals, mobilised by the oxidation of sulfides, will adsorb to the freshly created adsorption surface. The net outcome of these two counteractive processes thus depends on how fast the processes proceed. If oxidation of sulfides would proceed more rapidly than the oxidation of iron, then the adsorption onto precipitated iron cannot compensate entirely the mobilisation of heavy metals. If, however, the oxidation of iron is faster, then there is ample adsorption surface for heavy metals and the oxidation of sulfides is slowed down because particles get covered by a layer of iron-hydroxide and the penetration of oxygen into the particles is hampered.

Available measurements of the rate of oxidation of iron and sulfide suggest that the oxidation of iron is faster than sulfide oxidation (Pugh *et al.,* 1984; Millero *et al.,* 1987; Ahmad and Nye, 1990). Some preliminary measurements of the change in concentration of dissolved metals in the vicinity of a dumping site during dumping confirm the expected decrease of dissolved heavy metal concentrations (Hegeman *et al.,* 1991).

In summary, the present amount of heavy metals will probably show a shift from precipitated mode to the adsorbed mode, during dredging. Both modes are particulate, but adsorbed heavy metals can be released very quickly following a pH decrease in the water.
In the "after dredging" situation problems may arise when sedimentation yields a top layer polluted with heavy metals.
Frequent resuspension (wind, navigation) promotes continuous desorption of heavy metals, under control of the prevalent environmental conditions. Once the material is transferred to anoxic conditions (e.g. after burial by sedimentation), the heavy metals will be transferred back to their stable sulfide precipitates.

The possible mobilisation of organic micropollutants during dredging is hardly dependent on the chemical conditions. Here, the distribution over different fractions is determined by the continuous equilibration exchanges of pollutants between particles and surrounding water. When the environmental conditions are more or less constant, an equilibrium will be reached, dependent on the characteristics of pollutant and adsorbent.

During dredging, several changes occur when sedimentary material is dispersed into the water column:

1. the particle concentration in the water increases
2. DOM-bound pollutant concentration in the water column increases
3. the total concentration of pollutant in the water increases
4. particles with different pollutant concentrations are mixed.

According to the partition theory, a new equilibrium will be established. The concentrations in this newly equilibrated situation can be estimated using the theory which says that, for a given compound, the ratio of the concentration on the particles (µg/g) and the dissolved concentration in the water (in µg/l) is a constant, characteristic for that compound.

What will happen when polluted material enters the water column?
The dissolved concentration in the water column will increase due to the mixing of pore water bearing a higher concentration. However, the amount of pore water will be very small, generally, compared to the volume of the receiving watercolumn and the resulting increase of concentration will be small, unless mixing is substantial. Substantial mixing may occur when using silt screens.
Since most of the pollutant enters the water column in particulate (adsorbed) state, the dissolved concentration is determined primarily by desorption and adsorption processes. The change in the adsorbed concentration depends on whether the particulate matter in the water column and in the sediment have different concentrations.
When both concentrations are the same, no desorption or adsorption will occur when sedimentary material enters the water column.

It is important to realise that in the first instance the number of particles present in the water column is irrelevant. It is the difference in concentration of the particles which determines whether or not desorption occurs. When the sedimentary particles have a lower concentration than the water particles, the dissolved concentration in the water will even get lower, due to adsorption.
Finally, in cases where the particulate concentration in the sediment to be dredged is lower than the concentration in the suspended matter, it is sufficient to control the dispersion of the particles. Only when the pollution concentration on the sediment particles is greater, does the particle concentration also become important, because this determines the total amount which can be liberated.

In many cases the concentration on the sediment particles can be expected to be higher than the suspended matter concentration, because dredging of polluted sediments will often take place in systems where measures are taken to reduce the loads to the water system. In that case, mixing of sediment particles will cause desorption, according to the partition theory, to restore the equilibrium. It is not very clear how much time this desorption process will take, but desorption seems to be slow (Coates and Elzerman, 1986; Shorten *et al.,* 1990). It is difficult to estimate how much time is spent in the water column by a sediment particle brought into the water during dredging. The water movements, as well the natural movements as those resulting from the dredging equipment, are very important. In quiet conditions and salt water, the settling time for the generated turbidity is about hours. In fresh water sedimentation may take some more time. However, in less quiet conditions (rivers, tidal waters) the residence time in the water column can be much higher for “fine” particles, which generally carry the highest pollutant concentrations, than for “coarse” particles. For the fine particles the water residence time will be much longer and a substantial mobilisation (and dispersion) of pollutants might be the result.

The Consequences

What can be done to reduce the risks of dredging polluted sediments? In the first place, dispersion of pollutants to the surroundings, either in dissolved or in particulate state, should be prevented as much as possible. In the second place, care should be taken that the pollution level of the new top layer is much lower than that of the existing top layer, because release of pollutants may be high due to exposition to the environmental conditions in the water column.

Preventive actions are different for heavy metals and organic micropollutants.
For heavy metals the precipitation of iron-(oxo)hydroxides provides a certain safety belt. This safety belt is present in the turbidity cloud, and offers protection against dispersion in dissolved state on the very short term. In those circumstances, the mode of occurrence of the metals changes from precipitated to adsorbed. When the adsorbed metals are quickly transferred back to anoxic conditions, the original precipitated mode of occurrence is restored.
However, frequent resuspension of sediment containing adsorbed heavy metals might cause continuous desorption of pollutants to the water column.
The removal of heavy metal polluted material must therefore be as complete as possible. As long as there is good control of the dispersion of the water which comes into contact with the sediment material (e.g. properly functioning silt screens, isolated dredging location), the generation of turbidity is less important. However, the control of dispersion of the most riskful fine material and of the water itself, may offer as yet unresolved technical problems.

Figure 4. The Willem Bever at work with auger in a box. Specially designed and constructed dredger heads may reduce the turbidity generation substantially. Turbidity clouds seen here in the lower righthand corner are caused by a multicat and the traffic of a working vessel, not by the dredger.

For organic micropollutants, any mixing of sedimentary material and the water column should be avoided as much as possible. The amount of pollutants adsorbed to the DOM in the pore water may cause an increase of the dissolved pollutant concentration in the water column. In addition, the amount of pollutant released depends on the concentration difference between sediment and suspended matter. When the concentration in the dredging layer is higher than the concentration of the suspended matter, mixing within a volume of water isolated by silt screens may cause a substantial release of organic micropollutant into the dissolved state. This amount will escape control because of its dissolved nature.

Therefore, isolation of the sediment and process water from the water column should be achieved (e.g. by proper dredger head design, construction and operation (e.g. Figure 4).

The desorption from polluted particulate matter depends on the actual rate of release. It is as yet not clear whether the rate of desorption under dredging conditions is high enough to cause a substantial increase of the concentration in the water column.

A proper evaluation of the potential impact of dredging operations requires a reliable assessment of the background concentrations in the water column prior to dredging (i.e. suspended matter concentrations), because mobilisation is primarily determined by the difference in concentration between sediment and suspended matter. Due to the low concentrations in the water column and the analytical detection limits, this requirement deserves special attention.

Conclusions

1. The risks of dredging polluted sediments depend heavily on the local situation. Measures to reduce the risk can only be designed properly after a detailed analysis, using site specific data.
2. There is an urgent need for proper data collection during dredging activities to verify the results of this general, theoretical evaluation.
3. The environmental risks of dredging polluted sediments are primarily uncontrolled dispersion of pollutants and shifts in mode of occurrence towards dissolved forms, which have a higher bioavailability.
4. To reduce the risk of dredging polluted sediments, the dispersion of pollutants, either in dissolved or in particulate state, should be prevented as much as possible.
5. For heavy metals, a complete removal of the polluted sediment is more important than a temporary mixing of sedimentary matter with the water column, as long as dispersion from this mixing zone is prevented. Iron chemistry provides a temporary safety belt against dispersion in the dissolved state.
6. For organic micropollutants, mixing of sedimentary matter with the water column may result in a substantial, lasting increase in water column concentration due to the transfer of pollutants bound to Dissolved Organic Matter to the water column and to the desorption of pollutants from particles (see also 7).

7. For organic micropollutants the risks of dredging depend on the difference between the pollutant concentrations of the sediment and of the suspended matter. When the suspended matter concentration is lower than the sediment concentration, any mixing of sedimentary matter might cause a substantial release of pollutants to the water column.
8. The role of desorption kinetics in the mobilisation process in relation to the residence time of particles in the water column is as yet not very clear.

Further investigations will be directed towards the confirmation of the results of this evaluation in practical situations. These include performing monitoring programmes during dredging projects, evaluation of the kinetics of sulfide oxidation and desorption processes in relation to sedimentation rates, and the development of measuring equipment to monitor the dispersion of pollutants and (fine) particles.

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Charles W. Hummer, Jr.

Books/ Periodicals Reviewed

Back to the Future: The Potential in Infrastructure Privatisation.
American Express Bank. Oxford University Press.
November 1994, pp. 28. No charge.
Michael Klein and Roger Neil

This intriguing essay was originally published by *Finance and the International Economy: 8,* and received the Silver Award from the AMEX Bank Review Prize Essays. It covers an amazing array of thoughts in a relatively few pages. As one of the comments in Annex I states:
"The analysis of problems associated with privatisation of infrastructure, and experience to date, is masterfully done. The reasoning behind the advocacy of repeated franchise bidding is compelling. All those interested in the privatisation alternative for infrastructure will learn from this highly readable and original essay".

Both authors are part of the World Bank's new advisory group on Private Participation in Infrastructure.
Michael Klein, a German national, is manager of the group. He holds a Ph.D. in economics from the University of Bonn, Germany. Neil Roger, a Senior Economist in the group, is Australian and studied economics at the University of Western Australia.
The premise of the book is based on the wave of privatisation and deregulation which is sweeping infrastructure sectors around the globe. It is emphasised that such a move historically is not unique, and that this trend has occurred in the past only to see reverses towards state solutions. The question is then posed whether this current direction is merely part of a cycle of prior behaviours or is a new trend which portends a more lasting regime permitted by recent shifts in policy and advances in technology.

Clearly privatisation is indeed sweeping the world, with the Northwestern Hemisphere predominating, but with India, China, Australia and the rest of the Far East not far behind. The reasons forwarded for this trend in OECD and Latin American countries are the disenchantment with the efficacy of State solutions and precarious government finances. A more general factor may be technical changes, particularly in telecommunications where new transmission and compression techniques allow private competition in what was a model of monopolies.

Of interest is the explanation of the cycle of national solutions to privatised ones. The question posed is whether this observed flourishing of privatisation is simply a repeat of past cycles, or is it somehow different this time around due to contemporaneous factors. The "Privatisation-Nationalisation Wheel" is thought-provoking. Starting with an entrepreneurial phase, it evolved through succeeding phases of consolidation; regulation of fees and franchises; decline in profitability; withdrawal of capital and services; public takeover; public subsidies; declining efficiency; dilemma of subsidy cuts, fee increases, and service cuts; and finally, privatisation before returning to the entrepreneurial phase. The essay then briefly discusses the factors which are involved in the cycle and the historical rationales and the strengths of private solutions. Some historical reasons for reversal to national solutions are thought to be misguided: subsidisation of industry, inflation control, and patronage. Other factors seem quite compatible with private solutions: namely, system integration, national security, concerns over health and safety and mistrust of foreigners.

It is suggested that although governments can achieve all socially desirable objectives for the provision of infrastructure under private ownership, there remain some major issues and potential drawbacks because in many cases lack of competition may lead to pricing exploitation. A discussion of regulatory systems to protect against exploitation by engendering competitive settings follows. The importance of competition is discussed, including the increasing importance of reputation as a motivating factor for firms engaged in multinational markets. Positive reputation in one national setting has become more observable and transferrable on a global basis.
Furthermore the suggestion is made that governments

should expand the scope of competition in the market wherever possible and allow take-over bids from the private sector on natural monopoly franchises. Multiple jurisdiction operations would allow the replacement of non-performing firms. Larger firms can effectively operate in several markets, even worldwide, and in doing so the acquisition of a good reputation is very important and efficiency motivating.

The essay concludes with five ostensibly uncontroversial assumptions:
- all socially desirable policy goals for infrastructure provision can be achieved under private ownership;
- private firms are likely to perform at least as efficiently as public enterprises;
- expanding the scope for effective competition amongst infrastructure firms is desirable;
- franchise bidding is no worse than traditional utility regulation, but holds more promise to increase competition;
- financial market deregulation and liberalisation is desirable including for reasons unrelated to infrastructure.

The conclusion further states that strategy of introduction of competition and repeated franchise bidding has important implications for the international economy leading to the emergence of new types of international infrastructure companies and growth in cross-border flows for infrastructure finance.

Dredging and Marine Construction

Though the dredging and marine construction industries are not considered directly, those involved in these areas, either from a private or public perspective, will make meaningful and relevant connections as they read through the essay. The trends in privatisation in dredging-related activities certainly seem to be consistent with the trend in other infrastructure provision areas. But in some dredging markets, such as Japan, France and the United States, the movement towards privatisation and open international competition of dredging has been much slower, and vestiges of protectionism persist in this relatively small part of an otherwise relatively open and competitive construction market. Recent agreements between the United States and the European Union again demonstrate an open competition in various infrastructure and construction areas. Dredging is notably the exception. This essay would propose that these anachronisms will in due course most likely be swept up in the general trend towards privatisation and open markets.
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DEBBY (Dredging and Environmental BiBligraphY): An Update

The need for a comprehensive bibliography of dredging literature, reports and data which are generally not available to the public was first clearly identified by the London Convention of 1972 (LC72). In an admirable demonstration of teamwork, various dredging organisations took the initiative to develop a bibliographic service for the International Maritime Organization (IMO). The Central, Eastern and Western Dredging Associations (CEDA, EADA, WEDA), the International Association of Ports and Harbors (IAPH), the Permanent International Association of Navigation Congresses (PIANC) and the International Association of Dredging Companies (IADC) joined forces to develop this computerised dredging and environmental bibliography, known as DEBBY (see *Terra et Aqua,* nr. 58).

In March 1995, a year ago, it was reported that the system was in its third generation prototype and available for field testing and evaluation. This evaluation has taken place, and at the World Dredging Conference in Amsterdam in November 1995 the working group reported that DEBBY is now ready for distribution.

The present database contains some 2,500 entries which includes data from all the participating organisations. Since the test version presented last March, new material has been added from Dredging '94 (complete conference); EADA '95 (complete conference), from *Terra et Aqua,* volumes 46-53 and 1994-1995, IMO (London Convention documents); World Dredging Conference '95 (complete conference); and from Delft University of Technology.

The Minimum System Requirements for the database are: IBM personal computer (or compatible) running under MS-DOS; AT-level computer with 640 kilobytes internal memory; 40 megabyte internal hard disk drive; 4 1/2-inch floppy disk drive.
The DEBBY disk provided will install itself on the user's computer in such a way as to load the programme, database and other files needed to use the system.
In other words, it is a self-contained system. The software as now configured has two modules: a maintenance module and a retrieval module. Maintenance of the database will be conducted via CEDA/MTEC which will act as a central hub for updating.

IADC has acted as the contracting agent for the developmental contract, and will now coordinate the distribution of the programme. The programme is available from the IADC Secretariat in The Hague.
An evaluation copy of the full database, manual on floppy disk, no registration and retrieval module only, costs NLG 25. The full version including the full database, printed manuals, one year free updates, and retrieval and maintenance modules is NLG 100.

Seminars/ Conferences/ Events

CATS III Congress

Ostend, Belgium
March 18-20 1996

The theme of the third edition of the international CATS Congress is “Characterisation and Treatment of Clean-up Sludge from Dredging, Sewage Sludge and Comparable Industrial Process Sludge”. Each CATS Congress is structured around the same major topics: Characterisation of sludges; treatment techniques; environmental impact of processing and storage; practical, economical and environmental aspects; and legal regulations. The congress is organised by the Technological Institute of the Royal Flemish Society of Engineers.

For further information contact:
CATS III Congress c/o Ingenieurshuis vzw
Att: Ms Rita Peys
Desguinlei 214
B-2018, Antwerpen 1, Belgium
tel. +32 (3) 216 0996, fax +32 (3) 216 0689

Maritime Vietnam ’96

International Exhibition & Convention Centre
Ho Chi Minh City, Vietnam
April 17-19 1996

Reflecting the emergence of Vietnam as an important market, Maritime Vietnam 96 is organised in cooperation with the Chamber of Commerce and Industry of Vietnam (VCCI) and Vietnam National Maritime Bureau. With a more than 2,800 nautical-mile long coastline, Vietnam is clearly a maritime country, and inland water transportation is crucial for trade. Investments are being made in the development of port facilities, deep seaports, export processing zones (EPZ), ship repair, dredging, ship and marine equipment and so on. The second Vietnam Maritime & Inland Shipping Exhibition incorporates Vietnam Port ’96.

For further information contact:
RAI Exhibitions Singapore Pte Ltd
1 Maritime Square, #09-49
World Trade Centre, Singapore 099253
tel. +65 272 2250, fax +65 272 6744

Amsterdam RAI, P.O. Box 77777
1070 MS Amsterdam, The Netherlands
tel. +31 (20) 549 1212, fax +31 (20) 646 4469

C.P. Wulf, Roosens Park 2
22605 Hamburg, Germany
tel. +49 (40) 880 2467, fax +49 (40) 880 7172

RAI Exhibitions London Ltd
Glen House, Suite 509
200/208 Tottenham Court Road
London W1P 9LA, U.K.
tel. +44 (71) 436 9774, fax +44 (71) 436 5694

32nd International Seminar on Port Management

Institute for Hydraulic Engineering
Delft, The Netherlands
May 17-June 14 1996

The Seminar provides port directors, terminal managers, freight forwarders and senior policy makers with ”state of the art” knowledge about port management and transport. The Seminar is organised in cooperation with the Rotterdam and Amsterdam Municipal Port Managements. It includes observation visits to the ports of Amsterdam and Rotterdam as well as a one-week study tour to Antwerp, Ghent and Zeebrugge in Belgium, Calais, Eurotunnel terminal and Paris, France and London and Felixstowe in the U.K.
Special one-day seminars on such topics as “Intermodal Transport and the Role of the Port” and “Port Privatisation” plus 2 and 3 day workshops on “Europort Management Simulation” and “Human Resource Control Management” are included. The course fee is NLG 5000 which includes tuition, travel costs and lodgings during study tours. A limited number of scholarships for students from developing countries are available.

For further information contact:
International Institute for Infrastructural,
Hydraulic and Environmental Engineering (IHE)
P.O. Box 3015, 2601 DA Delft, The Netherlands
tel. +31 15 215 1715 or 1700, fax +31 15 212 2921
e-mail: rdh@ihe.nl

11th International Harbour Congress

Antwerp, Belgium
June 17-21 1996

Organised by the Royal Flemish Society of Engineers, this five-day congress will be held together with the 8th International Harbour Exhibiton. Topics will include all aspects of port and harbour technology such as:

- port planning: extension, renovation, future policy making, environment, financing through privatisation;
- port infrastructure design: reducing wave agitation; quality control and care; measurements, instrumention; design in third world situations;
- port construction: innovative techniques, new ship types, protection of water bottom;
- port access: approach channels, captial dredging and maintenance in rivers; and
- maintenance: planning, reducing work on piers, breakwaters, etc.; maintenance dredging; emergency intervention; third world ports.

For further information contact:
Ms Rita Peys
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B-2018 Antwerp, Belgium
tel. +32 (3) 216 0996, fax +32 (3) 216 0689

Coastal Engineering Education Programme

Texas A&M University/CERC
Fall 1996-Summer 1997

A one-year Masters of Engineering programme in Ocean Engineering is being offered through the Waterways Experiment Station Graduate Institute jointly by Texas A&M University (TAMU) and the Coastal Engineering Research Center (CERC). Though the course is tailored to meet the needs of the US Army Corps of Engineers for coastal engineering and maintenance, all qualified candidates are invited to apply.
Applicants must have a BSc in engineering; a good scholastic record; acceptable Graduate Record Examination scores; and international students must pass the TOEFL exam. The course will run from the Fall of 1996 through the Summer of 1997, and will require a minimum of 36 credit hours for the completion of a degree.

For further information please contact as soon as possible:
Dr C. H. Pennington, Director, WES Graduate Institute, 3909 Halls Ferry Road, Vicksburg MS 39180-6199, USA
tel. +1 601 634 3549, fax +1 601 634 4180,
or
Dr. B.L. Edge or Dr. Robert E. Randall,
Ocean Engineering Programme
Texas A&M University, College Station,
TX 77843-3136, USA
tel. +1 409 847 8712 / 845 4515,
fax +1 409 862 1542

PIANC Conference on Inland and Maritime Navigation and Coastal Problems of East European Countries

Gdansk, Poland
September 1-5 1996

The Marine Civil Engineering Department of the Technical University of Gdansk is the site of the PIANC (Permanent International Association of Navigation Congresses) conference on inland and coastal problems in Eastern Europe. The conference will be running simultaneously with Baltexpo. Focussing on East European waterways, the topics to be discussed are:

- inland navigation in East European countries and its link to other countries;
- maritime navigation with particular consideration of shipping in the Baltic, Black, Adriatic and other seas;
- competitiveness of navigable waterways;
- pollution of seas due to contaminated rivers in Eastern Europe;
- coastal problems such as sediment, beach and harbour pollution in Eastern Europe;
- rehabilitation and modernistation of existing structures; and
- particular areas of shipping such as from Scandinavian ports to Northeast Europe.

Further information is available from:
Prof. B.K. Mazurkiewicz
Technical University of Gdansk
ul. G. Narutowicza 11/12
80 - 952 Gdansk, Poland
tel. +48 58 472611, fax +48 58 471436
telex 0512302 plg pl

Hydro 96

De Doelen Congress Centre
Rotterdam, The Netherlands
September 24-26, 1996

The tenth international biennial symposium of The Hydrographic Society is being organised by The Society's Benelux Branch and will take place in September 1996. The Symposium's topics will address key hydrographic issues affecting port and other applications, including: port and coastal surveys; port and coast geodesy and navigation; dredging surveys; mapping; and water management. The proceedings will be supported by an exhibition of equipment and services at which the Port of Rotterdam will be a major participant.

For further information contact:
Mrs P.Y. van den Berg
Hydro 96 Organising Committee
Oceanographic Company of The Netherlands
P.O. Box 7429
2701 AK Zoetermeer, The Netherlands
tel. +31 79 342 8316, fax +31 79 341 5084

Membership List IADC 1996

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

Africa

Boskalis Togo Sarl., Lomé, Togo
Boskalis Westminster Cameroun Sarl., Douala, Cameroun
Dredging International Services Nigeria Ltd., Lagos, Nigeria
HAM Dredging (Nigeria) Ltd., Ikeja, Nigeria
Nigerian Dredging and Marine Ltd., Apapa, Nigeria
Westminster Dredging Nigeria Ltd., Lagos, Nigeria
Zinkcon Nigeria Ltd., Lagos, Nigeria

The Americas

ACZ Marine Contractors Ltd., Brampton, Ont., Canada
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Gulf Coast Trailing Company, New Orleans, LA, USA
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Australia

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Almagià S.p.A., Rome, Italy
Anglo-Dutch Dredging Company Ltd., Beaconsfield, United Kingdom
A/S Jebsens ACZ, Bergen, Norway
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Espadraga, Los Alcázares (Murcia), Spain
HAM Dredging Danmark Aps, Korsør, Denmark
HAM Dredging Ltd., Camberley, United Kingdom
HAM, dredging and marine contractors, Capelle a/d IJssel, Netherlands
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N.V. Baggerwerken Decloedt & Zoon, Brussels, Belgium
Philipp Holzmann Aktiengesellschaft, Hamburg, Germany
S.A. Overseas Decloedt & Fils, Brussels, Belgium
Skanska Dredging AB, Gothenborg, Sweden
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Sociedad Española de Dragados SA., Madrid, Spain
Società Italiana Dragaggi SpA. “SIDRA”, Rome, Italy
Société de Dragage Holland (France) S.A., Bondues, France
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