REVIEW OF DREDGING PRACTICE IN THE NETHERLANDS

GEO REPORT No. 17

S.T. Gibert & P.W.T. To

GEOTECHNICAL ENGINEERING OFFICE
CIVIL ENGINEERING DEPARTMENT
HONG KONG

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PREFACE

In keeping with our policy of releasing information of general technical interest, we make available some of our internal reports in a series of publications termed the GEO Report series. The reports in this series, of which this is one, are selected from a wide range of reports produced by the staff of the Office and our consultants.

Copies of GEO Reports have previously been made available free of charge in limited numbers. The demand for the reports in this series has increased greatly, necessitating new arrangements for supply. In future a charge will be made to cover the cost of printing.

The Geotechnical Engineering Office also publishes guidance documents and presents the results of research work of general interest in GEO Publications. These publications and the GEO Reports are disseminated through the Government's Information Services Department. Information on how to purchase them is given on the last page of this report.

A. W. Malone
Principal Government Geotechnical Engineer
April 1995

FOREWORD

This report is based on a duty visit by S.T. Gilbert and P.W.T. To to the Netherlands between 28 January and 6 February 1991 to examine Dutch dredging and mud disposal technology. The visit was arranged through CED Agreement CE 44/90 with DEMAS, a Dutch dredging consultancy firm, who have been undertaking dredging studies for the GEO as part of Phase II of the Fill Management Study.

The number of major dredging projects carried out in Hong Kong so far have been very limited. To undertake the scale of dredging operations required for construction of the new airport and associated port and urban developments over the next 10 years it will be necessary to call on considerable overseas dredging expertise. The Netherlands is generally considered to be at the forefront of dredging and disposal practice. The employment of DEMAS under CED Agreement CE 44/90 provided a good opportunity for the GEO to improve its knowledge in these areas.

The programme consisted of visits to a number of dredging and disposal sites within the Netherlands, mainly in the port of Rotterdam, and Belgium, and meetings with dredging personnel and specialists within Government organisations, consulting firms, dredging contractors and research institutions.

The main topics reviewed in the report are the status of the dredging industry in the Netherlands and Belgium, dredging methods, contracts and research, methods of transportation and reclamation, and the removal, treatment and disposal of contaminated materials.

The authors acknowledge the considerable efforts of Messrs. T.W. van der Steege and K. Ooms of DEMAS in organising the visit and the hospitality of the personnel from the various Dutch and Belgium dredging organisations met during the visit. Mr M.C. Yeung, STO(G) in the Planning Division, assisted in the production of the report.

(R. P. Martin)
Chief Geotechnical Engineer/Planning

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1. INTRODUCTION

As part of the GEO's Fill Management Study - Phase II a small consultancy study (Agreement CE 44/90) has recently been carried out by Dredging, Engineering & Management Studies (DEMAS) to review current site investigation and dredging practice in Hong Kong. DEMAS is a foundation established in 1984 by the Dutch Association of Dredging Contractors at the request of the Dutch Government. Its aims are to provide the expertise and services of the Dutch dredging industry mainly to developing countries. DEMAS carries out feasibility studies, preparatory planning and design in the fields of dredging, offshore site investigation, coastal engineering, marine and environmental regulations. In project work DEMAS draws on the skill and knowledge of the entire Dutch marine, dredging and hydraulic engineering industries.

The amount of dredging carried out in Hong Kong so far has been very limited compared with major ports elsewhere in the world. However this situation will change rapidly in the next few years because of the new airport and port developments. To improve and develop knowledge of dredging and related issues, a duty visit was arranged through DEMAS for GEO staff to visit The Netherlands between 28.1.91 and 6.2.91. The main aims of the visit were to examine different aspects of Dutch dredging practice and in particular to focus on the major dredging issues relevant to Hong Kong over the next ten to fifteen years.

The programme for the duty visit was organised by DEMAS and consisted of visits to major maintenance and capital dredging operations, and meetings with representatives from the Dutch Government Departments responsible for dredging works, dredging contractors, consulting engineers and research institutions closely involved with the dredging industry. Details of the itinerary and a summary of the daily activities carried out during the duty visit are given in Appendix A. A list of the contacts made during the duty visit is given in Appendix B.

In view of the large number of sites and institutions visited, it was decided to draw together all the information gathered during the visit and to present it as a Natural Resources Report.

2. STATUS OF THE DREDGING INDUSTRY

2.1 The Netherlands

2.1.1 General

The history of the Netherlands is linked to that of a never ending fight against water. The country's very survival depends on its ability to keep the sea out and to regulate three big European rivers and their deltas. Ports, rivers and canals must remain accessible to ships of all kinds, and water provided where it is needed.

It is therefore not surprising that Dutch technology in the fields of coastal and waterway engineering is versatile and unrivalled in the world. Dutch dredging, shore protection and erosion control industries are called upon by countries worldwide. Despite suffering greatly from the effects of a major worldwide recession in the early to mid 1980's the Dutch dredging industry has survived and restructured itself to form some of the largest private dredging organisations worldwide. These firms are capable not just of undertaking dredging but also a whole package of activities related to marine and civil engineering works. There are currently less than ten major international Dutch dredging contractors. Details of some of these organisations are given in Section 2.1.4.

There is now little major capital dredging within the Netherlands and maintenance dredging represents the primary dredging activity. However the recent upturn in the overseas capital dredging market, particularly in the Far East, is likely to result in relatively full order books "for the forseeable future".

Unlike Hong Kong, in the Netherlands and Belgium a very close relationship exists between Government, which represents the main client for dredging works, and dredging contractors. Consultation between Government and dredging contractors frequently takes place before major or difficult dredging projects are let to discuss design of the project, the most appropriate methodology and the selection of dredging plant for undertaking the works. This cooperation has often resulted in improved quality of the dredging works, and in many cases an overall reduction in project cost, construction time, disputes and subsequent claims. In addition much of the dredging research work undertaken by research institutions in the Netherlands over the last 25 years has been with the joint backing of the Dutch Government and a number of the major dredging contractors (discussed later).

2.1.2 Government

Very broadly the dredging industry in the Netherlands can be divided into firstly, capital dredging activities which are mainly carried out in lakes and adjacent areas of the North Sea and which are currently at a low level of activity, and secondly, maintenance dredging of waterways and harbour areas which constitutes the major part of the dredging work carried out in the Netherlands.

Most maintenance dredging carried out in the Netherlands is the Port of Rotterdam. This necessitates the removal of approximately 23M m^3 of silt from the harbour and rivers each year, of which around 10M m^3 is lightly to heavily polluted.

Control of dredging activities is carried out at central, provincial and local government levels. Most maintenance dredging work is commissioned by the Rijkswaterstaat (or the Ministry of Transport and Public Works) which is responsible for maintaining the depth of navigation channels leading to the harbours, in the estuarine areas and in the sea. The Rijkswaterstaat is divided into a number of regional, technical and scientific and construction directorates as shown in Appendix C. In the inner harbour areas, such as in Rotterdam port, the responsibility or maintaining navigable depths lies with the Port Authority who in turn delegate this responsibility to the respective Public Works Departments.

In addition to the activities described above the Rijkswaterstaat, together with the major dredging contractors, also forms a consortium which commissions basic dredging research as discussed in Section 2.1.5.

2.1.3 Consultants

A number of specialist dredging consultants are present in the Netherlands but generally do not play a major role in the operation of the dredging industry as a result of the very limited amount of consultancy work undertaken for the Government and the policy of many of the major dredging contractors to set up their own specialist consultancy subsidiaries. Their activities are mainly concentrated in overseas countries. Some large engineering consultants also have specialist dredging departments which mainly provide advice on planning and design aspects of dredging operations in multidisciplinary projects.

Consulting engineers in the Netherlands are represented by two associations. Firstly, within the Netherlands, by the Dutch Association of Consulting Engineers (ONRI), and secondly, overseas, by the Netherlands Engineering Consultants (NEDECO), an umbrella organisation comprising independent Dutch consulting engineers working together on international projects.

During the duty visit meetings were held with a number of specialist and multidisciplinary consulting firms. Details are given in Appendix A.

2.1.4 Contractors

As a consequence of the major worldwide recession in the dredging industry in the early to mid 1980's, as discussed above, the Dutch dredging industry comprises a small number of relatively large dredging contractors which dominate the market (particularly in capital dredging and long term maintenance dredging) and a large number of relatively small dredging contractors whose main activities are short term maintenance dredging works. It is not the purpose of this report to produce an in-depth profile of all the dredging contractors operating in the Netherlands. However it is considered relevant to briefly describe the main expertise of the major contractors who are currently tendering for, or undertaking some of the major dredging works in Hong Kong. These are:

(1) Ballast Nedam Dredging b.v. Ballast Nedam Dredging, a subsidiary of Ballast Nedam b.v. - a major multidisciplinary building and civil/marine engineering contractor, has a modern and versatile fleet of around thirty dredgers, consisting predominantly of cutter suction and trailer (including the world's third largest) dredgers. Their research and development facilities were set up as far back as the 1950's and they are now at the forefront of technological developments within the dredging industry. These include developments in the use of deep suction dredgers (including the two largest in the world) to depths in excess of 80 m and the use of trailer dredgers to dredge rock and hard materials. Their current workload in the Netherlands includes a long term sand borrowing operation in the North Sea and reclamation works for a major new town development in northern Holland (see Figure 1) both of which were visited during the duty visit. They had previously been involved, through their subsidiary dredging company, Broekhoven, in the construction of the Slufter contaminated spoil containment area in Rotterdam Harbour (discussed later in this Report). Ballast Nedam Dredging have extensive overseas experience particularly in the Middle and Far Easts, and Australasia. In conjunction with Jan de Nul they are now undertaking the dredging works for Container Terminal 8. Their main areas of expertise include:

(a) dredging and maintenance of ports and waterways,
(b) reclamation for industrial and other developments,
(c) coastal protection work and beach replenishment,
(d) offshore trenching and backfilling,
(e) breakwater construction and slope protection works,
(f) hydraulic transport of fill over long distances,
(g) winning of marine fill with deep suction methods,
(h) dredging and processing of polluted soil from river and lake beds,
(i) soil improvement by vertical drainage and compaction methods.

(2) Boskalis International b.v. Boskalis is the world's largest private sector dredging organisation and presently commands around 30-35% of the international free market dredging. This is mainly as a result of their recent takeovers of Breejenbout and Zanen Verstoep. Europe (mainly the Netherlands) and Asia are the main markets for their operations, however they also undertake a significant amount of work in Africa and the Americas. Their present fleet comprises over 60 dredgers, predominantly cutter suction, trailer and grab dredgers together with a wide variety of

auxiliary craft, plant and equipment. They are currently undertaking the dredging works for West Kowloon Reclamation (Southern Section).

Their major areas of expertise include:

(a) dredging and maintenance of ports and waterways,
(b) reclamation, including beach replenishment and construction of man-made islands,
(c) trenching for pipelines and immersed tunnels.

Other services provided by Boskalis through its subsidiary companies include:

(a) surveys and site investigations,
(b) port and waterway engineering,
(c) marine civil engineering,
(d) coastal, river and bank protection.

Boskalis have recently expanded its operations to include dredging and treatment of contaminated materials and is now a market leader in the Netherlands in these fields. This work is undertaken through its subsidiary Boskalis Dolman b.v.. In particular, developments in the following techniques have been carried out by the company:

(a) the use of closed grabs for removing contaminated materials,

(b) disc bottom cutter for removing thin layers of contaminated materials (Rosenbrand 1990),

(c) the development of both pilot units and large scale equipment specifically designed for the treatment of contaminated mud (van Raalte, 1990).

A visit was made to the headquarters of Boskalis in Rotterdam on 3.2.91 during which a number of their dredging operations were observed including the removal of contaminated silt using closed grabs in Rotterdam Harbour (discussed later).

(3) Van Oord Group. Van Oord Group is a family-owned international dredging and marine contractor. They have a small fleet of between 10 and 20 medium to large dredgers, consisting mainly of trailer and cutter suction dredgers, as well as a large fleet of auxiliary vessels and plant mainly for placement of rock for underwater slope protection. They are currently active worldwide and have recently been awarded the dredging works for the Third Industrial Estate in Tseung Kwan O New Town Development. Their main areas of expertise include:

(a) dredging and maintenance of ports and waterways,
(b) harbour and breakwater construction,
(c) artificial island construction,
(d) underwater slope, bank and bed protection,
(e) rock dumping,
(f) pipeline trenching, protection and stabilisation,
(g) reclamation and beach replenishment.

(4) Volker Stevin Dredging. Volker Stevin Dredging, a subsidiary of the Royal Volker Stevin Group a major construction and civil/marine engineering contractor, recently merged with Ham

Dredging and is one of the most innovative of the major Dutch dredging contractors. Their major developments have included:

(a) the use of a special suction head for the removal of contaminated material,

(b) water injection dredging (movement of dredged material as a density current by water injection into the dredged material) (See Appendix D),

(c) the development of trailer dredgers with closed holds and dragheads that can be specially adjusted,

(d) the development of a ceramic process (ECOGRIND) to convert contaminated dredged material into a building material (Schouten & Rang, 1989).

Volker Stevin have developed considerable experience from undertaking major maintenance and capital dredging projects in the Netherlands including the construction and maintenance of waterways and the development of sea defence works. They are currently active throughout much of the world and have a very diverse fleet of almost 30 dredgers which includes some of the world's largest trailer and suction dredgers. In conjunction with HAM dredging they are currently undertaking the dredging works for West Kowloon Reclamation (Northern Section) and for the advanced works for the New Airport.

Their major fields of expertise include:

(a) construction and maintenance of harbours, offshore channels and inland waterways,
(b) reclamation of land and beach replenishment,
(c) trenching for and covering of underwater pipelines,
(d) construction of artificial islands,
(e) marine surveys and site investigation.

They have recently set up an environmental affairs department which initiates and co-ordinates developments concerning dredging, treatment and/or disposal of contaminated sediments, as well as safety aspects relating to these operations.

(5) HAM Dredging. HAM Dredging, a subsidiary of Hollandsche Aanneming Maatschappij, who recently merged with Volker Stevin are a major international dredging contractor. They have a small fleet of between 10 and 20 moderate to large dredgers, consisting mainly of trailer and cutter suction dredgers, as well as an associated fleet of auxiliary vessels and plant.

Their overseas activities are particularly developed in Europe, Asia, Africa and Australia (in joint venture with Boskalis). Ham have already build up an impressive track record of dredging projects in Hong Kong over the last 5 years. This includes deepening part of the access channel used by large coal carriers to the Castle Peak power station, dredging and reclamation work for the construction of Container Terminals 6 and 7, and the recent replenishments of Repulse Bay beach and part of South Bay beach on Hong Kong Island. In conjunction with Volker Stevin Dredging they are currently undertaking the dredging works for West Kowloon Reclamation (Northern Section) and for the advanced works for the New Airport.

Their main areas of expertise are:

(a) dredging and maintenance of ports and waterways,
(b) reclamation and beach replenishment
(c) shore and bed protection
(d) offshore trenching and protection of pipelines and offshore facilities
(e) underwater rockbreaking

In addition to the activities described above these contractors together form a consortium which commissions basic dredging research within the Netherlands as discussed below in the next Section.

2.1.5 Research Institutions

For over twenty five years the major Dutch dredging contractors (Amsterdam Ballast Dredging, Royal Boskalis Westminster b.v., HAM, Van Oord-Utrecht b.v., Volker Stevin Dredging, & Zanen Verstoep n.v. (now part of the Boskalis Group), in conjunction with the Ministry of Transport and Public Works (Rijkswaterstaat), have commissioned basic research to Delft Geotechnics and Delft Hydraulics (Steeghs et al, 1989). These research activities are managed by a consortium called Dredging Research Association (CSB). The programme is funded by the participants themselves; however in recent years substantial subsidies have been awarded through the Dutch Government programmes to further technological innovations.

Two main fields of basic research have been carried out. Firstly there is research into the principles of soil excavation by dredging. This has been mainly concentrated at Delft Hydraulics with the support of Delft Geotechnics. The second field is the development of field and laboratory tests and procedures to establish the value of the relevant soil parameters. This has taken place mainly at Delft Geotechnics with Delft Hydraulics giving support. From this research theories have been formulated for cutting, suction, jetting, and deposition processes on the basis of methodical experimental testing in large scale facilities, supported by computer modelling.

During the same period the Delft University of Technology has focused its activities on education and research into new or improved equipment for the dredging industry.

A more detailed review of the activities of research institutions within the dredging industry is given in Section 7.

2.2 Belgium

Belgium operates a closed domestic market. Most of the maintenance and capital dredging work is undertaken by three main contractors : Dredging International N.V., Decloedte & Fils N.V., and Jan de Nul. They also undertake a considerable volume of overseas dredging. As only a brief visit was made to Antwerp insufficient time was available to examine and review the status of the dredging market. However from this brief examination a considerable volume of dredging work, both maintenance and capital, is apparently being carried out.

The expertise of two of these contractors is briefly described below as they are considered likely potential candidates to undertake major dredging contracts in Hong Kong.

(1) Jan de Nul. The Jan de Nul Group of companies specialises in dredging for civil engineering and maritime works. They have concentrated on dredging (particularly rock dredging and

reclamation) since 1951. They have a very modern fleet of over 20 dredgers, particularly of cutter suction dredgers, including the world's two largest cutters and the recently commissioned world's largest trailer dredger. Their particular areas of expertise include:

(a) dredging and maintenance of ports and waterways,
(b) trench dredging for pipelines in the nearshore and offshore regions,
(c) sandwave dredging in the open sea,
(d) pipeline backfilling with dynamically positioned vessels by the fall pipe method and with sidestone dumpers,
(e) dredging, treatment and disposal of contaminated soils,
(f) hard rock dredging in the open sea,
(g) coastal defence by beach replenishment.

Previous projects in Belgium have involved widening and deepening of existing waterways. Their main areas of overseas experience are in Western Europe, Latin America and SE Asia. In conjunction with Ballast Nedam Dredging they are undertaking the dredging works for Container Terminal 8.

(2) Dredging International (DI). DI operates a modern and diversified fleet of some 50 main dredging units. In Belgium DI does most of the maintenance dredging in the River Scheldt for the Port of Antwerp and during the recent visit were also undertaking a considerable amount of capital dredging projects. Overseas DI have undertaken many major dredging projects particularly in the UK, Middle East and Far East. They are currently constructing a new deep-water port at Laem Chabang, Thailand. They have not yet undertaken dredging work in Hong Kong.

Their particular areas of expertise include:

(a) dredging and maintenance of ports and waterways,
(b) the construction and the development of harbours,
(c) artificial islands,
(d) estuarine dams,
(e) canal and river improvement works,
(f) shore and bank protection,
(g) pipeline trenching and backfill,
(h) beach replenishment,
(i) supply of sea dredged aggregates.

In addition to the parent dredging company DI also has a number of specialist subsidiaries. These include the following:

Silt

DI in collaboration with Decloedte established this new company in 1988 to specialise in the treatment of contaminated dredged material. SILT's activities include research in the following fields :

(a) Fundamental research into the physical-chemical characteristics and behaviour of mud.

(b) Applied scientific research and application of various treatment techniques.

(c) Research into the environmental, social and financial impact of treatment techniques.

The research has led to the development of both pilot units and large scale equipment specifically designed for the treatment of contaminated mud. Several projects have already been successfully completed in Western Europe using this plant. Other projects have involved capping dredged contaminated materials dumped in borrow pits at sea and the use of chemical treatment methods to reduce and remove contaminants.

Hydro Soil Services (HSS)

This subsidiary provides specialist geotechnical consultancy and site investigation services. Their activities and services include hydrographic surveys, marine site investigation, environmental geotechnics, and strengthening and restoration of old harbour structures. HSS operates several self-elevating drilling platforms for undertaking offshore investigations. These platforms are designed to operate up to 15 km from the coast in water depths up to 23 m.

A visit was made to the headquarters of Dredging International in Antwerp on 31.1.91 during which a number of their dredging operations were observed including dredging associated with the construction of a tunnel across the River Scheldt and lake and river dredging for the reclamation of low lying areas. Subsequently on 5.2.91 a meeting was held with representatives of SILT to discuss their expertise in the removal and treatment of contaminated materials.

3. CONTRACTS

3.1 Maintenance Dredging

3.1.1 General

The responsibilities for maintenance dredging within the Netherlands are subdivided into two jurisdictions:

(a) Rivers and fairways - Rijkswaterstaat (Ministry of Transport and Public Works).

(b) Harbour areas - Port Authorities (carried out by dredging contractors on their behalf under the control of the respective public works depts).

Most maintenance dredging in the Netherlands is carried out in the port of Rotterdam, with only small amounts at other ports.

Rotterdam port is situated at the mouth of the Rivers Rhine, Meuse and Scheldt. The silt is mainly brought down by the River Rhine and is deposited generally within the estuary of the river at the brackish/salt water interface. Siltation also occurs at the mouth of the estuary as a result of washing in of material by tidal action from the North Sea. Currently as much as 70 cm/week siltation takes place in the inner harbour area. On average some 23M m^3 of sediments have to be removed from the port every year.

Within the Port of Rotterdam, areas requiring maintenance dredging are identified from regular sounding surveys and comparing the results against a "dredging atlas". This gives the maintenance depths which are contractually guaranteed by the Port Authority to the companies located beside the quays. Also recorded in this "atlas" are the boundaries of the harbour areas, the buoyed areas, silt traps (deeper harbour areas used to collect silt), levels along the quay walls, pockets between jetties, and the various construction depths of the quay walls.

The Port Authority of Rotterdam contracts out all its maintenance dredging (except within the navigation areas bounded by locks which is not under their jurisdiction). They consider this to be a more cost effective option than the port maintaining its own maintenance dredging fleet.

In order to minimise the disturbance to marine traffic, about 95% of maintenance dredging in the Port of Rotterdam today is undertaken by trailer dredgers (van de Ridder & de Wit, 1989). In areas of heavily contaminated silt alternative methods such as closed grabs or suction disc bottom cutters are used. Other methods such as special rake ploughs are also employed where obstructions are known to be present on the seabed. Also, bed levellers or scrapers may be deployed if maintenance dredging is to be carried out along quaywalls, where use of suction dredgers might cause undermining. Bed levellers can also be used to remove material between berthed ships where other types of dredgers are unable to gain access.

Maintenance dredging is carried out in the Port of Rotterdam by both long and short term contracts.

Disposal of the dredged material is carried out according to the level of contamination present and the contamination class. This is discussed in detail in Section 6.

3.1.2 Short-Term Contracts

Short-term maintenance dredging contracts are operated on an 'option charter basis' which consists of contracts, awarded directly without tendering, using fixed rates for dredging work. The selection of contractors is based mainly on the availability of plant at short notice. Those known to have idle plant of the right type are approached directly, and dredging can usually commence within a few days of the approach being made. Contracts are prepared and supervised by the Public Works Department. The Government policy (Public Works Department) on short term contracts is, if possible, to give priority to the small contractors. At the beginning of each year prices are fixed before knowong whether dredgers will be employed.

3.1.3 Long-Term Contracts

Long-term maintenance dredging contracts (up to 5 years) are run on a basis similar to site investigation 'term contracts' operated by the Geotechnical Engineering Office with fixed rates for dredging. However the Dutch Government does not maintain a list of approved contractors but instead keeps detailed records of past performance as a basis for selection. Long term contracts are awarded by either open tender or direct appointment. Any shortfalls in the hired capacity under these contracts are supplemented by short term contracts carried out on the 'option charter basis'. Separate long term contracts are attached to each dredger employed by the Government. These dredgers are employed under the contract for a minimum of twenty weeks per year. The contractor has the flexibility of either using his dredger for other projects during the remaining thirty two weeks of each year or to continue with further work under the long term contract, if required by the client. The Rijkswaterstaat currently has one main long-term contract (3 years with Volker Stevin/Boskalis) using trailer dredgers to maintain the Rotterdam Waterway and the Europort area (see Figure 2), whilst the Public Works Department of Rotterdam has long-term contracts in operation using a number of trailer dredgers (between 1700 & 3800 m^3), grab dredgers and bed levellers to maintain the harbour areas of Rotterdam.

3.1.4 Methods of Measurement

Until very recently payment for maintenance dredging works was only based on measurement of m^3 in the hopper. Additionally, for special circumstances, e.g. for dredging in small spots, payment per hour is also used. An additional method of measurement has recently been introduced called "the tonnes dry solids" method. The introduction of this new system of measurement is to provide contractors with further incentive to increase the density of the payload. Nautical depth for the purposes of maintenance dredging is defined as the level at which the in situ density of the seabed materials is 1.2 tonnes/m^3. Maintenance dredging then involves removing materials between a defined design depth and the nautical depth. Nuclear density probes are used by the port to determine the nautical depth in any area that requires maintenance dredging. Details of the two systems which are presently in operation are:

(1) 'Tonnes Dry Solids' System (Rijkswaterstaat) (Rijkswaterstaat, 1990). This method of measurement is based on calculating the weight of the dry solids in the hopper. Acoustic sensors on the side of the hoppers are used to measure top levels in the hopper, and transducers at the bottom of the dredger to measure the draught of the dredger below the unloaded position. These measurements allow determination of the volume and tonnage of the material in the hopper. 'Tonnes Dry Solids'(TDS) is calculated using the following formulae:

$$\text{mass density hopper load} = \frac{W_v - W_{ev}}{HV} \quad \text{. . . . (1)}$$

where W_v = weight of the vessel
W_{ev} = weight of the empty vessel
HV = total hopper load volume

$$TDS = \frac{(md_{hl} - md_w)}{(md_{dm} - md_w)} * md_{dm} * HV \quad \text{. . . . (2)}$$

where md_{hl} = mass density hopper load
md_{dm} = mass density dry material
md_w = mass density water
HV = total hopper load volume

The Rijkswaterstaat considers this method more realistic than the older system employed by the Public Works Departments as it gives the contractor more incentive to increase silt volumes and hence dredge more material.

(2) Public Works System. The older system of measurement employed by the Public Works Departments comprises payment per cubic metre, or per hour in special circumstances, e.g. for dredging in small spots. The form of measurement is usually agreed with the contractor during negotiation. Payment by volume is usually calculated only for hopper material with a density equal to or over 1.2 tonnes/m^3. Volume is usually measured by lowering into the hopper a lead ball weight whose submerged weight usually causes it to rest on top of the material with a density greater than 1.2 tonnes/m^3. Usually several positions are measured to account for any irregularities in the measured surface. A sample of the material above this level is collected and subsequently centrifuged to

determine the silt volume. This volume of solids is then added to the figure already determined for the material previously measured in the hopper with a density over 1.2 tonnes/m^3. Payment is then made for this total volume of material.

3.2 Capital Dredging

Only a few major capital dredging projects were being carried out in the Netherlands during the duty visit. Most capital dredging is carried out in either the neighbouring part of the North Sea to win sand for construction purposes, or as inland lake dredging for sand for reclamation of low-lying polder areas. Most of these projects are long-term and are operated on a similar contractual basis to the long-term maintenance dredging contracts. In addition capital dredging of sand is frequently carried out to replenish beaches (mainly sacrificially) to increase coastal protection along the coastline.

Several of these projects were visited and are discussed briefly in Section 4 and Appendix A.

3.3 Dredging Contracts in Belgium

The domestic dredging market in Belgium is dominated by three main contractors: Dredging International, Decloedte, and Jan de Nul. Non-Belgian firms are not allowed to work within Belgium as main dredging contractors although some dredging operations are occasionally carried out using Dutch sub-contractors.

Maintenance dredging contracts are mainly long term, occasionally short term. A volumetric method of measurement is usually employed. Contractors can also get additional payment for unforseen circumstances. Payment for fuel costs, etc are also index linked. Generally dredging rates in Belgium are higher than in the Netherlands, probably as a result of the closed market.

Maintenance contracts are usually divided equally amongst the three contractors without going to tender. However, capital dredging contracts, both soil and rock dredging, are usually let by open tender.

A number of projects were visited in Belgium on 31.1.91 and are discussed briefly in Section 4 and Appendix A.

3.4 Legislative Control

Historically most dredging works carried out in the Netherlands came under legislative controls dealing specifically with the handling and transportation of materials. More recently, additional environmental legislative controls have been introduced particularly in relation to the dredging and disposal of contaminated materials. This is discussed in more detail in Sections 4 & 6.

In addition to central government legislative controls, there are more specific controls at provincial and local government levels. This is particularly the case in the Municipality of Rotterdam where most Dutch maintenance dredging takes place.

Dredging licences are issued by both central government and the local authorities. The issue of dredging licences for the disposal of contaminated materials in the special containment areas (see Section 6) is usually carried out by both Central Government (Rijkswaterstaat) and local Government Authorities.

4. DREDGING OPERATIONS

4.1 General

Several dredging operations, involving a variety of dredging and transportation methods, were observed during the visit both in the Netherlands and Belgium.

The site visits allowed a variety of dredger types to be seen and a comparative assessment of dredging methods to be made (Table 1). Discussions were also held with DEMAS after the site visits on the general features of different types of dredgers, and their suitability and cost-effectiveness for various site conditions.

Dredging operations can be categorised broadly into maintenance dredging and capital dredging. The former involves primarily the removal of soft silt in thin layers to maintain navigation facilities in existing waterways, whereas bulk excavation for subsequent land reclamation is usually carried out in the latter. In capital dredging, however, project specifications may allow overdredging to certain tolerances, allowing the contractor to dredge an excess volume rather than mobilizing extra precision dredging plant to complete the job. The difference in nature between these two main types of dredging influences the choice in dredging equipment.

The main phases of dredging are :

(a) loosening (by means of mechanical and/or suction methods),

(b) transportation, by hydraulic transport in slurry form through pipelines, barges, or trailer suction hopper dredgers, and

(c) deposition in reclamation or disposal sites.

These are discussed separately in the following sections.

A review of these dredging methods is given below with reference to the sites visited and where relevant, their appropriateness to Hong Kong.

A variety of modern dredgers are shown in Figure 3. They can be classified broadly into hydraulic or suction dredgers and mechanical dredgers. Some combine the features of both types. Descriptions of different types of dredgers can be found in a number of references, e.g. Bray (1981), Groothuizen (1988), van Drimmelen & Loevendie (1988)), and are not discussed in detail here. The details given below are based on the observations and discussions carried out during the site visits, and are given to highlight some of the main advantages and disadvantages of the dredging methods examined. These comments should supplement the information contained in the references given above.

4.2 Suction Dredgers

4.2.1 General

Suction dredgers mainly excavate the soil by virtue of the suction power of a dredge pump, or in the case of cutter suction dredgers, by the additional action of the cutterhead. Common types include:

(a) trailing suction hopper dredger,
(b) deep suction dredger,
(c) cutter suction dredger,
(d) dustpan dredger,
(e) reclamation dredger, and
(f) water injection dredger.

The production rate is influenced to a great extent by the suction head produced by the pump and the rate of flow of the dredged material towards the suction inlet. The use of a submerged pump in the suction pipe can improve production rates and increase dredging depth, particularly in deep suction dredgers where they are more commonly used.

One obvious disadvantage of suction dredgers is that the dredged material is normally in the form of a low density slurry as a result of mixing with water during the dredging process. In barge and hopper transport, overflowing during the dredging process is often allowed, subject to turbidity constraints, to increase the density of the transported load. However in environmentally sensitive areas overflowing may not be permitted and a considerable volume of water will be transported with the dredged spoil. In contrast mechanical dredgers normally remove material at a much higher density, often close to the in situ density, than hydraulic methods as a result of less mixing with water during the dredging process.

Some of the main features of the types of dredgers examined during the duty visit are given below.

4.2.2 Trailer Suction Hopper Dredgers (See Figure 4 and Plate 1)

There are essentially two types of construction for trailing suction hopper dredgers (or "trailers") i.e. bottom-dumping (occasionally bow-discharging) and split-hull. Small trailers may have a hopper volume of about 500 m^3, while the largest can carry over 10,000 m^3 of material, the equivalent of many barge loads. Modern medium to large trailer dredgers can dredge to depths up to 30-35 m without the use of submerged pumps. Some of the largest Dutch trailer dredgers (e.g. the Leleystadt of Ballast Nedam) can dredge well in excess of these depths. The split-hull trailer (see Plate 2) is especially effective in discharging cohesive soils, as a result of the larger and wider opening over which dumping can be achieved. Split hull trailers were being used during the visit to Belgium on 31.1.91 in the construction of the Liefkenshoektunnel on the River Scheldt being carried out by Dredging International. The construction of the split-hull trailer is relatively simple, as its articulation relies on only two hinges. However, it is more expensive because of the more robust and complex structural framework for the vessel. The largest split-hull trailers are around 5000 m^3 in capacity. Above this size the heavy structural construction requirements render split-hull trailers uneconomical.

As for the bottom-dumping trailers, structural considerations require the bottom opening to be in form of a series of doors (see Figure 4): conical (funnel-shaped), sliding or flapping. When the dredged material consists of clays or boulders, it is sometimes difficult to ensure complete discharge of all materials in the hopper.

The trailer operates by slowly sailing over the dredging area and removing material using one or two dragheads deployed over the seabed. By combining mechanical excavation of the draghead (often by using water jets to first loosen the soil) and the suction forces of the dredge pump, soil is taken up and loaded into the vessel's hopper (Figure 4). At the bottom of the hopper, there is an inverted triangular structure (called the "chicken cage") which acts as structural support, and is used to ensure balanced distribution of the hopper contents. During loading, the density of the dredged slurry in the hopper may be increased by means of an overflow system, whereby the lean mixture resulting from the settling of the spoil is displaced overboard. This is achieved by discharging through an overflow outlet in the hull of the vessel. This can have the added benefit of removing much of the fines in sandy deposits containing significant quantities of silt and clay.

When loading is completed, the suction pipe is lifted and the vessel sails to the unloading location. The hopper load is then either bottom-dumped, pumped from the bow of the dredger directly ('rainbow' discharge), or pumped via a pipeline to the disposal or reclamation area.

The main advantage of a trailer is its mobility and ability to operate in exposed conditions where significant swells may be present such as in many of the marine borrow areas in the eastern waters of Hong Kong. No anchors are needed. This makes them very suitable for dredging in busy harbours such as Hong Kong, especially in or close to the fairways. However, the trailer operates most efficiently with free-flowing materials. The presence of clay interburden, which is present in some of the marine sands in Hong Kong, can significantly reduce the production rates. Furthermore, if the seabed is littered with debris such anchor wires, etc, which is a common problem in harbour areas in the Netherlands and also it is assumed in Hong Kong, significant downtime may be required to remove this rubbish from the dragheads.

The trailer suction hopper dredger is now the main type used for maintenance dredging of lightly to moderately contaminated materials in the Netherlands. Maintenance dredging usually involves the removal of relatively thin, superficial soil layers. In order to achieve the necessary design levels, the control of dredging depth is very important. All trailer dredgers observed during the duty visit incorporated heave compensation systems which mitigate the influence of wave action on the dragheads. Electronic sensors were also installed in the dragheads to provide continuous monitoring of the dredging depth.

Although the trailer represents a very effective method of dredging, particularly in busy navigation channels and over short haulage distances, significant reductions in the production rate may result if the transport distance (and hence the cycle time) is long. This point is further discussed in Section 5. Also because of draught requirements of many medium to large trailer dredgers only the very smallest trailers are able to operate in water depths of a few metres.

While there is concern that dredging in thin superficial layers using trailers will result in low-mixture concentrations in the hopper, one of the dredging contractors (Boskalis) has developed a recirculation system which is able to improve the density of the hopper mixture without causing increased turbidity by overflowing (van Doorn, 1988).

The trailer is the most common type used in Hong Kong to date having been most recently employed in the construction of Container Terminals 6 & 7.

4.2.3 Deep Suction Dredgers (See Figure 4 and Plate 3)

Unlike a trailer which is mobile during the dredging operation, a deep suction dredger remains stationary during dredging. This type of dredger is one of the most cost-effective methods for long-term sand-borrowing operations. It is ideal for dredging thick beds of cohesionless, free-flowing sand, with no silty or clayey overburden. In Hong Kong, it has been used in the dredging operations for the Tin Shui Wai reclamation.

In order to dredge materials at depth, this type of dredger is equipped with a submerged pump positioned on the ladder supporting the extendable suction pipe. Some contractors (e.g. Ballast Nedam) claim that dredging depths as much as 85 m can be achieved using this method. Unlike the trailer, the transportation of dredged materials is normally handled by barges or pipeline. The production rate can hence be maintained at a constant high level as a result of the continuity in the dredging operation.

Although termed a stationary dredger, it is not actually perfectly stationary, but is slowly moved back-and-forth on six anchor lines. The suction creates a 'conical well of depression' whereby the sand flows towards the mouth of the suction pipe. The dredger also has water jets at the suction mouth, which can be used to fluidise the soil during dredging.

Another possible application of the deep suction dredger is to underdredge a deep sand layer without removing the overburden layers as was carried out during dredging for the Tin Shui Wai reclamation. For this to be feasible, the overburden layers must be loose or soft enough for the suction pipe to penetrate. The stiffness or strength of the overburden should therefore be thoroughly investigated in advance. In addition, the operation must be well controlled so that the overburden will not collapse and cause blockage or damage to the suction pipe.

Deep suction dredgers are generally not suitable for use in exposed areas with significant swell, because the wave action can easily buckle the suction pipe. This factor, together with their stationary nature, would appear to limit their applicability to dredging in sheltered areas away from busy navigation channels.

Examples of the use of deep suction dredgers were observed during the duty visit at Almere new town reclamation and the long term sand borrowing project at Ijmuiden in the northern part of the Netherlands (see Figure 1).

4.2.4 Cutter Suction Dredgers (see Figure 4 and Plate 4)

The cutter suction dredger (or "cutter") was initially conceived from experience in mining operations. It is another type of stationary dredger, which operates most effectively in water depths of 30 m or less. On the larger cutters, submerged pumps located on an extended ladder are normally used, in addition to the dredge pump, to achieve greater dredging depths.

This type of dredger comprises two main components; the rotating cutterhead and the dredging pump. The cutter dredger operates by loosening or breaking down the soil (or rock) mass with a rotating cutterhead, installed at the end of a rigid suction ladder. Vertical movement of the ladder is controlled by hoist wires which can raise or lower the ladder. The dredged spoil is lifted by the suction action of the dredge pump located in the hull of the dredger. Most soils and even rock can be dredged by this method. The usual cutterheads are: the crown cutterhead, which is most commonly used, the bucket wheel (or dredge wheel), and the disc bottom cutterhead which is particularly suitable for dredging of thin layers and for precision dredging. One contractor (Boskalis) is presently developing an environmental disc bottom cutter for the dredging of contaminated soils (Rosenbrand, 1990).

A cutter is very efficient in bulk dredging. However, the cutting action induces significant disturbance to the soil 0.5 to 1 m beneath the cutting level. Although it is claimed by some contractors that a tolerance of about 25 cm can be achieved by experienced dredgemasters, it is generally considered that this is not the most suitable method for high precision dredging (except where a disc bottom cutter is used). A cutter also generates more turbidity in the dredging operation, by virtue of the rotating action of the cutterhead. Cutter suction dredgers normally discharge their materials through a pipeline, often initially via a floating flexible pipeline to a fixed pipeline on land.

A cutter moves using the pivoting action of spuds or, in certain cases, particularly for dredging to greater depths (say below 30 m), using a system of anchors, commonly a 3-point system referred to as a 'christmas tree'. For relatively shallow dredging, usually two spuds are used, one of which remains anchored at the seabed. The other spud, which can be lifted, tilted or slid along a carriage, allows forward and lateral movement of the dredger. During cutting, the dredger is pivoted on one spud which penetrates into the ground. The cutter then swings from side to side, using side wires which are anchored on either side of the dredging area, cutting the soil in an arc-like motion. After cutting, the second spud is lowered, and the pivoting spud is raised and moved (either transversely or in an inclined manner), so that the cutter effectively steps forward by a nominal amount. In general, tilting spuds are advantageous for large water depths, since the magnitude of movement will increase proportionally with the water depth. On the other hand, transverse-moving spuds are good for shallow water depths, as in this case the movement magnitude will be the same (usually up to 6 m) regardless of the water depth. The latter also requires more stoppage time in moving forward.

In the dredging operation, the vessel should be suitably oriented taking the tide into account. If the site is small or being constrained by various structures, the cutter may not be able to make a full swing, and the operation and consequently the production rate may be impaired.

As with other types of stationary dredgers, the cutter operates best in sheltered locations with little or no swell.

Cutter suction dredgers were used in some of the earlier dredging operations carried out in Hong Kong such as in the construction of Kai Tak Airport in the 1950's. The most recent use was in the dredging for the Tin Shui Wai reclamation where the Bilberg (currently the world's third largest cutter), was used for rehandling material for subsequent transport by pipeline to the reclamation site.

4.2.5 Dustpan Dredgers (See Figure 4)

A dustpan dredger operates in a similar fashion to a suction dredger but has a very large suction head similar to a vacuum cleaner. It is most effective in dredging thin layers of silty or sandy materials. Tight tolerances of the order of 10 to 15 cm can be achieved, which are about the same as a bucket dredger (discussed below). At the Liefkenshoektunnel near Antwerp in Belgium (see Figure 1), which was visited on 31.1.91, a dustpan was being used to clear loose debris and siltation materials on the seabed. Built-in water jets are used to facilitate the fluidisation of the materials to be dredged. It is however not very effective in dredging submarine slopes to small tolerances.

A dredger of this type was recently used in the dredging for the Tin Shui Wai reclamation.

4.2.6 Reclamation Dredgers (See Figure 3)

A reclamation dredger is used for rehandling material for further transportation to the disposal or reclamation site. It pumps and transfers material from a stockpile source or a barge to other barges for further transport. Water jets are used if necessary for fluidizing the stockpile materials or materials in the barge hold to facilitate pumping. A dredger of this type was examined during the visit to Belgium on 31.1.91.

4.2.7 Water Injection Dredgers (See Figure 3)

In all the types of dredgers described so far, the dredging operation involves removal of material from the seabed for subsequent transportation to the disposal or reclamation site. A newly-developed mode of dredging is to let the spoil stay close to the seafloor, but to induce flow of the material by fluidisation. The difference in density between the fluidised water-sediment mixture and the surrounding water will induce flow along the seafloor. Depending on the soil properties, the water-sediment mixture may range from 1 to 3 m thick. Currently this type of operation is employed by one contractor (Volker Stevin) in the Netherlands, using a special type of dredger called Jetsed (See Apendix D). The main advantage of this type of dredging is the lower transportation cost. It is well suited to projects with dredging in fine grained materials and where the distance between the borrow area and reclamation site is short.

4.3 Mechanical Dredgers

4.3.1 Bucket Dredgers (Figure 5 and Plate 5)

Prior to the 1980s, bucket dredgers were the main type used for maintenance dredging in the Netherlands. However their use for this type of dredging is now rather limited, particularly in navigation channels, as a result of their stationary nature and the increased use of mobile trailer dredgers. Nevertheless, the level of precision achieved during dredging is high (tolerances to about 10-15 cm). The bucket dredger can dredge a wide range of material types including rock and is particularly suited for dredging clays and bouldery soils (e.g. glacial clays in Northern Europe).

A bucket dredger performs most efficiently in dredge depths up to 15 m, although some of the larger plant can dredge deeper. It has a continuous chain of buckets positioned on a ladder which is lowered onto the sea bed to commence dredging. This type of dredger commonly employs a six-point anchor system. As with the cutter suction dredger side wires are used to move the dredger laterally during dredging. The excavated material, which is cut by the outer rims of the buckets, is retained in the buckets and discharged via a chute to barges moored alongside the dredger. For normal operation, the bucket chain is left slack, but it can be tightened if high precision is required. Larger buckets are generally used for dredging soft materials and smaller buckets used for hard materials including rock.

As with other types of mechanical dredgers, bucket dredgers generally remove materials at close to their in situ density as little mixing with the surrounding water takes place during the dredging process. However, the operation is often noisy.

Another disadvantage of bucket dredgers, particularly in busy waterways, is the anchorage system required. Head wires in the anchor system, which are used to slowly advance the dredger and also provide the main reaction during dredging, can be several hundred metres long. For the construction of the Liefkenshoektunnel in Belgium across the River Scheldt (300 m wide at the site), which was visited on 31.1.91, a bucket dredger was being used in the final stage of dredging a trench for the tunnel sections to achieve the tight tolerances at design formation level. In order to minimise disturbance to marine traffic in the River Scheldt, the existing navigation channel was temporarily repositioned by dredging a replacement channel, using a cutter suction dredger, between the existing channel and the river bank. During this operation no disruption to marine traffic was made. To further reduce disruption to marine traffic during dredging, the bucket dredger (which had a head wire approximately 700 m long) lowered the wires of its side anchors on fairleads given several metres of clearance between the anchor wire and the water surface (see Figure 5). This permitted the movement of shallow draughted vessels close to the dredger without disturbance to the anchor system (Plate 6).

4.3.2 Backhoe Dredgers (Figure 5)

The backhoe operates in a similar fashion to a backhoe excavator on land. It consists of a backacter excavator positioned on a barge and anchored on spuds which provide the reaction during digging. A backhoe dredger is suited more to dredging of gravel, bouldery soils and rock. Bucket sizes are chosen according to the type of material to be dredged, but as with the bucket dredger smaller buckets are used for harder materials.

The dredging control and accuracy of backhoes are higher than that of a grab. A backhoe dredger can achieve tighter tolerance (within 10 to 20 cm, in the presence of tides) than a grab or clamshell.

Most backhoe dredgers are only capable of dredging to relatively shallow depths, generally less than 20 m.

It was not possible to observe a backhoe dredging operation during the duty visit although a tour of a backhoe dredger in dock was made during the visit to Belgium on 31.1.91 (Plate 7).

4.3.3 Grab Dredgers (Figure 5)

The grab dredger is one of the most common types of mechanical dredger in use. A grab or clamshell dredger is basically a slewing crane, installed at an end of a barge or pontoon, which is used to raise or lower a suspended grab. Grab dredgers usually employ a four or six point anchorage system.

Material is removed from the seabed by the weight and cutting action of the jaws of the grab, which are closed hydraulically or by winch, and deposited normally into barges moored alongside for transport to the disposal or reclamation site thus enabling almost continuous operation. Some types of grab dredgers have been constructed with a built-in hopper (Figure 3). Two main types of grabs are commonly used : open form and closed form (see Figure 5). Grab dredgers perform most efficiently in loose or soft materials.

The shape and size of grabs (as with bucket dredgers) varies according to the type of the material to be dredged although the digging principle is generally common to all forms. More recently water-tight closed grabs (Figure 5 and Plates 8 to 10), have been developed for dredging contaminated materials to limit turbidity and the dispersion of contaminants during dredging. Three forms of closed grabs used to remove contaminated material, together with silt screens, were observed during the duty visit in the Rotterdam harbour areas. These were the orange-peel grab, closed-box grab and bucket grab with visor.

Large orange-peel grabs (see Plate 8) are particularly suitable for removing debris such as wires, because they have a large closing force, but they are generally less suited to dredging where tight tolerances on depth are necessary.

Closed-box grabs (see Plate 9) are generally suited to carrying out the bulk removal of contaminated materials following the removal of overlying debris by orange-peel grabs. Again, however, they are generally less suited to dredging where tight tolerances on depth are necessary.

The bucket-type closed grab incorporating a visor (see Plate 10), which can be hydraulically closed to retain the contaminated material during removal, is best suited to dredging contaminated materials where tight depth tolerances are required. They are often used together with orange-peel and closed-box types to complete dredging to the design formation level.

Similar to other types of mechanical dredgers, grab dredgers do not normally result in significant bulking of dredged material during extraction and generally retain the in situ density of the borrow material. When bucket dredgers were extensively used for maintenance dredging in the Netherlands before the 1980s, grab dredgers were used to complement the bucket dredgers for dredging close to quay walls and jetties, for which they are particularly suited.

Grab dredgers have been used previously in Hong Kong mainly for dredging relatively shallow deposits with little or no mud cover such as for the construction of the Plover Cove Dam and the early development of the Kwai Chung Container areas.

4.3.4 Bottom Levellers (Figure 3)

The bottom or bed leveller (basically a seabed plough towed by a tug) and the amphibious bulldozer are equipment which help level the seabed and remove materials below structures, for more efficient working of the dredgers. In the Netherlands these tools are used mainly in maintenance dredging contracts in Rotterdam. In the Rotterdam port, bottom levellers are employed to remove silt adjacent to quay walls where the use of suction dredgers could cause undermining or where hindered by moored ships.

4.4 Discussion on Dredging Methods

Based on observations made during the site visits, there seemed to be obvious advantages in designing dredging operations to be adaptable to different site situations and dredging operations. Such adaption may be required in the course of the dredging work, or may even be necessary in the event of unforeseen site conditions (e.g. in the deployment of dredgers overseas where site conditions may be less well known by the contractor).

An interesting example of this was observed in the dredging work being carried out for the construction of the Liefkenshoektunnel in Belgium, where a variety of dredgers were employed for different purposes in a busy navigation channel on the River Scheldt near the port of Antwerp. Here cutter suction dredgers were used to carry out the bulk of the dredging, but due to the strict tolerances in the formation levels bucket dredgers were used to dredge to the final levels.

Another example of the flexibility incorporated into dredging methods within the Netherlands is in lake dredging, for example at Almere. Artificial lakes were created from flat lowlands by mechanically excavating a large pit to depths below the water table, so that a dredger can be deployed for further extraction. Initial dredging is often carried out with a cutter suction dredger, which is subsequently converted to a deep suction mode to cope with the deeper deposits without the need to mobilise a separate dredger.

It would appear desirable to incorporate as much flexibility as possible within the operating plant, so that unforeseen conditions can be overcome and the need to introduce different types of dredgers is reduced. A large part of the versatility displayed in the dredging operations examined was of course due to the generous availability of plant in the "home base" of the dredging contractors. However, many innovative adaptations and modifications to dredgers to cope with unexpected conditions may have to be employed on overseas operations where the availability of plant may be less.

4.5 Impact of Dredging on Marine Traffic and Utilities

In the various dredging sites visited, the authorities and dredging contractors expressed very little concern over the impact of dredging operations on marine traffic. In the Rotterdam port, there is a stipulation that only trailers are to be used for maintenance dredging and sand borrowing in the main navigation channels. However up until the start of the 1980's bucket dredgers were used predominantly for undertaking maintenance dredging. In Belgium, in the Liefkenshoektunnel project on the River Scheldt (See Figure 1), stationary dredgers (bucket and cutter suction dredgers) were operating in a busy fairway, some 300 m wide, used by large bulk carriers which were able to pass close to the dredging operation (Plate 11). A trailer operating in the same project was observed to pass above the 700 m long anchor head wire of the bucket dredger with no problem.

The major problem in using stationary dredgers in busy waterways is the effect of anchors on the movement of normal marine traffic and the difficulty of these dredgers to move position at short notice to allow the passage of ships. The use of anchor systems where the anchor wires can be lowered on sleeves below the hull of the dredger allows a clearance of several metres depth which can allow relatively shallow-draughted vessels to pass close to the dredging operation. This can obviously allow stationary-type dredgers to operate within or at the edge of navigation channels without affecting marine traffic.

The effect of utilities on dredging operations was raised during many of the meetings with Dutch Government Depts. In the Netherlands (and also it is understood in Belgium), unlike in Hong Kong, most utilities are apparently placed several metres below the seabed. The Port of Rotterdam require that utilities are placed at least 3.5 m below existing seabed, i.e. below design levels for maintenance dredging. As a result, very little research has been carried out in the Netherlands to determine 'safe' distances between dredging and cable positions.

4.6 Submerged Slopes

In the continual land-winning operations in the Netherlands nowadays, sand dredging has created deep pits in many stretches of water and also artificial lakes inland. Temporary slopes in sand, ranged from 1:3 in Almere, to 1:7 at the Liefkenshoektunnel site (Figure 1). Permanent slopes tend to have gentle gradients of 1:10 (in sand) to 1:20, particularly those influenced by tidal currents.

The gradients of permanent slopes seem to be based on experience. It is understood that the gradients of 1:10 to 1:20 stem from environmental rather than stability considerations. However, the formation of such gentle slopes in borrow pits are relatively costly as they will involve a greater volume of dredging.

4.7 Removal of Contaminated Material

Research studies carried out in the Netherlands (Dijkman et al, 1989) show that approximately 90% of contaminants are rather immobile and attach themselves to the fine sediment fraction. Dispersal of contaminants may develop as a result of:

(a) Fine sediment being brought into suspension, as a result of natural processes such as gas escape, currents, wave action, or by human-related action such as dredging, ship movements, etc.

(b) A change in conditions whereby the contaminants are disconnected from the sediments and enter the water column. This may occur through salt water exchange or change in pH, change in oxygen content or by chemical action.

Prevention of dispersal can be carried out by:

(a) Immobilising the contaminants by increasing the sediment sorption forces artificially by electrokinetical or biochemical processes (Lageman, 1988).

(b) Isolation by screen construction (sheet piles, bentonite walls), capping with clean sediments (one recent study carried out in Belgium, in the Port of Antwerp, by SILT (subsidiary of Dredging International) involved the sub-aqueous capping of 300,000 m^3 of slightly contaminated dredged sediments), or by protecting the subsoil with clay or a geotextile layer following temporary removal and storage of material before replacement (Kabos & van Rhee (1987), Malherbe et al, 1988; Woestenenk, 1989; Shields & Montgomery, 1984; Heuvel & Wilderom, 1986).

(c) Dredging the sediment for long-term storage or temporary storage on a (land) disposal area and/or with treatment or cleaning (Veltman, 1989).

Disposal and treatment methods for contaminated materials used in the Netherlands are discussed further in Section 6.3.

A considerable volume of contaminated material and chemical waste is dumped into the river Rhine from factories and heavy industry developments located within countries upstream and also within the Netherlands. Much of the contaminants are transported downstream within the silty sediments and deposited at the river mouth at the fresh/salt water interface, where the Rotterdam port is situated. Approximately 23M m^3 of materials have to be removed by maintenance dredging in order to maintain the navigation depths within the port of which around 10M m^3 is contaminated.

In the Netherlands, the dredging contractors have to comply with strict environmental regulations with respect to dredging-induced turbidity (discussed in Section 4.10) and the removal of contaminated materials.

The selection of dredging equipment for removal of contaminated materials depends on a number of factors, including:

(a) The environmental regulations governing the removal and transportation, e.g. resuspension of the polluted soil should not occur or should be kept to the absolute minimum.

(b) The type of material to be removed and the type and level of contamination present.

(c) Marine trafficking controls and regulations in force, e.g. for dredging in fairways and operating harbours.

A variety of methods are being used in the Netherlands for removing and handling contaminated materials during maintenance dredging. Slightly to moderately contaminated material is mainly removed by conventional trailer dredgers. The most commonly used method of removing heavily contaminated material is by closed grabs in combination with silt screens. A silt screen is a barrier which is permeable to water but not to silt. A weighted geotextile membrane is the most common type, suspended from a floating boom and extending to a nominal depth above the mud (Plates 8 & 9). By this means, the dredging area is isolated from the surrounding water. One dredging operation is using closed grabs and silt screens to remove approximately 120,000 m^3 of highly contaminated material from Geulhaven harbour (a heavily oil-polluted harbour in Rotterdam (See Figure 2)). Three different types of closed grabs were being used as a result of differences in material type. Details of these methods are discussed above in Section 4.3.3.

Other techniques being employed to remove contaminated materials include the disc bottom cutter (Rosenbrand, 1990) and special suction heads.

At the academic institutions in Delft, some research work is currently being carried out on the mitigation of turbidity generated from dredging (See Section 4.10) and from disposal, as well as studies on the use of silt screens. This obviously helps to lessen the environmental impact of dredging.

4.8 Gas in Sediments

From decades of maintenance dredging experience in the Rotterdam port and the numerous site investigations performed over the years, it is well known that the sediments transported along the river Rhine and deposited in the Rotterdam harbour area contain gas derived from the decomposition of organic matter. The rate of gas generation is very rapid. Field measurements undertaken by the Rotterdam Port Authority in the Europort area indicate an average of 5% gas by volume in the silt within harbour areas (van de Ridder & de Wit, 1989). In some cases, it can be up to 10% by volume in situ. Over 90% of the gas is methane. The amount of gas is greater in summer than in winter, as the higher temperatures in summer promote faster degradation of organic remains transported with the sediments.

Gas-bearing sediments were also reported at dredging sites further north offshore from Ijmuiden (See Figure 1), which the Dutch engineers believe to be Rhine sediments transported northwards by the current. Gas was also encountered in the sediments at the entrance to the docks at the mouth of the River Scheldt in Zwijndrecht, Belgium.

Historically, gas detection has been carried out only occasionally in the Rotterdam port. It is understood that a very basic in situ testing device was employed to identify broadly where gas was present. Nowadays, dredging contractors have developed sophisticated degassing systems. Routine investigations of pore gas in sediments are not considered necessary any more.

The presence of gas in sediments can reduce the pump efficiency by more than 50%. The production rate will consequently be lowered, and there will also be risks of pump cavitation. During dredging some gas escapes as a result of the disturbance of the sediment. The remaining gas will expand in the suction pipe. If the gas is allowed to enter the suction pump in place of the silt, the pump may be blocked, the suction and pump efficiency will be lowered, and the dredging will be interrupted. If complete blockage occurs, the dredging operation has to be temporarily suspended, the suction head lifted, and the mixture restarted. Dredging may become extremely ineffective if there are many stops and restarts. Degassing of silts is therefore very important to the efficiency of maintenance dredging operations.

Although the presence of gas in marine mud in the Rotterdam area requires the use of degassing systems to maintain dredging efficiency and production rates, a recent study of gas in Hong Kong sediments concluded that the amount of gas present is low (Premchitt et al, 1990).

Another problem with gas is that it causes difficulties in the determination of soil properties. In order to obtain undisturbed soil properties of gas-bearing soil, insitu testing is recommended, because the expansion of the gas in the samples through stress release during recovery will very likely causes sampling disturbance.

Degassing systems consist of a box placed directly in front of the pump which incorporates a system to remove the gas. There are basically two methods of removing the gas: by a water ejector (i.e. hydraulic system) or by vacuum pumps (i.e. pneumatic system) (d'Angremond, 1984; van de Ridder & de Wit, 1989).

The first system is cheaper to build, but is more expensive to operate because it requires one order more energy to run than the pneumatic system. It also requires a much greater amount of process water, which may cause problems in the case of contaminated materials where overflow of process water is not permitted. The use of the pneumatic degassing system which requires little process water is therefore advantageous for dredging contaminated materials.

It is important to have a regulated gas removal system to take account of variations in gas levels and water depths. A degassing system is indispensable for effective dredging at depth, but even then the pipe velocities are still lower than the norm. For dredging operations in heavily contaminated silt, the discharge of process water from the degassing system can be taken account of by the addition of a separator.

Despite the use of degassing systems, measurements show that some gas still remains in the hopper load. This has led to further improvements by introducing additional degassing via the suction pipe at the centre of the pump. Such extra degassing results in a slightly higher velocity at the suction pipe, as well as a higher density of the hopper load and a shorter dredging time.

The design of degassing systems is very much a trade secret for each dredging contractor, since different contractors tend to use somewhat different layouts.

During a visit to a maintenance dredging operation in the Botlek area in the Rotterdam port, (see Figure 2), gas bubbles of about 4-6 cm in diameter were seen coming out from the sediments in the hopper towards the end of dredging (Plate 12).

4.9 Supervision and Recording of Data

Most modern dredgers in the Netherlands employ a high level of automation, which has improved both the control and monitoring of dredging operations.

Typically for a modern trailer carrying out maintenance dredging in Rotterdam, some 20 parameters are automatically recorded, including:

(a) the position, pressure and sideways movement of the dragheads,
(b) density of the mixture in the suction pipe,
(c) velocity of the mixture in the suction pipe,
(d) trailing speed,
(e) tension of the winches,
(e) pressure and rotation speed of the suction pump,

(f) position of the swell compensators,
(f) the hopper load, and
(g) track to be followed.

For a cutter suction dredger, additional information collected includes:

(a) swing speed of the dredger
(b) tension load of the winches

The Dutch Government deploys a full time supervisor on board each maintenance dredger who will direct the operations on board. For most maintenance dredging in Rotterdam, close monitoring of progress and performance is carried out by both the client and the contractor. This is achieved by deploying real-time computer monitoring systems both on board the dredger and in the client's (Rijkswaterstaat or Public Works Depts) office. The setup collects and stores monitoring data for analysis of performance, maintenance, to give timely warnings on faults in the operating system, and to contribute to the effectiveness and safety of the dredging operation. Some of the data is interpreted on board, and may be used to modify the forthcoming dredging programme.

For positioning, trailers employ radio-positioning systems which measure distances from known reference points, while courses are tracked with the aid of a gyro-compass. The interpreted position is shown on the dredgemaster's display on board, and recorded on a track plotter at the same time.

Tidal information is acquired by telemetric signal from tidal gauges.

4.10 Measurement of Turbidity

Current research into dredging-induced turbidity was discussed with Mr J.G.S. Pennekamp during a visit to Delft Hydraulics on 1.2.91. An outline of the work undertaken to date is given below, with reference to recent publications by Mr Pennekamp and others.

Turbidity can be defined as the quantity of sediment introduced into the surrounding water per unit time. Turbidity can be caused by several actions including the effects of dredging and shipping movements, effluent discharges, storms, wave and current action, and escape of gas from the seabed.

The effect of dredging operations on turbidity must therefore be evaluated in relation to other influencing factors.

In the 1970's there was a growing awareness in the Netherlands of the impact of dredging on the environment. As a result very stringent environmental demands were placed on dredging operations by the Dutch Government. These demands led to unnecessarily high dredging costs and there soon became a need to place more realistic regulations on dredging, in particular the consequences of dredging-induced turbidity.

Since 1981 extensive research into dredging-induced turbidity has been undertaken, involving a number of large-scale field trials. The trials involved different types of dredgers and measurements of turbidity levels, their horizontal and vertical distributions, and resettlement times. The programme established turbidity as a function of soil type, the type of dredger, and the hydrodynamic conditions and water quality.

The earlier part of the research was undertaken by the MKO Group (Minimising the Cost of Maintenance Dredging) who were primarily interested in the resuspension of sediment under the conditions encountered in the harbours of Rotterdam. The findings of the initial studies are given by Blockland (1986, 1987); MKO (1987); Vellinge (1987); and van Raalte & Blockland (1988).

More recent research has been undertaken by the CSB Group (Dredging Research Association) as discussed later in Section 7. This group are examining the measurement of sediment resuspension for different types of soil under various water and current conditions and with practically every available type of equipment. The results of this more recent research is given in Pennekamp & Quaak (1990).

The information obtained from this research programme will provide a database which will be used to estimate the potential effects on the environment caused by future dredging operations.

Turbidity measurements carried out by Delft Hydraulics on behalf of CSB are by optical turbidity gauges (translucency gauges) and follow a fixed measuring routine which has been developed by the Public Works Department of Rotterdam (Vellinge, 1987; MKO, 1987). Normally a limited site investigation is carried out in the area to be dredged followed by turbidity measurements taken over a grid with a spacing of 25-50 m. At each point on the grid between two and seven measurements are made depending on the water depth.

Average background turbidity levels are measured before dredging and also during periods of no dredging. During dredging, measurements are taken at each point at least once every thirty minutes until turbidity levels reach a constant value. Dredging is then stopped but the measurements continue until the background levels are re-established. During the measurement process representative water samples are collected and analysed in the laboratory and compared against the field measurements to determine the concentrations of materials in suspension (van Raalte & Blockland, 1988). On this basis a number of comparative trials have been carried out for different dredging methods, viz grab dredgers (Blockland, 1986; Pennekamp, 1989), bucket dredgers (Gemeentewerken (Rotterdam), 1988), and trailer dredgers (Blockland, 1986). These have all been reviewed by Pennekamp & Quaak (1990).

The results of these trials to date suggest that the additional turbidity generated by the dredgers examined is usually slight. Van Raalte & Blockland (1988) have stressed however that in evaluating turbidity measurements at the site of a dredging operation the background turbidity levels must always be taken into account. These levels may vary considerably over the time of the dredging and should be monitored continuously during the measurement operation.

The research described above has led to a better understanding of potential impact of dredging on the environment. As a result standard control methods are now being proposed for incorporation in contract documents for maintenance dredging projects (CROW, 1989).

5. TRANSPORT OF DREDGED MATERIALS AND RECLAMATION

5.1 Transport Methods

Three main methods are commonly used to transportation dredged material from the borrow site to the dumping site. These are:

(a) hydraulic transportation by pipeline,
(b) the use of trailer suction hopper dredgers, and
(c) the use of barges.

Occasionally combinations of the above methods may be used where project requirements dictate.

5.1.1 Hydraulic Transport by Pipelines

In the Netherlands, the land is flat and the sand fill is generally fine (200-300 μm). Pumping of dredged material through a pipeline is a very effective method of transportation. For pumping over longer distances, booster stations are often installed to augment the pumping head.

From discussions with DEMAS during the duty visit, the average density for pipeline transport of silt is about 1.2 Mg/m^3, and for sand about 1.3 Mg/m^3. If the density is too low, not only will the rate of sand delivery be low but also additional work will be required to remove excess water at the reclamation site. If the density is too high, the slurry may become too viscous and the pipeline may become blocked which may result in pressure build up within the pipeline. The viscosity is a function of the particle size of the soil. Well graded soil is easier to pump than uniformly graded soil. If transportation by pumping is envisaged, grading information is very important for dredging contractors to be able to price their tenders properly. The pumping head should also be carefully chosen. In several of the sites visited, pumping rates ranged from 500 to 2000 m^3/hr.

One of the main uses of pipeline transport in the Netherlands (and also in Belgium) is for transport of lake dredged material, where the reclamation site is a relatively large distance (several km) from the dredging site and transport by other means is not possible/practical. Some examples of pumping distances greater than 10 km were observed during the duty visit (See Plate 13).

Gas venting valves are present at regular intervals along the pipeline, in order to avoid excessive pressures built up by gas bubbles or cavitation effects. In crossing roads, the pipes are either routed through an underpass, or through a temporary viaduct (which causes head loss at the bends and pipe scour).

As a result of the fine grain size of most of the sand dredged in the Netherlands there is very little wear of the pipelines. The closest analogy in Hong Kong to date to the sites examined in the Netherlands, where pipeline transport is in use, is the recent reclamation in Tin Shui Wai. However because of the coarseness of the local marine sand, the wear of the pipes were very significant (highest wear and tear in the lower quadrant). In order to minimise replacement of sections of the pipe, they were manually turned 90 degrees after a specified period, and the pipe segments were only replaced after the inside faces had completely worn out.

The overall impression gained from the sites visited is that the Dutch prefer to use pipeline transport of dredged material to reclamation sites wherever possible unless barge transport is cheaper.

For design of pipeline systems, the interested reader is referred to a recent publication by Henderson (1988).

5.1.2 Trailing Suction Hopper Dredgers

In the Netherlands trailer suction hopper dredgers constitute the main method used to transport maintenance dredged material (see Plate 12) and for sand borrowed from the North Sea. This is seen as the most efficient and practical form of transport of maintenance dredged material where the dredge volumes are high and the cycle times relatively short.

The amount of material transported in each cycle depends on two parameters: the volume of the hopper, and the density of the dredged material in the hopper.

In order to be cost-effective, the size of the trailer for a particular project should be carefully chosen. The availability of suitably-sized trailers or otherwise can be the cause of differences in tender prices quoted by different contractors.

In order to maximize efficiency of the dredging operation, it is desirable to increase the density of the payload as far as practicable. This can be achieved by minimizing the amount of process water, which can be reduced by overflowing. The increased density of the dredged mixture raises concerns about other parameters, since at high densities a small variation in density can have a significant influence on the dredging and subsequent transportation process. In order to cope with dredging and processing of dredged materials at a higher density, a number of improvements have been implemented on modern trailers. The high viscosity of the slurry may influence the pump behaviour, and the flow in the pipeline will become more laminar. The wall friction in pipelines increases exponentially with the slurry velocity. The Rijkswaterstaat has devised methods of measurement for payment to encourage the contractors to increase the density of the payload. This has been discussed earlier in Section 3.

5.1.3 Barges

If the transportation distance is significant, the use of a trailer will not be cost-effective, because of the long cycle time and the inactivity of the dredging equipment during transportation. In such case, barges can be used for transportation. If the borrowing source is close to shore, the use of grabs and trucks can also be considered. The main use of barge transport in the sites visited is for commercial sand borrowing (for use in the construction industry, see Plate 14). Barge transport is particularly suited for deep suction dredging operations. Another major use of barges is for the transport of heavily contaminated material to the containment areas such as the Slufter and the Parrot's-beak (discussed in Section 6).

5.1.4 Trailer Versus Barge

For projects requiring transportation over long distances (generally greater than 10 km), pipeline transportation may not be the most cost effective or practical option. The choice then falls on whether trailer or barge transport should be employed. In general, where the cycle time is short, transport by trailers may be more economical, as extra barges do not need to be engaged. For longer distances and long term borrowing operations, the cycle time of the dredger is longer and barge transport may prove to be more cost effective and productive.

If the travelling distance is excessive, or if the placement rate has to be significantly slower than the rate of dredging, the use of a rehandling basin may be applicable. This allows different dredgers to be used to suit different placement rates. An example of this was observed at Ijmuiden (see Figure 1). Here a trailer brings in sand from a North Sea source to a rehandling basin at Ijmuiden. The sand is re-excavated by a deep suction dredger and loaded onto shuttling barges, then transported to reclamation sites around Amsterdam. In order to minimize the waste of having no payload after deposition, the trailer also carried out some maintenance dredging on its return trip.

5.2 Reclamation Methods

5.2.1 General

The major form of reclamation undertaken in the Netherlands is the raising of low-lying land for subsequent development (often more than a decade later). This is similar to Tin Shui Wai in Hong Kong. Much of the sand borrowing is carried out by creating artificial lakes by excavation, which in some cases become subsequently part of the development. Much of the placement of the dredged material is done by pipeline. A high level of coordination between town planning, civil engineering and dredging aspects is important for the success of such projects. A number of these types of reclamation sites were visited in both the Netherlands and Belgium during the duty visit. Details of the reclamation methods being used at some of these sites is discussed below.

5.2.2 Methods of Placement

A dredging and reclamation project worth mentioning is the Almere site. Almere is a new town (see Figure 1) designed to house between 120,000 and 180,000 inhabitants by the year 2000. It is being developed on the lowlands east of Amsterdam. One of the projects undertaken by Ballast Nedam at Almere was the formation of a large site for residential purposes. It involved excavating a piece of lowland to form a lake. The borrowed sand was transported to reclaim the nearby low-lying areas, and the lake eventually formed would be used for recreation. Such dual-purpose earth-moving work (borrowing of sand together with the creation of recreational lakes) is rather typical in modern town planning practice in the Netherlands. At Almere a pumping distance of 8 km was needed. Quick-coupling pipes of 500 mm-diameter were employed at the reclamation site (See Plate 15). These pipes cost around DFl 200 (HKD 1,000) per metre. The pipes were moved around by a small front-loader equipped with electromagnetic measurement devices for level control (Plate 16). A gentle gradient is maintained on the site, so that the water from the slurry can run off to a collecting drain.

When the water depth in the lake was shallow, a cutter suction dredger ("Aegir") was assembled on a segmented pontoon, which could be placed on the inland lake after an adequate draught was achieved. Following the removal of overburden material, the cutter suction dredger was converted into a deep suction dredger to carry out the dredging of the underlying sand.

5.2.3 Ground Improvement

Unlike Hong Kong, the Dutch can afford to wait up to twenty years before reclaimed land is used for development, except in the case of road construction by sand reclamation. This is the same policy as the draining of polders where it was necessary to allow the salt water to drain away before development took place. As a result, ground improvement works seem to be the exception rather than the rule.

In the widening of the Highway A4 between The Hague and Amsterdam constructed by Boskalis (see Figure 1), band drains were used to accelerate the settlement of the 4 m thick clay layer beneath the hydraulically-placed fill. They were installed after a 1 m thick layer of fine sand had been placed. The band drains employed were of a grooved-core type called Duverdrain, similar in appearance to the Amerdrains (grooved versions) and Mebradrains being promoted in Hong Kong. Although the Boskalis staff did not explain the basis of drain selection to us, they claimed that the performance of the chosen drain was very satisfactory. For the interested reader a review of the use of band drains has recently been carried out by the GEO (To, 1991).

During a meeting with Dredging International of Belgium, it was mentioned that they have extensive experience in the use of gravel piles in treating soft compressible soils.

From discussion with DEMAS, a number of underdrainage techniques for dewatering/densifying fine-grained dredged material have been studied by Hammer (1981). These include:

(a) gravity underdrainage,
(b) partial vacuum in an underdrainage layer,
(c) seepage consolidation, and
(d) seepage consolidation with partial vacuum in the underdrainage layer.

5.2.4 Monitoring

An advantage of hydraulic fill is that the flow of water will allow even placement, thereby ensuring uniform compression within the hydraulic fill under its own weight. For land fill, more monitoring will be required.

One observation rather unconventional to Hong Kong is that instrumentation in Dutch and Belgian reclamation sites is sparse. Only a few tell-tales are placed, for controlling the placement of fill and for subsequent monitoring of post-construction settlement. The frequency of monitoring is also very scarce.

The general impression is that the Dutch are not worried about total settlement. It is however not difficult to find houses and buildings in the Netherlands which are tilted or distorted as a result of differential settlement. They have to tolerate this anyway, because the western half of the Netherlands is underlain by a layer of peat, which itself settles by 1 to 3 m. In new suburbs of some cities, there is a programme to raise the grade of roads by some 25 cm. Modern houses and buildings are generally founded on 10-20 m long piles into the sand beneath the peat.

The only reclamation job in which piezometers were observed was the Highway A4 road-widening project (Figure 1). Hydraulic piezometers were installed for the sake of construction control, to ensure embankment stability. The sand fill was placed in layers. The next layer was placed after both pore pressure and settlement have steadied. The total settlement was about 40% of the thickness of the layer.

We asked the site staff about the comparison of water levels before and after reclamation. They said that post-construction ground water levels were higher, possibly due to the importation of process water from sand pumping.

6. DISPOSAL OF MATERIALS FROM MAINTENANCE DREDGING

6.1 Historical Background

A considerable volume of suspended sediments is transported by the Rivers Rhine, Meuse and Scheldt and deposited in their deltas which are located in the Netherlands. Some material is also washed in by the tidal action of the sea at the mouth of the deltas. In order to maintain the drainage function and the navigable depth for shipping lanes, Dutch waterways (except for the River Scheldt, within which all maintenance dredging is carried out by the Belgian Authorities as a result of the location of the Belgian port of Antwerp upriver) must be continuously dredged. In the past virtually no problems were encountered in the dumping and reuse of material removed during maintenance dredging. Some of this material was used for raising low lying wetlands. In Rotterdam, parts of the industrialised hinterland, formerly 5 to 6 m below sea level, have been reclaimed and raised using dredged marine silts mainly during the 1960's and 1970's (and at one location during the early 1980's). One of these former land fill sites at Schiedam (see Figure 2 and Plate 17) was examined during the duty visit. At this location some 30M m^3 of slightly to moderately contaminated material was placed between 1964 and 1984.

During the 1970's the traditional practice of using landfill sites as a major outlet for the disposal of dredged silts began to change markedly. Increased industrialisation during this period, in parts of Switzerland, Germany, France, and the Netherlands itself, bordering these river systems, resulted in the discharge of effluent into the rivers and led to a huge increase in the level of contaminants such as heavy metals and organic pollutants. Many of these substances have been adsorbed on the suspended silt carried down by the rivers. The presence of pollutants in these sediments has until recently impeded the potential reuse or dumping of these materials.

Since 1972 chemical analysis of the river silt has been regularly assessed throughout the entire Rotterdam port area. Because of the increased level of contamination of the dredged material, Rotterdam found it increasingly difficult to find new inland sites for the disposal of dredged material, whilst there was increasing opposition to the disposal of this material at sea and into existing landfill sites.

From the 1970's Rotterdam could not obtain a single new inland disposal site. As a result of this, in 1975, the Rotterdam City Council and the Provincial Executive of South-Holland decided to set up a Steering Committee (SGBB) to devise a policy for the disposal of dredged silt from the lower Rhine delta region. In 1979 the SGBB produced a report on the disposal of dredged sludge which concluded that disposal at sea by dumping was undesirable as this led to widespread and uncontrolled dispersion of pollutants. It was proposed that a better option would be to store the polluted material on land or in lakes. Subsequently in 1982 a Policy Plan was developed, and an Environmental Impact Statement was prepared for the disposal of dredged spoil in specially constructed containment areas.

The plan proposed the construction of a large containment area ("Slufter") off the coast of the Maasvlakte, at the western end of Rotterdam Port (Figure 2), for the long term disposal (until 2005) of slightly to moderately contaminated silt dredged from the Rotterdam harbour area. The containment area, which has a design volume of 90M m^3, has been in operation since 1987 and can receive up to 150M m^3 of contaminated material. In addition a separate containment area ("Parrot's Beak"), with a design volume of 900,000 m^3, and a capacity to receive upto 1.5M m^3, was constructed for the disposal of highly contaminated dredged silt until 1995 when an alternative solution will have to be found. Uncontaminated dredged silt however continued to be dumped at sea.

At present few conditions are imposed on dredging of contaminated materials. Only for the most heavily contaminated class is there any restriction on the method of dredging and these are mainly concerned with turbidity levels in the surrounding water column, and transportation and safety safety requirements.

In the Netherlands dredged material removed through maintenance dredging, primarily in Rotterdam port, is classified into four categories which reflect the level of contamination of the material. In the Rotterdam Port area this classification started off as a geographical distribution. As a result of the mixing of the river and sea silt there is a decrease in the degree of contamination from east to west. The classification of the dredged material is discussed in detail in section 6.3.1.

6.2 Uncontaminated Dredged Materials

The majority of the uncontaminated dredged material removed by maintenance dredging in the Rotterdam port area is located in the outermost harbour area and is deposited mainly from the sea by tidal current. This material is dumped at sea in a very large dumping ground north of the Hoek of Holland (see Figure 2). This dumping ground has been in operation for approximately 23 years and has accepted an estimated 500M m^3 of dredged silt over this period. Currently around 13M m^3 of uncontaminated dredged material is dumped here annually. Dumping activities are carefully controlled and monitored by the Rijkswaterstaat.

As mentioned previously a continuous computer record of each maintenance dredging and dumping operation is maintained by the Public Works Department. The dumping ground is divided into a number of blocks within which dumping activities are normally confined at any one time. Generally a line of blocks will be progressively filled up before dumping is permitted in an adjacent strip. As a result of the strong littoral drift at the dumping ground a lot of the fines in the dredged material are subsequently removed. Monitoring of the dumping ground comes under the responsibility of the Directorate of Tidal Waters (DGW) of the Rijkswaterstaat (See Appendix C). Nuclear tracers have been placed within the dumped sediments to monitor movements following dumping (in tests only).

6.3 Contaminated Dredged Materials

6.3.1 Dutch System for Classification of Contaminated Dredged Materials

In the early 1980's, as a result of increasing concern over the level of contamination in the silt deposited in harbour areas, particularly Rotterdam, the Dutch Government developed a policy plan for the disposal of dredged material generated from maintenance dredging. As part of this plan, a classification system was developed to define the levels and types of contamination present within the sediments.

An extensive programme of sampling and laboratory testing was carried out, starting in the Rotterdam Port area, to identify the types and concentrations of contaminants present. Four classes of material were defined, ranging from Class I, with little or no pollutants present, to Class IV with the highest level of contamination (Table 2). Although this classification system is currently adopted, it appears from recent work carried out by the Rijkswaterstaat that the current threshold for Class I is too high, i.e. a number of substances in Class I can still lead to the possibility of adverse effects on the reproduction and growth of organisms. It also appears from the evaluation that a greater number of substances than had so far been considered form a potential threat to aquatic life. As a result the Rijkswaterstaat has proposed the introduction of new standards for the general environmental quality of sediments. These provisional new standards are given in Appendix E.

Disposal options have been developed for the different classes of material. As discussed in Section 6.1, Class I material (Table 2) is mainly disposed of in a large offshore dumping ground in the North Sea, located north of the Hoek of Holland. The disposal of Class II, III, and IV material is discussed in detail in Section 6.3.2.

The Belgian Government also uses a similar system of classification for contaminated materials. However as a result of the short period of time spent in Belgium during the duty visit it was not possible to obtain details of the system.

6.3.2 Disposal Sites for Contaminated Dredged Materials

Of the 10M m^3 of contaminated sediments dredged annually from the rivers and Harbour areas, almost all falls within Classes II and III. Class IV material, although the most problematic in terms of handling and disposal, amounts to only around 200,000 m^3 of material annually.

(1) Disposal of slightly to moderately contaminated materials. The construction of a special containment area (called the 'Slufter') for the storage of Class II & III dredged materials was completed at the end of 1987. This DFl 230 million construction, covering an area of 260 ha on the south-east corner of the Maasvlakte, involved the dredging and reclamation (mainly the construction of the ring dyke) of some 37M m^3 of material, using two cutter suction dredgers and one reclamation

dredger (see Figure 2 and Plates 18 & 19). The containment area has a depth of around 50 m with the base at -28 m below Chart Datum and is surrounded by a ring dyke with a crest level of +24 m above Chart Datum. It can receive upto 150M m^3 of contaminated material over a 15 year period. Following subsequent consolidation of the dumped material, the design volume of 90M m^3 would be reached. No special liner is present over the base of the containment area although a clay lining has been placed over the side slopes of the ring dyke to prevent lateral seepage of pollutants. The downward seepage of water and pollutants below the base is prevented by the formation of an density barrier between the relatively fresh water within the Slufter and the saline water in the subsoil below (Plate 20). Detailed reviews of the construction and background to the development of the Slufter are given in Rotterdam Public Works Department (1986) and Van Zetten (1987).

Contaminated material for disposal in the Slufter is brought to a mooring terminal outside the containment area where an automatic coupling device connects the discharge outlet from the dredger to a pipeline to the Slufter (Plate 21). The contaminated material is then pumped, using the dredge pump on the trailer, via the pipeline to a special discharge outlet approximately in the centre of the containment area (Plate 22). In order to reduce the level of turbidity during deposition, the contaminated material is discharged using a special diffuser device which reduces flow from 2 m/sec to 0.5 m/sec (Plates 18 and 23). Currently only one discharge outlet is present but a second outlet is being considered.

Approximately 200,000 m^3/week is currently deposited in the Slufter which raises the base by approximately 10 cm. Within the Slufter two sampling structures have been constructed to allow water quality monitoring to be carried out at regular intervals.

(2) <u>Disposal of highly contaminated materials.</u> Material falling within Class IV in Table 2 is generally highly polluted and concentrated in the inner harbour areas of Rotterdam port. The general policy for its removal and subsequent disposal is based on the premise that as soon as it is removed no more material in this category will be allowed to form subsequently at the same localities as a result of recent strict controls governing the discharge of pollutants and waste into the river systems both in the Netherlands and also in neighbouring countries. Therefore the view of the Dutch authorities is that the problem of Class IV material disposal is short term. As such the current solution has a planning life extending only to 1995, although some alternative solution will probably still be necessary after this date.

The current solution for the disposal of Class IV material is a small containment area located on a peninsula in the Maasvlakte (see Figure 2 and Plates 24 and 25). As a result of its shape this area has been given the name of the "Parrot's-beak" (Plate 24). The site is about 40 ha in size and can receive upto 1.5M m^3 until 1995, which following consolidation would reach the design volume of 900,000 m^3. The site partly belongs to the Dutch Government and partly to the Municipality of Rotterdam. About 80% of the designed storage capacity is reserved for the Rijkswaterstaat and the remainder for the Municipality of Rotterdam who in turn have reserved part of their allocation to third parties such as shipyards. The cost of constructing the Parrot's-beak was approximately Dfl 7 million and the estimated cost of disposal of Class IV material is Dfl 27 million. Construction was completed at the end of 1986.

Similar to the Slufter, the construction of the Parrot's-beak has used dredged sand to form a ring dyke over 3 m high. The slopes of this ring dyke and the base of the containment area have been lined with a 2 mm thick impermeable heavy duty polyethylene membrane (HDPE) to prevent the escape of polluted water and material (Plate 26). Drains are installed underneath the membrane to check for leakage. More recently a sub-containment area has been constructed within the Parrot's-beak to retain the most polluted of the Class IV material (Plate 26).

During filling contaminated materials are placed in layers of about 1.5 m thick and allowed to drain before another layer is placed. Water is removed via an overflow into a settlement basin separated by a bund from the containment area (Plates 24 & 27). The base and sides of the settlement basin are similarly lined with the same heavy duty fabric. Baffles are present within the basin to regulate flow and to ensure that very little silt is present in suspension. Any floating debris is removed during the process. Water takes three days to pass through before it is discharged into the sea via a overflow system.

Class IV material is brought to the Parrot's-beak mainly by barge. Material brought by barge is taken to a special rehandling points outside the containment area where it is unloaded by either a reclamation dredger, or by an adapted conventional excavator with a hydraulically-operated closed grab attachment, and transferred into a special hopper (Plate 28). Process water is then added and the material is pumped via a pipeline to a discharge outlet within the containment area (Plates 26 and 29). Material brought in by trailer dredgers is discharged via a mooring pontoon into a pipeline to a second discharge outlet within the Parrot's-beak (Plates 25 and 30).

6.3.3 Treatment Methods for Dredged Contaminated Materials

Increasing attention has been given by the Dutch Government over the last few years to treatment of contaminated material, either in conjunction with disposal within an existing containment area or as an alternative to disposal. This has been necessary partly as a result of the limited capacity within existing containment areas, particularly the Parrot's-beak, but also because some of the materials are so heavily polluted that direct storage without treatment may be environmentally unacceptable (van Raalte, 1990). The Dutch and Belgian Governments are presently funding a number of research projects involving trials of pilot treatment schemes in conjunction with specialist dredging methods. In addition, a number of the major dredging contractors have set their own specialist subsidiaries to focus on this issue (discussed in Sections 2.1.3 and 2.2). The range of possibilities for the treatment of contaminated sediments is shown in Figure 6.

Typically a number of stages are involved in the treatment process. These are as follows:

(a) Removal of the contaminated material using specialist dredging plant (discussed in Sections 4.3.3 and 4.7).

(b) Separation of the fine and coarse fractions.

(c) Dewatering of the separated fine fraction (which normally contains most of the contaminants) to reduce the volume of this material for subsequent storage.

(d) Cleaning of the dewatered fine fraction by separating the contaminants from the soil particles.

Some details of the treatment stages are given below (van Raalte, 1990).

(1) Separation of the fine and coarse fractions. The most common method of separation used is hydrocyclonage. Hydrocyclones are designed to separate the dredged material into two size fractions; silt (usually < 40 microns) which usually contains as much as 90% of the contaminants, and sand (usually > 40 microns) which is usually relatively clean. Output capacity from pilot schemes currently being used is in the order of 10 to 100 m^3/hr depending on the number of hydrocyclones used. Some other separation methods used are screening and flotation techniques.

Following the separation stage the clean coarse fraction, usually sand, can be stored separately or, if of sufficient quality, be reused such as for fine aggregate in the construction industry.

(2) Dewatering of the fine fraction containing most of the contaminants. A number of techniques are currently used, such as belt pressing, pressure filters, vacuum filters, and decanting centrifuges in combination with flocculating additives to squeeze out the water to form a silt cake containing the concentrated contaminants. This production can then be transported in 'dry' form for further treatment. The extracted process water is further treated before being drained off to open water.

(3) Cleaning of the dewatered fine fraction. Specialist techniques have been developed to separate the contaminants from the fine fraction of the dredged contaminated material by either extraction, destruction, or neutralisation. These include froth flotation, steam stripping, biodegredation, ceramic processing, and incineration.

During the duty visit discussions were held with three major dredging contractors whose specialist subsidiary companies have developed pilot treatment plant and methods for the treatment of contaminated dredged materials. These were as follows:

(a) Dredging International (Specialist subsidiary - SILT). Pilot system called 'KRANKELOON' (Plate 31).

(b) Boskalis (Specialist subsidiary. DOLMAN). Pilot system called 'DOLMAN'.

(c) Volker Stevin (Specialist subsidiary - ECOTECHNIEK). Pilot system called 'ECOGRIND' (Schouten & Rang, 1989).

All three firms anticipate that full-scale commercial versions of their pilot plant will be in operation in the near future.

7. RESEARCH ACTIVITIES

7.1 Research Institutions undertaking Dredging Research

7.1.1 General

In the Netherlands, basic research work related to dredging is centred at Delft. The institutions involved are Delft Hydraulics, Delft Geotechnics and Delft University of Technology. In addition some other non-dredging related research activities were examined during the duty visit and are discussed later in Section 7.2.

The Delft institutions collaborate and complement each other in their work. Broadly speaking, their scopes of studies are :

(a) Delft Hydraulics concentrates on the principles and physical processes of soil excavation.

(b) Delft Geotechnics develops testing methods and procedures to establish the soil parameters required for dredging.

(c) Delft University of Technology concentrates on education as well as research into new or improved dredging equipment.

Delft Hydraulics and Delft Geotechnics are non-profit making institutes (or "foundations"). They are financially independent of the Government although they generate most of their work from the government. Most of the research work carried out at Delft Hydraulics and Delft Geotechnics is jointly commissioned by the Dredging Research Association (with the Dutch acronym CSB), a research partnership formed from the Public Works Department of the Dutch Ministry of Transport and Public Works (Rijkswaterstaat) and a number of major dredging companies. A general view of the research scene is presented in Steeghs et al (1989).

This basic work is primarily directed to improve the efficiency of the dredging operations. This is important, for example, in the dredging of gas-bearing sediments, which has led to the development in degassing installations. There is also some basic research carried out which focuses on pump hydraulics, design of cutterheads, engine room automation, etc. Strict environmental control measures have also prompted dredging companies into additional research work such as methods to mitigate turbidity associated with dredging (See Section 4.10) and disposal operations. More detailed research projects (e.g. shapes of dragheads, the installation of water jets and knives) are generally carried out by the dredging companies in confidence in their own research and development departments.

7.1.2 Delft Hydraulics

The studies carried out in Delft Hydraulics are categorised into hydrodynamics, hydrology, oceanology, morphology, ecology and water resources management aspects. Dredging studies are carried out by the hydrodynamics division, and are under the direction of Mr J.G.S. Pennekamp. In discussion with Mr Pennekamp, he emphasized that their work is basic in nature, aiming at a better understanding of the physical processes involved in dredging, and identifying the various parameters influencing the dredging operation.

The main equipment used by Delft Hydraulics is the "Dredging Flume", which is a 50 m long x 9 m wide x 2.5 m deep flume dedicated to dredging research (Plate 32). It has a carriage which can be moved at rates of 0 to 2.5 m/s, and from which model cutter drives or dredge pumps can be mounted to simulate cutter suction and trailer suction modes respectively. A large, movable glass panel is present on one side of the flume to facilitate observation. Mr Pennekamp did not expect the flume to suffer from boundary effects to a significant extent. The observations in physical modelling are often followed up by numerical analysis.

Other work carried out in the dredging flume includes studies of hydraulic fill and submerged slopes. A comprehensive research programme was carried out by Delft Geotechnics, Delft Hydraulics, Delft University of Technology and Rijkswaterstaat on the slopes and densities of dams comprising hydraulically placed sand fills, and the relationship of these to the grain size and the specific flow rate of the sand slurry. This work, including field measurement, laboratory model tests and theoretical studies, has been reported by de Groot et al (1988).

The basic research extends to assessment of degree of wear (e.g. wear of cutting teeth in dredging rock of different degrees of hardness), and to environmental impact studies such as dredging-induced and dumping-induced turbidity around the dredgers. Delft Hydraulics used a numerical model code-named PLUMA for modelling mud dispersion in the dumping operation. This is a model which at present runs on a mainframe computer, and is based on an existing U.S. Army Corps of Engineers numerical model, with some improvements. Its operation is very expensive, costing some Dfl 30,000 (HKD 140,000) per run. However, the Dredging Research Association has commissioned the conversion of the program to a PC-version, and this should be available shortly. The staff member of Delft Hydraulics responsible for the work is Dr G.A.L. Delvigne.

Increasing concern over environmental pollution has prompted studies of dredging-induced turbidity (See Section 4.10). More recently the main focus has been on improvements at the disposal stage, whereas previously the emphasis had been placed on the dredging stage. In the case of disposal, effort is directed on improvement in the use of diffusers (see Section 6.3.2 and Plate 23), a trumpet-like structure for the deposition of spoil near the seafloor, and studies of silt screens.

Mr Pennekamp also talked about the separation of the clean sand fraction from contaminated soils. His view is one of scepticism because the remaining finer, contaminated fractions will take a long time to consolidate, hence rapidly using up space in the storage basins.

7.1.3 Delft Geotechnics

In the visit to Delft Geotechnics, discussions were held with Mr P. Lubking (Head of the Hydraulic and Marine Structures Division) and Mr J.L. van de Velde (Marketing Manager). Mr F. Molenkamp (Engineer in Research and Development Division) also gave a presentation of his numerical studies on stability of submerged slopes and liquefaction (Ebbens et al, 1988).

Discussion with Mr Lubking centred on the soil parameters and information required by the dredging contractors. On the subject of site investigation data provided for dredging contractors, Mr Lubking considered that the SPT values provided by contractors (in the Netherlands) were generally not reliable enough. Research was being carried out at Delft Geotechnics on the feasibility of installing a sensor at the bottom of the SPT split spoon to measure the cutting force, as an indirect indication of the soil strength. For dredging in sand, he considered the in-situ permeability value to be very important for the dredging contractors. However, he acknowledged that this is difficult to determine with high accuracy. Delft Geotechnics was currently researching into the use of a dipole probe to measure the permeability of sand.

Another important parameter is the in situ density of sand. Mr Lubking explained that two types of in situ density probes are commonly employed in investigations, viz. the electrical probe and the nuclear probe. While the electrical density probe is suitable for density measurement in a salt water environment, Mr Lubking considered the nuclear density probe as being more versatile, because of its effectiveness in virtually all types of soils. The latter utilises the nuclear backscatter technique, and is capable of measuring the in-situ density at depth (after calibration against aluminium of known density in the laboratory). The measurement of in-situ density of submarine sand is carried out as a matter of routine in many other parts of the world, but not in Hong Kong. Such measurements are very important in the context of dredging, hydraulic fill, and slope stability assessments and there is no reason why the construction industry in Hong Kong should be deprived of this technique. The interested reader is referred to a relevant paper by Plewes et al (1988) for further information.

On laboratory tests associated with dredging, Delft Geotechnics has developed special triaxial testing equipment capable of performing tensile triaxial tests at a high strain rate (2 m/s). They believe that this gives a better estimation of the strength of the soil taking into account the high cutting speed of the dredging equipment. The actual details of the test equipment or results were not disclosed during the meeting.

Delft Geotechnics and the University of Utrecht are collaborating on the development of geophysical survey and interpretation techniques. Mr Lubking also mentioned collaboration between Delft Geotechnics and the U.S. Army Waterways Experiment Station on studies of consolidation of silt.

It should also be noted that Delft Geotechnics possesses a 15 m diameter centrifuge, with maximum acceleration of 300 g, although it was not disclosed whether the centrifuge has been used for dredging-related studies.

7.1.4 Delft University of Technology

A meeting was held with Mr Peter N.W. Verhoef, a lecturer in Engineering Geology in the Faculty of Mining and Petroleum Engineering. Some research work is undertaken in the Engineering Geology unit on cutter suction dredging in rock, in particular the abrasive wear and durability of cutting tools. The techniques used in underwater cutting of rock are very much a trade secret among competing dredging companies.

Part of the research work undertaken by Mr Verhoef was to develop simple index tests for predicting abrasion of the rock cutting tools (Verhoef, 1988, 1990). One important site investigation parameter mentioned by Mr Verhoef was the quartz content of sands or decomposed rocks, which should be stated as part of the site investigation information available to the dredging contractor. This is important both on aspects of pricing and on the deployment of the right equipment as a result of the more abrasive nature of some minerals. Mr Verhoef felt that information on Quaternary geological history is often under-emphasized. He mentioned as an example a case of a claim on a dredging project in Thailand for which he provided advice to the dredging contractor. The crux of the dispute was the high quartz content of the "clay" material to be dredged, which was not expected by the contractor. The material was later identified to be decomposed granite. Mr Verhoef opined that had the quartz content of the material been included in the pre-tender site investigation information, the claim could have been obviated.

For site investigation, he considered that a lot of seismic surveys should be performed and that boreholes should be high-quality. There is little use in carrying out a large number of low quality boreholes. Geostatistical packages are often used by dredging industries in analysing ground investigation information.

7.2 Other Research Activities

7.2.1 Rock Suitability for Breakwater Construction

Further discussion was held with Mr Verhoef of Delft University of Technology regarding the choice of armour stone for breakwaters. One area of expertise of Delft is the examination of mineralogy and petrography of rock. They used methylene blue absorption to detect clay minerals in weathered rock (Latham et al, 1990). If there are expansive clay elements, a high methylene blue absorption (MBA) will result. They have suggested a criteria in sampling a rock source, such that when MBA is greater than 10% for the samples selected, the rock source will be rejected. On discussing sampling frequency and representativeness, Mr Verhoef did not offer any suggestions on an objective standard.

7.2.2 Cone Penetrometer Testing

Discussions were held with Fugro-McClelland on their research work. An innovation was a pocket-size miniature piezocone (11mm in diameter), which was claimed to be potentially very useful in soft soil probing. The probe has been applied as a measurement device in post dredging surveys. It is interesting that pore pressure was measured at the tip of this small cone, contrary to the currently-proposed standardization of pore pressure measurement behind the cone.

Problems of piezocone testing in Hong Kong were also discussed. In Hong Kong the cone is sometimes required to probe soil layers of very different strengths (e.g. the soft upper clay and the stiff lower clays). It was explained to Fugro-McClelland that two techniques were tried out in the 1990 site investigation at Chek Lap Kok: overloading a lower calibration range, and switching of calibration factors at change of stratum. Fugro informed that they were actually working on the installation of dual channels in a piezocone, i.e. two different sensors built into the piezocone which can be adjusted to suit different calibration ranges. It were also learnt that Fugro-McClelland Geotechnical Services in Hong Kong was about to team up with a site investigation contractor to install their Seacalf unit on a more substantial barge with a moonpool unit. This should improve the quality of piezocone results in Hong Kong.

8. SUMMARY AND CONCLUSIONS

Dredging practice in The Netherlands has a long history and is well developed. Maintenance dredging currently represents the primary form of dredging. A more limited amount of capital dredging is being undertaken, mainly for reclamation of low-lying areas for future development, long-term sand borrowing for use in the construction industry, or for beach replenishment.

As a result of a worldwide recession in the dredging industry during the early to mid 1980's, major restructuring of the Dutch dredging industry has taken place over the last few years. This has left a small number of large dredging contractors dominating the market both in the Netherlands and also overseas. This select group of contractors, which includes the world's largest dredging firm, can provide considerable expertise in the fields of dredging, marine engineering and construction, as well as having the capability to mobilise large and diverse fleets of well-equipped modern dredgers (mainly trailer and cutter suction dredgers) and associated auxiliary plant to projects worldwide.

Control of dredging activities in the Netherlands is carried out at central, provincial and local Government levels. Most dredging work is carried out by contractors for either the Rijkswaterstaat (Ministry of Transport and Public Works) or the Public Works Department of the Rotterdam Port Authority using a system of short- and long-term contracts. Close supervision of most dredging operations, particularly maintenance dredging, is in force and a high degree of automation and computerisation is employed in the dredging operations and the recording of data. The use of both mobile and stationary-type dredgers was observed during the duty visit both in and adjacent to navigation channels and harbour areas in both the Netherlands and Belgium. However, within the navigation channels of the port of Rotterdam mainly trailer dredgers are employed.

A close relationship exists in the Netherlands between Government and the dredging contractors with frequent consultation on the design of dredging works, particularly on major or difficult projects. This has frequently resulted in a reduction in overall project costs and construction time, as well as lessening the possibilities for disputes and subsequent claims.

Present dredging activities in the Netherlands (and also to some extent in Belgium) are designed where possible to be adaptable to site conditions and dredging requirements. Considerable improvisation and testing of new techniques, such as the use of degassing units, submerged pumps to increase dredging depths, and special methods for the removal and treatment of highly contaminated material, are employed by dredging contractors and are actively encouraged by the Dutch Government.

Most utilities in the Netherlands (and also apparently in Belgium) are placed below expected dredge levels, particularly in developed areas such as Rotterdam port. Therefore few problems are normally encountered during dredging operations in areas known to contain cables, etc. As a result very little research has apparently been undertaken to assess the need for 'safety zones' between dredging activities and utility positions.

As a result of the conventional long-term practice of reclaiming low lying and nearshore areas to create land for future use development, it has not been the practice in the Netherlands to employ elaborate or extensive methods of monitoring of reclamations. However, for sea defences more extensive methods of monitoring are deployed.

As a consequence of the low-lying, flat nature of much of the Netherlands and the fine and only slightly abrasive nature of sand deposits used in most reclamation sites, pipeline transport is frequently favoured for the transport of dredged material. In contrast, for maintenance dredging, trailer dredgers and to a lesser extent barges are commonly used to transport dredged material to the disposal grounds, mainly because of the considerable volumes of material to be dredged.

As a result of industrial pollutants and domestic waste being deposited into the river systems upstream and in the Netherlands itself, a considerable volume of contaminated material has to be removed annually by maintenance dredging from harbours and waterways, particularly in the Port of Rotterdam. A four-fold classification scheme has been introduced in the Netherlands to define the types and levels of contaminants present in these materials. The scheme is also used to determine the disposal grounds for the different types of materials. Uncontaminated material is disposed of at sea or, if possible, on land as reclamation fill. Slightly to moderately contaminated material is deposited in a large long-term containment area. The most highly contaminated material is currently disposed of in a smaller short-term containment area. Considerable efforts are underway to reduce contamination of these materials at the source by introducing strict regulations governing the discharge of pollutants into river systems.

Basic research on dredging is undertaken primarily by academic institutions centred in Delft. More detailed operational research is mostly undertaken by dredging contractors through specialist subsidiary firms or within their research and development departments. Currently the main areas of research interest are the efficiency of dredging equipment and environmental aspects such as turbidity mitigation and treatment of contaminated materials.

As a result of the duty visits and various discussions, a number of topics relevant to improving the effectiveness and efficiency of dredging in Hong Kong have been identified and are considered worth following up. The general areas of interest are dredging methods, contracts & research, transportation and reclamation, and removal, treatment & disposal of contaminated mud etc. Specific recommendation are given in the following section.

9. RECOMMENDATIONS

Based on the findings of the duty visit, the following actions are recommended to be considered for possible implementation in Hong Kong:

(a) Increase the level of consultation with dredging contractors in the design of projects involving a major dredging component.

(b) Increase the awareness and knowledge of Government Departments involved in dredging projects, of the range of capabilities of major international dredging contractors.

(c) Increase the level and quality of supervision carried out by the client/consultant on major dredging operations. This should include practical training of supervisory personnel, particularly in dredging practices. In addition more use should be made of information that can be provided via on-board computer systems (now present on many medium to large size dredgers) which monitor dredging performance and progress, locational control and navigation.

(d) Give greater consideration to the use of "stationary" type dredgers in general, and in particular with respect to dredging in navigation areas and for the dredging of contaminated materials.

(e) Consider locating future utilities away from known deposits of marine sands or placing utilities where possible below anticipated dredge levels. If this proves to be impractical then studies should be undertaken to assess the need for 'safety zones' between dredging activities and utility positions.

(f) Ensure that appropriate parameters necessary for assessing dredgeability of materials are obtained in all site investigations carried out for dredging works.

(g) Establish a local system to classify marine mud according to degree of contamination and ascertain the quantity and location of mud falling within each category. Establish an environmental policy for the dredging, transport, disposal and/or treatment of the material in each category.

(h) Give consideration to the possible benefits of treatment of contaminated mud prior to or instead of disposal, in particular for operations where the quantities of contaminated materials are small, e.g. as generated from maintenance dredging of nullahs, etc.

(k) Give closer consideration to the imposition of environmental controls on dredging activities, particularly with respect to dredging-induced turbidity and dredging of contaminated materials. In this respect a detailed examination of the considerable experience developed in the Netherlands of the application and use of environmental controls, particularly in contract documents, should be carried out.

(l) Set up technical exchanges with research institutions in Delft particularly in the fields of dredging and marine geotechnology.

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LIST OF TABLES

Table 1 - Dredging Sites Visited

Location of Site	Nature of Dredging	Name of Contractor	Type of Dredger	Name of Dredger	Remarks
Rotterdam Port, Netherlands	Maintenance	van der Kamp International	Trailer	Rhine Delta	Silt Dredging
Ijmuiden, Netherlands	Maintenance/ Capital	Boskalis	Trailer	Cornelia	Sand Dredging in in North Sea. Silt Dredging in maintenance
Ijmuiden, Netherlands	Rehandling	Ballast Nedam	Deep Suction	Weeskarspel	Commercial Sand Dredging
Almere New Town, Netherlands	Capital	Ballast Nedam	Deep Suction (Converted from cutter)	Aegir	Lake Dredging for Sand
Liefkenshoek-tunnel, Antwerp, Belgium	Capital	Dredging International	(a) Bucket	(a) Adriatico	Precision dredging close to design level
	Capital/ Maintenance		(b) Split-hull Trailer	(b) Krankeloon	Sand dredging in River Scheldt
Antwerp, Belgium	Capital	Dredging International	Cutter (Inclining Spuds)	Brabo	Sand Dredging in River Scheldt
Geulhaven, Rotterdam, Netherlands	Maintenance	Boskalis	Closed grabs Orange-Peel grab Closed-Box Grab Bucket-Type Grab		Dredging heavily contaminated sediments within silt screen enclosure

Percentage	unity	warning value	assessment value	basic quality
chromium	mg/kg	600	155	100
nickel	mg/kg	100	45	35
copper	mg/kg	400	90	36
zink	mg/kg	2500	1000	140
cadmium	mg/kg	30	7.5	0.8
mercury	mg/kg	15	1.6	0.3
lead	mg/kg	700	160	85
arsenic	mg/kg	100	45	29
oil	mg/kg	5000	3000	500
EOX	mg/kg	20	7	5.5
PAC's				
fluoranthene	mg/kg	7000	2000	1200
Benz(b)fluoranthene	mg/kg	3000	750	550
Benz(k)fluoranthene	mg/kg	3000	750	550
Benz(a)pyrene	mg/kg	3000	750	220
Benz(ghi)perylene	mg/kg	3000	750	200
Indeno (1,2,3,c,d) pyrene	mg/kg	3000	750	200
6 PAC's Borneff	mg/kg	17000	4600	2300
Various indiv. PAC's	mg/kg	3000	750	200
Various dilorine hydrocarbons	mg/kg	500	15	2.5
Various Cl HC's	mg/kg	2500	100	20
Various PCB's	mg/kg	100	30	4
6 PCB's	mg/kg	400	150	20

CLASS I - SATISFIES THE BASIC QUALITY

CLASS II - EXCEEDS THE BASIC QUALITY BUT SATISFIES THE ASSESSMENT VALUE

CLASS III - EXCEEDS THE ASSESSMENT VALUE BUT SATISFIES THE WARNING VALUE

CLASS IV - EXCEEDS THE WARNING VALUE

Table 2 - Dutch Classification System for Contaminated Sediments

LIST OF FIGURES

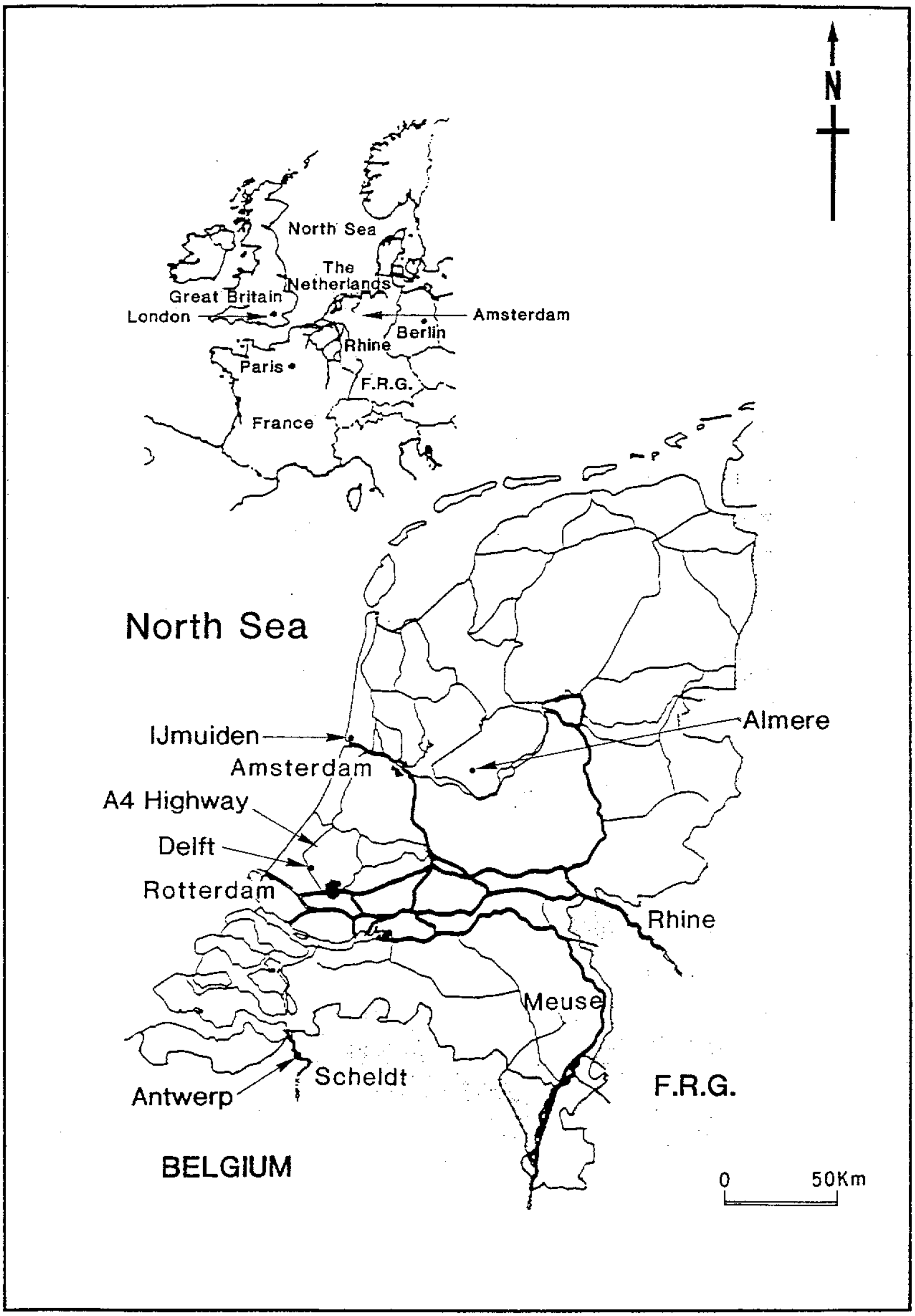


Figure 1 - General Location Plan of the Netherlands and Belgium. (After Dijkman et al (1989))

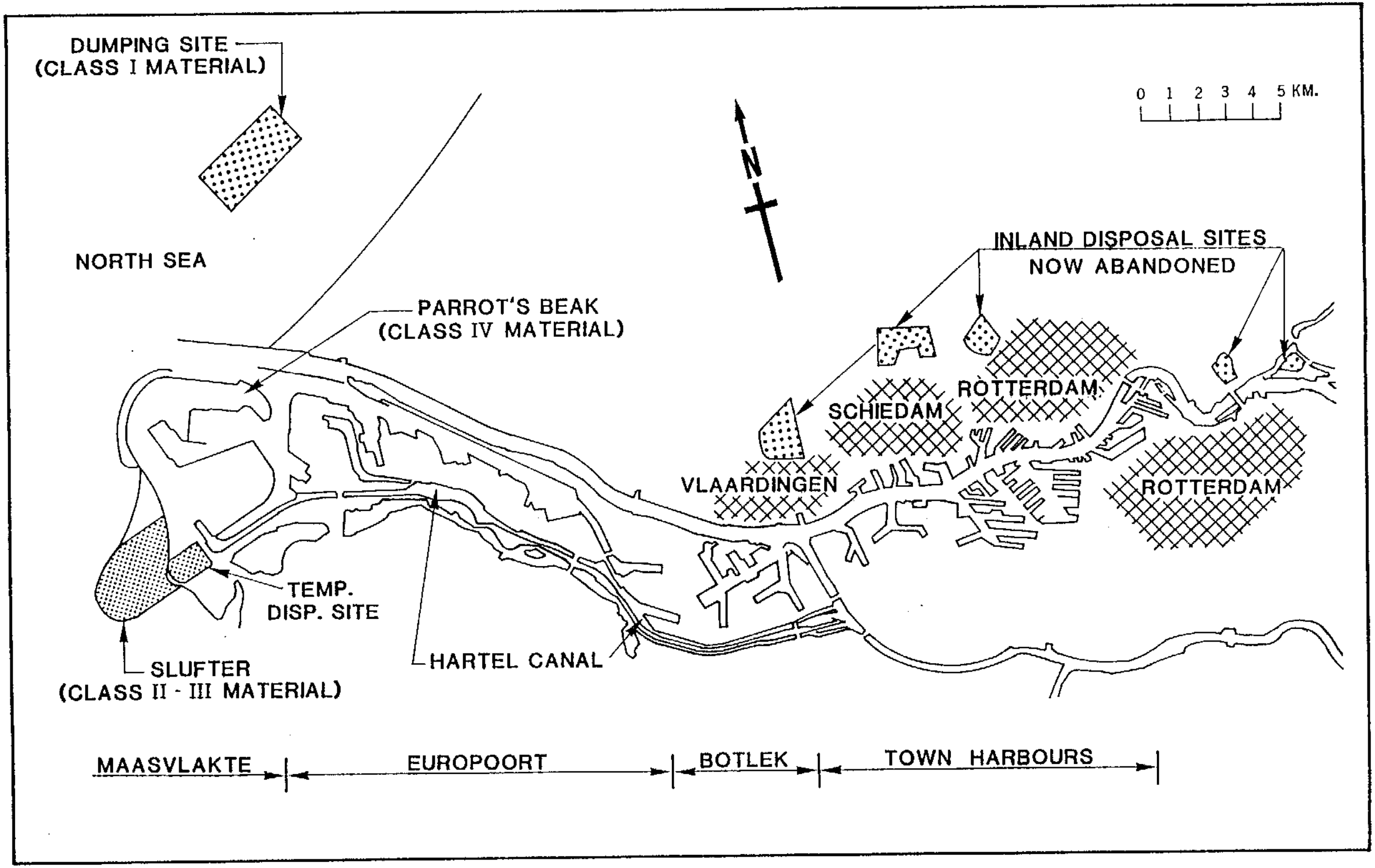


Figure 2 - Location Plan of the Port of Rotterdam (After Van de Ridder & De Wit (1988))

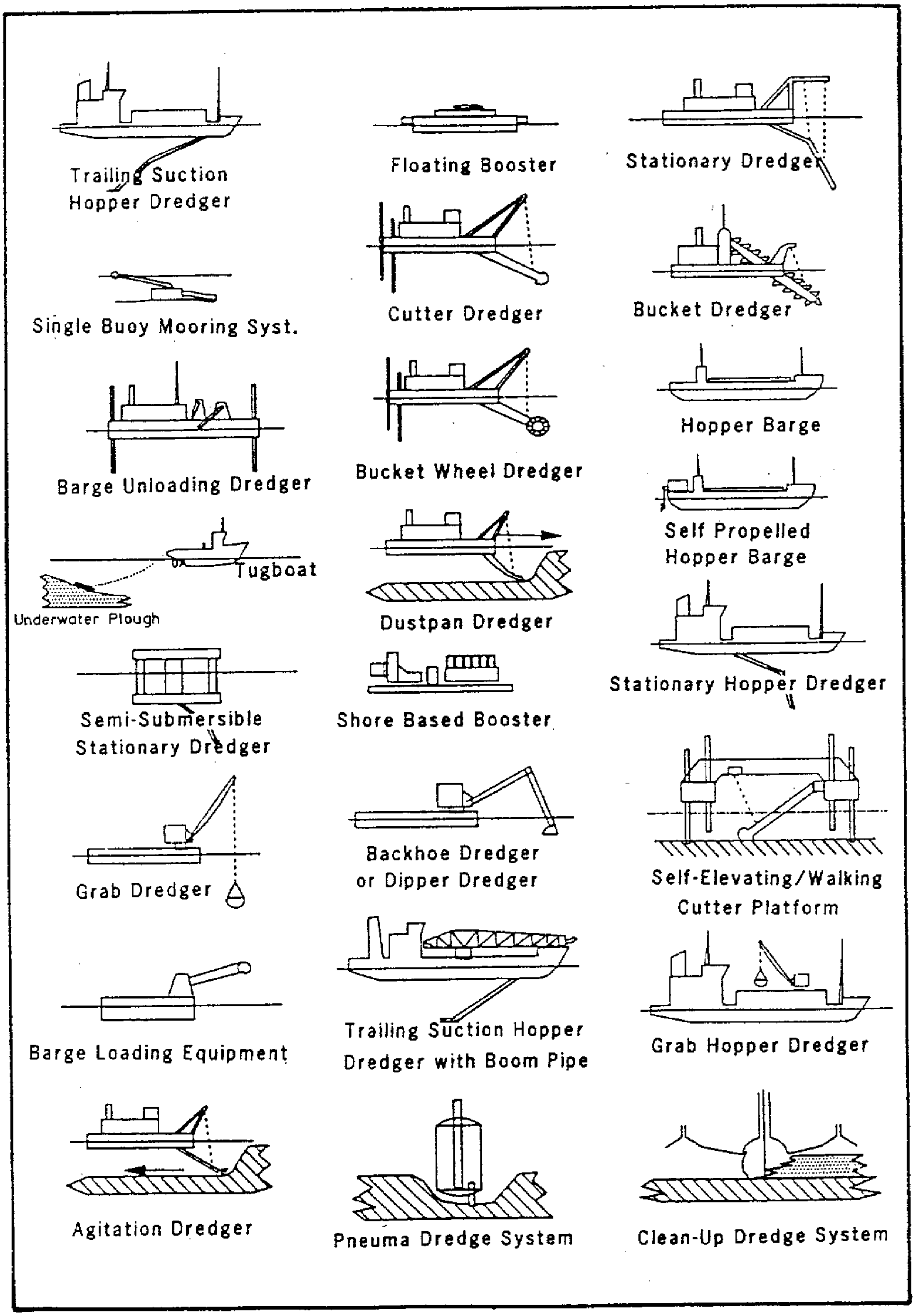
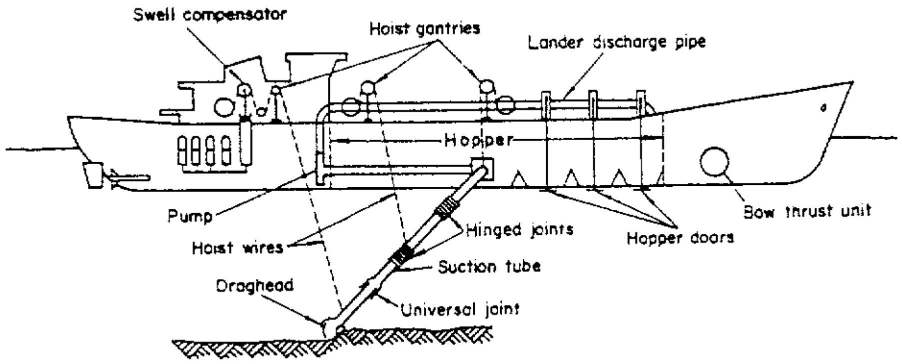
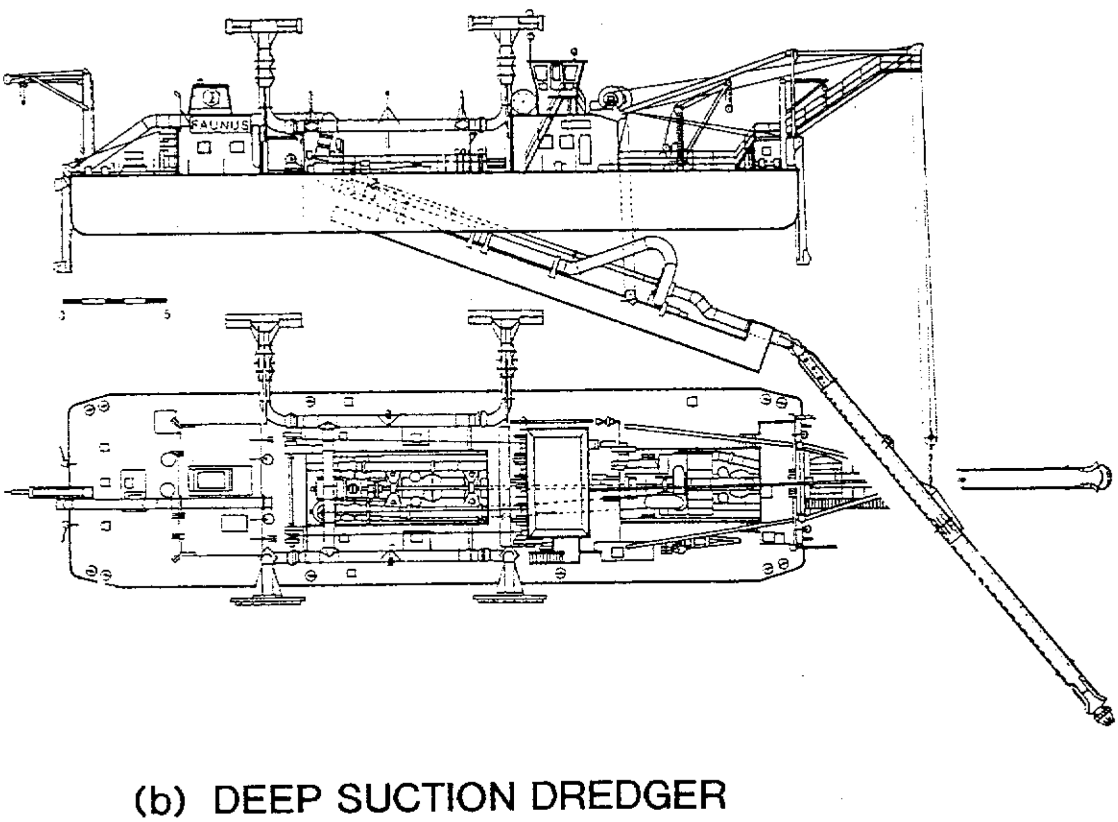


Figure 3 - Varieties of Modern Dredgers

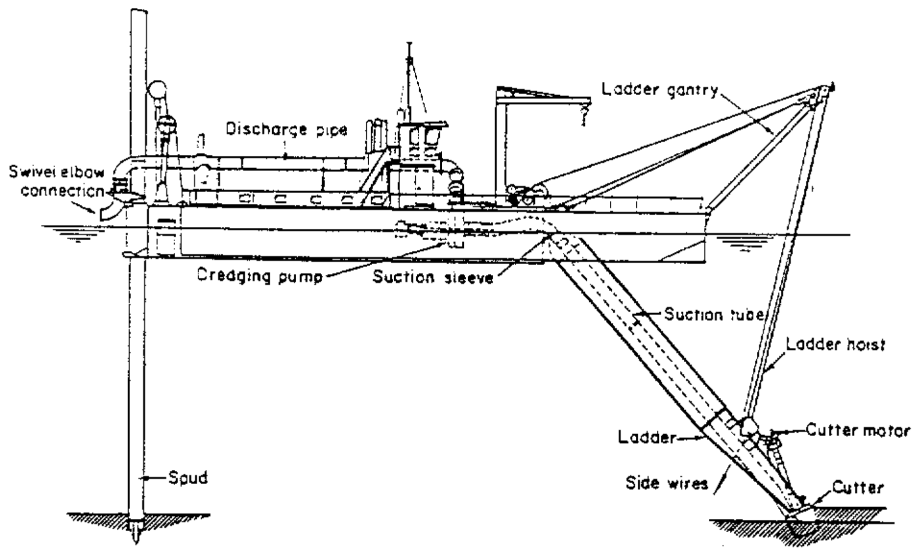


(a) TRAILER DREDGER

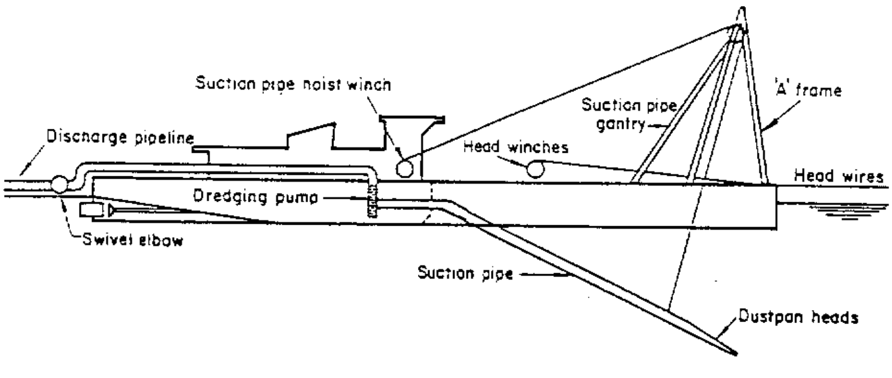


(b) DEEP SUCTION DREDGER

Figure 4 - Main Types of Hydraulic (Suction) Dredgers (After Bray (1981))



(c) CUTTER SUCTION DREDGER



(d) DUSTPAN DREDGER

Figure 4 (Cont) - Main Types of Hydraulic (Suction) Dredgers (After Bray (1981))

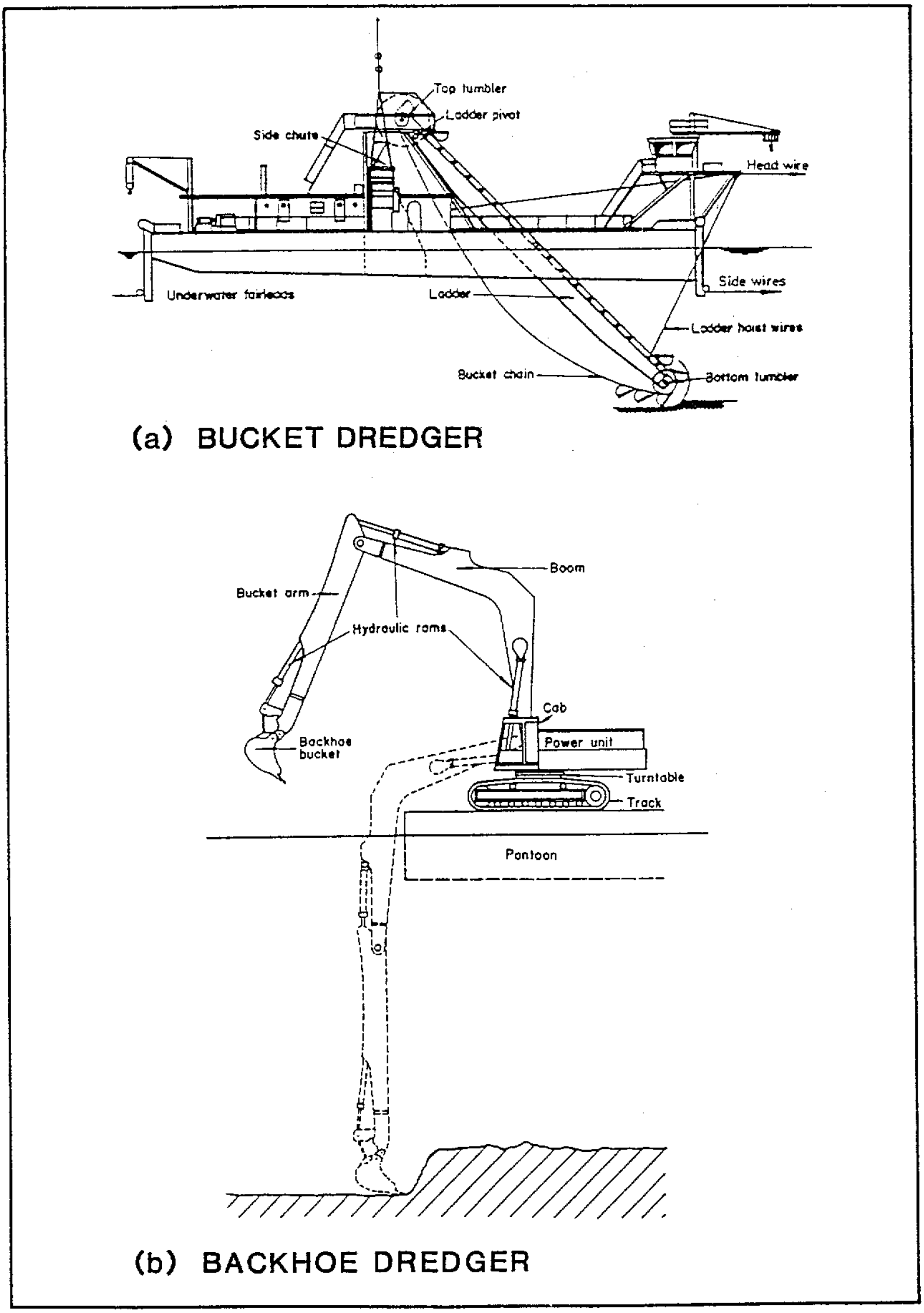
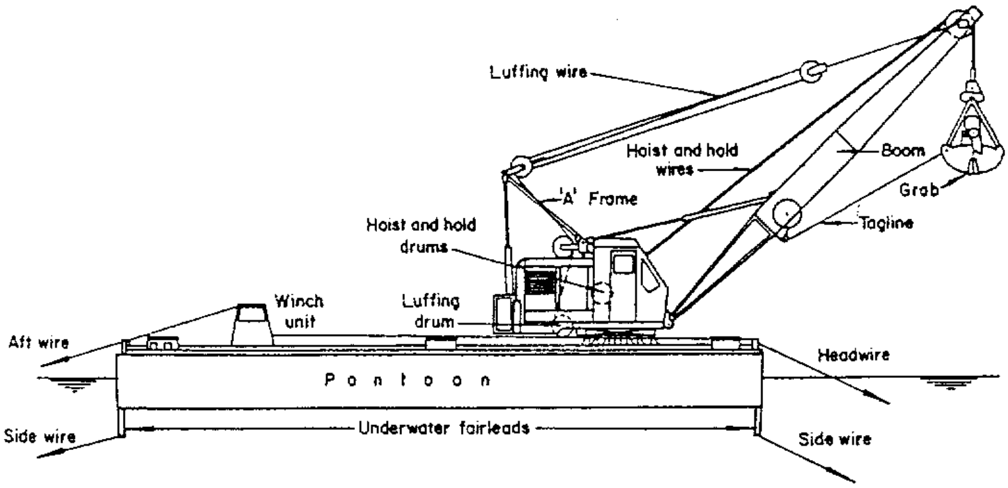
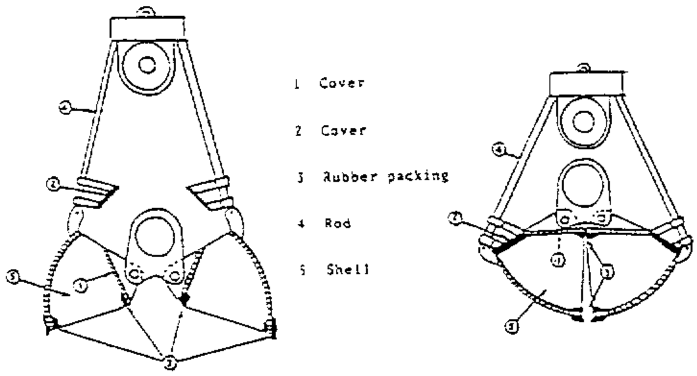


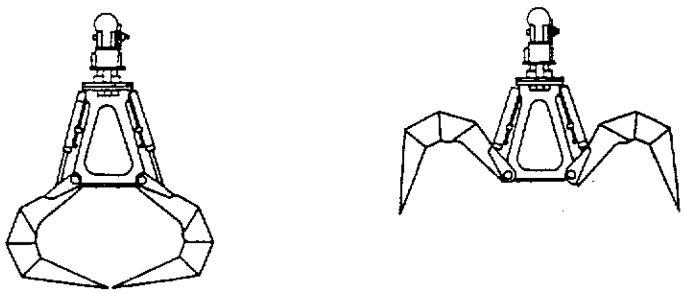
Figure 5 - Main Types of Mechanical Dredgers (After Bray (1981))



(c) GRAB DREDGER



CLOSED-FORM GRAB



OPEN-FORM GRAB

(d) DIFFERENT TYPES OF GRABS

Figure 5 (Cont) - Main Types of Mechanical Dredgers (After Bray (1981))

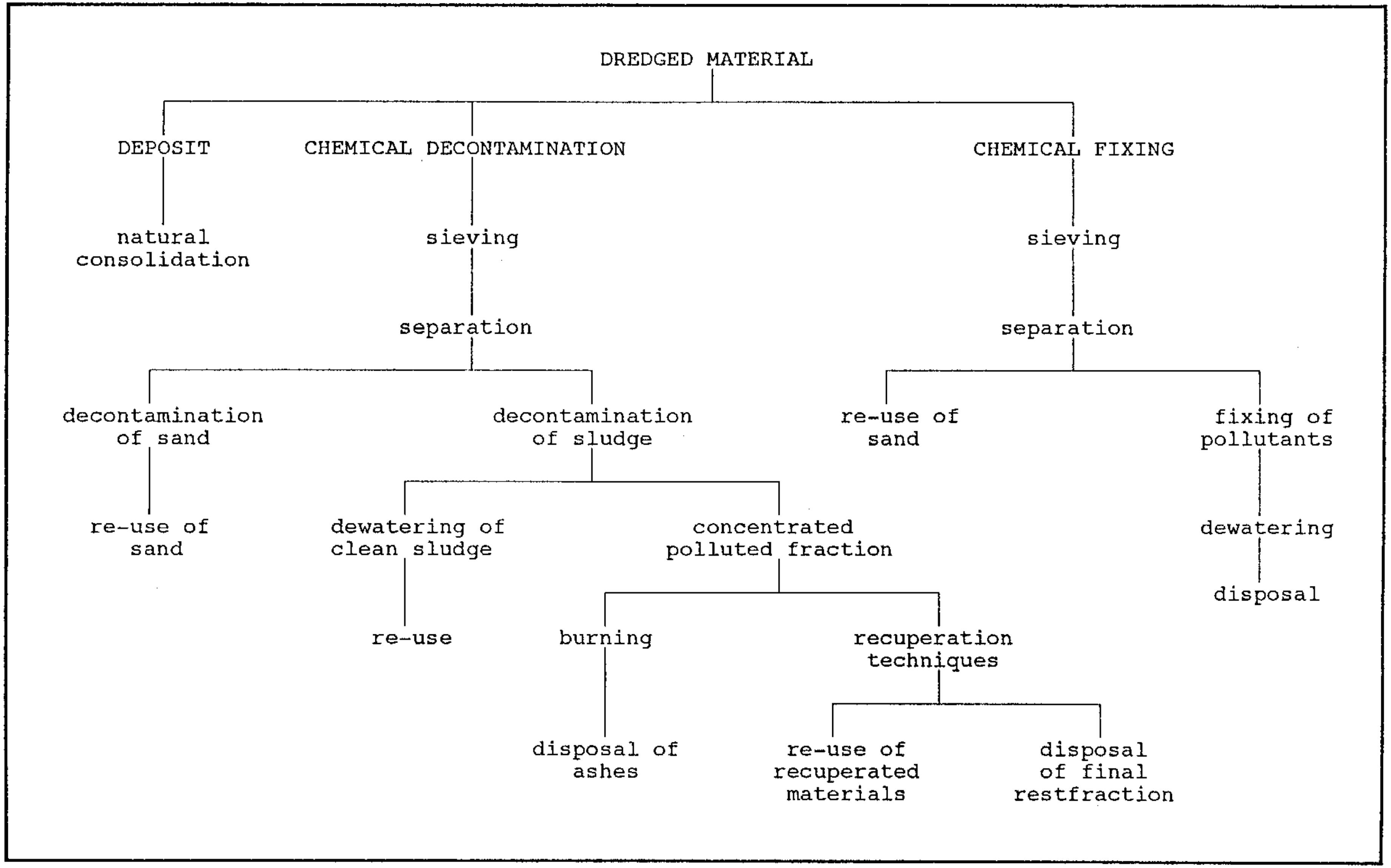


Figure 6 - Range of Possibilities for the Treatment of Contaminated Sediments (After Silt (1990))

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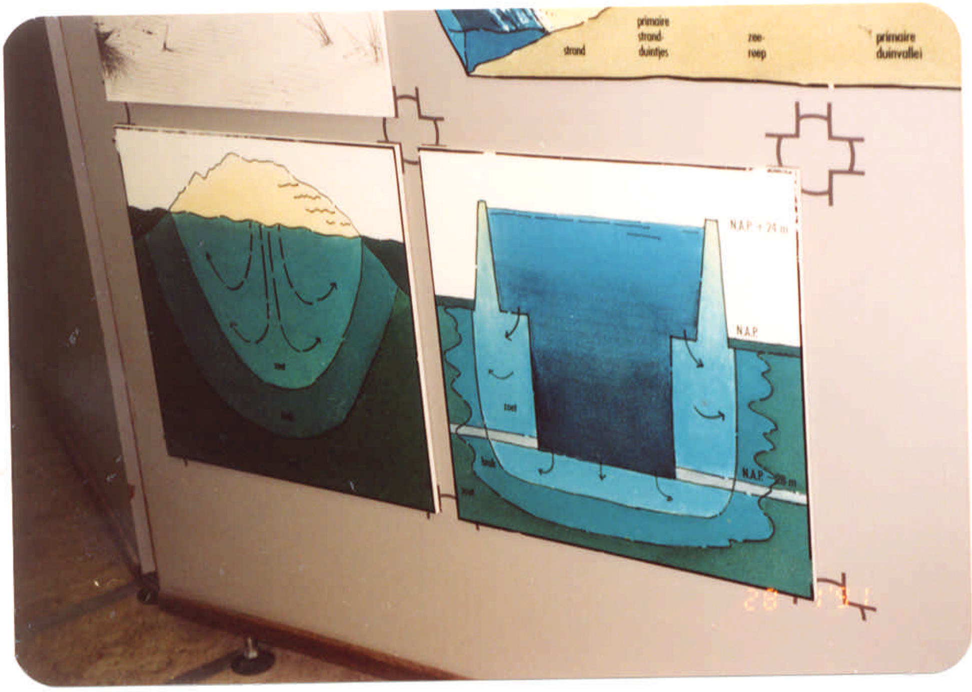

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Plate 26 - Sub-Containment Area within the Parrot's-Beak

Plate 27 - Settlement Basin of Parrot's-Beak Containment Area

Plate 28 - Mooring terminal for Barges at Parrot's-Beak Containment Area

Plate 29 - Discharge outlet at Parrot's-Beak Containment Area

Plate 30 - Discharge outlet at Parrot's-Beak Containment Area

Plate 31 - Pilot Plant 'KRANKELOON' for Treatment of Containment Sediments

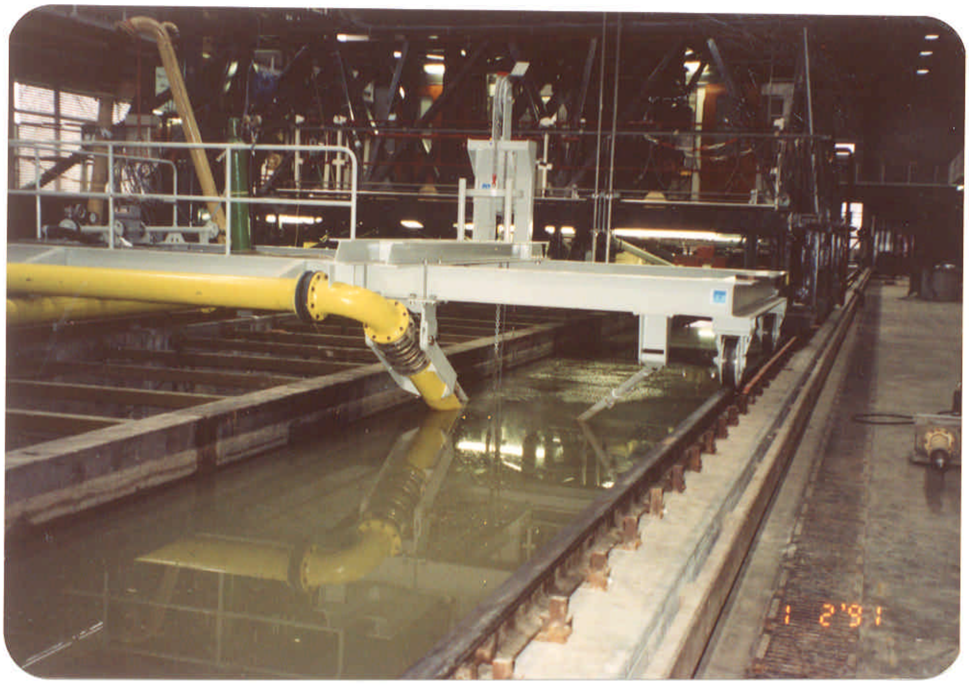

Plate 32 - Model Dredging Flume at Delft Hydraulics

APPENDIX A

ITINERARY OF THE DUTY VISIT

APPENDIX A

ITINERARY OF THE DUTY VISIT

27.1.91 (Sun) - Arrival in the Netherlands.

- Meeting with DEMAS (Mr T.W. van der Steege, Managing Director) to discuss objectives of duty visit and details of the programme of visits and meetings..

28.1.91 (Mon) - Meeting with the Public Works Department (Gemeenten Werken) of Rotterdam (Ing J.W. Zwakhals, Process Control Manager) to discuss maintenance dredging practice and disposal of contaminated silt in Rotterdam.

- Site visit with Ing Zwakhals to Rotterdam's storage basins for contaminated dredged silts, namely the Slufter (for slightly to moderately contaminated materials) and the Parrot's Beak (for heavily contaminated materials).

- Meeting with the Port Authority of Rotterdam (Mr R.W. van der Weijde) on the client's view of dredging and mud disposal in Rotterdam. Examined video of maintenance dredging.

29.1.91 (Tue) - Meeting with the Public Works Department (Gemeenten werken) of Rotterdam (Mr P.C. de Wit, Operations Manager) to discuss site operations of maintenance dredging activities in the Port of Rotterdam.

- Visit aboard the trailer dredger "Rhine Delta" with Mr de Wit and the dredging contractor's (van der Kamp International B.V.) Project Manager (Mr A. Fasse) to observe a maintenance dredging cycle in Rotterdam of the removal of slightly comtaminated material.

- Meeting with Mr A.M. de Jonge, Manager of the Dredging Division, North Sea Directorate of the Ministry of Transport and Public Works (Rijkswaterstaat) on maintenance dredging activities carried out at the access channels to Rotterdam, capital dredging for sand in the North Sea, and automation techniques of supervision and measurement.

30.1.91 (Wed) - Meeting with Mr M. Strauss, Business Development Manager of Ballast Nedam Dredging B.V. to discuss general dredging activities undertaken by the firm.

- Visit to the Ballast/Boskalis joint-venture project of combined maintenance dredging and sand-winning works at Agmatine, Ijmuiden. On board the trailer dredger "Cornelia" (maintenance dredging and sand winning in North Sea; depositing borrowed sand in rehandling basin in Ijmuiden), and the deep suction dredger "Weesperkarspel" (dredging sand from the rehandling basin and loading barges at the Ijmuiden rehandling basin onto shuttling barges).

- Visit to a new town development project at Almere (east of Amsterdam). Observed sand borrowing by the deep suction dredger "Aegir"within an artificial lake, and the deposition of the sand via pipelines into low-lying areas targeted for future development.

31.1.91 (Thu) - Meeting with Dredging International (DI), Belgium

- Meeting with DI personnel to discuss companies operations.

- Visit to DI's dock at the Zwijndrecht headquarter, where a variety of dredgers were moored.

- Visit to the Liefkenshoektunnel project on the River Scheldt near Antwerp, where a number of dredgers were in operation:

  (a) Split-hull trailer "Krankeloon" carrying in borrowed sand and carrying out silt as maintenance;

  (b) Bucket dredger "Adriatico" carrying out precision dredging to design level of trench for placement of the concrete tunnel sections;

- Visit to a dredging site on the river Scheldt in Belgium, where river sand was borrowed by the cutter suction dredger "Brabo", and the sand was pumped to a low-lying reclamation site 4km away.

1.2.91 (Fri) - Meeting with Delft Hydraulics (Mr J.G.S. Pennekamp, Project Manager) to discuss research activities at Delft Hydraulics

- Meeting with Fugro-McClelland Engineers B.V. (Mr H.M. Zuidberg, Director; Mr R. Kee, Managing Director; Mr C. Rosendahl, Project Manager) to discuss site investigation interests particularly in Hong Kong, developments in cone penetrometer testing, and dynamic pile testing.

- Meeting with Delft Geotechnics (Ir P. Lubking, Head of Hydraulic and Marine Constructions Division; Mr J.L. van de Velde, Marketing Manager; Mr F. Molenkamp, Civil Engineer) to discuss on research activities at Delft Geotechnics.

2.2.91 (Sat) - Meeting with DEMAS (Mr T.W. van der Steege and Mr K. Ooms) to review progress, topics discussed and visits made, and to discuss the merits and limitations of different types of dredgers.

3.2.91 (Sun) - Day off

4.2.91 (Mon) - Meeting with Royal Boskalis Westminster B.V. (Mr F.J.M. Lambregts, Marketing Department; Mr J.J.L.M. Enneking, Marketing Manager; ir J.R. Kraaijeveld van Hermert, Assistant Director) to discuss company's activities and in particular techniques for the treatment and removal of contaminated materials and the use of geostatistical software for assessing site investigation data.

- Visits to a dredging operation in Geulhaven (a heavily oil-contaminated Rotterdam harbour) where different types of closed-grab dredgers were being used to removed highly contaminated material and a road-widening project at Vlietlanden, near Leischendam using lake derived sand as filling material.

5.2.91 (Tue) - Meeting with Federick R. Harris Inc. (Mr S.J. Reeves, Vice President; Mr Han Ligteringen, Vice President) to discuss fill management work in Hong Kong and their involvement in the Port Peninsula and Western Harbour Studies in Hong Kong.

- Meeting with the Ministry of Transport and Public Works (Rijkswaterstaat) (Mr J.W. van Nouhuys, Legal Advisor) to discuss general mud disposal management in the Netherlands and environmental legislation covering dredging operations.

- Meeting with SILT, a subsidiary of Dredging International (Dr Ir J.de Brabandere, Project Engineer; Ir I. Goemaere, Project Engineer) to discuss companies activities and in particular methods of treating contaminated soils.

6.2.91 (Wed)

- Meeting with Geocom (Mr B.T.A.J. Degen, Consultant; Ir J. Herbschleb, Engineering Geologist) to discuss use of geostatistical software and interpretation of results from geophysical surveys.

- Meeting with Delft University of Technology (Mr P.N.W. Verhoef, Lecturer in Engineering Geology) to discuss research work in rock dredging and in armour selection for breakwaters.

Note: DEMAS (Mr T.W. van der Steege or Mr K. Ooms) accompanied the GCO staff to all meetings and site visits in the Netherlands.

APPENDIX B

LIST OF CONTACTS

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LIST OF CONTACTS

GEMEENTE WERKEN (Rotterdam) - Mr J.W. Zwakhals, Manager Process Control
- Mr P.C. de Wit, Manager Operations

ROTTERDAM PORT AUTHORITY - Mr J. van der Weijde

VAN der KAMP INTERNATIONAL DREDGING bv - Mr A. Faasse, Project Manager

RIJKSWATERSTAAT - Mr J.W. van Nouhuys, Legal Dept
- Mr A.M. de Jong, North Sea Directorate

DREDGING INTERNATIONAL - Mr Theo van de Kerckhove, Project Manager
- Mr D. Westelinck, Civil Engineer R+D

HYDROSOIL SERVICES - Mr P. van den Bergh, Project Manager
(DI Subsidiary)

SILT - Miss I. Goemaere, Project Engineer
(DI Subsidiary) - Dr J. de Brabandere, Project Engineer

BALLAST NEDAM - Mr M. Strauss, Business Development Manager

DELFT GRONDMECHANICA - Mr P. Lubking, Head of Hydraulic and Marine Construction Division

- Mr J.L. van de Velde

FUGRO-McCLELLAND ENGINEERS bv - Mr R. Kee, Managing Director
- Mr H.M. Zuidberg, Director
- Mr C. Rosendahl, Project Manager

DELFT HYDRAULICS - Mr J.G.S. Pennekamp, Project Manager, Dredging Technology Division

GEOCOM - Mr B.T.A.J. Degen, Consultant Engineering Geologist
- Mr J. Herbschleb, Engineering Geologist
- Miss I. Deibel, Engineering Geologist

BOSKALIS INTERNATIONAL bv - Mr J.J.L.M. Enneking, Marketing Manager
- Mr F.J.M. Lambregts, Marketing Dept
- Mr Berkbout, Geologist

BOSKALIS DOLMAN bv - Mr J.R. Kraaijeveld van Hemert, Assistant Director

FREDERIC R. HARRIS Inc - Mr H. Ligteringen, Vice President
- Mr S.J. Reeves, Vice President

DELFT TECHNICAL UNIVERSITY - Mr P.M. Maurenbrecher, Lecturer in Engineering Geology

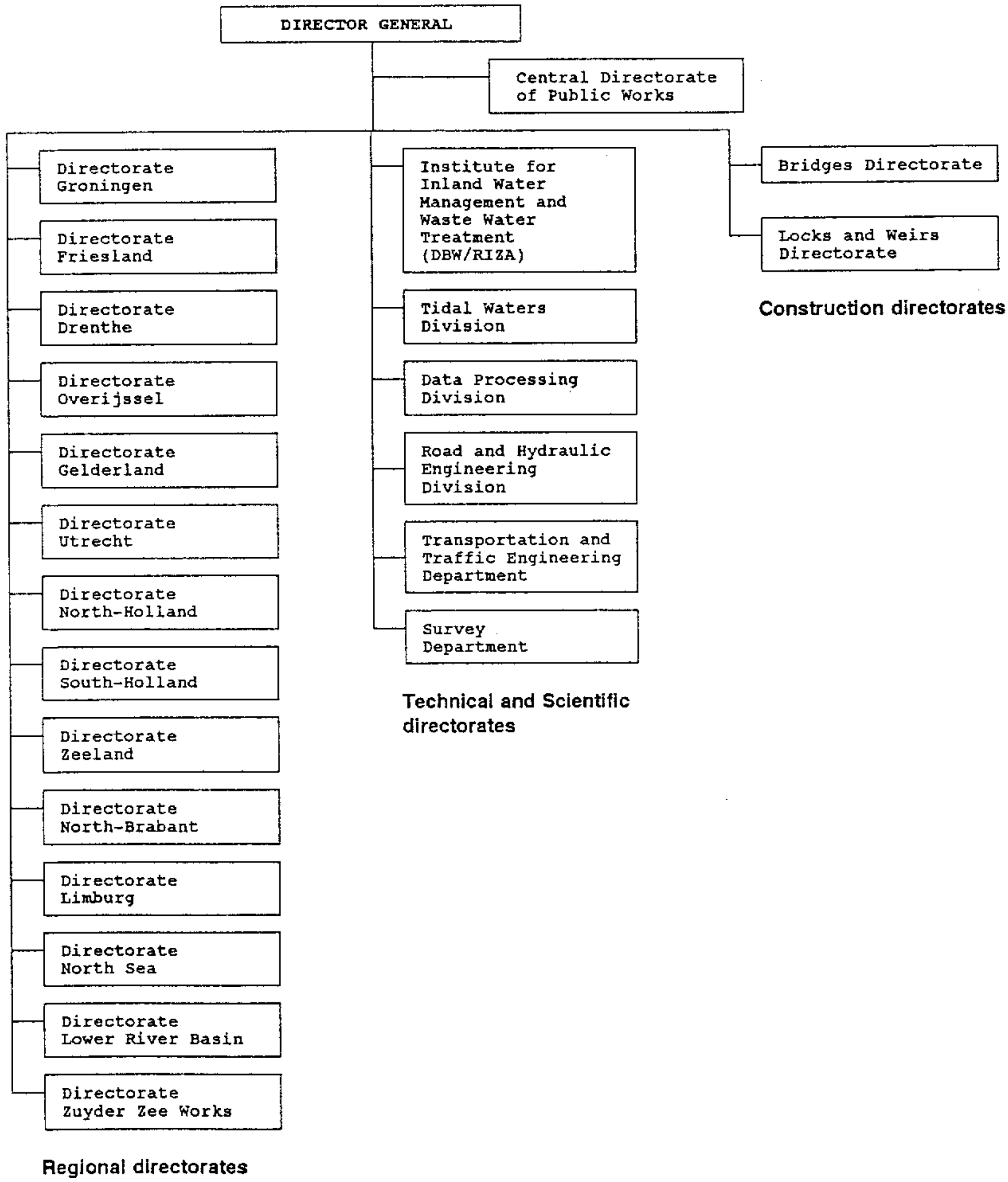
- Mr P.N.W. Verhoef, Lecturer in Engineering Geology

DEMAS - Mr T. van der Steege, Managing Director
- Mr K. Ooms, Project Manager

APPENDIX C

ORGANISATION OF THE RIJKSWATERSTAAT

Organization of Rijkswaterstaat



APPENDIX D

TRADE LITERATURE ON WATER INJECTION DREDGING

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Theory and practice of water injection dredging

In terms of cost, water injection dredging can often be compared very favourably with conventional dredging methods, since the dredged material is transported by a naturally occurring density current – a result of differences in density between, on the one hand, a mixture of water and sediment and, on the other hand, water.
Jet penetration, jet dispersal, density flow and sedimentation play an important role in this type of dredging process. These have been explored with the aid of theoretical research, scale model tests and in situ measurements. Some of these results are described in this brochure.
The water injection dredging theory has been put into practice using the water injection vessel Jetsed and some of the working methods employed are briefly considered. A number of cases illustrate the capacity and capabilities of the Jetsed.

Introduction

Maintenance dredging or comparable dredging work, in terms of soil type, can often be carried out more cheaply and quickly by a water injection dredging vessel than by conventional dredging equipment such as trailers, cutter suction dredgers or bucket dredgers. During water injection dredging water is injected into the sediment creating a water-sediment mixture with fluid properties and an extremely low viscosity. The thickness of this mixture may, depending on the soil properties, vary between one and three metres [figure 1]. Since this mixture has a higher density than its surroundings a density or turbidity current is created which carries the mixture away. This natural transportation of dredged material is an important feature of water injection dredging and is one reason why water injection dredging is in some cases a financially attractive solution.
Much valuable experience has been gained on various Dutch and overseas dredging works using the water injection dredging vessel Jetsed.
During a number of these operations conducted in co-operation with the Dutch Ministry of Public Works, extensive in situ measurements were taken to ascertain conditions during the process such as soil properties, turbidity, dispersion of the sediment, current velocities and working methods. From the experimental and test results obtained a mathematical model could be developed. It also transpired that in addition to the

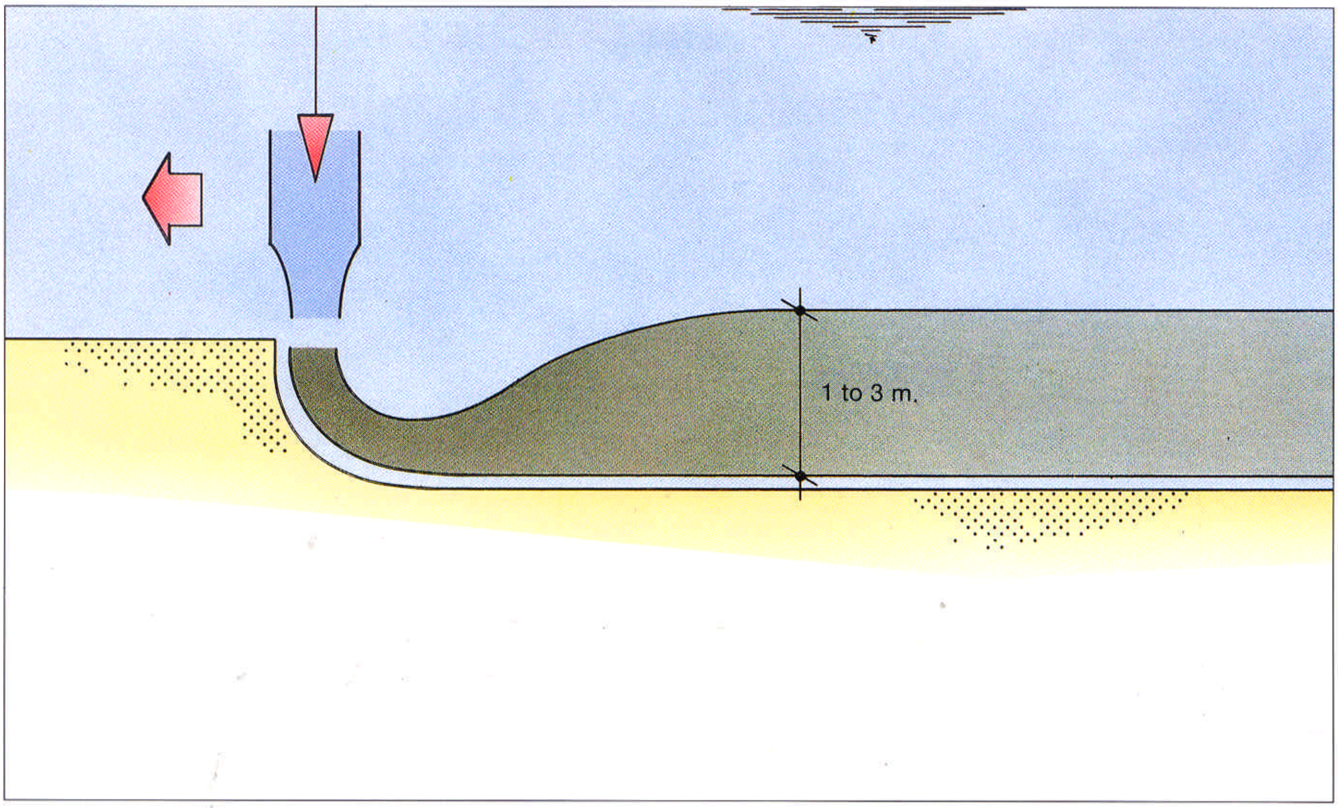


Figure 1. During the water injection dredging process, water is injected into the sediment creating a water/sediment mixture which, because of its higher density, disperses as a density current

governing conditions, some practical aspects of execution of the work play a very important role in the production process.
This article deals with the following subjects:
– the theory of water injection dredging and the verification of this theory by measurements made during dredging;
– the water injection vessel Jetsed;
– practical experience with water injection dredging.

Jet penetration of a sediment
If a water jet is held directly above the surface of a sediment for any length of time the stream of water emanating from the jet will penetrate the sediment and form a mixture with the subsequently loosened soil. The penetration performance of a jet has been investigated both by model testing [figure 2] and by practical trials. Results thus obtained show that the depth of penetration of the water jet is strongly dependent upon the characteristics of the particular soil being penetrated. In noncohesive sand

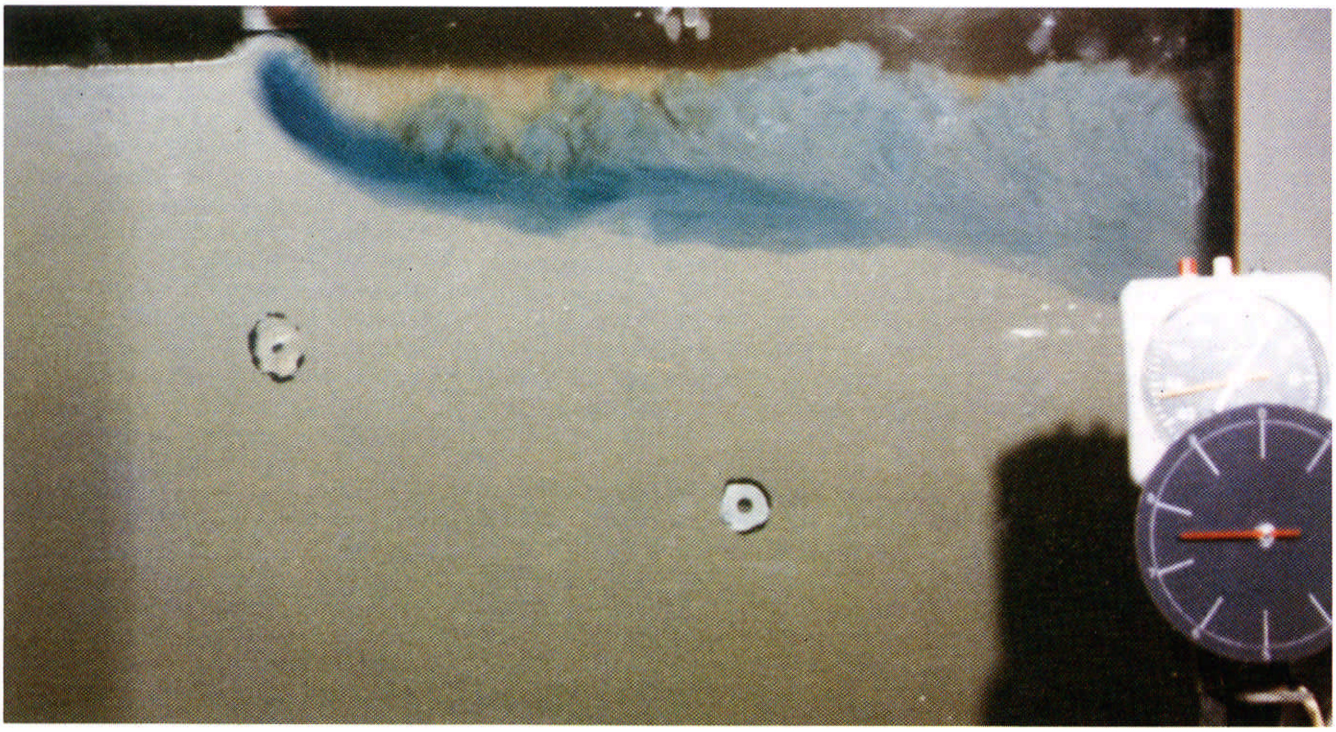
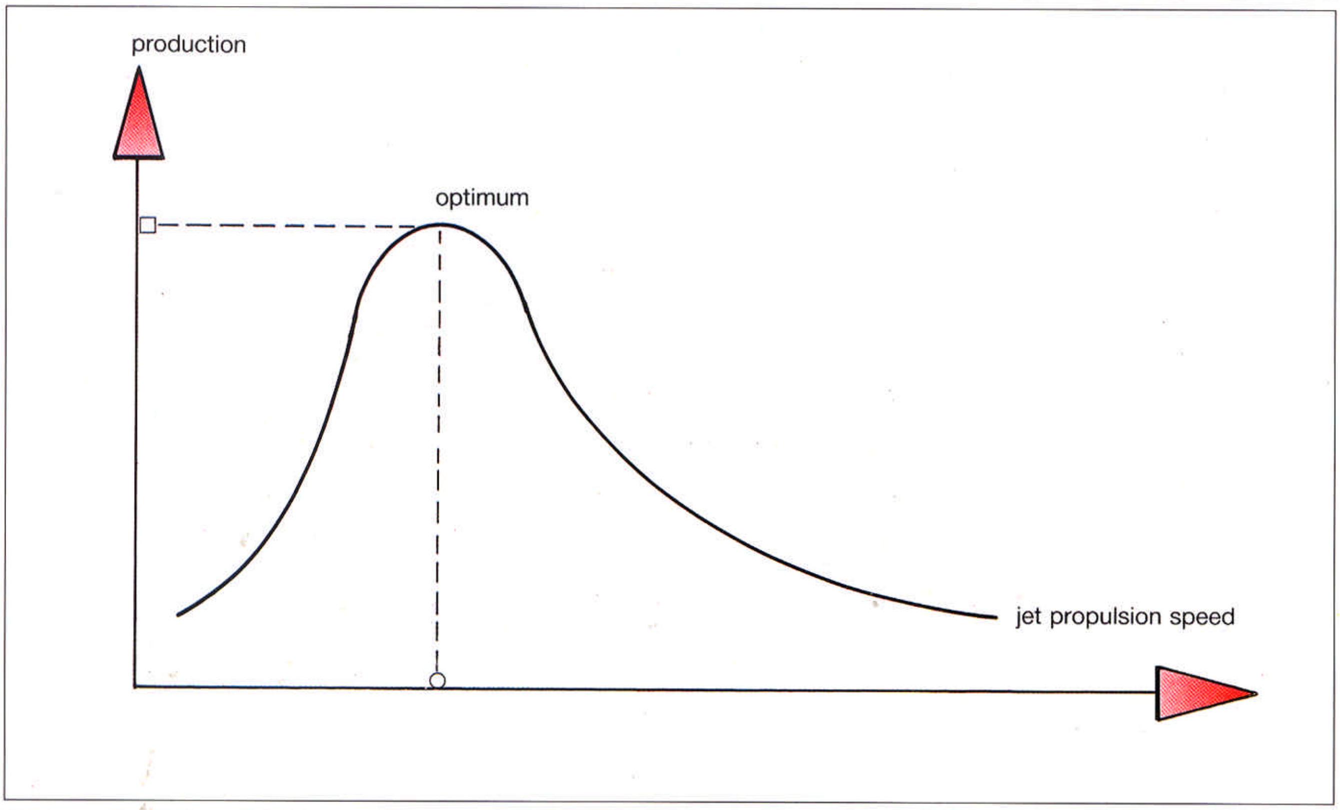


Figure 2. In model tests a water jet was propelled along a sediment of fine sand at a constant velocity. Jet penetration and jet dispersal can be clearly observed. These tests were carried out by the Delft Hydraulics Laboratory



the characteristic properties are grain size and permeability. Where a jet is moving above the sediment layer results show that the depth of penetration in sand increases with the grain size and permeability. This is not necessarily the case if the jet is stationary. In silt the determining factors for jet penetration are its in situ density, viscosity and permeability.
In addition to the soil properties, the amount of penetration is governed by the characteristics of the jet itself. These are the jet's diameter, the exit velocity of the water from the jet, the forward velocity of the jet pipe, and the distance between the jet and the surface of the sediment, known as the 'stand-off distance'.

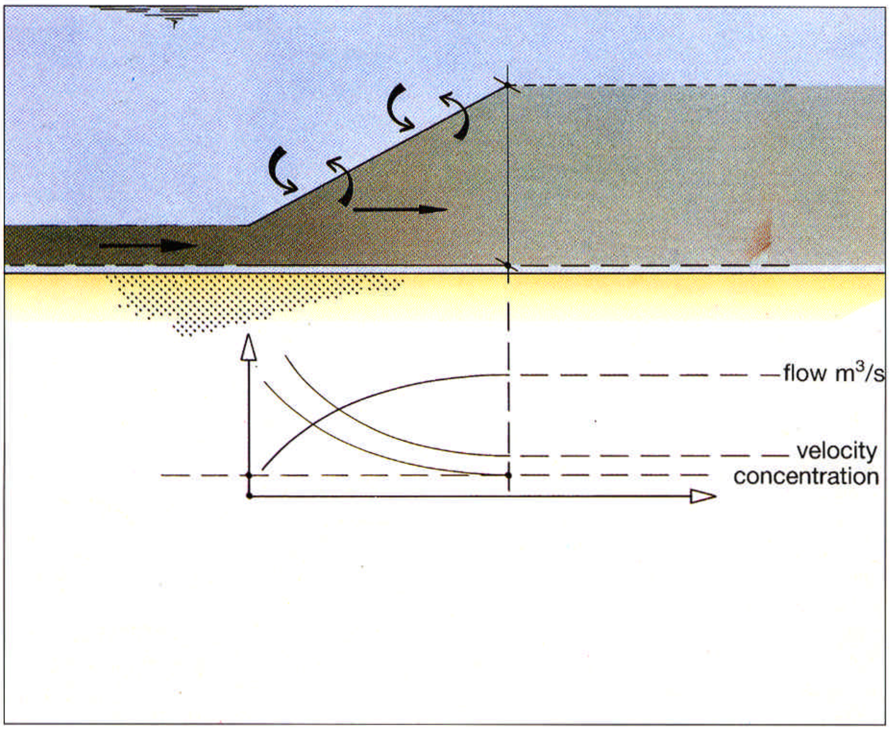
Empirial formulae have been developed to make calculation of the penetration depth of a water jet possible. When this penetration depth is multiplied by the forward velocity of the jet an estimate of the amount of soil loosened as a function of time is obtained. There is a maximum in the relationship between the quantity of soil loosened and the forward velocity of the jet [figure 3]. This maximum is important in the optimization of the water injection dredging process.

When the jet's flow has reached maximum penetration, the initially vertical stream will curve away horizontally and the resultant water-sediment mixture will then disperse.

Dispersal of a high-velocity water-sediment mixture
A high-velocity water-sediment mixture flowing within a body of water will disperse in a direction perpendicular to the direction of flow because of the presence of eddies, which entrain water from its surroundings [figures 2 and 4]. As a result, the sediment concentration and the average velocity of the mixture decrease in the direction of the flow and the discharge of the jet stream increases. At a certain distance from the source of a horizontally directed jet stream the average

Figure 3. The amount of soil moved by a jet reaches a maximum at only one jet propulsion speed. This optimum propulsion speed is of importance in the production process of water injection dredging

Figure 4. A high-velocity stream of water/ sediment mixture disperses. At the same time, water from the surrounding area is entrained, whereby the average velocity of the stream decreases. If the stream has reached critical velocity further lifting of the sediment will become negligible. The critical velocity and thus the lift height is dependent upon the grain size



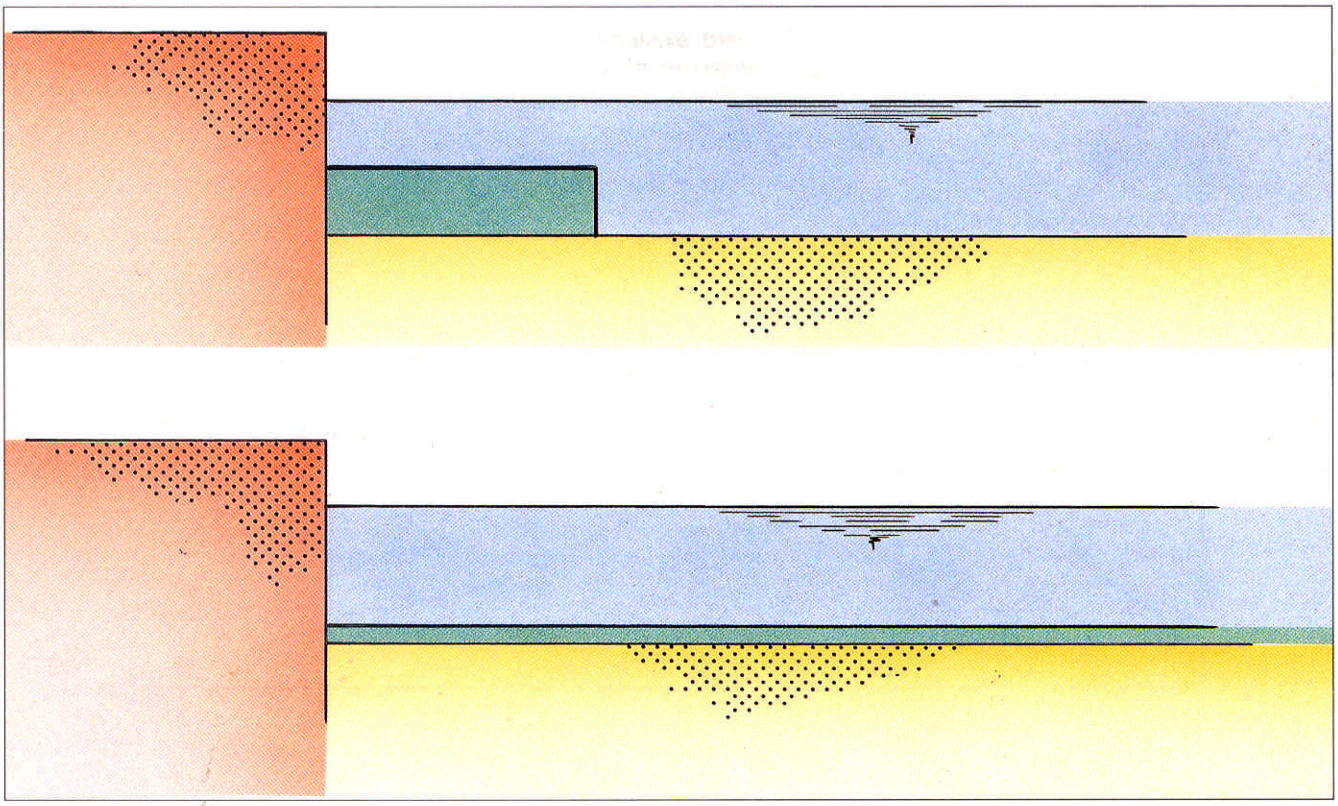


Figure 5. The quantity of salt water present in the initial situation will later spread over the entire length of the channel.
This is called a density current

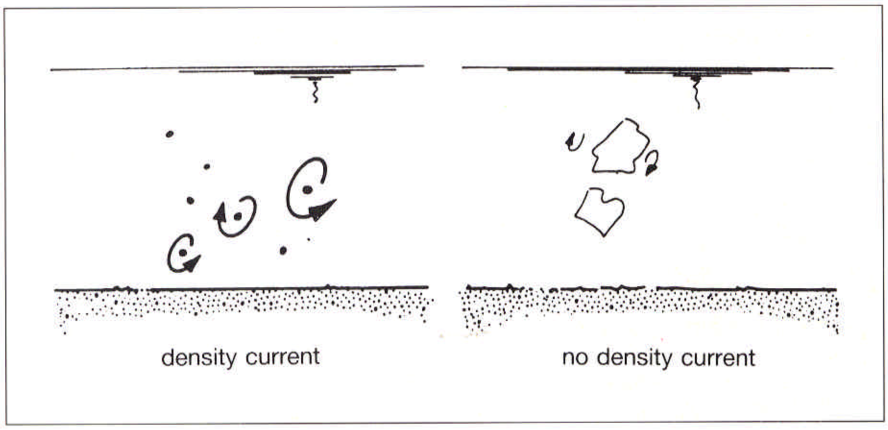


Figure 6. The relationship between grain size and the size of eddies in the current is a measure of the homogeneity of a mixture. If the mixture is homogeneous a density or turbidity current can be said to exist

velocity, and hence the velocity within the eddies, drops so far that further dispersal of the sediment becomes negligible. This distance will be less for a jet stream of sand and water than for a stream of silt and water. The average velocity of the jet stream at this distance is known as the critical velocity of the respective soil type. The

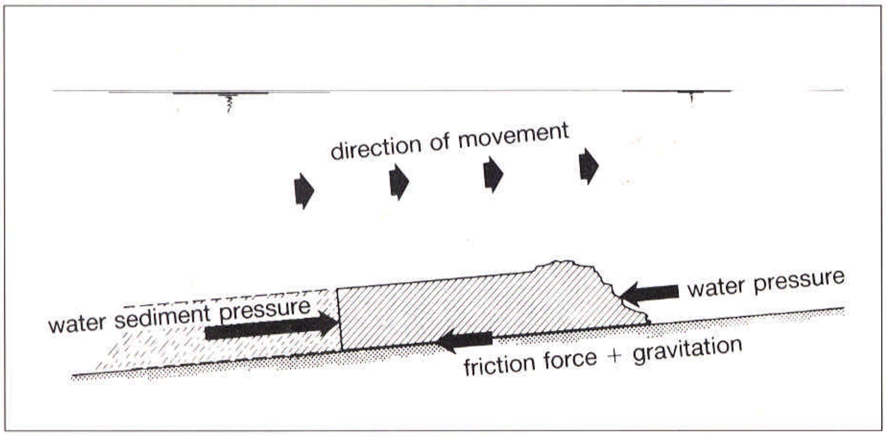


Figure 7. Hydrostatic forces, friction and gravity play an important role in the equilibrium of the front of a density current. The current may even be flowing against a gentle upward gradient

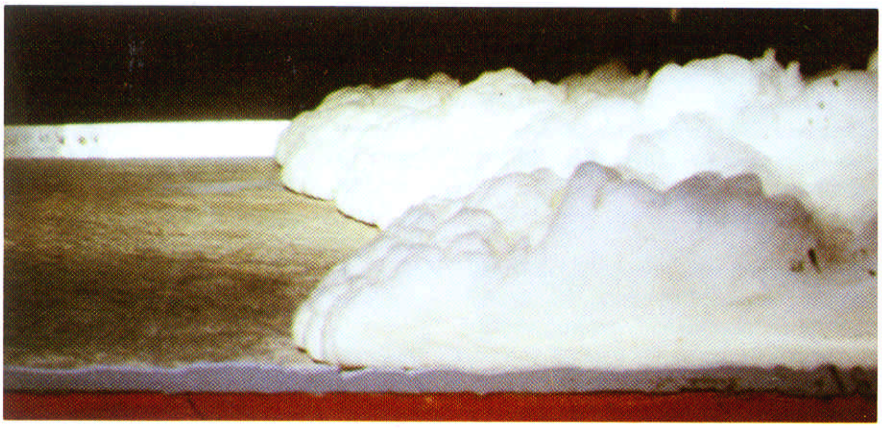
ultimate lifting height of a mixture of water and sand is consequently less than that of a mixture of water and silt [figure 4].
The dispersal of a water jet freely discharged within a body of water can be accurately formulated from the results of previous model tests. The dispersal of a jet of soil-water mixture, bounded on one side by a layer of sediment and discharged within a water body can, with more limited accuracy, be formulated. Using this formula, all parameters mentioned previously can be calculated. In practice it was observed that in some cases, following dispersal, the flow rate of the mixture had increased to approximately 10 times its initial value through entrainment of surrounding water. In such cases, a maximum thickness of the mixture [i.e. a lifted height] of approximately 1m. was recorded [figure 9].

Density or turbidity currents

Once a mixture layer has formed, the difference in density between it and its surroundings may make it flow. This phenomenon is known as a density current. A hypothetical example of this may be an infinitely long channel enclosed on one side, containing both fresh water and, on the enclosed side, a certain amount of salt water with a higher density [figure 5]. This situation will be unstable. The heavier salt water will, as a result of the prevailing difference in density, flow and spread over the entire length of the channel. The resultant current in the channel is the density current.

Density differences can, for example, result from differences in salt concentration or temperature, but also from differences in concentrations of soil particles. In the last case, if the mixture flow of water, sand and/or silt may be considered homogeneous, it is known as a density or turbidity current. The movements of this homogeneous mixture can be described in terms of

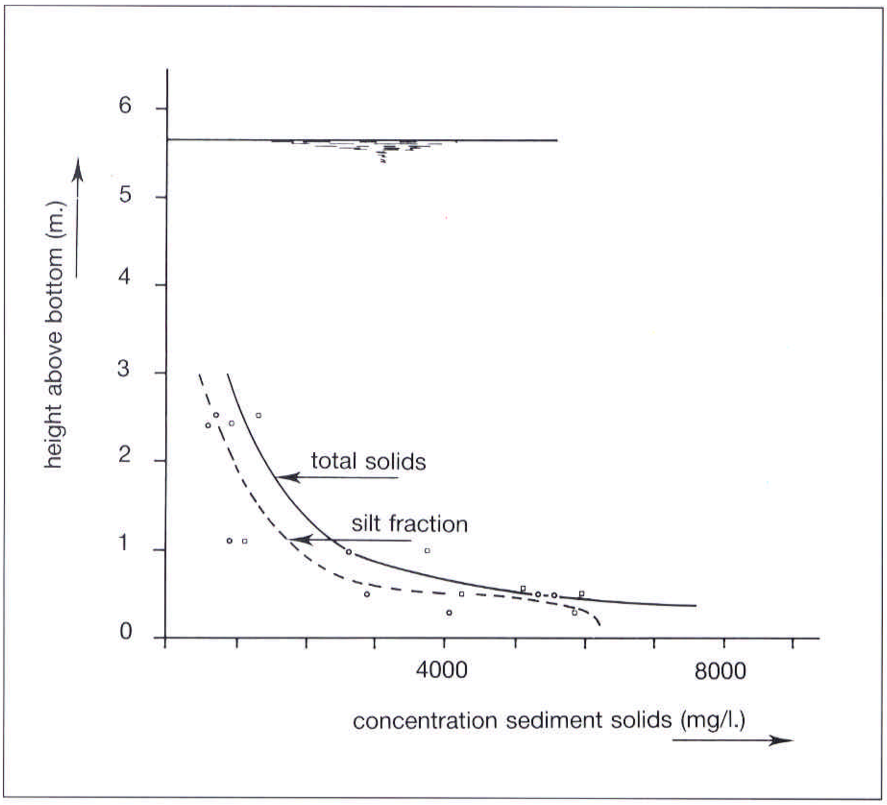
Figure 8. Model research into the transport of silt in water showed clearly that a density current can act as a transport mechanism; transportation of silt in this manner can be observed on this photograph. This research was carried out by the Delft Hydraulics Laboratory



the density current theory. A mixture is considered homogeneous where certain criteria are met, the most important of these being the relationship between the size of the eddies in the current and the size of the particles of sand or silt. Where the eddies are relatively small and the particles relatively large, the mixture is not homogeneous. The eddies are then simply not strong enough to support the particles. Where the eddies are large with respect to the particles, one condition for homogeneity is fulfilled and in many cases a density current can be said to exist [figure 6].
The size of the eddies depends, among other things, on the viscosity, water depth and velocity of the mixture. If these parameters are known, the size of the eddies can be calculated using a certain formula.
By examining the equilibrium forces at the front of a density current, the factors influencing the formation of the current can be identified. In figure 7 the following forces are distinguished:
– Hydrostatic forces. The resultant of these forces moves the front of the mixture forward, since the hydrostatic force of a water-sediment column is greater than that of a water column [F1>F2].
– Gravitational forces. In the case shown, these work against the resultant of the hydrostatic forces, since the sea bed has a gentle upward gradient.
– Velocity-dependent forces. If, because of the above forces, the mixture moves, certain velocity-dependent forces develop in the direction opposite to that of the current; such as friction on the sea bed, boundary and sides, or energy losses in the front [which can be converted to force].
– An additional force may exist in the case where an existing current flows with or against the density current.

Where the forces working upon the stationary mixture are not in equilibrium the mixture will begin to move. Consequently, an equilibrium will then be established with the velocity-dependent forces, which imparts a particular velocity to the subsequent density current. This velocity can be calculated, as long as the initial conditions and governing conditions are known.
In the case shown in figure 7 the density current is moving against a gentle upward gradient. In fact this can occur in practice [see for example, the case of Texel], as well as in theory. In figure 8 a density current is moving over the horizontal bed of a model flume. During dredging in the Epon harbour near Delfzijl, The Netherlands, measurements were taken of the concentration of solids in the density current and the velocity of the density current [figures 9 and 10]. These showed that the concentration of sand and silt in the density current in a number of cases amounted to around 20 000 mg/l and that in these cases the density current was then moving out of the harbour at a rate of 30 to 40 cm/s against a tidal stream of approximately 5 cm/s. During dredging activities in a 3 m. deep shipping channel near Harlingen, The Netherlands, sonar measurements of the density current were taken with the aid of a video recorder.
These measurements clearly indicated the existence of a moving density current [figure 11]. Unfortunately, there is no accurate information concerning the concentration level of sediment at

Figure 9. Measurements taken during dredging operations in the Epon harbour near Delfzijl, The Netherlands revealed that the height to which the sediment was lifted was roughly one metre. Simultaneous measurements were taken of the flow velocity



which a sonar signal of 500 kHz is reflected. It is therefore difficult to interpret the sonar measurements on a quantitative basis, although the recordings give valuable qualitative information.

Sedimentation and transport distance

Grains of sand or silt in a density current will eventually settle under the influence of gravity, the result being sedimentation. The velocity with which a single grain settles in clear, still-standing water, the free-fall settling velocity, can be predicted accurately by a formula. This settling velocity is dependent, amongst other things, on grain size, viscosity of the medium and density of the grains.
Where not one single grain but several grains are settling at the same time they will collide with each other while sinking and as a result will fall less quickly. A formula has been devised to allow for this 'hindered settling' effect, enabling correction after calculating the free-fall settling velocity.
A second correction is necessary where the viscosity of the medium in which the grain is settling differs from the viscosity of the medium in which the free-fall settling velocity was measured. Increase in viscosity can result from drop in temperature or from a higher level of, for example, clay particles in the water. Finally, the settling velocity is influenced by the turbulence present in the mixture flow. This turbulence results in a reduction in the settling velocity of the particles. The extent of this reduction depends upon the intensity of the turbulence, which, in turn, depends upon the mean current velocity of the mixture. The actual settling velocity of the particles can be calculated by using the original free-fall settling velocity and applying correcting formulae for each of the three effects mentioned.
The initial thickness of the layer of mixture, the velocity of the density current and the actual settling velocity of the particles together form a basis from which an average and a maximum transport distance can be calculated [see figure 11]. If other transport mechanisms, such as dispersion, interchanging currents and circulation currents come into play, the above methods of calculation are insufficient. More extensive

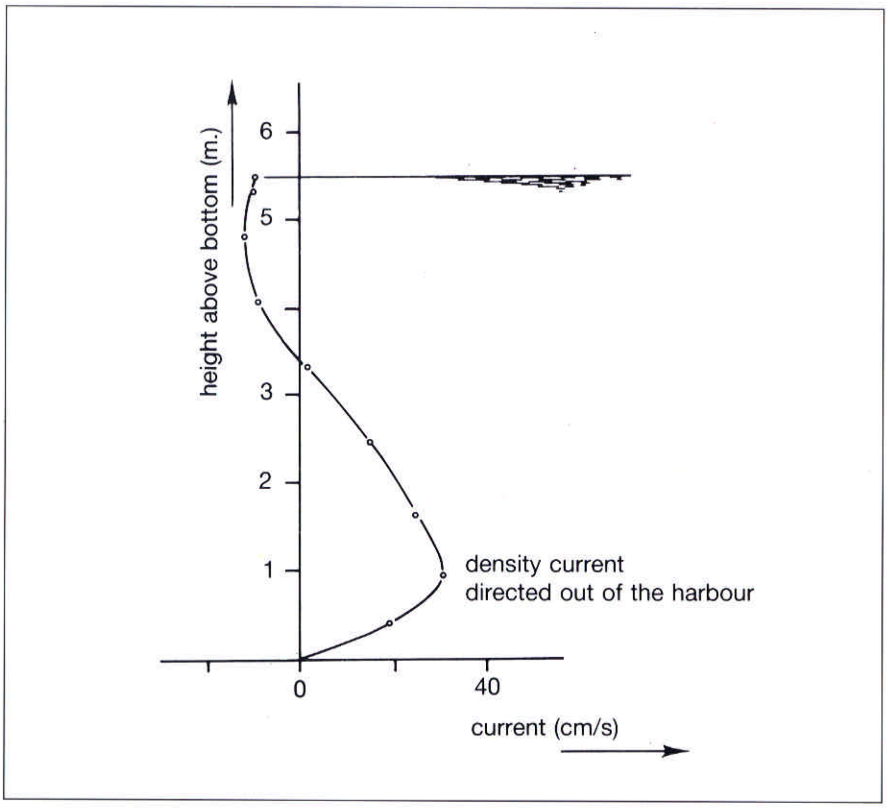


Figure 10. During dredging operations in the Epon harbour it transpired that the density current which was created moved out of the harbour at a rate of between 30 and 40 cm/s, while at the same time a flood stream of approximately 5 cm/s was flowing in the opposite direction

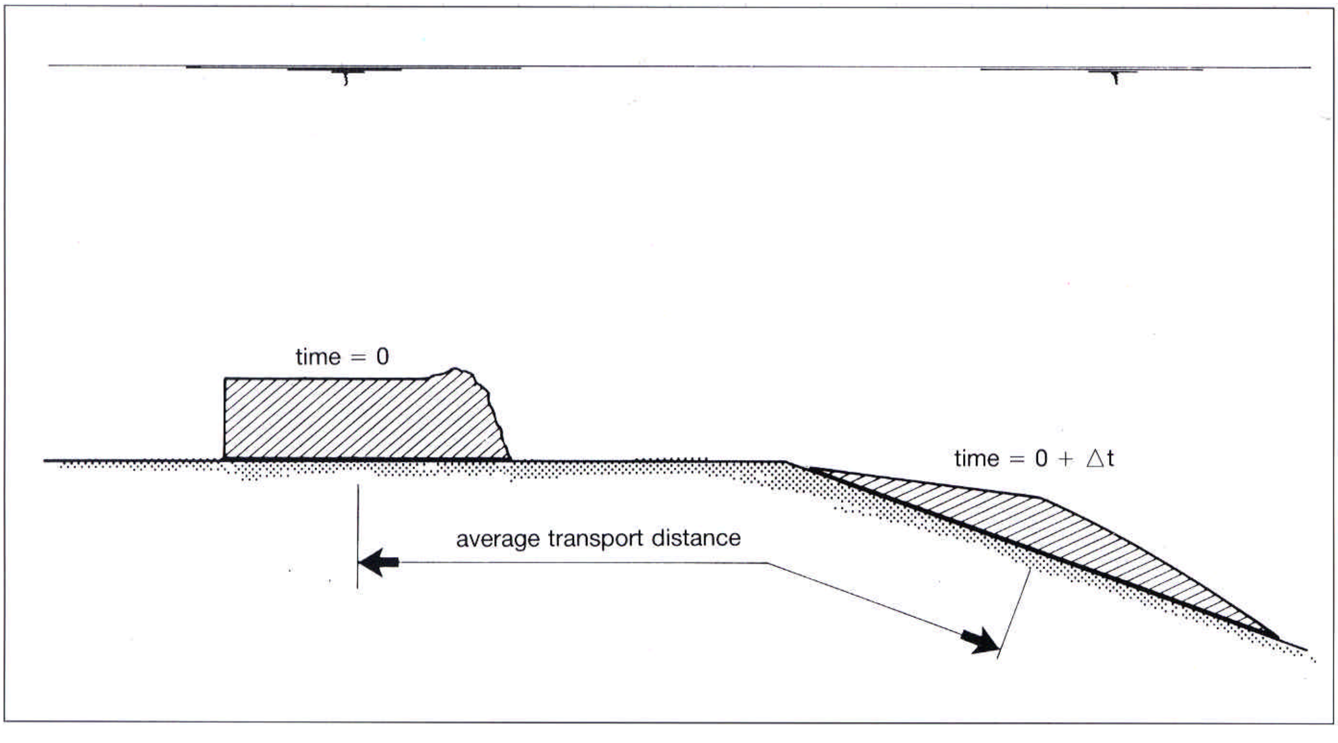


Figure 11. As a result of the sinking of particles in the density current sedimentation occurs. The resultant transport distance can be calculated

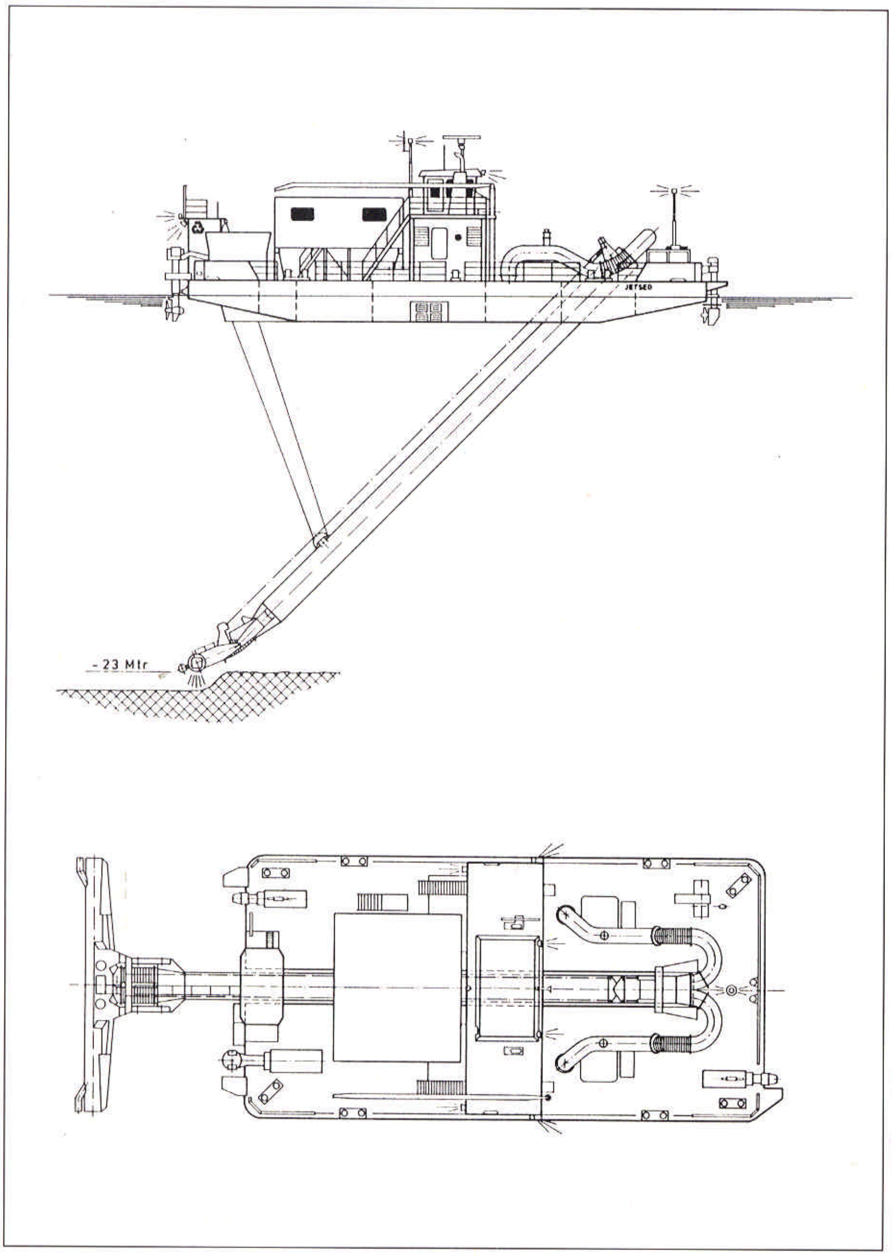


Figure 12. The water injection dredging vessel Jetsed. She is equipped with her own propulsion and has a jet pipe which is 14 m. wide. The vessel was put into service in October 1987 by Water Injection Dredging bv

mathematical models will then have to be applied. Using these models which are based on the theory of dispersal of pollutants it can be estimated where sedimentation will take place.

Factors influencing production

On the basis not only of these considerations but also of in situ measurements, a number of factors which determine the eventual production can be isolated. These are:
- the characteristics of the working vessel such as properties of the jet nozzles [including flow rate] and total jet pipe width.
- the prevailing conditions, such as soil type, bathymetry [potential bars or slopes], length, breadth and depth of the basin, existing current, existing density current and density differences in the water column.
- technical factors during execution of the work: working method, variations in sailing speed and the average distance of the jet from the sea bed.

With the help of formulae based on the theory described earlier, these factors can be taken into account when making production calculations.
On the basis of in situ tests with a prototype, model tests and theoretical considerations, Water Injection Dredging bv decided to have a water injection dredging vessel built and put into operation.

The water injection dredging vessel Jetsed

The name of the water injection dredging vessel Jetsed [figure 12] derives from 'jetting sediment'. This ship is a catamaran construction consisting of two pontoons. Her total length is 29 m. and total width 14m. A central pipe through which water is pumped downwards hangs between the two halves of the dredger. This pipe can be moved up and down with the aid of a winch. At the end of this pipe is a jet pipe which has a number of smaller jet nozzles. This 14m. wide jet pipe hangs just above the sea bed, so that water coming out of the nozzles is injected into the sediment.

In addition, two large-diameter closeable jet nozzles are situated at the ends of the jet pipe. There is a pump in each pontoon and together these pumps have a pumping capacity of 12.000 m^3/hr. This quantity can be pumped at an effective pressure of approximately 1.5 bar. The intake openings of the pumps are in the slanting bow-section of the vessel. The water goes from the pumps to the jet pipe through two deck pipes and through the central pipe. The vessel is moved by three steerable propellers. One propulsion unit is on the starboard side of the bow, while the two others are mounted on the stern. As a result, the ship is extremely manoeuvrable. In the wheel house there is a depth meter which, in combination with a tide gauge gives the depth of the jet pipe in relation to a fixed reference level.

Furthermore there is a positioning system by which a working plan, a map of the dredging area and the location of the vessel and jet pipe can be transmitted on to a monitor screen.

Some working methods

Various methods can be employed when using the Jetsed. The most common is to propel the jet pipe directly above the sea bed with the jets directed vertically downwards [figure 13a]. With regard to this particular method extensive practical research was undertaken to calculate the most efficient method of sailing. One of the results was that, with respect to the movement of the turbidity current, sailing over long tracks appeared to be far more efficient than sailing over short tracks. In some instances, such as harbours that dry at low tide, it may be necessary to employ a different working method and to hoist the jet pipe above water. Consequently, a gully can be made in an area above water [figure 13c]. With both methods there is a choice of different jet diameters and distances between the jet nozzles.
A third working method can be employed by opening the two side jets [figures 13b and 13d]. These side jets have a large diameter and thus a larger penetration distance in water and sediment. By using this method it is possible to dredge places with difficult

access, e.g. under jetties. By making use of the various work methods available with the water injection vessel, much valuable experience has been gained since taking delivery in October 1987.

Cases

Epon harbour near Delfzijl, The Netherlands:
Dredging of very dense, fine sand with density current against a flood stream

The Epon harbour project in the north of The Netherlands, entailed dredging approximately 160.000 m^3 of very fine sand. The sand was very dense, of low permeability and contained on average 10% silt. The dredging of this material with a small trailing suction hopper with no jets in the draghead proved to be extremely difficult. When a grab crane was used it was only possible to attain sufficient production by using a grap made heavier specially for that purpose.
The reason for this is that penetrating or cutting a mass of sand with a low permeability results in reduced pore water pressures in the sand and therefore the required cutting force is high. These low pore water pressures are the result of dilation of the sand during the cutting process. Since in water injection the dredging soil is not cut but jetted, excess pore water pressures occur. There is then less force and so less energy required to remove the soil. This resulted in a production rate of approximately 800 m^3/hr during this project.
Whilst dredging on this project, extensive measurements were taken in co-operation with the Dutch Ministry of Public Works in respect of certain process parameters. Some of the results obtained are shown in figures 9 and 10. As stated earlier, it was apparent from these measurements that the density current was moving against a tidal stream current in this case.

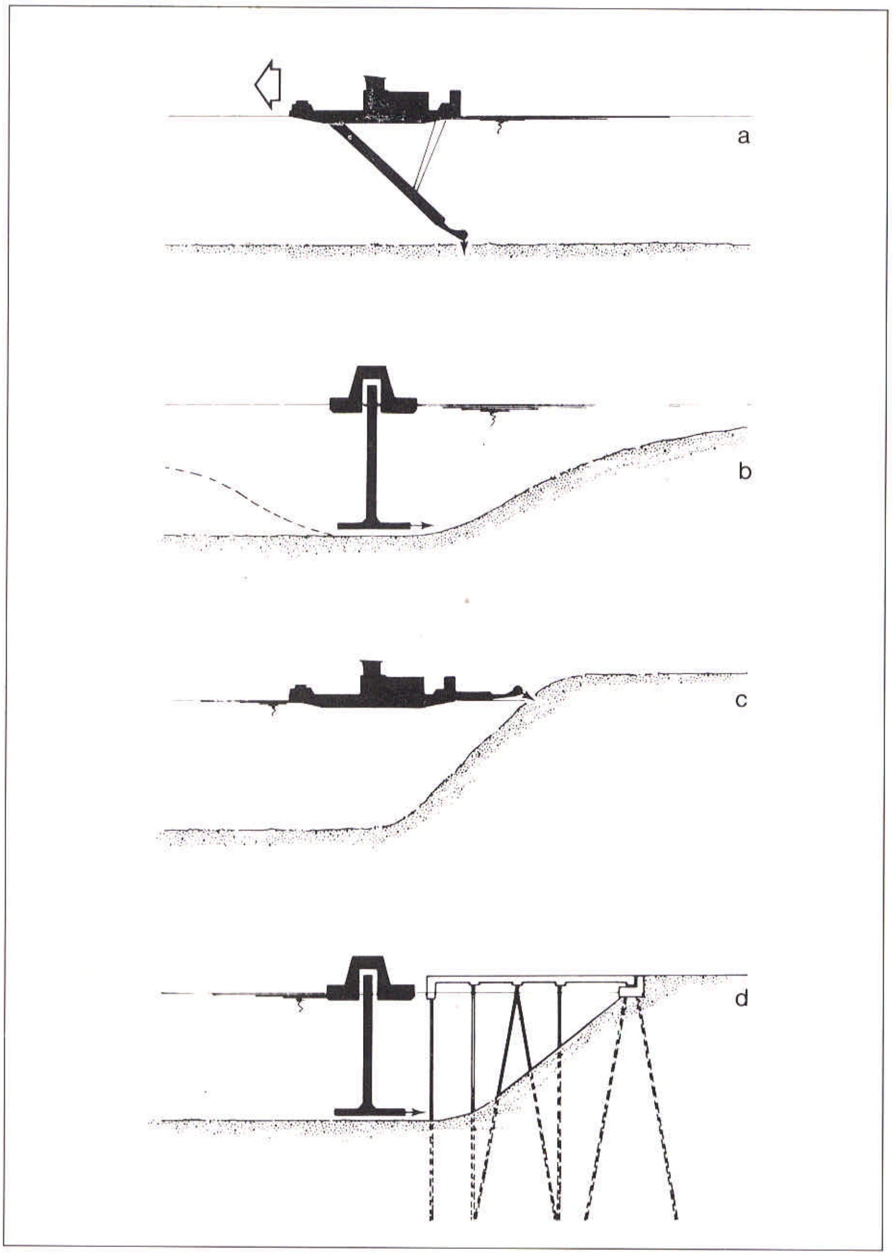


Figure 13. Different working methods are possible when using the water injection vessel. Some are shown above

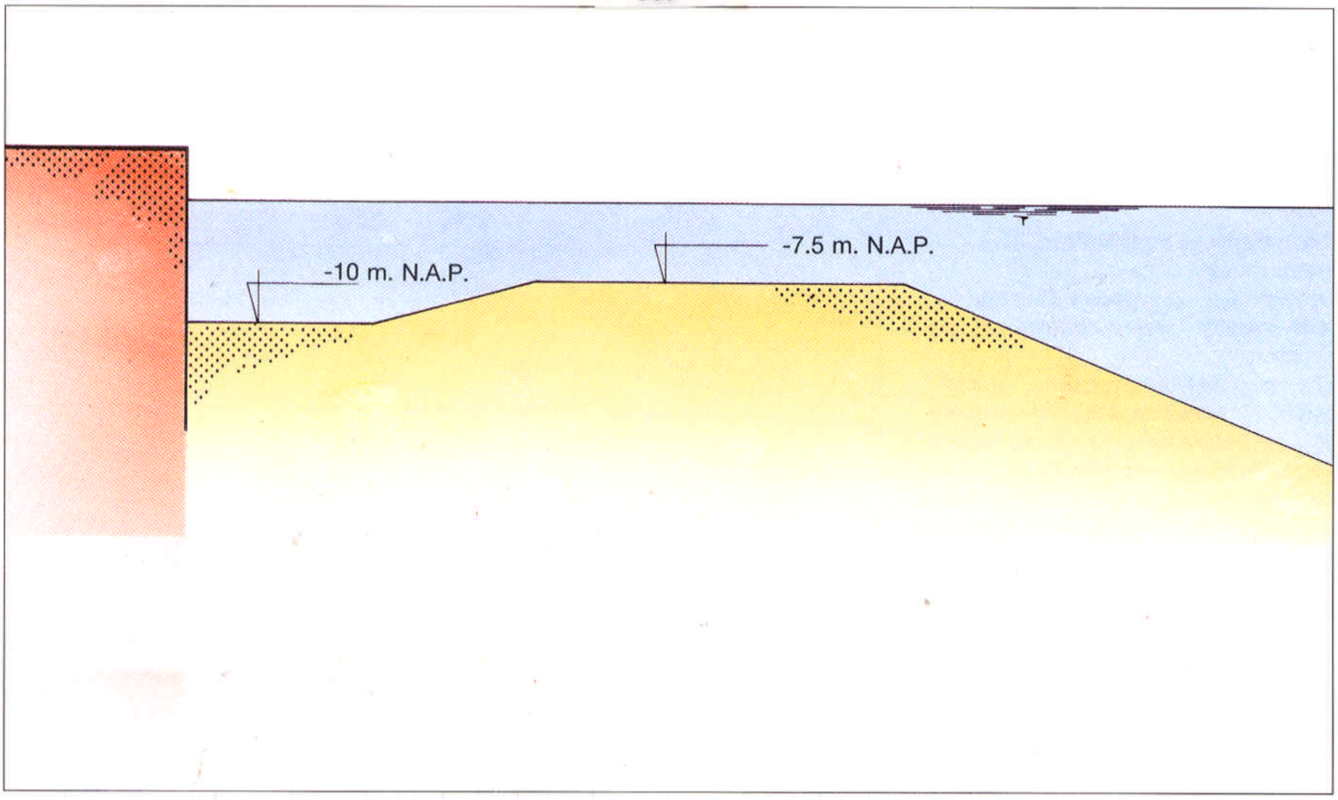
Shipping Lane Boontjes in the Waddenzee, The Netherlands:
Dredging soft clay and heavily consolidated silt with relatively little lateral turbidity

This project comprised the deepening of part of an existing shipping lane near Harlingen in the tidal area of the Waddenzee in the north of The Netherlands. Since the channel had never previously been dredged to the depth now required this could not be described as maintenance dredging. The soil to be dredged was principally a clay and silt mixture with a maximum shear strength of 25 kPa, the description of such soil being 'soft clay'. Silt encountered in maintenance dredging generally has a shear strength far below 5 kPa. This was therefore both a challenge and an ideal opportunity for a 'try-out'. On completion of the work it was seen that in this soil and under the prevailing site conditions a production rate of up to 800 m^3/hr could be attained without any difficulty. The total amount of dredged material was about 15.000 m^3.

During this project, in co-operation with the Dutch Ministry of Public Works, measurements were taken of the turbidity in the immediate area of the dredging operations. Results showed the density current created by dredging being swept away fairly quickly by the tidal current present. To the side of the density current the concentration of sediment was found to be a hundred times lower than in the density current itself.

Ferry harbour and entrance channel Den Burg, Texel, The Netherlands:
Removal of silt from a deep to a shallow area

On both sides of the entrance channel material had to be removed to a depth of about 7.5 m. below NAP [Dutch datum level]. In the ferry harbour itself there was siltation with an estimated in situ density of 1.25-1.5 t/m^3.
Approximately 20.000 m^3 of silt was to be taken from the slopes in the ferry harbour and removed via the entrance channel. In the centre of the harbour was a deeper area of approximately 12 m. below NAP. Reduction of the depth of this area was prohibited by the client.
With regard to dredging, this meant that a considerable part of the ferry harbour's silt had first to be transported from a depth of between 9 and 12 m. below NAP to the entrance channel, 7.5 m. below NAP, and then had to be removed from the channel. In short, this meant carrying the silt over a bar [figure 14]. Despite this

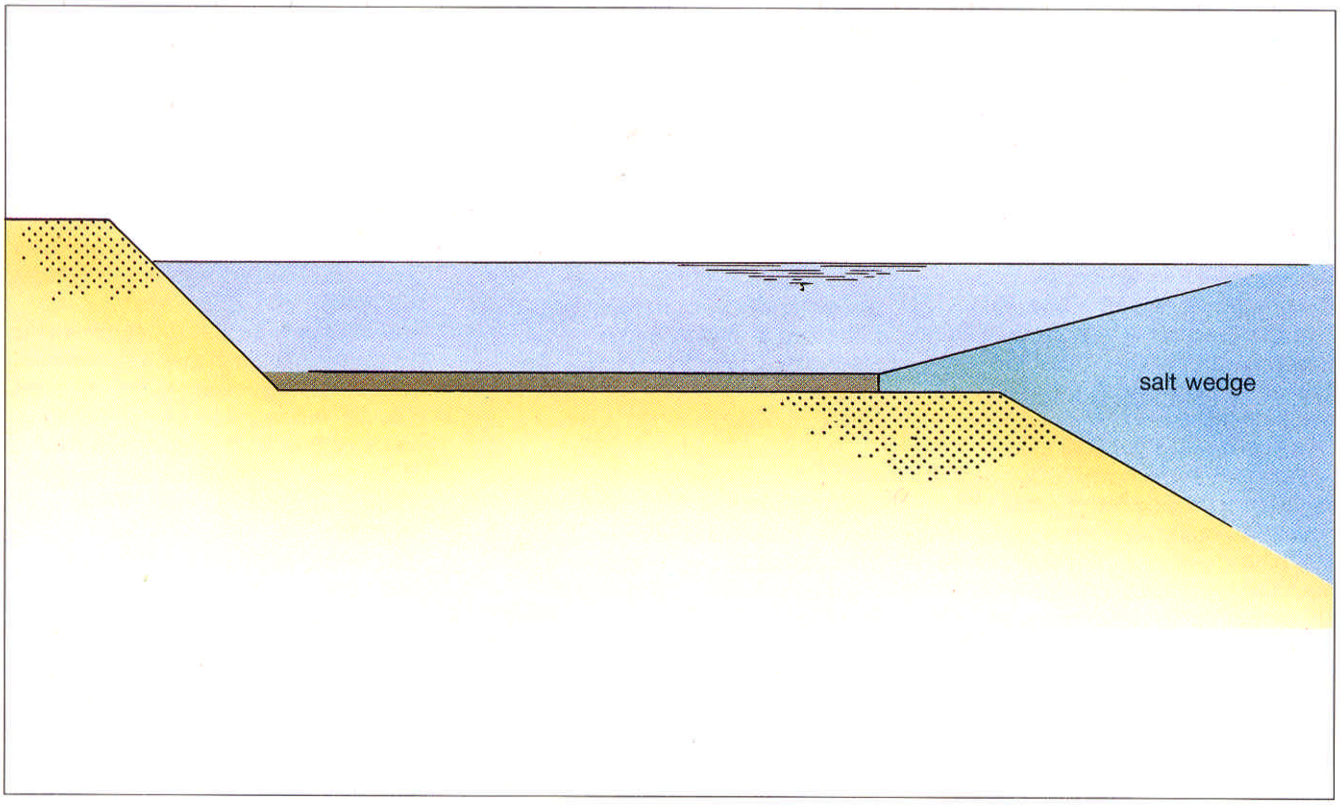


obstacle an average production rate of around 1500 m^3/hr was attained in the ferry harbour itself.

Westbuitenhaven, Terneuzen, The Netherlands:
Maintenance dredging in a long harbour containing a salt wedge
The annual maintenance of this harbour involves dredging around 500.000 m^3 of silt. The harbour opens into the Westerschelde, is approximately 1600 m. long and its dredged depth is approximately 14 m. At the back of the harbour is a lock from which fresh water can be discharged. The water in the Westerschelde at the mouth of the harbour is saline, which means that some density difference will exist in the harbour as a result of the varying salt concentrations along its length. The presence of density differences can have a negative influence on a density current created by waterinjection dredging.
During part of the execution period extensive measurements were undertaken in co-operation with the Ministry of Public Works to establish

Figure 14. A considerable part of the silt in the ferry harbour at Texel, The Netherlands, first had to be transported from a depth of between 9 and 12 m. below NAP to the entrance channel, 7.5 m. below NAP, and then had to be removed from the channel. This meant carrying the silt over a bar

Figure 15. During dredging of the harbour in Terneuzen, The Netherlands, a slowly settling silt cloud remained in the harbour because of a salt wedge. This silt cloud was sounded on a number of occasions by an echo sounder



various process parameters, such as salt concentration, temperature and turbidity. Results showed that the density as a result of turbidity was higher than that as a result of salinity, although the difference was not especially great. This meant that the velocity of the turbidity current, and therefore the distance the sediment was carried, decreased. This resulted in a drop in production. The final production rate varied between 1500 and 3000 m^3/hr. In a comparable situation where no density differences were present, production levels of up to 4000 m^3/hr were attained.
Every week, following a period of about 60 hrs during which no dredging took place, an echo-sounding survey was made. During the final phase of this work a particular phenomenon occurred: the weekly survey indicated the presence of a non-moving, low concentration silt cloud instead of a hard sediment layer. The density of this silt cloud was at a number of points similar to the density of the salt water of the Westerschelde at the mouth of the harbour. This may be one reason why the silt cloud did not flow out of the harbour [figure 15].
Settlement of the sediment in the silt cloud took a long time because of its extremely small particle size. Figure 16 shows the survey, made on this project.

Conclusions

Detailed study of relevant publications, model tests and practical experience have provided much insight into the theory and practice of water injection dredging. A number of conclusions concerning this patented dredging method are listed here.

Theoretical aspects

– The water injection process, jet penetration, jet dispersal, density or turbidity current and sedimentation can be described by formulae. These can be used to calculate dredger production in specific situations.
– Where the dredged material is transported not only by a density current but also by dispersion and cross currents at the mouth of the harbour, mathematical models can be used to estimate the dispersal of the material.
– Knowledge of prevailing conditions is essential for reliable results. The most important are:
- characteristics of the soil,
- geometry of the dredging area,
- bathymetry (any potential bars or slopes),
- existing currents.

These factors can have an important effect on the performance of a water injection vessel.

Water injection vessel Jetsed

– Using the Jetsed, working methods can be employed whereby even locations normally very difficult to access, such as under jetties, can be dredged.
– The Jetsed is simple, highly manoeuvrable and equipped with its own propulsion.

Practical aspects

– The density current created can move against a tidal current. See the case of Epon harbour,
– Similarly, it was shown that a large part of this density current could move over a sand bar. See the case of ferry harbour, Texel.
– In addition to maintenance dredging, it was shown that dredging work in which heavily consolidated silt is to be removed can sometimes be carried out by means of water injection dredging. See the case of Boontjes, Waddenzee,
– Water injection dredging is a technically sophisticated form of dredging and in many cases can be cost-saving.

This system is patented according to applicable laws in the following countries and/of areas: Europe [except Belgium] and the United States of America.

Figure 16. Survey of the harbour at Terneuzen. A total of around 500.000 m^3 was dredged in this harbour

Water Injection Dredging bv
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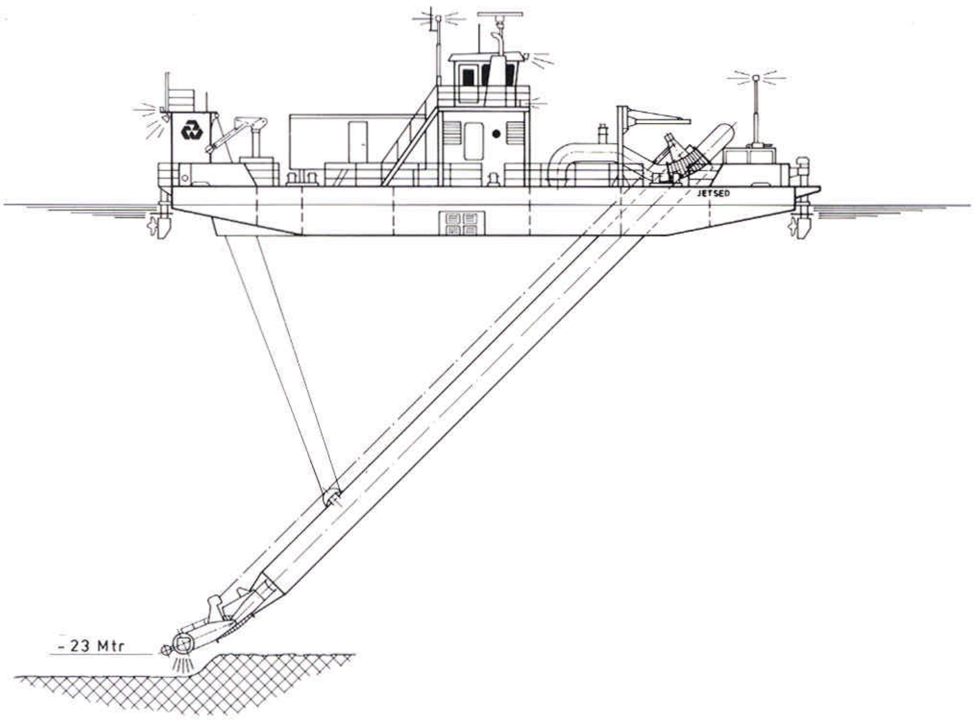
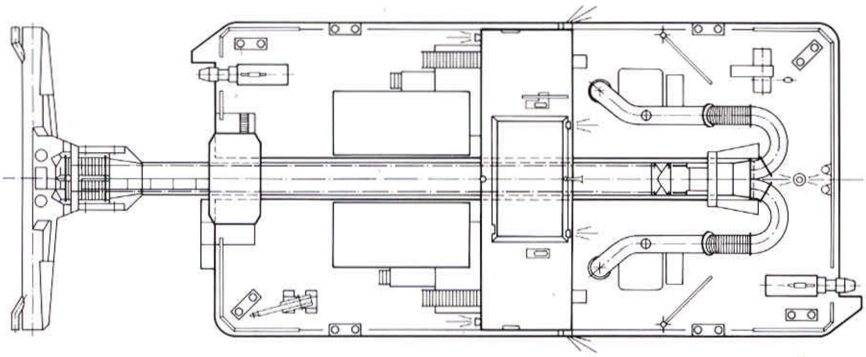
Water-injection vessel Jetsed

The Jetsed, our first water-injection vessel, is an entirely new type of maintenance dredging tool.
A water jet injection system with a capacity of up to 12,000 m^3 per hour lifts silt into suspension at production rates of up to 5,000 m^3 per hour, depending upon the configuration of the harbour and the percentage of fine sand in the silt.
The Jetsed is a self-propelled vessel and, being fitted with two rudder-propeller units – one forward and one aft, has exceptional manoeuvrability.





Principal particulars

Year of build	1987 Ravestein, Deest
Overall length hull	29.54 m
Overall length incl. discharge- and injectionpipe	37.00 m
Breadth, extreme outside	13.86 m
Depth, amidships at side	2.22 m
Draught at summer mark	1.40 m
Classification B.V.	I 3/3 Dredger/N.P. Sheltered Waters Deep Sea occasionally
Accommodation	4 persons
Propulsive power fwd. and aft	2 × 152 kW
Jet pump power SB and PS	2 × 375 kW
Total output of engines	1,107 kW
Diam. of discharge pipelines on board	800 mm
Max. dredging depth	23.00 m
Min. dredging depth	2.00 m

Water Injection Dredging bv

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Water Injection Dredging

Natural dredging

- **Activities:**
- Maintenance dredging
- Sea floor levelling

APPENDIX E

PROPOSED NEW DUTCH STANDARDS FOR GENERAL ENVIRONMENTAL QUALITY OF WATER AND SEDIMENT

General environmental quality standards (quality objective 2000)

General environmental quality (quality objective 2000), test values and warning values for fresh surface water and sediment

water = total content in water (in µg/l, unless stated otherwise)

sediment = content in sediment in water bed (in mg/kg), converted to standard sediment (10% organic matter and 25% lutum); for standard suspended matter (20% organic matter and 40% lutum) the values for heavy metals and organic matter resp. lie a factor of 1.5 and 2 higher than for the sediment.

Parameters	New						Old			
	M-list		I-list		provisional test value sediment	provisional warning value sediment	basic quality		provisional test value sediment	provisional warning value sediment
	water	sedi-ment	water	sedi-ment			water	sedi-ment		
General parameters										
colour, odour, foam, solid waste, turbidity	the water may not look or smell polluted						idem			
temperature (°C)	25						25			
oxygen (m/l)	5						5			
however:										
- normalized streams/dammed streams/canals/ pools/peat hollows	4						4			
- urban waters/ditches	3						3			
acidity (n, pH)	>6.5 <9.0						>6.5 <9.0			
visibility (s, n, metres)	0.4						0.5			
Nutrients and eutroph. parameters										
total phosphate (y, s, n, mg P/l)	0.15						0.15			
total nitrogen (s, n, mg N/l) (Kj-N + NO_3 + NO_2)	2.2									
chlorophyll-a (n, s, µg/l)	100						100			
ammonia (mg N/l)	0.02						0.02			
nitrate + nitrite (n, mg N/l)							10			
Salts										
chloride (n, mg, Cl/l)	200						200			
fluoride (mg F/l)			1.5							
bromide (mg/Br/l)			8							
sulphate (mg SO_4/l)	100						100			
Radioactivity parameters										
(Bg/l, 1Bg = 27 pCi)										
total α-activity (y)			0.1				0.1			
remaining ß-activity (y)			1.0				1.0			
tritium-activity (y)			200				200			
Balogical parameter										
thermotolerant coliform (median, MPN/ml)	20						20			
biological assessment system*			specify per water system*							

y = yearly average
n = natural deviation permitted
s = summer average value for eutrophication-sensitive, stagnant water, April tot September, inclusive
* = this specification can be done for stagnant waters according to a system based on Caspers and Karbe, and for running waters according to a system recently developed on behalf of the STORA

General environmental quality (quality objective 2000), test values and warning values for fresh surface water and sediment

water = total content in water (in µg/l, unless stated otherwise)

sediment = content in sediment in water bed (in mg/kg), converted to standard sediment (10% organic matter and 25% lutum); for standard suspended matter (20% organic matter and 40% lutum) the values for heavy metals and organic matter resp. lie a factor of 1.5 and 2 higher than for the sediment.

Parameters	New						Old			
	M-list		I-list		provisional test value sediment	provisional warning value sediment	basic quality		provisional test value sediment	provisional warning value sediment
	water	sedi-ment	water	sedi-ment			water	sedi-ment		
Metals										
cadmium	0.2	2			7.5	30	2.5	0.8	7.5	30
mercury	0.03	0.5			1.6	15	0.5	0.3	1.6	15
copper	3	35			90	400	50	36	90	400
nickel	10	35			45	200	50	35	45	100
lead	25	530			530	1000	50	85	160	700
zinc	30	480			1000	2500	200	140	1000	2500
chrome	25	480			480	1000	50	100	155	600
arsenic			15	85	85	150	50	29	45	100
EOX					7.0	20.0	5	5.5 (med.)	7.0	20.0
AOX						(med.)	40			
sum MA's							2 (med.)			
PAHs										
benzo(a)anthracene				0.05	0.8	3		0.2	0.8	3
benzo(ghi)perylene		0.05			0.8	3		0.2	0.8	3
benzo(a)pyrene		0.05			0.8	3		0.2	0.8	3
phenantrene				0.05	0.8	3		0.2	0.8	3
ideno(123cd)pyrene		0.05			0.8	3		0.2	0.8	3
pyrene				0.05	0.8	3		0.2	0.8	3
dibenzo(ah)anthracene				0.05	0.8	3		0.2	0.8	3
anthracene				0.05	0.8	3		0.2	0.8	3
benzo(b)fluoranthene		0.2			0.8	3		0.6	0.8	3
benzo(k)fluoranthene		0.2			0.8	3		0.6	0.8	3
chrysene				0.05	0.8	3		0.2	0.8	3
fluoranthene	0.07	0.3			2.0	7		1.2	2.0	7
sum PAHs (6 of Borneff)		0.6			4.5	17	0.1 (med.)	2.3	4.6	17
Volatile haloginated hydrocarbons										
VOX	5						5 (med.)			
1,3-dichloropropene			1							
trichloroethene			2							
hexachloroethane			1							
Chlorobenzenes										
dichlorobenzenes			2							
trichlorobenzenes			0.4	0.3						
tetrachlorobenzenes			0.2	0.3						
pentachlorobenzene			0.3	0.3	0.3	0.5		0.003	0.02	0.5
hexachlorobenzene		0.004			0.02	0.5	0.01 (med.)	0.003	0.02	0.5

General environmental quality (quality objective 2000), test values and warning values for fresh surface water and sediment

water = total content in water (in µg/l, unless stated otherwise)

sediment = content in sediment in water bed (in mg/kg), converted to standard sediment (10% organic matter and 25% lutum); for standard suspended matter (20% organic matter and 40% lutum) the values for heavy metals and organic matter resp. lie a factor of 1.5 and 2 higher than for the sediment.

Parameters	New						Old			
	M-list		I-list		provisional test value sediment	provisional warning value sediment	basic quality		provisional test value sediment	provisional warning value sediment
	water	sediment	water	sediment			water	sediment		
PCBs										
Pcb 28		0.004			0.03	0.1		0.004	0.03	0.1
PCB 52		0.004			0.03	0.1		0.004	0.03	0.1
PCB 101		0.004			0.03	0.1		0.004	0.03	0.1
PCB 118		0.004			0.03	0.1				
PCB 138		0.004			0.03	0.1		0.004	0.03	0.1
PCB 180		0.004			0.03	0.1		0.004	0.03	0.1
PCB 180		0.004			0.03	0.1		0.004	0.03	0.1
sum of PCBs(7)					0.2	0.4	0.007 (med.)	0.02	0.2	0.4
Organochloro-pesticides										
aldrin + dieldrin				0.04	0.04	0.5	0.01 (med.)	0.003	0.02	0.5
endrin				0.04	0.04	0.5	0.01 (med.)	0.003	0.02	0.5
DDT + derivatives				0.01	0.02	0.5	0.01	0.003	0.02	0.5
(-endosulphane + -sulphate	0.01	0.01			0.02	0.5	0.01 (med.)	0.003	0.02	0.5
α-HCH					0.02	0.5	0.01	0.003	0.02	0.5
ß-HCH					0.02	0.5		0.003	0.02	0.5
γ-HCH	0.01	0.001			0.02	0.5	0.01- (med.)	0.003	0.02	0.5
heptachlor + epoxide				0.02	0.02	0.5	0.01 (med.)	0.003	0.02	0.5
chlorodane			0.12	0.02				0.003	0.02	0.5
hexachlorobutadiene				0.02	0.02	0.5		0.003	0.02	0.5
total-pesticides					0.10	2.5	0.02 (med.)	0.02	0.10	2.5
anionic detergents							100 (med.)			
non-ionic and cationic detergents							100 (med.)			
Chlorinated phenols										
dichlorophenols			0.08							
pentachlorophenol	0.05	0.02					0.05 (med.)			
Steam-distillable phenols							5 (med.)			
Chloroanilines										
total anilines							1 (med.)			

General environmental quality (quality objective 2000), test values and warning values for fresh surface water and sediment

water = total content in water (in µg/l, unless stated otherwise)

sediment = content in sediment in water bed (in mg/kg), converted to standard sediment (10% organic matter and 25% lutum); for standard suspended matter (20% organic matter and 40% lutum) the values for heavy metals and organic matter resp. lie a factor of 1.5 and 2 higher than for the sediment.

Parameters	New						Old			
	M-list		I-list		provisional test value sediment	provisional warning value sediment	basic quality		provisional test value sediment	provisional warning value sediment
	water	sediment	water	sediment			water	sediment		
Organophosphorus pesticides										
Cholinesterase inhibition	0.5						0.5 (med.)			
DDVP			0.002							
Triazophos			0.03							
Azinphos-methyl			0.02							
Azinphos-ethyl			0.05							
Demeton			0.4							
Fenitrothion			0.05							
Methyl Parathion			0.2							
Ethyl Parathion			0.02							
Disulfoton			1.5							
Trichlorfon			0.005							
Cumaphos			0.002							
Diazinon			0.03							
Fenthion			0.02							
Phoxim			0.2							
Malathion			0.03							
Mevinphos			0.005							
Pyrazophos			0.003							
Oxydemeton-methyl			0.1							
Organo-tin compounds										
tributyl-tin compounds			0.01	1.5 (µg/kg)						
triphenyl-tin compounds			0.01	1.0 (µg/kg)						
Remaining non-halogenated compounds										
Phenol herbicides										
Dinoseb (DNBP)			0.02							
DNOC			0.3							
Carbamates										
Aldicarb			0.5							
Oxamyl			0.5							
Carbendazim			0.03							
Dithiocarbamates										
Maneb			1.0							
Thiram			0.02							
Zineb			0.6							
metham-sodium			0.01							
phenol			2							
petroleum hydrocabons		1000			3000	5000		500	3000	5000
aniline			2							
nitrilotriaceticacid			200							

* Supplementary specification because combination toxicity $\Sigma \frac{\text{measured content of substance}}{\text{general environmental quality standard (quality objective 2000)}} < 1$ is not taken into account

General environmental quality (quality objective 2000), test values and warning values for fresh surface water and sediment

water = total content in water (in µg/l, unless stated otherwise)

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Parameters	New						Old			
	M-list		I-list		provisional test value sediment	provisional warning value sediment	basic quality		provisional test value sediment	provisional warning value sediment
	water	sedi-ment	water	sedi-ment			water	sedi-ment		
Remaining haloginated compounds										
Chlorophenoxy carboxytic acids (herbicides)										
2,4-d			11							
mcpa			0.2							
mecoprop			0.1							
Triazines										
atrazine			0.1							
simazine			0.4							
Nalogenated Nitro-aromatics										
Trifluralin			0.2							
Quintozene			0.4							
Pyrethroid pesticedes										
Cypermethrin				0.6						
Delatmethrin				0.4						
Permethrin				0.8						
Bifenthrin				1.6						
Anilides										
Propachlor			0.1							
Aromatic chloro-amines										
Linuron			0.1							
3,3-dichlorobenzidine			0.2							
Carboximides										
Captafol			0.2							
Captan			0.3							

* Supplementary specification because combination toxicity $\sum_i \frac{\text{measured content of substance}}{\text{general environmental quality standard (quality objective 2000)}} \leq 1$ is not taken into account