UNITED NATIONS

ECONOMIC AND SOCIAL COMMISSION FOR ASIA AND THE PACIFIC

PROCEEDINGS OF THE SEMINAR-CUM-STUDY TOUR ON DREDGING OPERATIONS, PLANNING AND TRAINING

THE NETHERLANDS, OCTOBER, 1985

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The Seminar-cum-Study Tour on Dredging Operations, Plannning and Training was organized from 6 to 20 October 1985 in the Netherlands by the Economic and Social Commission for Asia and the Pacific (ESCAP) in co-operation with the Ministry of Transport and Public Works of the Royal Netherlands Government.

The Seminar-cum-Study Tour was attended by 17 participants from 12 countries: Burma, China, Fiji, India, Indonesia, Malaysia, Pakistan, the Philippines, Singapore, Sri Lanka, Thailand and Viet Nam.

The Seminar-cum-Study Tour on Dredging Operations, Planning and Training was designed to acquaint participants with the latest techniques in dredging and their application to operational jobs and training methodology for different levels of dredging personnel.

The objective was met through a series of lectures and visits to dredging sites, dredger builders, research and training institutions and major civil works having a large dredging component.

During the Seminar-cum-Study Tour the participants had the opportunity to gain knowledge in a broad field of subjects related to dredging, such as hydrographic surveying, site investigations, planning and design of dredging projects, dredging contracting, project execution, dredger building, equipment and instrumentation, disposal of dredged material, new developments in dredging techniques, project management and manpower training.

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CONTENTS

PART ONE

SEMINAR-CUM-STUDY TOUR ON DREDGING OPERATIONS, PLANNING AND TRAINING

		Page
Extracts from the opening message from the Officer-in-Charge of the Division for Shipping, Ports and Inland Waterways		1
Summary of conclusions and recommendations		2
Annex I.	Programme	5
Annex II.	List of participants	10
Annex III.	List of sites and institutions visited	13
Annex IV.	List of lectures delivered	14

PART TWO

PROCEEDINGS OF LECTURES AND SITE VISITS

1.	Introductory lecture	19
2.	Site investigations	45
3.	Planning and design of a dredging project	133
4.	Dredging contracting	191
5.	Project execution and site management	241
6.	Dredging and disposal of polluted material	299
7.	Dredger building	321
8.	Equipment and instrumentation	337
9.	New developments in dredging techniques	367
10.	Manpower training	373
11.	Country papers	381

Bibliography 399

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PART ONE

SEMINAR-CUM-STUDY TOUR ON DREDGING OPERATIONS, PLANNING AND TRAINING

EXTRACTS FROM THE OPENING MESSAGE FROM THE OFFICER-IN-CHARGE OF THE DIVISION FOR SHIPPING, PORTS AND INLAND WATERWAYS

An opening message from the Officer-in-Charge of the Division for Shipping, Ports and Inland Waterways of the ESCAP secretariat was read out on his behalf. In welcoming the participants on behalf of ESCAP, he expressed gratitude to the Royal Netherlands Government and the Ministry of Transport and Public Works for sponsoring the Seminar-cum-Study Tour and for providing excellent host facilities.

He stressed that the ESCAP region was a major user of the dredging activities which had increased considerably in the last decades. Large volumes of capital works were undertaken in ports and inland waterways to meet the demands of modern shipping technologies. There had been a rapid increase in the maintenance dredging requirements for ports and waterways at the operational level.

However, he pointed out that existing knowledge about dredging in most of the developing countries of the ESCAP region was not sufficient to make the most efficient use of that highly capital intensive activity. The lack of capability was one of the main reasons why the developing countries of the ESCAP region were not in a position to take full advantage of the latest developments in shipping technologies. It also put undue pressure on the finances of government agencies and port and inland waterway authorities and was a big drain on precious foreign exchange resources.

In that connection, the ESCAP secretariat had been requested by member countries at various ESCAP fora, such as the Committee on Shipping, Transport and Communications and the Commission, to develop an action programme aimed at rectifying that situation.

He stated that in carrying out that mandate, the secretariat had organized a number of activities with the financial and technical assistance of donor countries and agencies with a view to upgrading dredging capabilities within the region. Those activities included advisory services, regional dredging seminars, national dredging workshops and on-the-job training programmes. They were aimed at training manpower at all levels and in all phases, from senior planners to dredger crew members and from planning to execution of projects.

It was noted that the leader in new dredging technologies had been the dredging industry in the Netherlands, its dredger builders, the Public Works Department of the Ministry of Transport and Public Works, research laboratories and dredging companies. To meet the manpower demands for the industry, training institutions for different levels of personnel had been set up the Netherlands.

The objective of the Seminar-cum-Study Tour was to enable participants to acquire the latest techniques in dredging and to apply them to operational jobs and training methodologies for different levels of dredging personnel

SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

The Seminar-cum-Study Tour reiterated the important role of dredging in the development and maintenance of ports and inland waterways. However, it was acknowledged that existing knowledge about dredging, the latest developments in dredging technology and their application and manpower training to meet the requirements for increased activity in most of the developing countries of the ESCAP region was not at an appropriate level to make the most efficient use of such a highly capital intensive activity. The participants welcomed the convening of the Seminar-cum-Study Tour and felt that the knowledge and experience gained were most useful for them in the search for solutions to problems facing their own countries. It was therefore strongly requested that one such seminar should be arranged by ESCAP every year in developed as well as developing countries where dredging was comparatively well developed and better organized.

The participants expressed their appreciation to ESCAP for organizing the Seminar-cum-Study Tour and also to the Royal Netherlands Government for providing financial and technical support. They recommended that ESCAP should continue to seek funding from donor countries and agencies for future seminars on the following specific subjects:

(a) Hydrographic surveying and soil investigations
(b) Dredging instrumentation and ancillary equipment
(c) Planned maintenance of equipment
(d) Maintenance dredging in ports and inland waterways
(e) Sedimentology and design of silt traps
(f) Dredging contracts
(g) Manpower training methodologies
(h) Development of low-cost dredging technologies
(i) Research development
(j) Environmental aspects of dredging

The participants were generally of the opinion that the Seminar-cum-Study Tour was well organized, educative and enlightening. They appreciated the high quality of most of the lectures and the thorough coverage of the theme of the Seminar. They recognized the high level of dredging techniques in the Netherlands. The combination of lectures and visits to dredging works, engineering structures, dredge builders, research laboratories and training institutions was considered most effective and satisfactory as the visits provided the participants with an opportunity to observe the facilities in operation, which enabled them to have a wide knowledge of both theoretical and practical aspects of the subjects. It was observed, however, that there was a need to be more selective over visits and that appropriate time should be allotted for discussions in seminar programming. It was also suggested that the lecture papers should be made available to the participants in advance.

The subject of silt trap design, and the visit to the dredging school in Delfzijl and the maintenance dredging in the Port of Rotterdam were of particular interest to the participants. They felt that it would be fruitful, if some detailed information on silt trap design, in particular, could be made available to them for consideration for adoption in their own countries.

The presentation of country papers provided useful and comprehensive information and afforded the participants an opportunity to exchange views and experience.

Training of middle-level and operative-level personnel was considered to be very important. It was recommended that ESCAP should continue its efforts to help member countries by conducting training programmes in the operational and maintenance fields.

A regional approach and co-operation emphasizing intercountry exchange of experience was recommended.

It was also suggested that for future seminars participants should be selected and advised of the seminar details well in advance so that they could be adequately prepared.

In conclusion, the participants expressed their deep appreciation to ESCAP and the Royal Netherlands Government for their efforts in arranging the seminar. They also congratulated the Ministry of Transport and Public Works and the Training Institute for Dredging on the arrangements which had been made for the Seminar and the hospitality which had been extended to them during the Seminar.

Annex I

PROGRAMME

Monday, 7 October 1985

Morning:	Opening ceremony at Rijkswaterstaat, the Hague: - Welcoming address by Mr. Ir. C. Oudshoorn, Chief Engineer, Director, Bureau for International Relations and Co-operation, Ministry of Transport and Public Works. - Message from the Officer-in-Charge, Division for Shipping, Ports and Inland Waterways, ESCAP, Bangkok. - Introduction to the programme by Mr. Ir. W.M. van Nimwegen, Managing Director, Training Institute for Dredging. - Presentation of country papers by participants.
Afternoon:	- Presentation of country papers by participants. - Lecture by Mr. Ir. W.H.A. van Oostrum, ADC: "To dredge or not to dredge".

Tuesday, 8 October 1985

Morning:	- Lecture by Mr. Ir. W.G. Borst, F.C. de Weger International/NDC: "The design of a dredging project".

Afternoon:

- Lecture by Mr. Ir. van der Wal, NESA: "Survey - past, present and future".

Wednesday, 9 October 1985

Morning:

Visit to Oranje-Nassau Dredging School, Delfzijl:

- Presentation of the School by Mr. G.H. Heide, Director of the Royal Educational Foundation for Shipping and Inland Waterways, Mr. R.H. Post and Mr. J.H. Hoppzak, Director of the dredging school
- Visit of the School

Afternoon:

Visit to Delfzijl Port Authority:

- Lecture by Mr. Ir. G.P. Nijburg, Delfzijl Port Authority on "Dredging situation of the Port of Delfzijl"
- Visit of the Port of Delfzijl.

Thursday, 10 October 1985

Morning:

Visit to Delft Hydraulics Laboratory:

- Lecture by Mr. Ir. J.R. Moll, Delft Hydraulics Laboratory on "Mathematical modelling of river sediment transport".
- Visit to the model laboratories and the model for cutter investigation.

Afternoon:

Visit to Delft Soil Mechanics Laboratory:

- Lecture by Mr. H.A.M. Nelissen, Project Engineer of the Hydraulic and Marine Structures Department: "Soil analysis in relation to dredging".
- Visit of the laboratory facilities.

<u>Friday, 11 October 1985</u>

Visit to IHC Holland Kinderdijk and IHC Holland Sliedrecht Shipyards:

- Lecture by Mr. Loevendie, IHC Holland: "The multi-purpose dredger".
- Lecture by Mr. J.A. Piet, Bureau voor Scheepsbouw: "Spare parts position"
- Lecture by Mr. B. Kips, IHC Holland: "Wheel dredgers".
- Lecture by Mr. T. van Zupthen, IHC Holland: "Instrumentation and automation".

<u>Monday, 14 October 1985</u>

Morning:

- Lecture by Mr. Jack H. Hulscher, Volker Stevin: "Experience of dredging contracting".
- Lecture by Mr. Joep J. Athmer, Aveco: "Equipment and manpower".

Afternoon:

- Lecture by Mr. A. Lubbers, NEDECO and Mr. Ir. H. van Raalte, Breejenbout Dredging Company: "Management contract for a dredging project - a case story".

<u>Tuesday, 15 October 1985</u>

Visit to the Delta works:

Morning:

- Visit to Haringvliet Sluices.

Afternoon:

- Visit to the Oosterschelde works.

<u>Wednesday, 16 October 1985</u>

Visit to Dredging Division of Rijkswaterstaat, Hook of Holland:

Morning:

- Lecture by Mr. Ottevanger: "Maintenance dredging of the Rotterdam fairway".
- Lecture by Mr. Robert van Vechgel: "Reduction of dredging costs in relation

to research and development".

Afternoon:
- Visit to the dredger "Cosmos" in operation at the entrance to Rotterdam Port.

Thursday, 17 October 1985 Visit to the Port Authority of Rotterdam, Municipality of Rotterdam:

Morning:
- Lecture by Mr. J. Diefenbach: "History of Rotterdam Port".
- Introduction to the work of the Consultancy Department.
- Lecture by Mr. R.W. van der Weyde: "Capital dredging work in the Port of Rotterdam".
- Lecture by Mr. Ir. C. de Waard: "Environmental aspects and their effects on dredging in Rotterdam Harbour".

Afternoon:
- Visit to dredged material disposal areas at Maasvlakte and Vlaardingen.
- Reception given by Mr. Dixhoorn at Rijkswaterstaat, the Hague.

Friday, 18 October 1985

Morning:
- Visit to Civil Engineering Department, Delft University of Technology.
- Visit to International Institute for Hydraulic and Environmental Engineering, Delft.

Afternoon:
- Lecture by Prof. Ir. J. de Koning, Delft University of Technology: "New developments in dredging".

Saturday, 19 October 1985

Morning: Closing ceremony at hotel in Rotterdam:
- Discussion on the summary of conclusions and recommendations of the Seminar-cum-

Study Tour.

- Distribution of certificates.
- Conclusion of the Seminar-cum-Study Tour.

Annex II

LIST OF PARTICIPANTS

BURMA

Mr. Aung Thant Cin, Superintending Dredging Master, Waterway Department, Rangoon

Mr. Maung Maung Hla, Chief Civil Engineer, Burma Ports Corporation, Rangoon

CHINA

Mr. Wang Guqian, Acting Chief Engineer, Shanghai Waterway Bureau, Shanghai

Mr. Liang Weiyan, Vice Director, Guangzhou Waterway Bureau, Guangzhou

FIJI

Mr. Venket Ram Naidu, Port Engineer, Ports Authority of Fiji, Suva

INDIA

Mr. M.M. John, Chief Engineer, Paradip Port Trust, Ministry of Transport, Paradip

Mr. G.M. Rao, Officer on Special duty, Dredging Corporation of India Ltd., Visakhapatnam

INDONESIA

Mr. M. Djunaedi, Personnel Director, Perum Pengerukan, Jakarta-Utara

MALAYSIA

Mr. Rusli Bin Saad, Marine Officer, Federal Marine Department of Malaysia, Pelabuhan Kelang

PAKISTAN

Mr. Abdul Sattar Dero, Project Director Gwadur Fish Harbour Project, Ministry of Communications, Port and Shipping Wing, Karachi

PHILIPPINES

Mr. Danilo Ng, Acting Division Manager, Engineering and Equipment Division, Maintenance and Equipment Department, Philippine Ports Authority, Manila

SINGAPORE

Mr. Raman Radhakrishnan, Senior Civil Engineering, Port of Singapore Authority, Singapore

SRI LANKA

Mr. D. Godage, Deputy Chief Engineer, Sri Lanka Ports Authority, Colombo

THAILAND

Mr. Chalit Sukroongreung, Director, River Dredging and Maintenance Division, Harbour Department, Ministry of Communications, Bangkok

Mr. Burash Polmang, Coastal Dredging and Maintenance Division, Harbour Department, Ministry of Communications, Bangkok

VIET NAM

Mr. Nguyen Thanh Binh, General Director, Union of Waterway Enterprises, Haiphong

Mr. Le Manh Hung, Candidate-master of Port Engineering for Waterway Network, Institute of Designing and Surveying for Waterway Network, Hanoi

ESCAP SECRETARIAT

Economic Affairs Officer, Division for Shipping, Ports and Inland Waterways, ESCAP, Bangkok

Associate Expert on Dredging, Division for Shipping, Ports and Inland Waterways, ESCAP, Bangkok

Annex III

LIST OF SITES AND INSTITUTIONS VISITED

The participants visited the following sites and institutions relating to dredging activities in the Netherlands.

1. Rijkswaterstaat, the Hague.
2. Dredging Division of Rijkswaterstaat, Hook of Holland.
3. Municipal Port Authority, Rotterdam.
4. Dredged material disposal areas at Maasvlakte and Vlaardingen.
5. Civil Engineering Department, Delft University of Technology, Delft
6. International Institute for Hydraulic and Environmental Engineering, Delft.
7. Rijkswaterstaat, Haringvliet Sluices.
8. Rijkswaterstaat, Oosterschelde works.
9. Oranje-Nassau Dredging School, Delfzijl.
10. Delfzijl Port Authority, Delfzijl.
11. Delft Hydraulics Laboratory, Delft.
12. Delft Soil Mechanics Laboratory, Delft.
13. The trailing suction hopper dredger "Cosmos" in operation at the entrance to Rotterdam Port.
14. IHC Holland Kinderdijk and IHC Holland Sliedrecht Shipyards.

Annex IV

LIST OF LECTURES DELIVERED

1. "To dredge or not to dredge" by Mr. Ir. W.H.A. van Oostrum, Applied Dredging Consultancy (ADC), Rotterdam.

2. "The design of a dredging project" by Mr. Ir. W.G. Borst, F.C. de Weger International/NDC.

3. "Survey - past, present and future" by Mr. Ir. van der Wal, Nederland Survey Projecten en-Apparatuur (NESA), Rotterdam.

4. "Dredging situation of Port of Delfzijl" by Mr. Ir. G.P. Nijburg, Delfzijl Port Authority, Delfzijl.

5. "Mathematical modelling of river sediment transport" by Mr. Ir. J.R. Moll, Delft Hydraulics Laboratory (DHI).

6. "Soil analysis in relation to dredging" by Mr. H.A.M. Nelissen, Delft Soil Mechanics Laboratory.

7. "Multi-purpose dredger" by Mr. Loevendie, IHC Holland.

8. "Spare parts position" by Mr. Ir. J.A. Piet, Bureau voor Scheepsbouw.

9. "Wheel dredgers" by Mr. B. Kips, IHC Holland.

10. "Instrumentation and automatation by Mr. T. van Zupthen, IHC Holland.

11. "Experience of dredging contracting" by Mr. Jack H. Hulscher, Volker Stevin.

12. "Equipment and manpower" by Mr. Ir. Joep. J. Athmer, Aveco.

13. "Management of a dredging project" by Mr. A. Lubbers, NEDECO and Mr. Ir. H. van Raalte, Breejenbout Dredging Company.

14. "Maintenance dredging of the Rotterdam Fairway" by Mr. Ottevanger, Rijkswaterstaat, Hook of Holland.

15. "Reduction of dredging costs in relation to research and development" by Mr. Robert van Vechgel, Rijkswaterstaat, Hook of Holland.

16. "History of Rotterdam Port", by Mr. J. Diefenbach, Municipal Port Authority, Rotterdam.

17. "Capital dredging works in Port of Rotterdam" by Mr. R.W. van der Weyde, Municipal Port Authority, Rotterdam.

18. "Environmental aspects and their effects on dredging in the Rotterdam Habour" by Mr. Ir. C. de Waard, Municipal Port Authority, Rotterdam.

19. "New developments in dredging" by Prof. Ir. de Koning, Delft University of Technology.

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PART TWO

PROCEEDINGS OF LECTURES AND SITE VISITS

The main features of the Seminar-cum-Study Tour were the presentation of lectures and a series of visits to dredging sites, dredger builders, research and training institutions and major civil works having a large dredging component. Throughout the Seminar-cum-Study Tour the participants were accommodated in Rotterdam, a comparatively central location in relation to dredging activities in the Netherlands. The programme, list of participants, list of sites and institutions visited and list of lectures delivered are presented in Part One.

Each visit to an institution or site started with a brief introduction followed by a guided tour and discussion. Printed information on the various institutions and sites visited was also provided.

At the various lectures, lecture papers were distributed to the participants. Films, slides and overhead charts were shown during the lectures. Discussion took place after each lecture.

For an exchange of experience and views country papers were presented by participants. These presentations were followed by a discussion.

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1. INTRODUCTORY LECTURE

TO DREDGE OR NOT TO DREDGE

By Ir. W.H.A. van Oostrum, Applied Dredging Consultancy (ADC)
Rotterdam, the Netherlands.

I. INTRODUCTION

Like in other fields of industrial activities development in dredging equipment as well as in methods and management tools is an on-going exercise.

MICROPROCESSOR

The influence of the "microprocessor" and the concern about the environment is affecting the dredging industry fundamentally, moreover this process of changes is boosted heavily due to the increase of the international competition as a consequence of the staggering economy, nationalism and protectionism. In the past one could say: "dredging is a trade", nowadays: "dredging becomes an industry backed up by science". The industry is crossing the threshold to a new era. Almost every part of the wide dredging field is on the move, from surveying to completion of the dredging works.

RED TAPE

In this syllabus the red tape of a decision-tree is used to focus on the various achievements and their mutual relations.

Figure 1 Survey launch measuring density

II. TO DREDGE OR NOT TO DREDGE

PREPARATION

To take a decision to dredge is for some principals a regular activity, for others a unique event. The preparation for this decision can be split up in a comprehensive series of questions and the answers thereof placed in a logic sequence. Considering the main features will provide an excellent opportunity to look into the highlights of modern dredging.

SURVEYING

Herein surveying provides the decision-maker with up-to-date information of the actual information. Besides this surveying gives the basic information for the users of fairway and/or harbour basins and forms an important part of the technical facts and figures for the support of the dredging operations.

NAUTICAL DEPTH

A break-through is the acceptance of the proper definition of nautical depth in fluid mud areas, being for Rotterdam the layer with a density of 1.20 t/m³.

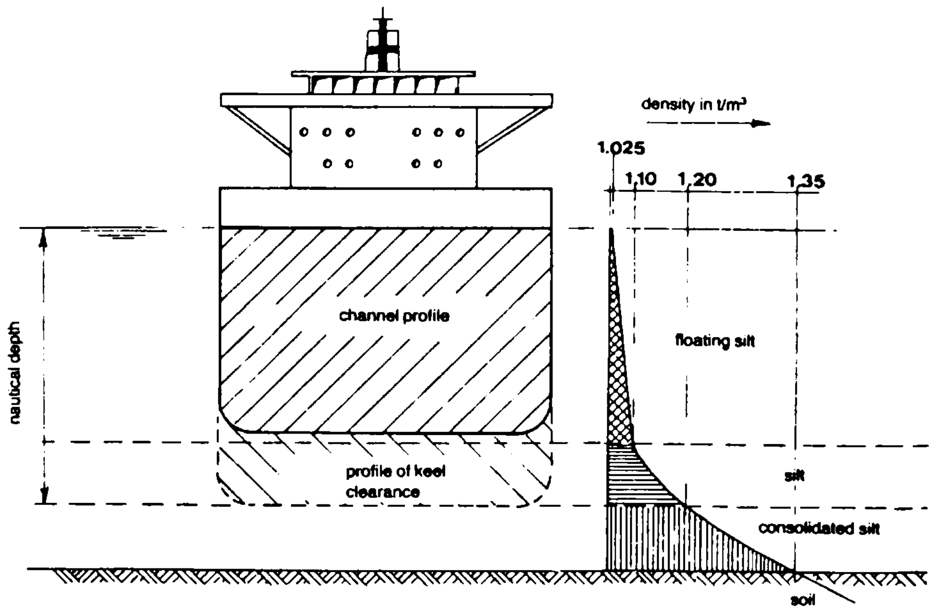


Figure 2 Nautical depth

Based on this definition and with the help of the nuclear density back-scatter probe a nautical depth map is produced every fortnight of the Europoort entrance. Prototype tests in scale 1 : 1 are on their way with a continuously recording density measuring device, the so called non linear echosounder with parametric transducer, to match the new depth standard in muddy areas.

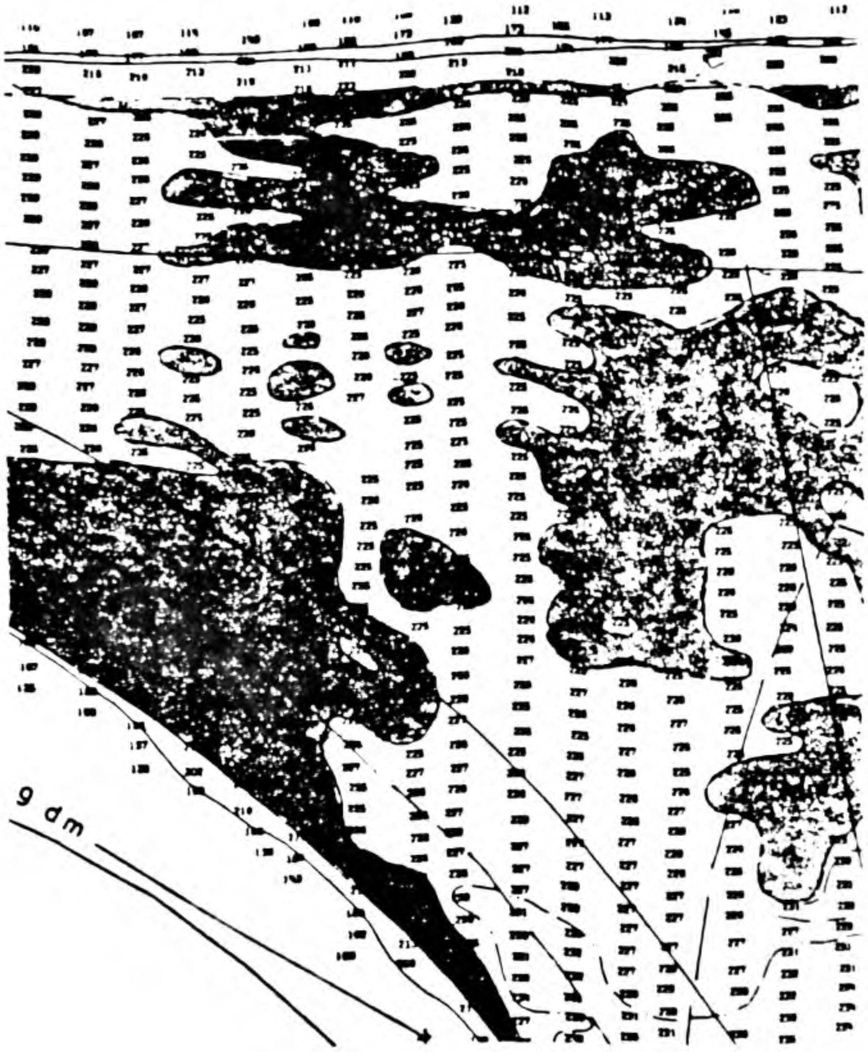


Figure 3 Nautical depth map

Fully automated data processing systems in the surveying field are rather common nowadays, producing survey maps with automatic tide level corrections and wave and swell compensated with the help of heave compensator(s).

TREND

The newest trend is to send the survey data directly via a radio data link from the survey launch to the shore computer or the shipborn computer on board of the dredger. Monitoring the dredger operations via a similar radio data link might be the next step; preparations and tests therefore are now carried out in Rotterdam.

III. WHY DREDGING?

IMPORTANT ASPECTS

The question "why dredging?" can best be answered as follows: because the information about the actual situation of the dredge area does not fit in with the requirements or in the case of capital dredging it does not comply with needs of potential users. Important aspects to be considered are:

Actual situation:
- nautical chart.
- aids to navigation.
- ship characteristics.
- seasonal circumstances.
- economical feasibility.
- political impact.
- organization aspects.

Investigations:
- technical feasibility.
- hydraulical feasibility.
- users requirements.
- financial funds.
- procedures for realization.

INFORMATION

Interpretation of the available information and comparing with the users and/or principals requirements is depending highly on the human factor and the reliability of the facts and figures. Therefore data acquisition and processing systems are very useful to provide quick information to enable the principal or the contractors staff to take decisions on a rational basis.

"Have a dredge, dredge" is an expensive principle; the necessity of dredging must thoroughly be investigated. To prevent, to avoid or to decrease dredging operations has to be the basic attitude of any principal. Users requirements, nature's behaviour, low maintenance design, the selection of dredging consultant, contractor and equipment and the positive influence of a proper system of aids to navigation should be studied sharply.

PROGRESS

Progress in this field is illustrated for instance by the developments of dredging in fluid mud areas. When dirty water dredging is avoided and the principal waits some time for consolidation of the mud, the need of peak capacity allocation is prevented. More consolidated silt gives a considerable increase in productivity, as shown by the increase in solids % of samples, due to consolidation in a bufferpit.

The opportunity of the availability of a dredger might well be in some cases a reason to dredge.

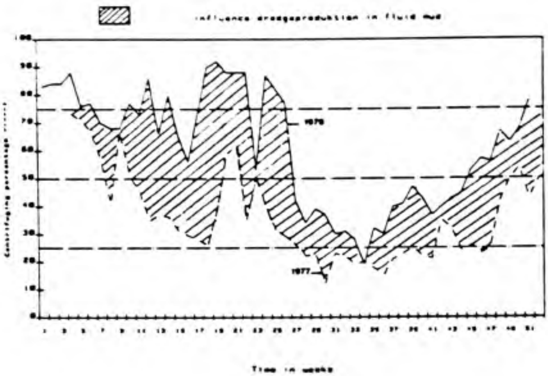


Figure 4 Improvement of production

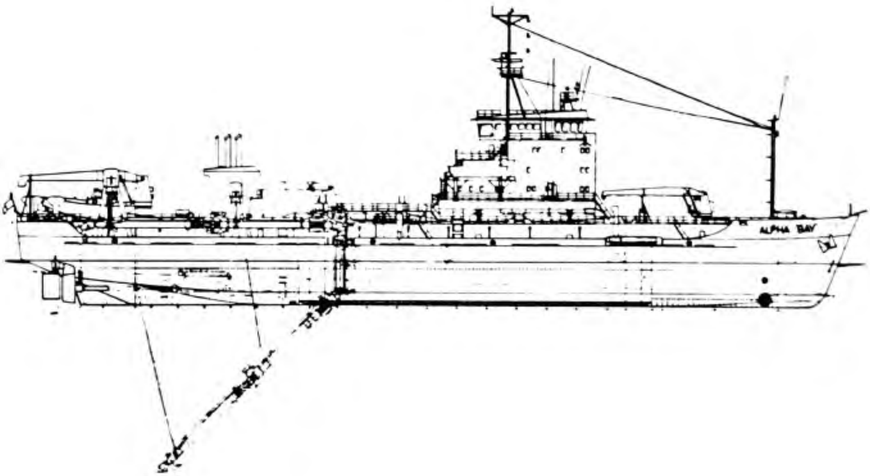


Figure 5 Split hopper dredger "Alpha Bay"

Mobilisation of dredging plant in relation to the magnitude of the demand can require quite some money. Especially in the case of highly sophisticated special purpose dredgers the costs/output ratio could be so beneficial that the occasion should not be neglected.

RECENT DEVELOPMENTS

Recent developments are:

- Adaptation of the shipping requirements to the composition of the bottom material.
- Investigations instead of dredging, resulting in practical solutions:
  - holding up the sedimentation by a siltscreen in a harbour-mouth.
  - catching the instreaming bottom-sediment in a pit in the harbour-mouth; sometimes in combination with a stationary suction system.
  - removing local shallow spots by a bed leveller.
  - increasing consolidation of the bottom material.

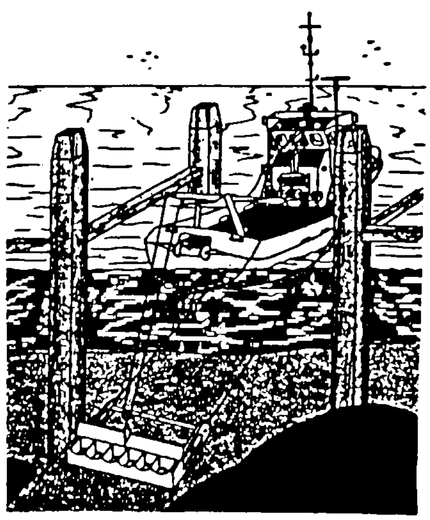


Figure 6 Bed leveller

- Balancing the costs of dredging against the shipping intensity.

NAUTICAL DEPTH

THICK WATER

TESTS

- And as a special topic: nautical depth. The point is that research has shown that the top layer of the waterways' bed often consists of a layer of water with floating particles of silt; going deeper, one will find that the concentration of silt particles increases. One might speak of a layer of "thick water"; 90 % water and 10 % silt. Due to the mentioned bottom composition the output of the dredgers was very small. Therefore the question arose whether the upper layer of floating particles should be dredged at all. Laboratory and practical tests showed a slight increase in the resistance experienced by ships sailing through the upper layer. However, their manoeuvrability remained the same or even improved slightly.

NAUTICAL BED

Thus a new definition of the "nautical bed" was drawn up. The nautical bed is the plane over which a ship, including its keel clearance, can manoeuvre safely. The tests also showed

1.20 t/m³

that consolidated silt with a density of 1.20 t/m³ has such internal friction that this concentration may be regarded as the firm nautical bed. This means that the upper layers with concentrations smaller than 1.20 t/m³ need not to be dredged.

IV. WHERE?

It seems obvious that the answer on the question "where to dredge?" should be: there where the required depth is not available. But if that is the policy, there is not only always a backlog in

BACKLOG

matching the maintenance target, but also quite some risk of great nautical problems due to a sudden siltation. In the case of capital dredging the sequence of operations related to locations can influence the progress and the occupancy rate of the various dredgers of the company very much, resulting in idle time and/or reduced production.

POSITIONING SYSTEMS

Adequate positioning systems in horizontal sense as well as vertically are of extreme importance. Dredging in the wrong spot does not help reaching the goal. Overdredging and dumping or dredging outside the limits of appropriate areas does cost money to the principal or the contractor. Limiting overdredging to very small values in relation to the operational characteristics of the dredger will lead to higher expenses as well. Certain influences as waves, currents, tides, river discharges, may affect the in situ results considerably. Timing and proper positioning are important in this case. The choice of the positioning system(s) should depend on the type of dredger(s) applied in the job and the way surveys are carried out. Modern electronic position fixing systems are indispensable for trailer dredgers. Offshore operations or operations in wide river estuaries require, depending on the distances, electronic position fixing systems as well. Recent developments in this field are among other things the replacement of the electro-

DISPLAYS

mechanical trackplotters by electronic displays. On the screen the helmsman gets a picture of the actual position of the draghead(s) projected on the background of the layout of the dredge/dump area.

For the dredgemasters on cutter suction and trailer dredgers displays are available showing the position of the cutterhead respectively the draghead in x, y and z in top view or in cross section. Traditional systems are in no way useless but they could be backed up by electronic systems, or replace the latter in case of failure.

Developments are on their way and some systems already have been operational, providing the position of the draghead(s) instead of the position of the antenna.

Figure 7 Electronic display

CLASSIFICATION OBSTACLES

In taking the decision where to dredge it becomes necessary to make distinctions between nautical obstacles according to a kind of scale, from very small to urgent and serious. Classification of nautical unwanted deviations of the target depth depends on a great variety of items to be considered. The shallow spot must be classified in relation to the layout, target depth and other design criteria:

- Area (offshore, inshore, bush).
- Deviation of target depth (small, considerable).
- Magnitude of the shallow spot (small, big area).
- Location (slope, centre line).
- Nature (sand, silt).
- Character (stable, fast growing).
- Danger aspects (ship's draught, keel clearance %, swell, season, cargo, experience).
- Standard of the port.

It must be said that classification of shallow spots is still being studied. For reasons of computerization and the creation of objective standards it is necessary to round off this study.

The accuracy of the measuring systems and the reliability of the results, as well as the age of the latest available information, are playing a considerable role.

DREDGE PROGRAM

This all should result in proper instructions in the form of a dredge program, submitted before start of operations to the dredgemaster and inspector.

RECENT DEVELOPMENTS

Summing up, recent developments are:

- Replacement of electro-mechanical positioning trackplotters by electronic displays.
- Cutterhead and draghead displays.
- Position control of the draghead.
- Identification of the density of fluid mud layers.

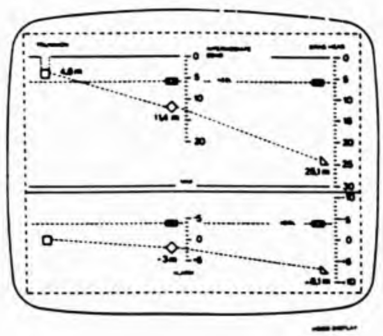


Figure 8 Draghead display

V. WHAT?

The question "what has to be dredged?" is related to the qualitative properties of the material to dredge.

INFORMATION

Information in this aspect is gained by means of sampling techniques and other in situ information acquisition systems. Sediment science, soil investigations and dredging boundary conditions together form the platform for the answer.

CHOICE

The difference of soils like hard rocksand, clay and silt are enormous and they require totally different dredging systems. To make the right choice of equipment, the type of soil and its specific condition is a leading factor.

PROGRESS

Especially in the last few years progress is made in the field of rock, silt and clay dredging. Behaviour and properties of silt (fluid mud) have been studied thoroughly. The influence of the gas content on the dredgeability, consolidation rate versus production of dense material in situ, and the pseudo plastic behaviour of silt are much better known now and have lead to modifications of the dredging plant, with a considerable increase of output as a consequence.

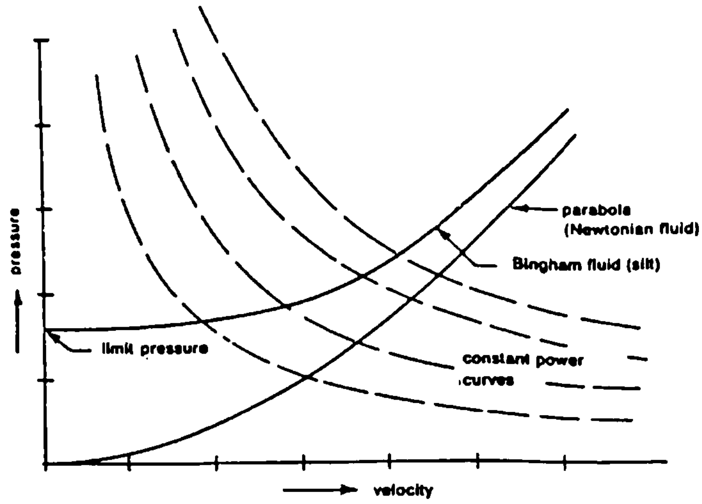


Figure 9 Pseudo plastic behaviour of silt

The large dredging works in the Middle East and fundamental investigations by the combined dredging research group, in which the Delft Hydraulic Laboratory, the Dutch Rijkswaterstaat and five contractors are participating, made much progress in hard rock cutter dredging.

RECENT DEVELOPMENTS

Recent developments are:

- Sampling systems for samples with a maximum length of 30 m.
- Development of a transmitting sonde.
- Diving ball for underwater bottom survey.
- Radio-active density meters.
- Large seegoing cutter suction dredgers.

VI. HOW MUCH?

IMPORTANT ASPECTS

Important aspects in relation to how much are:

- Survey maps comparison.
- Quantity calculation.
- Design dimensions.
- Accuracy.
- Reference level density maps.
- Standards.
- Prediction methods.
- In situ quantities.
- Production quantity.
- Deposit quantity.
- Bulking factor.
- Calculation methods and means.
- Production estimate.
- Time schedule.

The quantity determination plays a central role in the execution of dredging works because of the stipulations in the dredging contract concerning dredging achievements. At the same time the most often used calculation unit "m^3" is rather elastic. Much can be said in favour of using the "ton dry weight" instead.

TUNING RELIABILITY

To assure trustworthy quantity information for the bill of quantities, production estimate and execution time, it is necessary that the various parts contributing to the final results have a tuning reliability. And there are many factors influencing the final results.

RELIABILITY BELT

In such complex relations between parts it might be wise to look only to the overall result showing an average accuracy, as it is impossible to calculate the overall reliability on a theoretical basis. This method is applicable for repeating activities in a restricted area where the area characteristics could be considered as rather homogeneous throughout the area. Comparing survey charts by calculating each time an average quantity or depth figure for the defined area shows, if graphically worked out, a reliability belt, which can be converted in an accuracy figure. In the example of figure 10, the accuracy is about 10 cm or about 250 000 m^3.

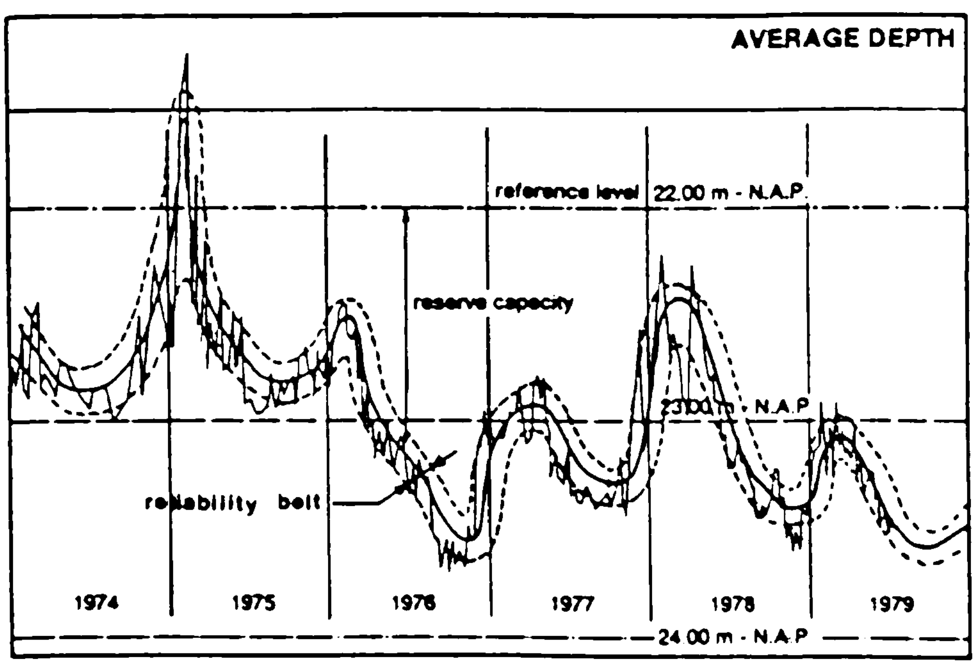


Figure 10 Average depth in surveys

EXTRAPOLATION

To give a reliable estimate of the production as measured in situ or in the means of transport (hopper), is possible by extrapolation of experience and figures of previous works. Soil characteristics play a key role in this exercise, but circumstances as weather, climate, waves, swell, currents, tides, etc. can affect the outcome of the calculation considerably.

The production trend during execution time has the shape of an S-curve (figure 11).

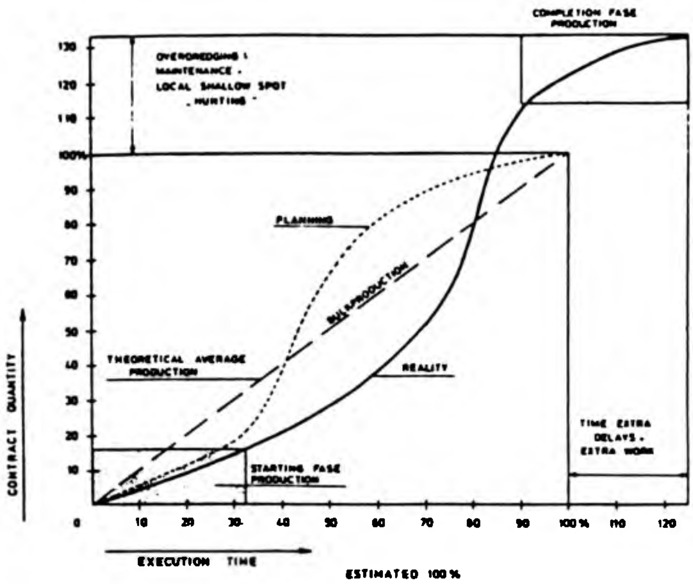


Figure 11 Planned and real production

FACTORS

There are many factors causing differences with planned execution time and quantity. Some of them are due to the quantity of organization and management, others are due to the quality of skill and know-how or the suitability of the equipment.

STAGES

For the latter cause it is very important to consider the suitability of the plant for all stages of the work. For instance, in the beginning there might be shallow water circumstances influencing the vessels carrying capacity due to draught restrictions; in the final stage of the work only some local shallow spots are to be removed causing low productivity for large capacity plant. In the case of regular maintenance dredging works there is a good opportunity to predict the amount of work to be carried out, on the basis of extrapolation of the past.

EXAMPLE

As an example: for the entrance of Europoort, Rotterdam, every week a complete survey is carried out. Every week the accretion of material can be calculated by adding the production of the dredgers over the period between both survey dates, to the difference in quantity of two sequential survey maps. By putting such results in a graph over several years a picture of the siltation is obtained.

SEASONAL INFLUENCES

Seasonal influences come clearly visible. If enough figures over lots of years are available "dry" and "wet" years can be determined as well as an "average" year.

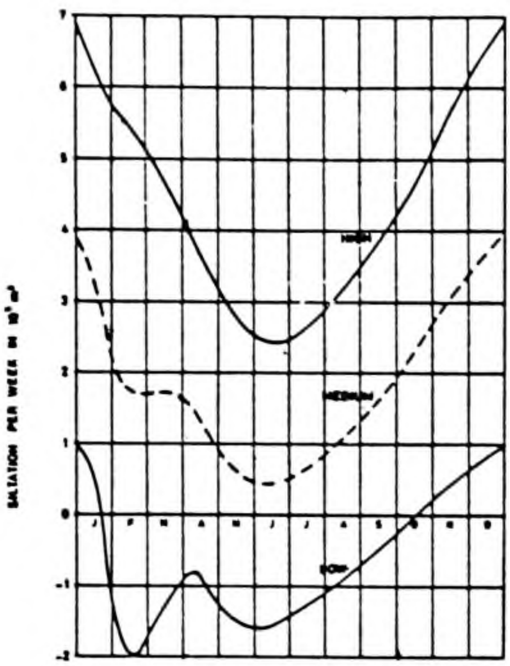


Figure 12 Seasonal variation in siltation

Putting the same data in a cumulative graph gives an easy possibility to calculate graphically the required capacity and the magnitude of the buffer capacity of a storage pit.

Probability intervals can be derived from the figures for chances of exceeding the expected dredge quantity once in 5, 10 or 15 years.

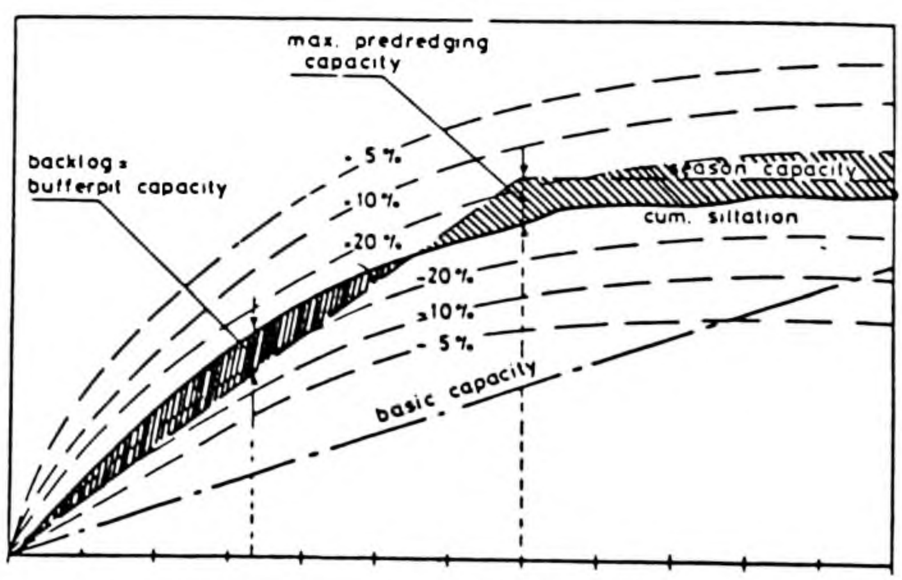


Figure 13 Siltation and capacity allocation

RECENT DEVELOPMENTS

Recent developments are:

- Hopper quantity measuring.
- Central data bank.
- Data information.
- Quantity prediction.

VII. HOW?

ASPECTS

Aspects are:

- Nautical requirements of dredge operations.
- Equipment properties.
- Dredging method.
- Supporting systems and instruments.
- Engineering.
- Total dredge chain approach.
- Safety of fairways and harbours.
- Workability.
- Environmental impact.
- Accuracy.
- Alternative.
- Recycling dredged material.
- Selection of equipment.

The selection of equipment should be based on the local circumstances in the first place. A leading point is the method suitable for the specific problems to tackle.

ENVIRONMENTAL EFFECTS

FUEL COSTS

Nowadays the care for environmental effects will have a big influence on the method and thus the tools. Systems with a low fuel consumption have an advantage with the constant increase in fuel costs.

SPECIAL PURPOSES

There is a trend in busy fairways to step over from stationary dredging systems to mobile dredging vessels. There is a further development in equipment for special purposes, such as "hard rock cutters" with an increase in horsepower for the cutter as well as for the pumps, mounting up to even more than 15 000 kW (20 000 hp). Light weight trailers are specially designed for mud dredging.

RECYCLING

Recycling of dredged material is a feature of growing importance. For environmental reasons it becomes more difficult to dump dredged material at sea or deposit it on land, especially if the material is contaminated with heavy metals or other pollutants.

INVESTIGATION

In Rotterdam a large program to investigate recycling possibilities of dredged material is carried out with some promising results, of which bricks for house construction and scour inhibitors to stabilize the riverbed are good examples.

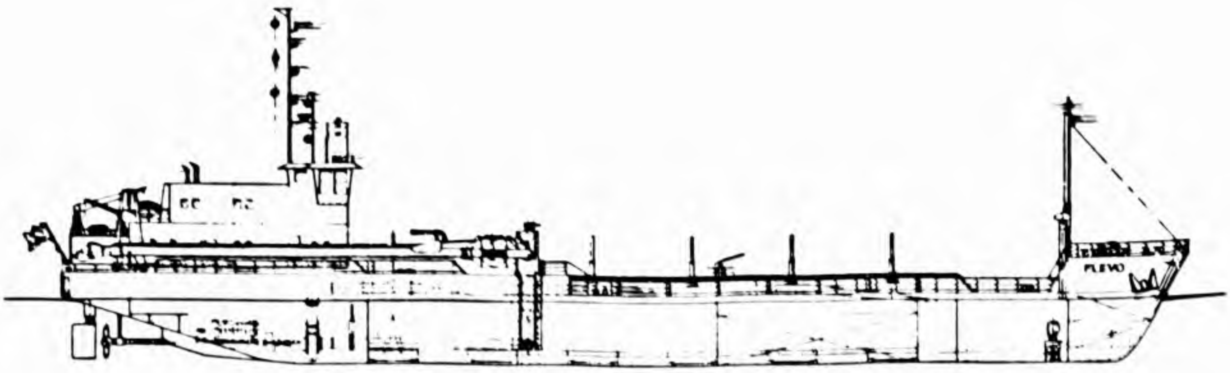


Figure 14 Light weight trailing suction hopper dredger for silt

RECENT DEVELOPMENTS

Recent developments are:

- Automatic suction tube handling systems for hopper dredgers.
- Fourth generation cutter control system for winch handling and process optimizing.
- Bucket dredger automation for moving of tin dredgers.
- New generation of concentration meters.

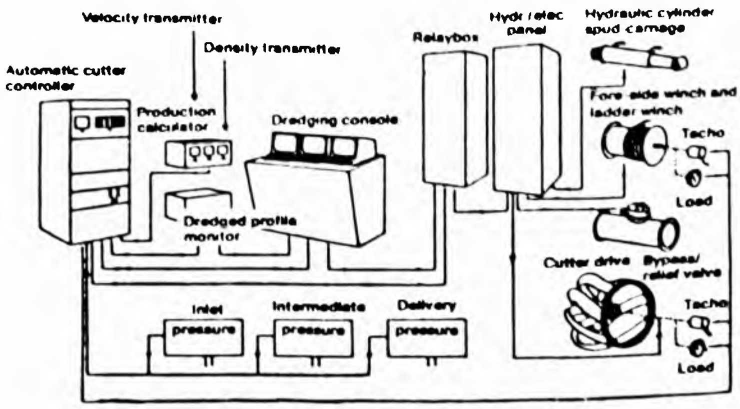


Figure 15 Cutter control system

HANDLING AUTOMATION

Handling automation comprises the efficient and safe execution of operation handling under human stated sequence and limits. It has reached at this moment a reasonable level.

PROCESS AUTOMATION

Process automation will say that after putting in the specific process parameters, the automation device executes (by its own or more or less adaptive) the process. Adaptive means in this case that the automation device independently chooses set-points, under dynamic circumstances within the frame work of the imposed limits; this results in optimizing the total process instead of steering to a static situation of balance. The process automation in relation to dredging is still in its infancy.

PROGRAMMED DREDGING

As a special topic we will look into programmed dredging.

The need and possibilities of dredging automation, depending on the changed opinions in the allocation of tasks between "human" and "machine", can be divided into:

- handling automation.
- process automation.

In practice automation is mainly associated with the process and handling comes in the second place, but to optimize the whole process it is very important to consider the handling automation first.

The previously mentioned developments in relation to process automation depend on three parameters:

1. The position of the handling automation in relation to the dredging process.
2. Knowledge of the process and the methodology to divide this into delimited functions, in such a way that this information is acceptable for intelligent "machine" assimilation.
3. The position of technology which must make it possible to realise reliably and accurately these complex functions.

TEST CRITERIA

FACTORS

In order to reach the conclusion that the dredging jobs are executed with optimal results, one needs to be able to measure the results and one needs to have test criteria to compare these results with. These test criteria consist of the descriptions of the optimal processes. Here the plural is used because we cannot speak of one dredging process. The optimal dredging process depends on quite a few factors, such as:

- type of soil to be removed.
- layout of the works.
- time schedule.
- environmental conditions.
- dredge performance characteristics.
- logistics.

We will not elaborate these factors, but merely will mention some aspects.

It makes a difference whether one has to dredge and reclaim or dump:

a. soft mud or hard rock.
b. at a large or short distance.

c. in a short or a long period.
d. with a grab dredge or a trailing suction hopper dredge.
e. near a harbour with all facilities or in an area where no harbour exists yet.

The optimal process description can only be made when one has available the know-how of the performance of each type of dredger in all different circumstances and when these circumstances to be met are well known.

CHANGE

Automation means a change in the substance of the function of the dredgemaster. Instead of operating the control handles, he operates by adjusting set-points. Instead of doing things with his hands, he is doing more and more with the brains. When the dredgemaster has more know-how about the dredging process and the working of the dredge components, he can obtain better results. This know-how he can acquire in practice, but also in schooling. The Dutch dredging industry has established schools for the education of dredging personnel. These schools are situated at Delfzijl. At the Lower Technical School for pupils of 12 - 18 years, a 4-year course is given. At the Secondary Technical School for pupils of 16 - 20 years, a 3-year course is given, of which one year is spent in a dredging company. This school has a newly developed cutter dredger simulator available, on which pupils can be taught to operate a cutter dredger in all kinds of circumstances and soil conditions. These schools deliver theoretically trained personnel, that will be able to become a dredgemaster of the modern dredgers, equipped with the newest developments. Also administrative, technical and organizational functions in the dredging industry can be filled.

SCHOOLING

VIII. WHO?

The answer to the question "who?" highly depends on the capacity policy and/or the tendering strategy of the principal. The question of dredging with own means or with private contractors has to be studied again and again to get the best results for an acceptable price.

COMPETITION

Nationalism and protectionism unfortunately have lead to situations where competition has been banned. In the Dutch situation there are no government owned dredgers; all the work is tendered among private contractors. The results as a consequence of competition, in price as well as in quality, are very good.

GOVERNMENT

If for any reason a government owned dredging fleet is assigned to carry out work, the lack of competition can be compensated by creating opportunities to compete with private contractors. Basic capacity for own equipment, peak capacity and capital work to be carried out by private contractors in competition with the state owned dredgers, will be beneficial for the productivity of the latter.

Five year contracts in combination with special purpose dredgers, such as the Cosmos, on a charter basis with an incentive for high productivity, is a very good alternative for public sector dredging.

DUTCH DREDGING

Since 50 years ago the market position of the Dutch dredging companies has changed. Now they operate in a strong competition. The main factors leading to this situation are:

- The rise of dredging companies in other countries.
- The rise in labour costs.
- Protectionism.
- Soft loans.

MARKET

Also the market has changed considerably:

- Growth in ship size led to deeper harbours and seaways.
- Dredging has to be carried out in large volumes, hard soils and in exposed waters.
- Technology development has led to improvement in dredge characteristics.

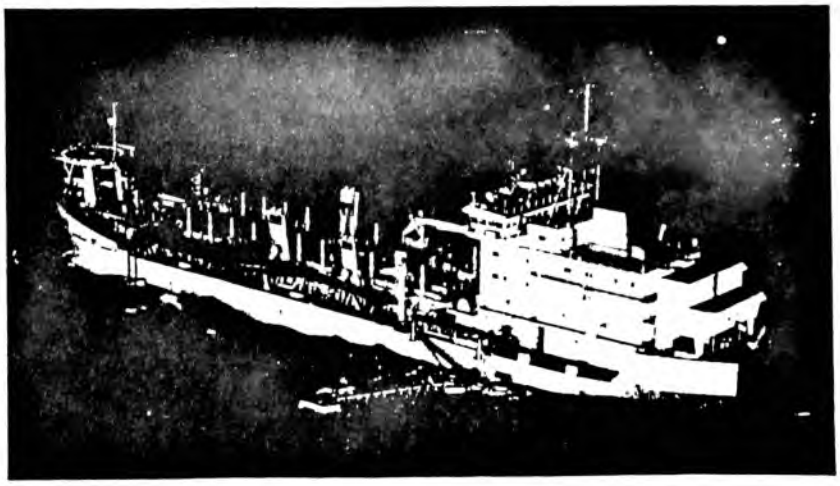


Figure 16 The Cosmos

Because of this change in market and market position, the process control used by the dredging contractors has shown a considerable development. The dredging is now on its way from a trade to an industry.

IX. HOW MUCH MONEY?

MAIN ASPECTS

The main aspects concerning prices are:

- Market situation.
- Prices.
- Market position.
- Data bank.
- Effective production time.
- Finance/budget.
- Quantity calculation.
- Capacity/output ratio.
- Alternative proposal.
- Contract form.
- Risk factor.

TWO APPROACHES

For many people involved in business the most important question is: how much money does the project require? In general two approaches are usual to come to the cost estimate of a work.

The price (costs) can be composed by adding together all price components of the parts of the cost factors of a dredging work. The second method is to compare prices of other works providing information of market prices. Both approaches have their advantages and their disadvantages; it depends on circumstances whether it is possible or not to transfer prices from one work to another. For contractors as well as for principals it is necessary to know prices of works elsewhere as a reference for estimate and competitive bidding.

ANALYSIS

To compare prices it is necessary to create a basis of fair and reliable standards. Plant costs, capacity, production and performance are therefore to be defined. Lowest price does not mean automatically that it is the cheapest solution. Analysis of real costs and expenses after completion of the work(s) often shows additional costs, claims etc., resulting in exceeding the original budget and/or bid.

Distinction between net and gross working time, in situ m^3 and effective m^3 in hopper, execution time, bonus systems, the rate of control by the engineer on the effectivity of the operations and the type of contract have to be taken into account for a proper evaluation of the price. Without specialized support it is almost impossible to review quality and price of dredging work.

POSSIBILITIES

Knowing the possibilities of specialized equipment of contractors and using such know-how during the design stage is necessary. For difficult and uncommon projects it is even advisable to design in close co-operation with a specialized (not in numbers of equipment but in variety of it) contractor, which certainly will lead to an optimum between quality and price.

For a fair evaluation of public owned equipment labour costs (including main office and overhead), depreciation, interest and occupancy rate are factors not to be forgotten.

X. WHEN?

The priority of dredge operations or the sequence of activities must be given the right value. Hurry can raise prices tremendously; in case of doubt it is cheaper to check survey results by another (detailed) survey instead of dredging right away.

NATURE

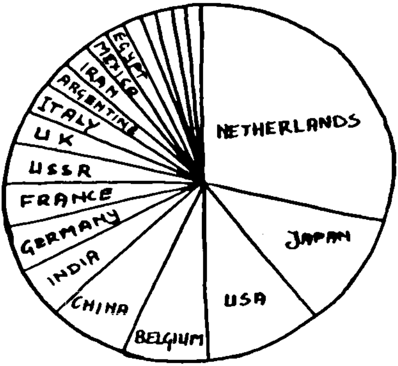
Nature is not predictable day by day, but trends, seasonal influences and their order of magnitude can be forecasted within an acceptable range of reliability.

PLANNING

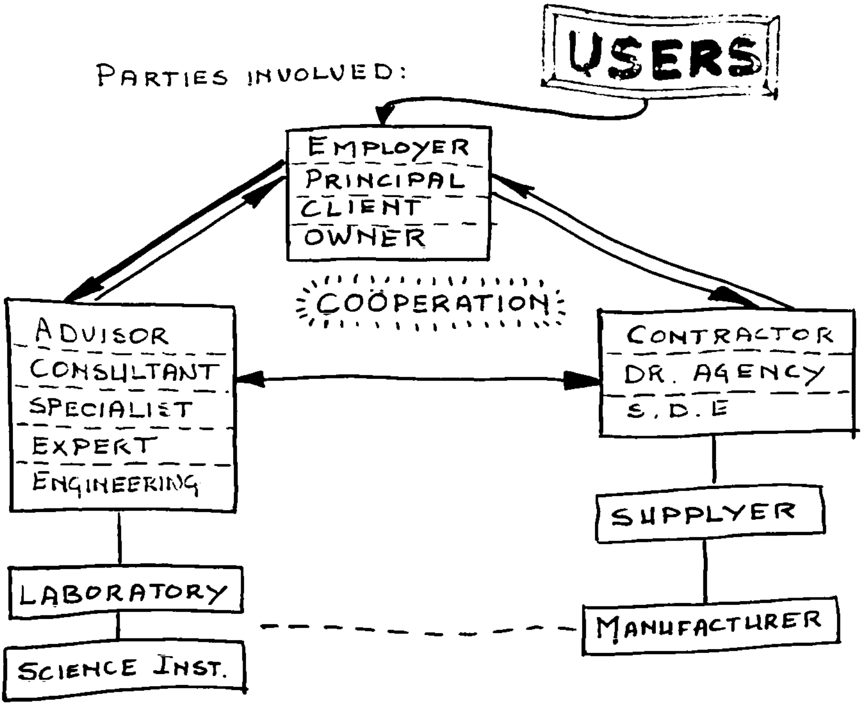
Good planning of not only the execution of the work but the financial and administrative procedures too, will lead to a well balanced capacity allocation during the year and keeps fluctuations in capacity limited.

The use of computers for progress control and administration is obvious. Feedback from the realization to the original plans will give improvement of figures of the data bank and the trustworthiness of the plans. Changes necessary in the operations can be discovered in an earlier stage and can more easily be implemented in the schemes.

15 LARGEST DREDGING NATIONS

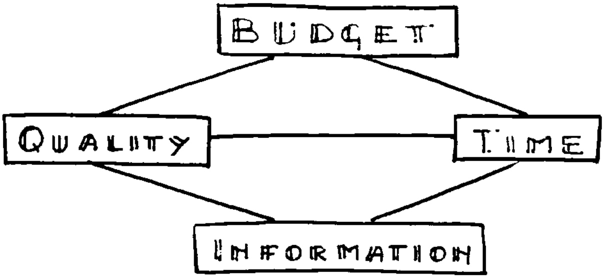


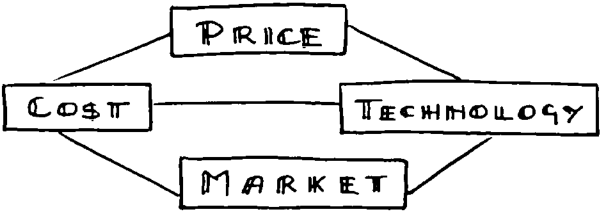
Project Organisation



Project Realisation Through Cooperation

Problems only exist in human minds!


BUDGET
QUALITY
TIME
INFORMATION


PRICE
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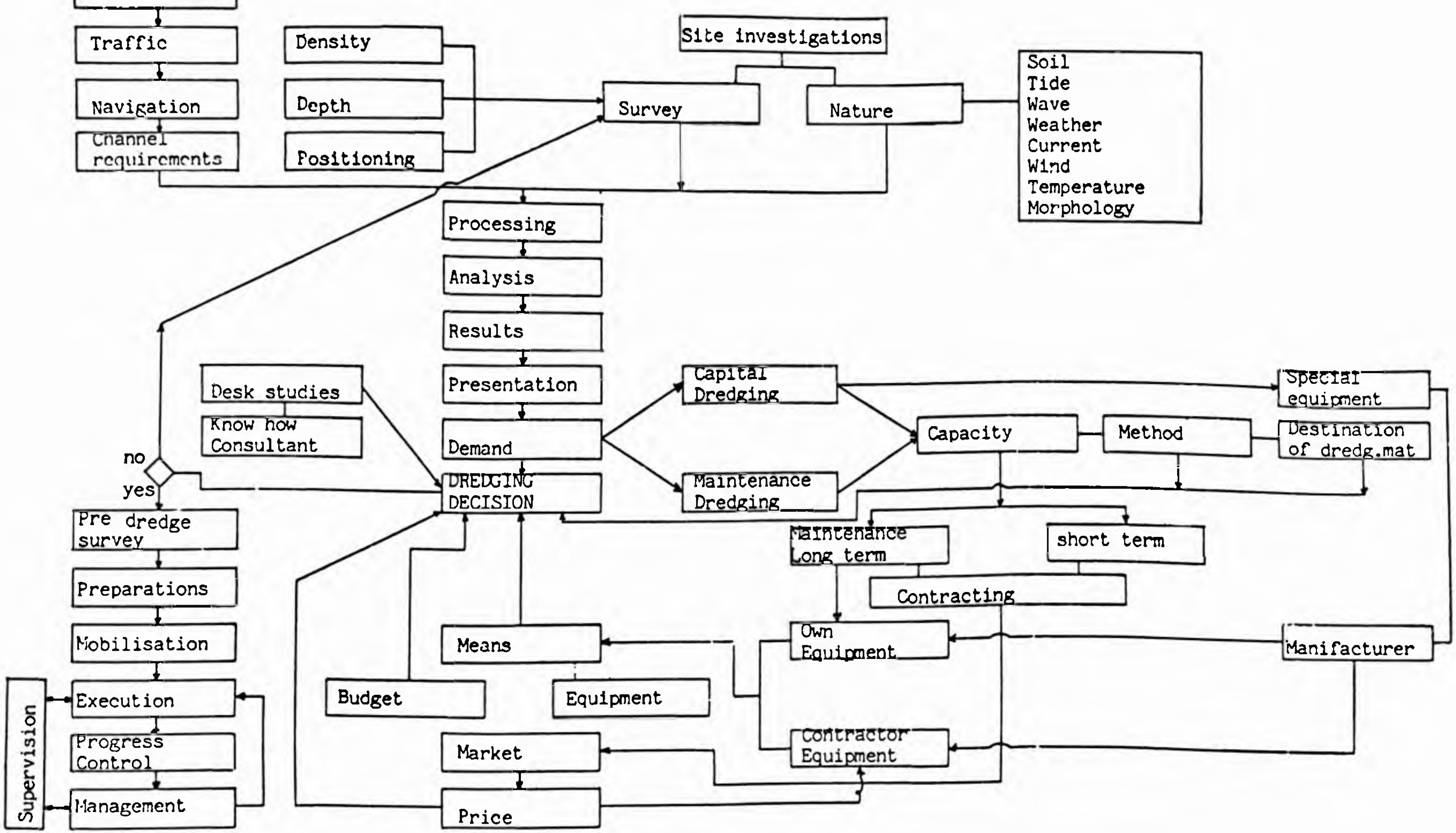
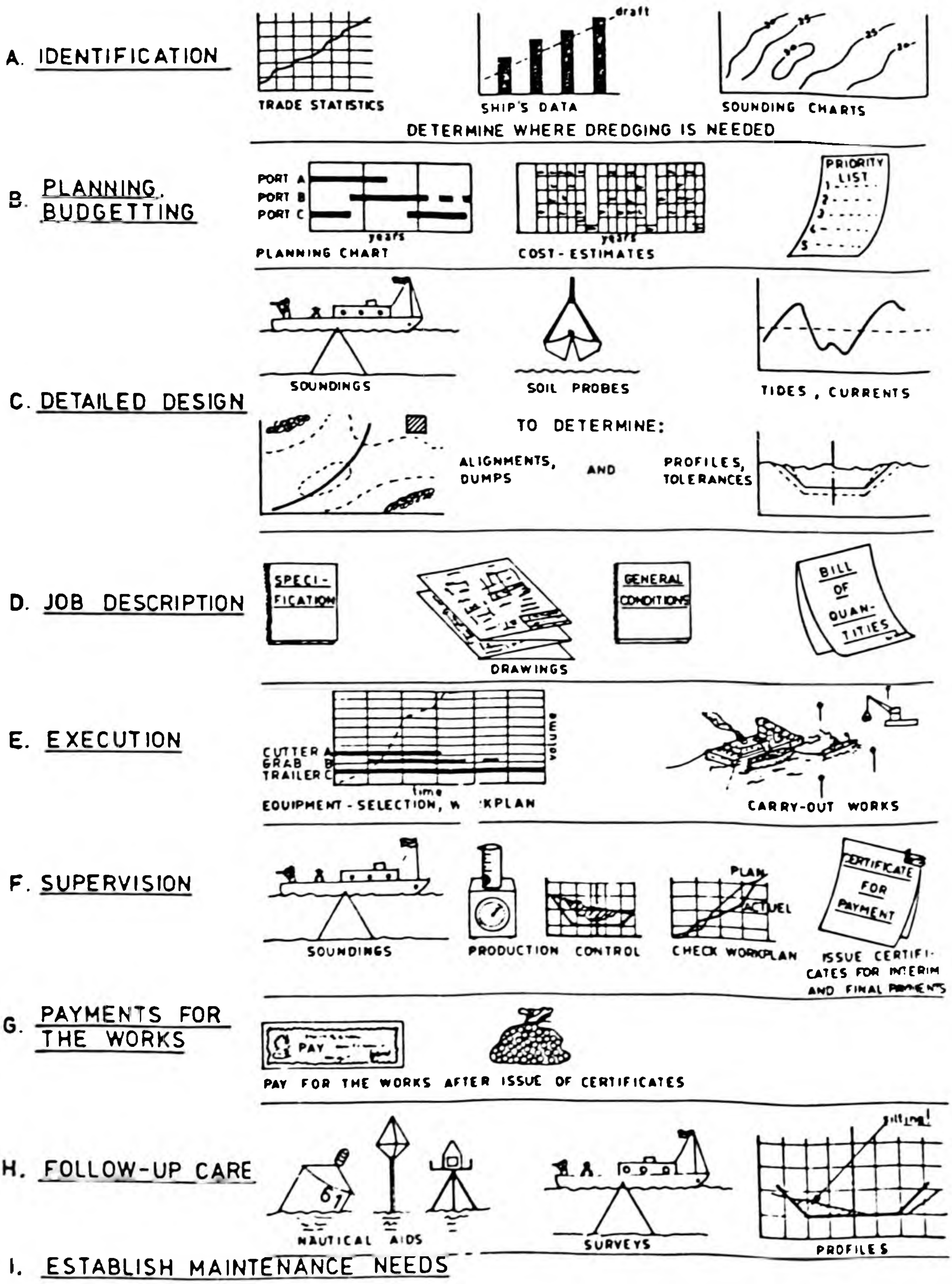
TECHNOLOGY
MARKET

DREDGING DECISION



THE SEQUENCE OF DREDGING WORKS



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2. SITE INVESTIGATIONS

The subject of site investigations was covered by two lectures during the Seminar-cum-Study Tour. The first lecture, entitled "Survey, the past, the present and the future", was presented by Mr. H.R. van der Wal, NESA. The lecture is reproduced in full text.

The second electure, entitled "Soil analysis in relation to dredging", was presented by Mr. H.A.M. Nelissen, Delft Soil Mechanics Laboratory. A paper presenting a review of the latest developments in the field of site investigations was circulated, and the first two chapters are reproduced here.

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2.1 SURVEY: THE PAST, THE PRESENT AND THE FUTURE

(Some aspects of survey operations as a support for dredging activities)

By Ir. H.R. van der Wal Nederland Survey Projecten
en-Apparatuur (NESA), Rotterdam

1. Introduction.

For centuries, most of the countries had their own merchant fleet, which was very important for the transport of raw materials to and from different harbours.
Due to the increase of the draught of the vessels it became more and more necessary to build new harbours or to deepen existing harbours, to dredge channels and to deepen the rivers, as well as the maritime entrance channels.
As a result of these developments extensive capital dredging operations have already been carried out worldwide, and this will continue.
To be able to guarantee a certain depth of a harbour, a river or a channel it is also necessary to carry out maintenance dredging operations in certain areas.

The dredging equipment used for both capital and maintenance dredging requires high capital investments. Therefore all attention has to be given to improve the efficiency of dredging operations.
Apart from mechanical and technical improvements of the dredgers which have already taken place, it is essential that the information which has to be supplied to the dredgers (where to dredge, how much etc.) is collected in an effective, efficient and accurate manner.
This information has to be supplied by the contractor. Therefore he has to execute survey operations. In this paper, the survey operations as a support for dredging activities will be described, new developments will be mentioned, and the interaction between dredging operations and survey operations will be explained.

2. What is Survey?

Survey is : "The measurements and/or observations which are necessary to be able to map the surface of the earth".

It is obvious that, using this definition, several main questions still have to be answered,. like:

- what kind of measurements/observations?
- what kind of equipment/procedures has to be used?
- what kind of accuracy is necessary?
- which part of the surface of the earth has to be mapped?
- how shall the measured and observed data be presented?

On the other hand several other questions can be deducible from this definition, like:

- for which purposes have the measurements/observations to be carried out?
- what kind of methods have to be used?
- what kind of diciplines are involved in the measurements/observations as well as the presentation of the data.
- who is responsible for the final product?
- are there any related measurements/observations which are incluaed in this definition of survey.

In principal surveys can be devided in landsurveys and seasurveys (including surveys of rivers, channels, etc.). It will be clear that the main difference between both surveys is caused by the fact from where the measurements/observations are carried out and which part of the surface of the earth has to be mapped.

Landsurveys are carried out from the fixed surface of the earth (land) and are used to map the surface of the earth above sealevel.

The measured data is normally presented as a topographical map.

Against that, in principal, seasurveys, are carried out by using a (survey) vessel, from which measurements/observations are taken to map the surface of the seabottom (the surface of the earth below sealevel).

The data gathered during the execution of seasurveys is presented as a sounding chart.

The deviding-line between landsurveys and seasurveys is not always very clear.

For instance : to be able to execute seasurveys and to present the gathered data in a proper way, it is necessary to use positioning fixing systems of which the transmissing/receiving stations are normally installed ashore.
The coordinates of these stations have to be known and therefore it is necessary to carry out a landsurvey. From known fixed points ashore angle and distance measurements or satellite observations have to be performed to the stations of which the coordinates are not known. By means of computation it is possible to express the coordinates of the shore based stations in a certain land based coordinate grid and to express the different positions of the surveyvessel in this grid.
Besides that it is sometimes necessary to present the results of a seasurvey as charts on which the coastline is shown as well. To prepare these charts, a landsurvey has to be carried out to measure and calculate the positions of different points along the coastline in the same coordinate grid as will be used for the presentation of data of the seasurvey.

The survey operations, which are carried out by surveyvessels (a.o. for dredging activities) are normally known as seasurveys. During the last decades, these survey operations have been subject of a number of changes due to the change in dredging equipments and methods, as well as the change in survey equipment and surveymethods, mainly because of the fact that nowadays use can be made of modern techniques like :
- automated process control
- integrated systems
- new processing and presentation techniques.

3. Positioning fixing systems.

During the second World War the first electronic positioning fixing system was developed and later on used by the Allies during the landing in Normandy. This system, consisting of three fixed transmitting stations onshore and receiving units on board the landingvessels of the Allies, was making use of radio waves with different frequencies (around 100 KHz). By using a chart of the area, on which the different lines of positioning resulting from combinations of two transmitting stations were drawn, it was possible to plot the actual positions of each landingvessel.
Based on the experiences obtained during these operations and the availability of electronic equipment, several new electronic positioning systems were developed during the previous years, using different methods.
Nowadays as "electronic positioning fixing systems" are defined all systems, by which radio-waves and micro-waves are used for the determination of the position of a location (i.e. vessel) relative to one or more locations, of which the geographic co-ordinates are known (i.e. shore based stations).
The electronic positioning systems available nowadays are based on one of the following principles of measurement:

a. distance differences (hyperbolic)
b. distance (circular)
c. range-bearing (polar)

In order to effect such measurements, electronic equipment (either or both transmitter and receiver) is installed at the fixed station(s) and the mobile station (ship).
For a position-fix of a vessel at the sea surface, generally a minimum of two observations are required. Each individual measurement provides only one line (the so-called line of positioning) on which the vessel is situated (locus).
Intersection of this line of positioning with a second line of positioning will then provide the ship's position (position-fix).
The point of intersection can be expressed in grid coordinates by means of computation.
It is also possible to predraw lines of positioning of a certain area on a chart.

The two observed lines of positioning can now be plotted on the chart through interpolation in the pattern and thus this position-fix is completed without extensive computations. Examples are the "decca" and "loran" patterns, plotted on a great number of navigation charts throughout the world.

3.1 Methods of electronic positioning measurements and type of patterns.

The shape of the lines of positioning (and therefore the pattern) is different for the various types of measurements. When measuring differences in distance the lines of positioning, or the patterns are generally hyperboles with foci at the locations on the fixed stations; measurements of distances give lines of positioning formed by concentric circles around the locations of the fixed stations, and distance and bearing measurements are expressed in straight lines through the location of the fixed station and circular lines of positioning around the fixed station.
Depending on the system chosen, the following methods of electronic positioning are nowadays used for dredging and survey operations.

a) Hyperbolic method

The difference in distance (or phase) between the vessel (mobile station with unknown position) and each of two shore stations with known co-ordinates is measured.
The method requires a minimum of three transmitting stations onshore, and a receiver onboard of the mobile station (ship) e.g. Loran C, Pulse/8, Decca Main Chain, Hi-Fix, Hyper-Fix.
A position-fix is obtained by intersection of two hyperbolic lines of positioning.

b) Circular method

Also named range-range ($\rho\ \rho$) method. The distance is measured between the vessel (unknown position) and each of two fixed points onshore at known positions (e.g. Motorola, Syledis, Trisponder, Micro-Fix)
Systems based upon the circular method, require one transmitter/receiver combination installed at each of the two fixed stations onshore as well as a transmitter/receiver combination on the vessel.
A position fix is obtained by intersection of two circular lines of positioning each with the location of its fixed stations as centre.

c) Polar method

Also named range bearing (ρ θ) method.
The distance between the vessel (unknown position) and one fixed station with known co-ordinates, as well as the angle between the vessel, the fixed station, and a reference direction is measured (e.g. Artemis)

3.2 Positioning fixing by using satellites.

Since 1964, the Navy of the United States, have launched five satellites for navigational positioning purposes of the navy's vessels.
These satellites have a polar orbit at a height of about 100 km above the earth and an orbit time of 110 minutes.
In 1967 this satellite system (Navy Navigation Satellite System or TRANSIT system) became available for commercial use, and several manufacturers developed satellite receivers.
Each satellite transmits every two minutes signals towards the earth (150 MHz and 400 MHz)together with information concerning the position of the satellite ("navigation message").
From landbased stations(tracking stations) in the United States and Hawai the position of the satellites is measured continiously. These information is send to the Headquarter in the United States, where a new position for the satellites is calculated and a new navigation message is prepared.
Via an injection station this new information is transmitted to the satellites twice a day.
The position of a vessel can be determined by doppler measurements.
The doppler principle is based on the fact that a relative motion between the satellite and the receiver can be converted into a difference in distance.
By measuring the differences of distance several times during one arbit, the position of the vessel can be determined.
The accuracy of a certain position (fix) of the vessel by using the satellite positioning fixing system is ± 25 m. Due to the fact that the satellites are in a popular arbit it is not possible to get continuous positioning information.
Therefore it is necessary to measure the course and the speed of the vessel between two fixes to be able to calculate the position afterwards at certain time intervals (dead-reckoning).

3.3 Future.

Developments are being made by the U.S. Government of Defence to implement a world-wide satellite positioning fixing system, called G.P.S. (Global Positioning System).
When this system shall be commissioned, expected to take place in 1989, the disadvantages, presently incorporated in the use of the NNSS system, will be past time. The GPS system will consist of 18 satellites, which provides a continuous, accurate coverage worldwide.
At the moment 5 GPS satellites are already in orbit for test purposes.
It may be expected that in the coming years, integration between GPS and radio positioning systems shall intensify with an increasing emphasis on the input of GPS.
It is assumed that the accuracy obtained from these integrated systems shall be acceptable for the dredging and survey industry.

4. Depth measurements.

To be able to determine the morphology of the seabottom, depth measurements have to be executed.
In the past depth measurements were carried out by using a leadline; this is a rope with marked distances.
A lead weight was mounted at the bottom, to ensure that the line remained vertical and was not swept away by current.
The deadline was swung in a forward direction from the side of a moving vessel.
When the line was in a vertical position and the lead on the seabottom the length of line in the water was determined by observing the marks.
Position was obtained by using sextant to observe angles in the horizontal plane (snellius observations)and bearing observation to known locations ashore using the vessel's compass.
Failing that celestial observations were carried out.

Nowadays, depth measurements(sounding)are carried out by using echosounding devices.
With these devices the time is measured for a sound pulse to travel from the sound source (transmitter) to the seabed beneath the transmitter and back to a receiver.
In most of the echosounders the transmitter and the receiver are combined in one piece of equipment: the "transducer".
An echosounder comprises a pulsegenerator, a transducer, an amplifier and a recorder.
On the recorder the actual configuration of the seabottom will be drawn by a stylus(pen) which is revolving in a direction from the seasurface to the seabottom.
When a soundpulse is transmitted the pen will mark the recording paper, whilst a second mark will be drawn when the soundpulse is received.
This second mark will appear under the first mark; by a continuous transmission of soundpulses the seabottom will appear on the recording paper on a certain preselected scale and in relation to the first mark, which is normally the seasurface.
The depth measured by the echosounder can be expressed as:

$$D = \frac{v.t.}{2}$$

where :

D = measured depth

t = time between transmission and receiving of a soundpulse

v = velocity of sound in water ($\approx$ 1500 m/sec.)

whilst the depth presented on the recorder can be expressed as :

$$D_1 = \frac{v_1.t_1}{2}$$

where:

D_1 = recorded depth

v_1 = revolving speed of recorder pen

t_1 = time between first mark on the recorder and the second mark on the recorder.

D should be equal to D_1 which means that $\frac{v_1.t_1}{2} = \frac{v.t}{2}$ from which

follows $v_1 = v$.

This means that the revolving speed of the recorder pen(stylus)has to be adjustable, depending on the velocity of sound in water.
To be able to adjust the revolving speed of the recorder pen, the echosounder has to be calibrated for the soundvelocity.
This can be done by measuring the salinity and temperature of the seawater or by measuring the depth of a fixed plate which is lowered below the transducer at a known depth.
Another important item which should be taken into account when executing depth measurements is the vertical movement of the vessel (i.c. transducer), due to tidal movements of the seasurface and/or movements caused by the wind (i.c. heave).
The depth measurements are meaningless, unless they are referred to a certain reference level or datum. Therefore a reference level must be chosen and each sounding must be corrected for the height of the tide above or beneath the chosen level at the instant and position of measurement.
The sounding datum can be obtained by using tide gauges,which are placed in the centre of the area which has to be surveyed together with gauges placed along the coastline.

Considering a few technical aspects together with a number of operational conditions of echosounding, the following information can be given.

a. Frequency, transducer beam width and waterdepth.

The beam width of a transducer is strongly related to the size of the transducer element and the frequency used. For waterdepth up to 200 m. usually a frequency is chosen in the band of 20 to 80 KHz., while for shallow water a frequency is selected in the band of 100 to 250 KHz. The use of the latter frequencies allows for application of the so called "pencil beam" transducers i.e. a very sharp beam obtained by using a high frequency. The disadvantage is however that not only heave compensation is required but also that roll and pitch corrections have to be given.

b. Number of pulses, pulse length, transmitted power and speed of the vessel.

The number of transmitted sound pulses per second varies usually with the selected range while the pulse length in most cases can be chosen depending upon circumstances and operational requirements. In greater water depth more power has to be used to compensate for the losses caused by the water depth.

Furthermore the speed of the vessel has to be adjusted for the water depth, to allow for a sufficient number of recorded depths per unit of length.

c. Heave, roll and pitch corrections.

The development of heave compensation based on a accelerometer sensors have introduced the possibility to correct the heave of survey vessels. The results obtained in the past few years are very promising but further development and refinement is necessary.

Corrections for roll and pitch of a vessel are more difficult and may require gyro stabilized transducers or to tow the transducer behind the vessel in a "fish".

4.1 New developments.

In water depth of approx 200 m. or even less, it is practically impossible to obtain a true, accurate and detailed picture of the seabed with a transducer fitted in the bottom of the survey vessel.

For this reason techniques have been developed to lower the transducer in a "fish" near to the seabed in a similar way as with shallow seismic equipment and side scan sonars.

The disadvantage is however that the position of the "fish" containing the transducer has to be calculated accurately in relation to the position of the vessel. A further development is to install a number of transducers in one single fish to be able to sweep a wide channel.
Simular techniques have been used succesfully in surveys of rivers, channels etc., i.e. in shallow water areas with an array of transducers on each side of the vessel.
The channel profiling system is a slightly different concept of surveying rivers, channels, dredged areas, locks etc.
With this system the transducer is swept in a twartship's plane through a 180° sector. This system has been used succesfully in specific areas and has become more popular in the last few years. The recording section of the echosounder system has in the past years improved considerably, while output information is available in an analog and/or digital form for computer interfacing. Furthermore new techniques allows to select on the depth range any required section and enlarge this particular part to a realistic scale.

4.2 Shallow seismic equipment.

To obtain accurate information of the stratification of the subbottom layers, a suitable system for this purpose has to be selected:a sparker, pinger or boomer system. The choice will be dictated mainly by the water depth, required penetration, the expected composition of the subbottom layers and the required discrimination or resolution.
A careful selection has to be made of the frequency to use, the strength of the transmitted pulse power, the pulse length, the type of transducer etc.
In many survey projects simultaneous operations with shallow seismic, side scan sonar and magnetometer take place. For correlation purposes a sufficient number of core borings have to be taken to be able to judge and interpret the results.
It will then be possible to pinpoint boulders, bedrock outcrops , wrecks and the dredgebility of the seabed.
Pipe line surveys are becoming more and more a necessity as the governments dealing with the respective continental shelfs are very conscious of possible dangers of the pipelines in or on the seabed.
The inspection of these pipelines is a tedious, time consuming and therefore costly operation with usually shallow seismic equipment, side scan sonar and magnetometer equipment involved. Investigations are being carried out to improve on the speed and results of these operations by trying to follow a pipeline automatically in longitudional direction instead of crossing the pipe at regular intervals.

If such a system can be developed satisfactorily it will mean an enormous time saving, allowing the responsible authorities to consider to increase the frequency of these operations.

4.3 Sonar systems.

Sonar systems, i.e. side scan and/or sectors scan sonars, are invaluable tools for mapping the topography of the seabed. With coverage of hundreds of meters on both sides of a moving ship, towing the fish, in which these sonars transducers are mounted, it provides an excellent means to rapidly survey a project area.

4.4 Magnetometer.

To locate the presence of ferreous objects on the sea floor the magnetometer is an extremely useful intrument for surveying purposes.
All ferreous objects (including ferreous minerals) distort the earth magnetic field. Measurements of the distortion can be used to determine the size and depths of the anomalies. Practical experience and know how to interpret the results is absolutely essential with these very sensitive instruments.

4.5 Oceanographic and meterological information.

Dredging and survey work is essentially a marine operation and information on oceanographic and meteorological conditions is therefore needed. These include an assessment of:

1. tides and tidal fluctuations
2, velocity and direction of currents
3. height, length and direction of waves
4. velocity and direction of winds
5. fog, mist, ice and temperature

Where work is carried in sheltered locations such full information is not always so important but for work offshore, such as that for a pipeline trenching projects, the available working time and thus the cost for dredging plant is dependent on such factoes. Probably the most important single influence on a dredging project is the existance and influence of swell. The relation between soil type, plant specifications and well is also very interesting and valid. For example, it is normally possible to dredge in soft soils with greater swells than in rock. For this reason research work of a practical nature is needed.

5. Data acquisition, processing and presentation systems.

Data acquisition, processing and presentation systems are used nowadays during survey operations to collect the maximum available data in the field and to process and present this data in the minimal possible time, and of the required format (sounding charts, cross-sections, colour displays, etc.).

To be able to do so, computers have to be utulized for computations equations, summaries and the storage of data on an information carrier.

Generally the above mentioned tasks of the computer are extended by additional routines and all tasks and routines require the appropriate software.

In principle the data acquisition, processing and presentation systems can be divided in three categories:

- Preparation and preplotting
- On line data collecting
- Off line postprocessing
- Presentation of the processed data

5.1 Preparation and preplotting

Prior to each survey, decisions have to be made how the survey will be carried out: which area, line spacing, direction of lines etc.

Preplot charts have to be made which contain the pattern of the positioning fixing system to be used, with geophysical co-ordinates, etc.

The lines to be sail can be drawn on to that chart and annotated giving also start and end of line. All information is stored on tape or disk, depending on the type of system used.

Basic data, such as co-ordinates of shore stations, frequencies used, etc. is also stored to be recalled during the on-line data collecting phase.

5.2 On line data collecting

Having arrived at the area of survey and after having checked that all peripheral equipment is in proper working order (a check which is carried out by the central processing computer using the appropriate software) the survey can commence.

The principle of each data collecting system is to collect position data and relating depth information to be able to draw a vertical profile which is identical to that shown on the echosounder recording.

To acquire this, the raw echosounder data, collected by the system, has to be filtered and drastically reduced in numbers, yet the vital data has to be preserved and stored.

The preplotted and prepared data is being recalled and under operator control displayed on a plotter and/or on one or more visual display units (VDU).

It is for instance possible to give the helmsman continious navigation information by displaying the line to sail and vessel's current position together with offtrack information and distance to go, where simultaneously the operator changes the parameters of the survey on his own terminal with VDU and yet not interrupting the continuous data collection.
These simultaneous routines are done in time sharing.

The operator can select "windows" for positioning system and depth information. These "windows" can be stationary of running. If a value which is entered in the system falls beyond the window, the information is discarded.
This routine prevents the system from storing erroneous data and therefore improves and simplifies the postprocessing.
The vessel's track is plotted on-line on a plotter which also shows the line which has to be sailed.
This enables the surveyor to ascertain right away if the track sailed is correct or the offtrack has been unacceptable.

5.3 Post-processing

After the survey has been completed the data collected shall be postprocessed. The first step in the postprocessing is to check and, when necessary, to edit the raw data.
Echosounder calibration corrections, positioning system monitor corrections can be added and the tidal reduction correction is applied.
All data points can be deleted, mofified or added.
After satisfaction that the data is now correct, the final drawing and plotting will commence.
The plotting of sounding charts can be done both on board the vessel or ashore in principle the same equipment as used for the online data collecting phase and shall consist of a great number of depth figures, so called fair charts.
No fair chart is complete unless being provided with contourlines (lines of equal depth).
This has been a manual task until recently advanced software has taken over this arduous and time consuming activity in this field as well.

5.4 Presentation of the processed data.

For dredging purposes the processed survey data is normally presented as a sounding chart, on which the depth figures, related to a reference level, are drawn in relation to a certian coordinate system.
This sounding chart is used by the project manager to check the progress of the dredging work and to draw up the programme for the coming period as well as by the helsman for navigation purposes of the dredger.
In this last case the information from the sounding chart has to be converted into another presentation (contourcharts) and has to be compared with previous sounding charts.

The dredging operations cause changes in the seabed configuration, which means that the sounding chart is becoming more and more outdated, the more the work is in progress. Therefore survey information has to be updated regularly and processed in a timely way.
It is common to devide the individual surveys which have to be executed for dredging purposes into three hinds of surveys:

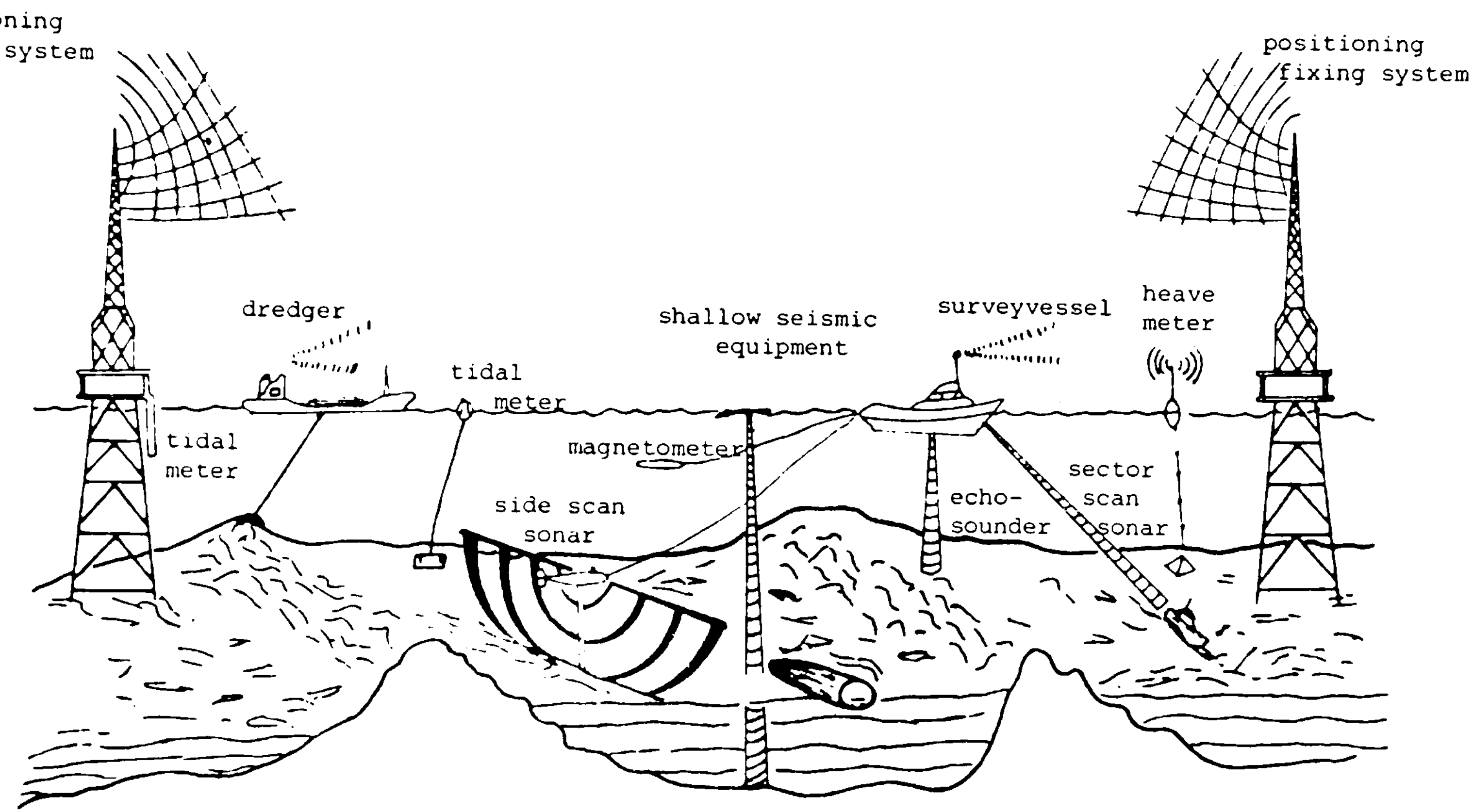
- pre-dredge surveys
- progress surveys
- post-dredge surveys.

Due to the necessity to execute progress surveys at regular intervals on one hand and the possibilities of modern electronics and software on the other hand it is nowadays possible to visualise processed data on video displays units.

6. Conclusions.

The dynamic development of the electronic industry in the past 10-15 years has caused an enormous increase in the application of electronic products and systems for survey and dredging operations.
These developments are a spin-off of the extensive research and development programmes of the space technology organisations. It can be expected that these increase will continue the coming decade and will have a certain influence on the automation of processes during survey and dredging operations, the equipment and systems which will be employed as well as the data processing systems.
We can think of the use of satellites for positioning applications, integrated system for the measuring of the depth simultaneously over large areas, the use of video display units for navigation purposes, the application of integrated dynamic positioning systems, etc.
To operate and maintain the equipment and systems, it will be necessary to train operators, surveyors and engineers adequatly to enable them to perform their tasks in an efficient manner. Furthermore it will be necessary to introduce new disciplines in the execution of survey and dredging operations like computer specialist, programmers.
Apart from these future trends it will be obvious, to be able to execute efficient dredging operations it is inevitable to have the support from the survey operations.

ARTIST IMPRESSION OF SURVEY OPERATIONS.



APPENDIX II

SURVEY OPERATIONS FOR THE SUPPORT OF DREDGING ACTIVITIES.

(THE DIFFERENT ASPECTS)

PREPARATIONS

- Execution of a landsurvey (determination of coordinates for shore based beacons and the presentation of a topographical map)
- selection of equipment
- testing and calibration of equipment
- selection of surveyvessel
- preparation of lattice charts
- processing facilities and possibilities
- methods of surveying
- selection of surveypersonnel
  - surveyors
  - electronic engineers
  - software specialists
- consumables
- spare units / spareparts
- organisation:
  - execution
  - processing
  - maintenance

GATHERING OF DATA
(execution of soundings)

By using:

- Basic equipment
  - positioning fixing system
  - depth sounder
  - tidal meters
  - logging/processing/presentation equipment
- Additional equipment
  - side scan sonar
  - shallow seismic
  - current meter
  - coring equipment
  - magnetometer
  - etc.

RECORDING OF DATA
($x, y, z, t, \Delta z$)

- on the echograms
- on sheets
- on magtapes
- on floppy discs
- on hard discs
- on punchtape.

PROCESSING OF DATA
(on-line and/or off-line)

- manual
- semi-automatic
- automatic

Results :

- sounding charts
- contour charts
- cross-sections
- difference-charts
- spot-charts
- video/monitor-charts

INTERPRETATION

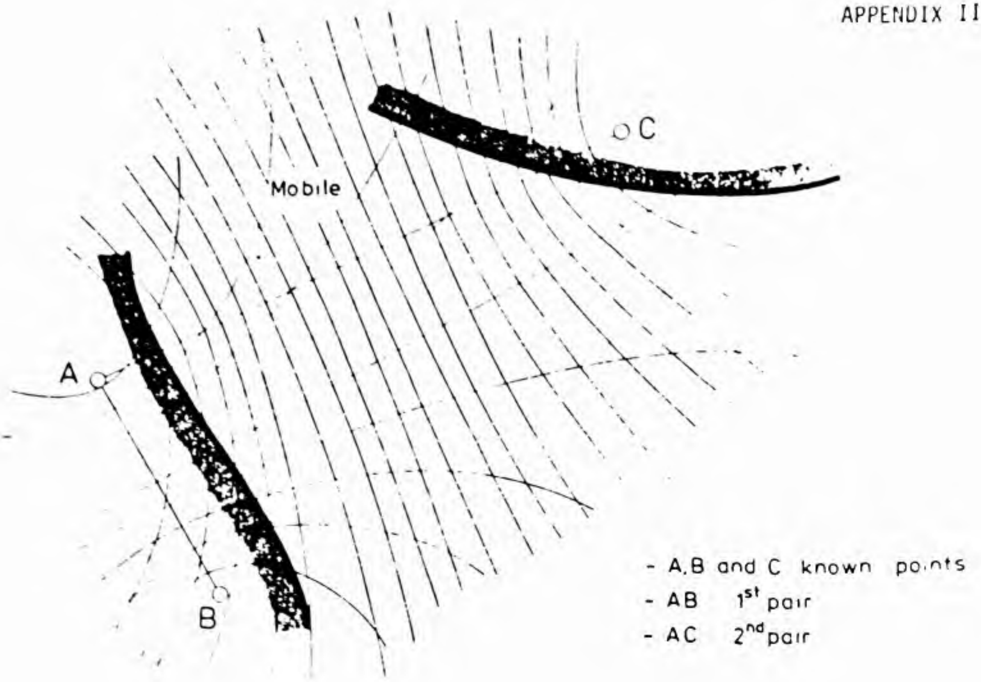
Areas that still have to be dredged →

EVALUATION OF PROCESSED DATA

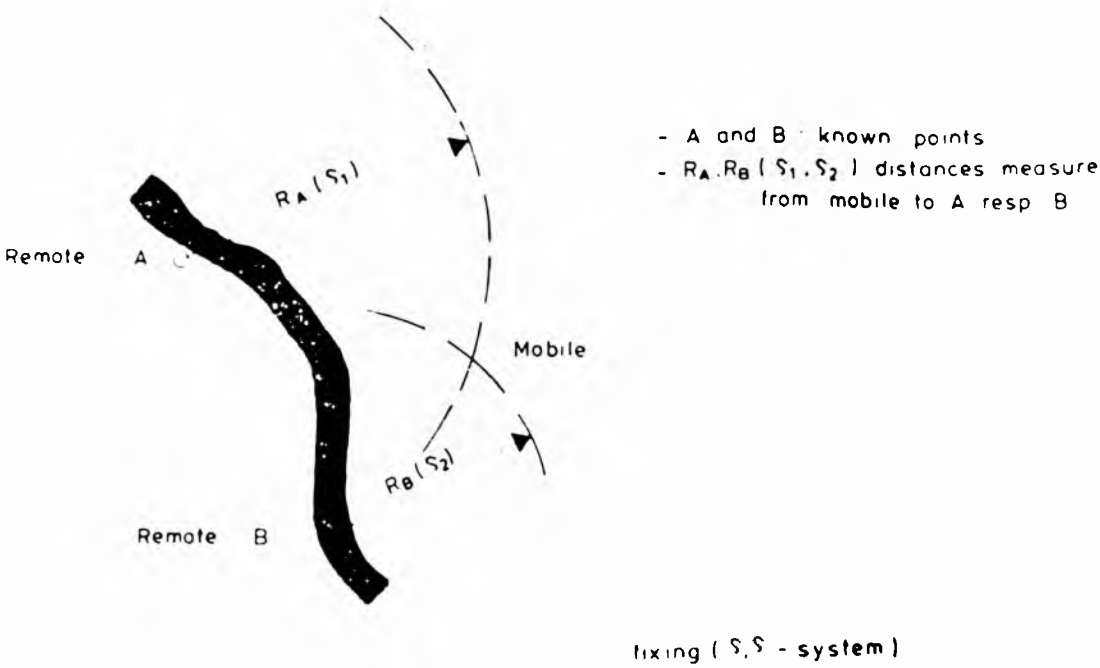
- Quantity calculations
- Sedimentation
- Movement of the Seabed
- Transfer of data to a (track) plotter or video/monitor for navigation purposes of the dredger.

Ir. H.R. van der Wal.

APPENDIX III

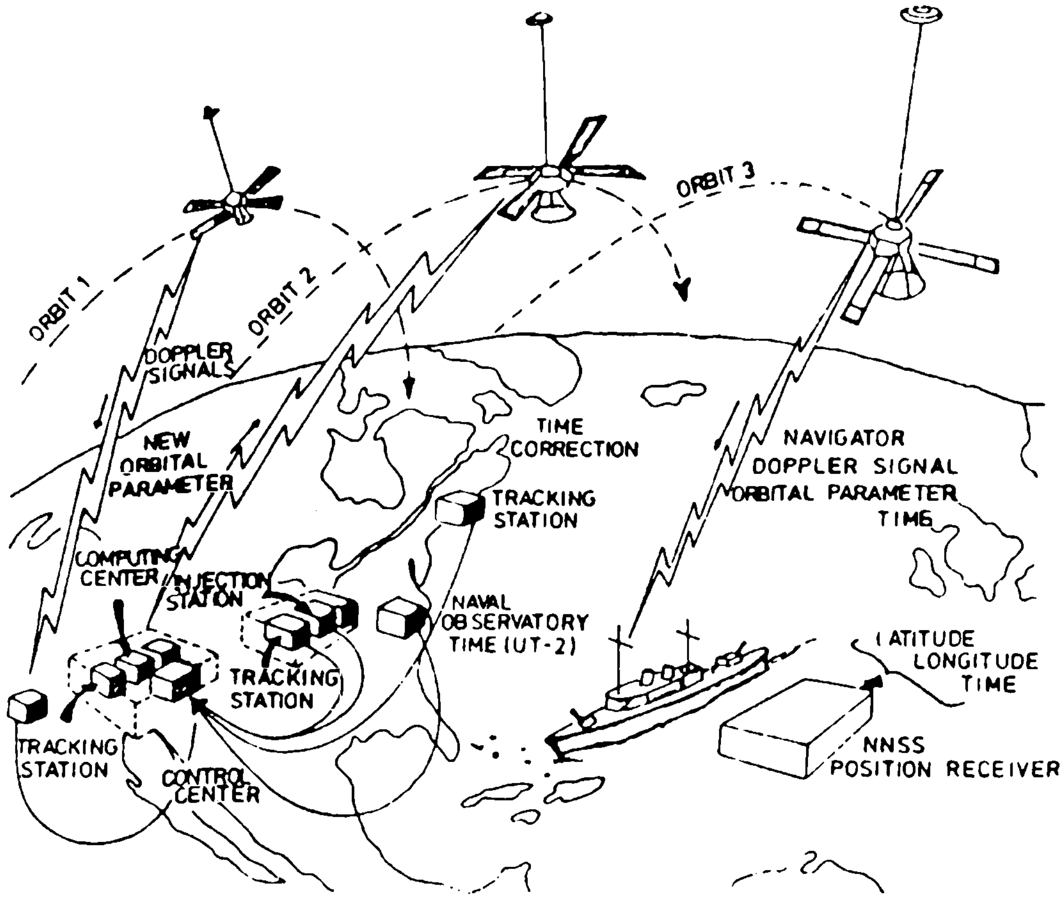


HYPERBOLIC METHOD OF POSITION FIXING

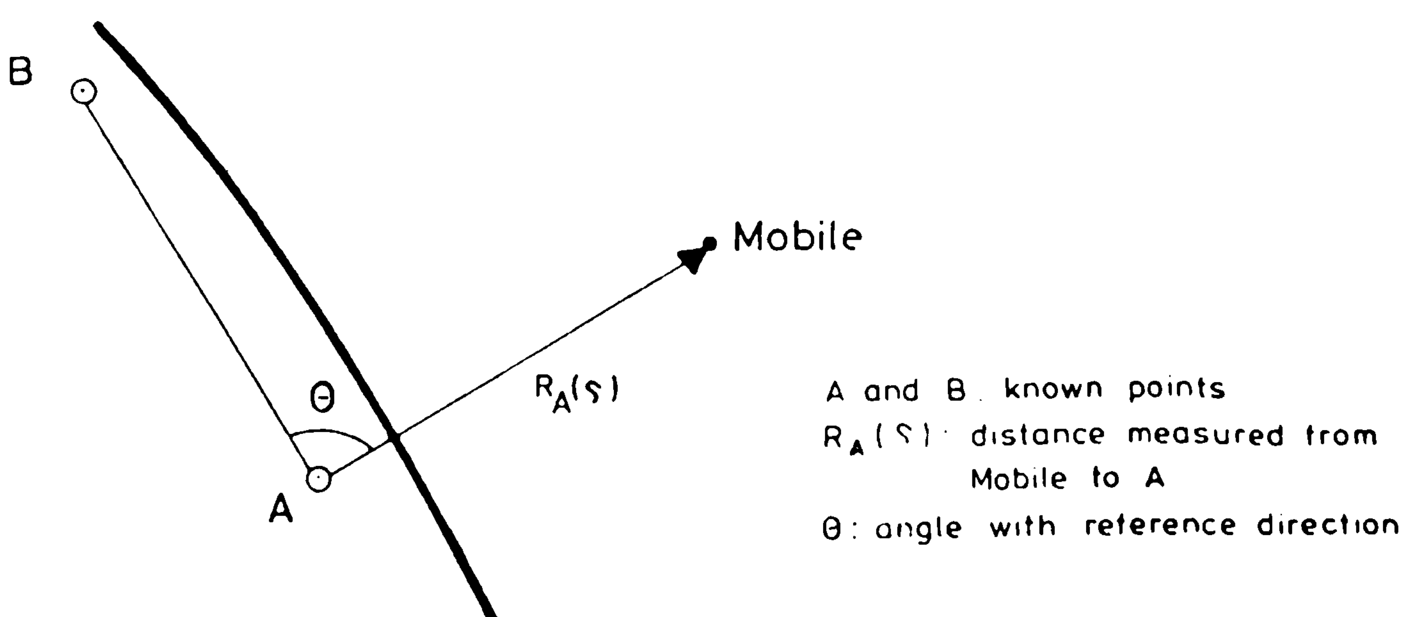


CIRCULAR METHOD OF POSITION FIXING

APPENDIX IV



NNSS-SYSTEM

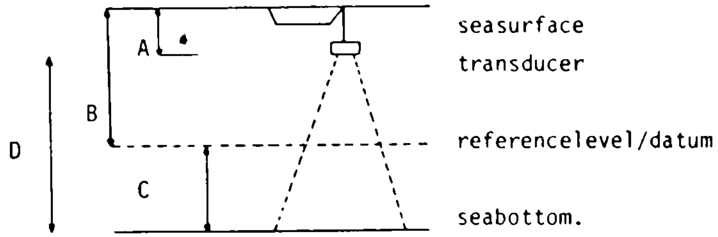


POLAR METHOD
OF POSITIONING FIXING

(ς, Θ system)

APPENDIX V

PRINCIPLE OF DEPTHMEASUREMENTS.



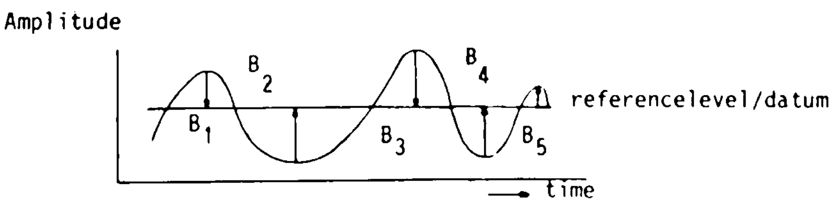
C = D + A - B

C = Depth which has to be presented on the charts.

D = Measured depth (sounding)

B = Tidal correction (depending on time of depthmeasurement)

A = Depth of transducer

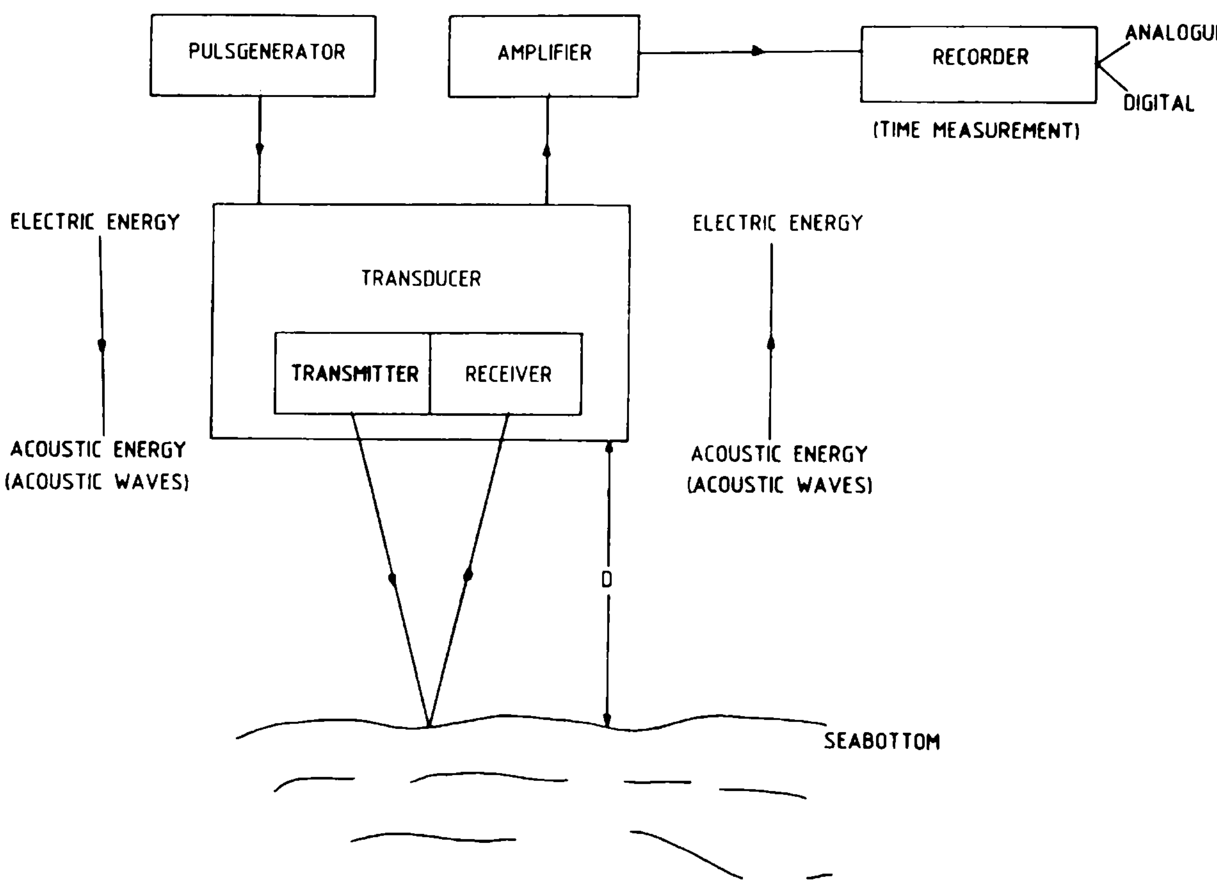


$B_{1,2,3 \ldots, N}$: Tidal corrections

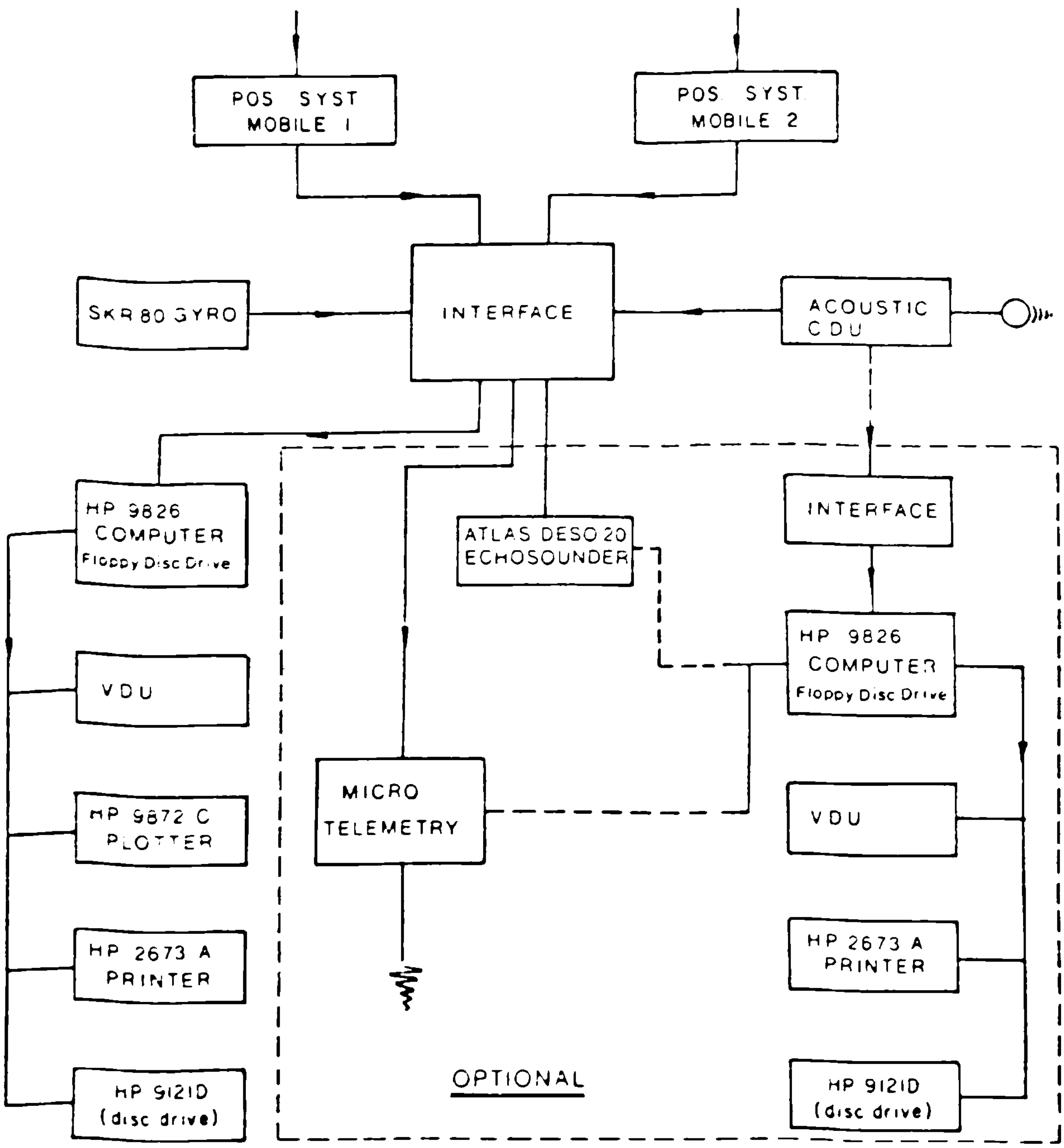
H. van der Wal.

APPENDIX VI

PRINCIPLE OF ECHOSOUNDER



APPENDIX VII

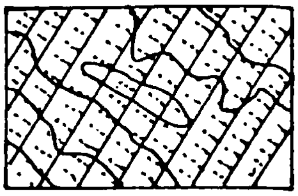


TODAYS INTEGRATED ON-LINE SURVEY SYSTEM, INCL ACOUSTICS

APPENDIX VIII

Possible results of dataprocessing.

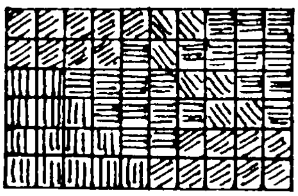
A: Sounding - charts



...: Depth - figures
: Contour lines

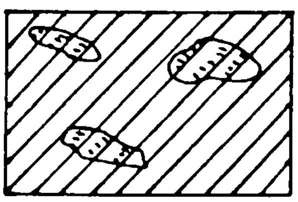
transformation and rotation to a rectangular grid

B: Difference - charts



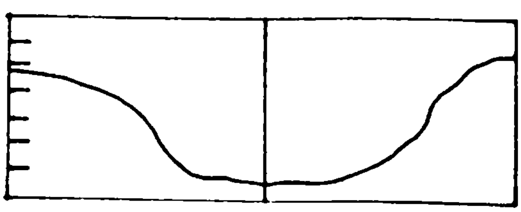
: Shallow
: Too deep
: Same depth
: More than ..... dm shallower

C: Depth figures above the designed depth



: Depth - figures
: Contour lines

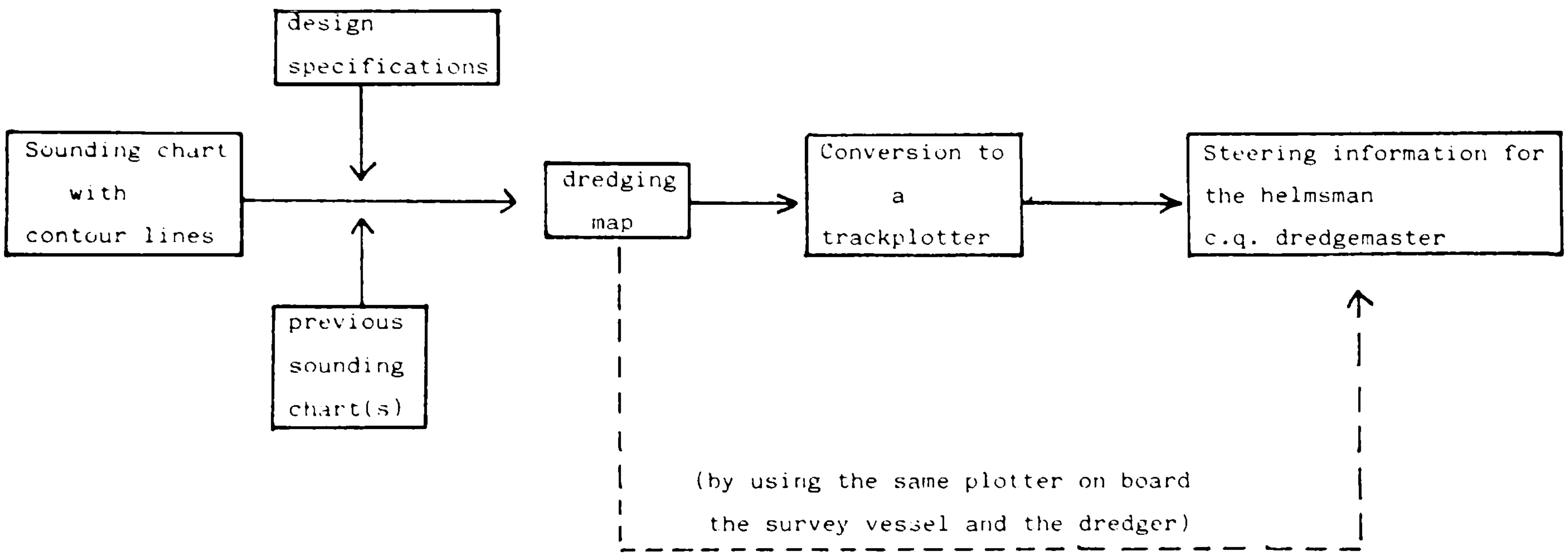
D: Cross - sections



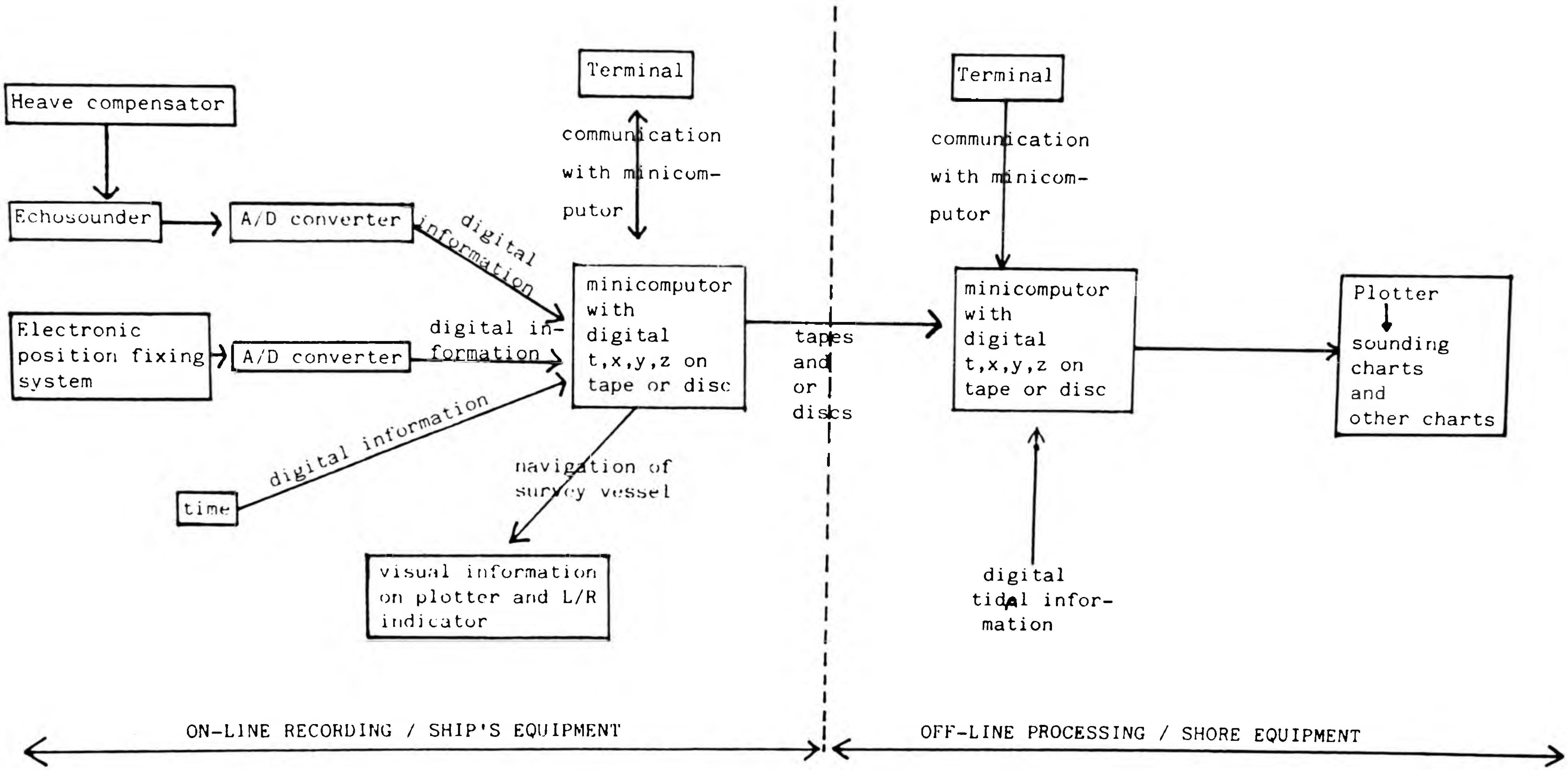
linenumber
distance out of central axis
depth information

Transfer of survey data into navigation data for the dredger.

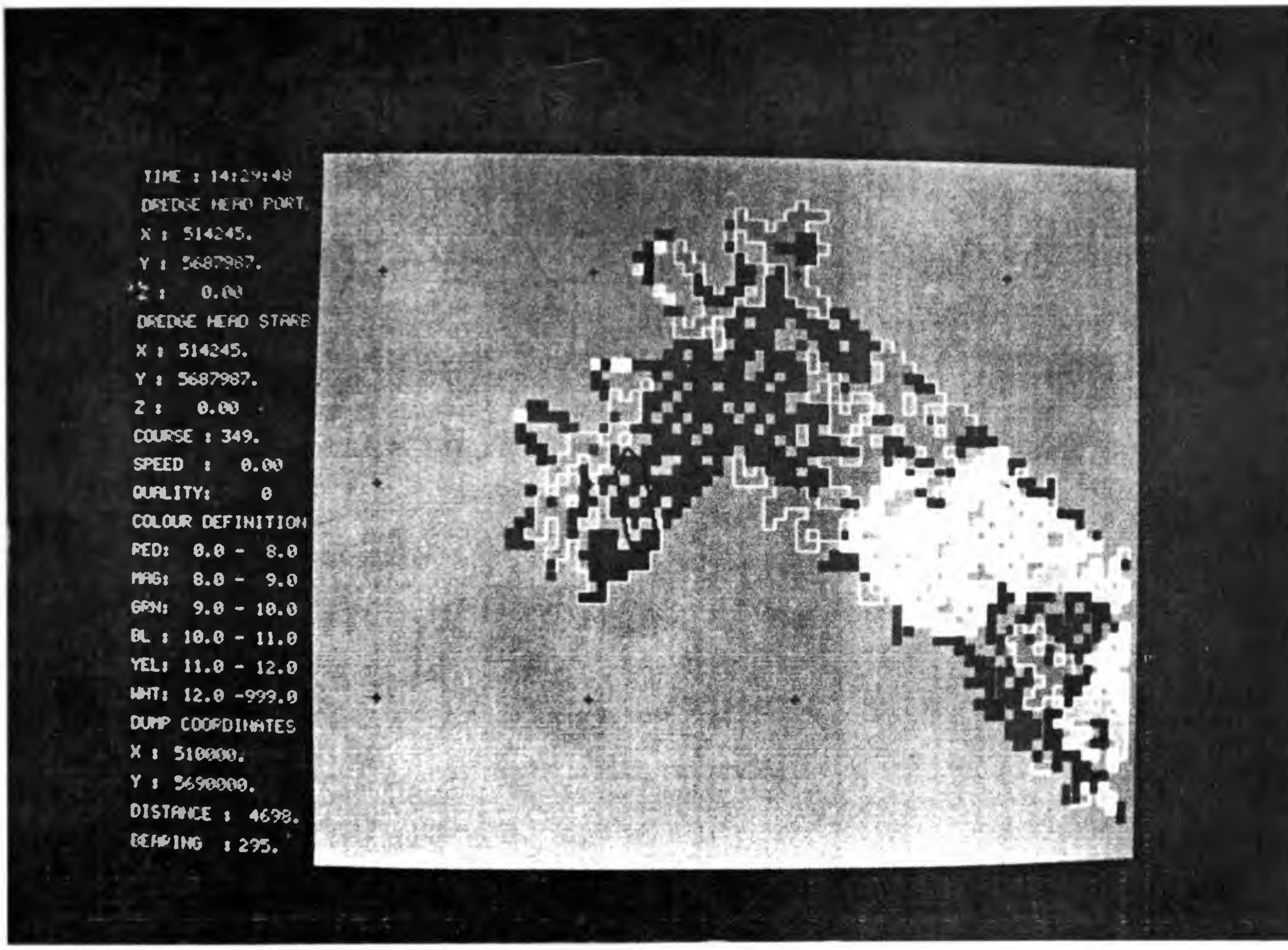
(simplified system)



RECORDING AND PROCESSING OF SURVEY DATA.



APPENDIX XI



<u>NESA's D.S.C. - system</u>
(Dredge and Survey Control system).

Photograph of video colour monitor, which shows the actual position of the dredger in relation to the dredging area. The various colours represent different depths, this being the result of extensive processing of survey data.

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2.2. Site investigations

Summary

All the investigations and measurements in the field which are carried out by the Delft Soil Mechanics Laboratory are reviewed as fully as possible. These comprise the whole range of methods extending from the determination of soil profiles (boreholes) to in-situ measurements of soil parameters and the execution of large-scale tests (see Contents).

0. INTRODUCTION

(Dr. Ir. H. K. S. Ph. Begemann)

There now exists a great variety of investigation methods and measurements which can be applied in the field — much greater than many engineers realize. A great deal has happened in this sphere of activities in recent years; not only have there been many improvements, but also new methods of determination and techniques have been added to existing ones.
For this reason it is indeed appropriate to present a complete review of all the investigation methods and measuring techniques currently applied by the Delft Soil Mechanics Laboratory. In this account it will be endeavoured as far as possible to indicate the object of the test or measurement described, the manner of execution, the accuracy and the possibilities of interpretation of the results obtained.

Site investigations can broadly be classified into three categories:

- **Determining the strata of which the soil is composed,**
  i.e., the nature and thickness of the various layers of soil.
  This can be done:
  (a) *directly*, by carrying out exploratory borings from which soil samples (or soil particles) are obtained in some way or other; the extraction of 'undisturbed' soil samples can also be listed under this heading;
  (b) *indirectly*, by measuring particular soil properties which are characteristic of the various types of soil, e.g., electrical conductivity (geo-electric exploration)
- **In-situ measurements:**
  (a) The measurement of particular mechanical properties of the various strata in situ. Obviously, if such measurements are performed at close intervals on one and the same vertical line, it will often also be possible to obtain information on the nature of the strata.
  (b) The determination of pore water pressures in the various strata
- **Special measurements:**
  These comprise deformation measurements in the field, the measurement of earth pressures, loading tests, checks performed during construction of buildings and civil engineering works, etc.

CONTENTS

Preface

0. Introduction

1. Determining the strata of which the soil is composed
   1.1 Soil samples
   1.2 Procedures for obtaining undisturbed samples
   1.3 Boring
      a. Wash borings
      b. Shell and auger borings
      c. Bailer borings with continuous sampling
      d. 1 inch Piston sampler boring
      e. Vibratory borings
      f. 29 mm diameter continuous borings
      g. 66 mm diameter continuous borings
      h. Core borings
         Additional remarks
   1.4 Indirect determination of the soil strata
      1.4.1 Ratio between cone penetration resistance and local friction
      1.4.2 Geo-electrical resistivity measurement
      1.4.3 Further geophysical exploration

2. In-situ measurements
   2.1 Measuring specific soil mechanical properties of the various strata in situ
      2.1.1 Cone Penetration Test (CPT)
         2.1.1.1 Object
         2.1.1.2 Procedure
         2.1.1.3 Cone penetration tests from the surface of water
         2.1.1.4 Possibilities for interpretation
         2.1.1.5 General remarks
      2.1.2 Density measurements in situ
         2.1.2.1 Electrical density measurement
         2.1.2.2 Density measurements with the aid of nuclear radiation
      2.1.3 Permeability measurements in situ
      2.1.4 Vane test
      2.1.5 Standard Penetration Test (SPT)
      2.1.6 Pressuremeter test
      2.1.7 Camkometer test
      2.1.8 In-situ California Bearing Ratio (CBR) test
      2.1.9 Plate bearing test
   2.2 Determining the ground-water pressures in the various strata
      2.2.1 Standpipes
      2.2.2 Bourdon water pressure gauges
      2.2.3 TPD water pressure gauges
      2.2.4 Pneumatic water pressure gauges
      2.2.5 Dynamic water pressure gauges

1. DETERMINING THE STRATA OF WHICH THE SOIL IS COMPOSED

(Dr. Ir. H. K. S. Ph. Begemann)

1.1 Soil samples

Before reviewing the *boring or drilling methods* in current use, it is desirable first to describe in some detail the procedures for obtaining soil samples.
The concepts of *disturbed* and *undisturbed* samples give rise to some confusion. Depending on the *purpose* for which the samples are to be taken and on the *local stratification*, the requirements applicable to the sample and to the method of obtaining it will vary.

Let us start with a very simple example: the upper surface of a solid bedrock formation has to be explored through an overlying homogeneous layer of sand. In this case it is not really necessary to take samples at all; it would, for example, suffice to insert a pipe provided with a water jetting nozzle into the sand and push it in until it encounters the rock. Under the circumstances this rapid method is sufficiently accurate.
However, if the underlying stratum is not rock, but clay, then the interface of this material with the sand cannot be so accurately determined by this jetting method. It will then, inter alia, be necessary to observe the change in colour of the water flowing back to the surface and to examine the soil particles carried along in it (obviously, the depth to which the jetting nozzle penetrates also affects the accuracy of the result). Whether this method can then be regarded as sufficiently accurate will depend on the nature of the problem to be investigated.

In a case where several strata of appreciable thickness are concerned it will soon be found necessary to obtain representative samples from various depths within the soil. This can be done in a variety of ways, including the use of a bailer (shell) or an auger. Samples obtained in this way must be classed as disturbed samples. The bailer, in particular, yields the most disturbed (and washed-out) sample. If it is desired, in view of the problems to be solved, to obtain accurate information on the strata, the first and foremost requirement would be that *the positions of the soil particles in relation to one another must remain unchanged*, certainly in a case where the subsoil is likely to show considerable variations ('streaky bacon formation'). For this purpose it is at least necessary to take core-type samples which, although they may be somewhat deformed, retain the soil particles in their correct relative positions.
It is proposed that such samples be referred to as 'unmixed' samples. The quality (degree of non-disturbance) and the number of samples will determine the quality and thus the informative value of the borehole exploration.
The requirements to be fulfilled by samples will have to be even more stringent in cases where *undisturbed samples for testing in the laboratory* have to be obtained, e.g. for the determination of compressibility coefficients, internal friction angles, etc. Not only must the relative positions of the soil particles remain unchanged, but their distances from one another must also undergo practically no change either. To fulfil this latter requirement implies that the original state of stress in the soil must in fact be preserved. Although it will probably never be possible completely to comply with this requirement, it should nevertheless always be endeavoured to keep the changes in stress as small as possible, which is a problem that is simpler to solve for cohesive soils than for non-cohesive ones (sand).

1.2 Procedures for obtaining undisturbed samples

To obtain undisturbed soil samples for testing in the laboratory is an extremely difficult problem which for long failed to receive sufficient attention. Appropriate efforts were, however, made for improving the sampling equipment enabling samples to be taken directly below the bottom of a borehole. The various types of

sampling device will not be discussed here, but it is certainly relevant to point out quite clearly that for obtaining undisturbed samples from the bottom of a hole a good sampler is *merely the first step.* The second and at least equally important step is to apply a drilling or boring technique which will ensure that the soil a short distance below the bottom of the hole can still be regarded as undisturbed. And it is this latter aspect that generally, also in the Netherlands, receives far too little attention. A common fault is that the water in the borehole is often not kept up to the proper level, as a lower level makes for easier and quicker working. The water level should in fact be so high that the pore water pressure in the soil around the bottom of the hole is compensated by it. Lower water levels in the hole will give rise to upward flow of water in that soil, resulting in considerable changes in stress, deformation and possibly even introduce boiling (inflow of water and soil particles). A sample extracted from such soil can certainly not be regarded as undisturbed, and even the most expensive sampling equipment can do nothing to improve this. The techniques used for forming the borehole may have a markedly disturbing effect on the soil below the bottom of the hole. This will be further discussed in connection with the description of the various drilling or boring methods. It should, however, already here be pointed out that the procedure of extracting a complete series of soil samples directly one below the other in samplers will not yield a single undisturbed sample (e.g., in an Ackermann boring).
When a sampler is forced into a saturated cohesive soil (clay) and then withdrawn, a vacuum is formed under the sampler on withdrawal and may cause serious deformation of the underlying soil, which, if it happens to be soft clay, may even be sucked up with the sampler. This last-mentioned effect is bound to occur when sampling is performed in sand below the ground-water level.
This means that, after a sample has been taken, the next one will have to be taken at least about 0.60 m deeper down – at any rate, if an *undisturbed* sample is desired. The intervening soil must be carefully removed with the aid of a shell or bailer (not by core extraction). Obviously, the quality of the samples depends on so many human and local factors that only well-trained and experienced drilling crews, working under strict supervision, can ensure that undisturbed samples of 'good quality' will indeed be obtained.

In recent years the Delft Soil Mechanics Laboratory has devised a new system in which many of the above-mentioned human factors are eliminated, so that *a substantially higher degree of certainty as to the good quality of the sample* is achieved at *no extra cost.*
To this end, a system was sought which would, in a single operation, enable one continuous cylinder of soil – extending from the surface of the ground down to the requisite depth of exploration – to be separated from its immediate surroundings, i.e., the aim was to develop a soil sampling apparatus which would extract not just one sample a few decimetres in length, but a sample with a length of, say, 20 m This is possible only if the sampling tool or, rather, the sampling tube does not exert any frictional forces upon the sample of soil contained in the tube.
If friction does occur, the sampled soil may form a plug in the first 0.5 – 2 m of the tube, so that continuation of that sampling operation fails and the short sample that has entered the tube can now not be regarded as undisturbed. In the new system this problem has been solved by enveloping the sample, immediately on entering the tube, with a thin waterproof nylon stocking and also by keeping the very narrow gap (0.3 mm) between this nylon stocking and the surrounding plastic inner tube continuously filled with a 'lubricating fluid' The latter is fed to the sample cutting shoe through the space between the plastic inner tube and the steel outer tube and is constantly topped up from above. After each extension of the sampling tube by the addition of a 1 m length of steel tubing, the tube is forced further into the ground by means of the 100-kN or 170-kN cone penetration apparatus. In this way it is possible to obtain an undisturbed sample (of 66 mm diameter) in one continuous length of 19 m. On extraction from the ground, the sample is cut up into lengths of 1 m which are sealed in the corresponding portions of

the plastic inner tube to prevent drying out and are thus transported to the laboratory. The transport of the samples, especially sand samples, likewise receives careful attention. With the aid of the above-mentioned continuous sampling apparatus (referred to as the 66 mm Begemann boring system) it is possible to obtain undisturbed samples of very high quality. In addition, a complete and wholly undisturbed soil profile is obtained.

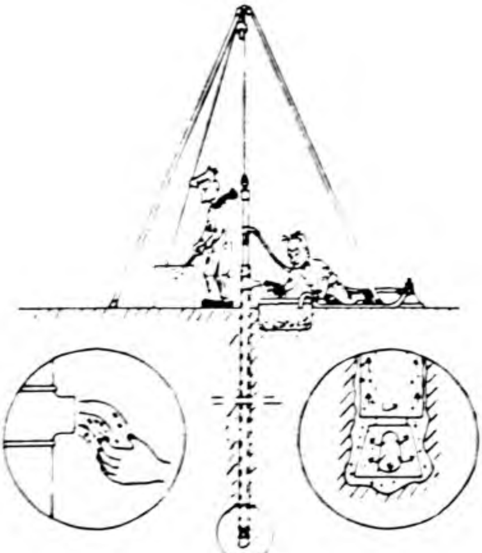
1.3 Boring

The boring methods most commonly used in the Netherlands are:

a. wash borings
b. shell and auger borings
c. bailer borings with continuous sampling (e.g. Ackermann boring)
d. 1 inch piston sampler borings
e. vibratory borings
f. 29 mm diameter continuous borings (Begemann boring)
g. 66 mm diameter continuous borings (Begemann boring)
h. core borings

It is not intended to give detailed descriptions of the methods enumerated here, but merely to indicate the principle on which each of them is based, the advantages and disadvantages, the sort of information that can be obtained and especially the quality of such information.

Re a. Wash borings



Wash boring

System:
The borehole is formed by means of a jetting nozzle (with or without a chisel or chopping bit under it) which is suspended from a trippod rig and performs up-and-down movements. It thus penetrates deeper and deeper into the ground.

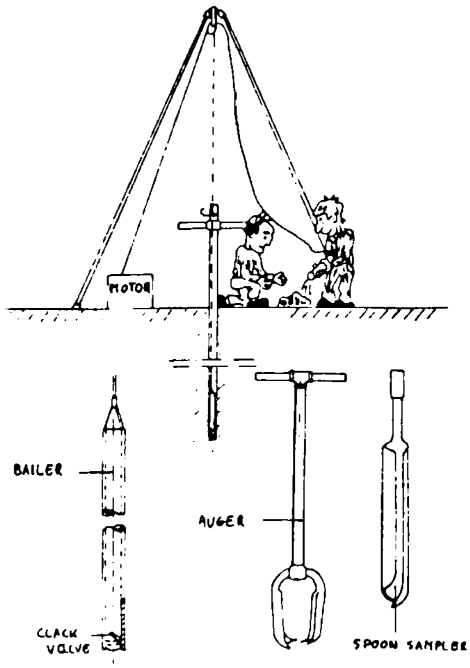
Determination of the strata:
This is endeavoured by examining the wash water that returns to the surface, more particularly with regard to its coulour and the soil particles it contains.

Accuracy:
Strata boundaries cannot, or can only roughly, be ascertained: the boring nozzle will already have entered the next stratum before this becomes clearly apparent from the condition of the return water. Complete segregation takes place: the fine particles rise more rapidly to the surface, the coarse ones come later. Wash boring is entirely unsuitable for the exploration of soils containing numerous thin strata.

'Undisturbed' samples cut in the borehole:
Since it is hardly possible to determine the depth to which the jetting action has disturbed the soil below the bottom of the hole, this method must in general be considered highly undesirable as a means of obtaining undisturbed soil samples.

Application:
It is seldom used for soil exploration in the Netherlands.

Re b. Shell and auger borings



Shell and auger boring.

System:
In this system the borehole is usually formed by means of a casing (boring tube) in which the soil is removed by means of a shell or bailer. The shell consists of a 1—1.5 m long tube which is suspended from a wire rope and is provided with a cutting edge at the bottom. A horizontally hinged clack valve is mounted a short distance above the cutting edge. The shell is alternately raised and allowed to fall, so that the soil at the bottom of the hole is loosened and churned up with the water in the hole to form a fluid mass which makes its way into the shell. When the latter is hauled up, the valve stops this fluid mass from flowing out.

Determination of the character of the strata:
This is based on the mixture found to be present in the shell.

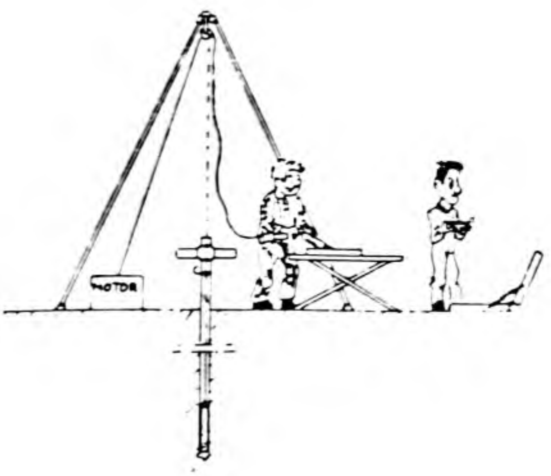
Accuracy:
It is obvious that loosening the soil in the manner described can be greatly promoted (and the rate of progress of boring thus greatly increased) by the creation of a powerful upward flow of ground-water within the soil mass yet to be penetrated by the shell. As already stated, this can be achieved quite simply by keeping the water level in the casing lower than the ground-water around the bottom of the borehole, so that relatively impermeable layers of soil are ruptured by the upward water pressure and „boils" may even develop. These phenomena can be intensified by applying excessively high speeds in raising the shell and/or by using a shell of too large a diameter in relation to the casing.
Under these circumstances the accuracy of identification of the various types of soil and the location of strata boundaries will depend to a great extent on the skill and reliability of the crew entrusted with the boring operations.
The following comments are applicable to *well executed* shell borings:
The soil samples extracted from the borehole are so mixed and intermixed that *nothing* can be said *concerning the structure* of the soil. Thin strata are not recognized as such, and in soils containing a sequence of numerous thin strata it is only possible to obtain an average picture. Thus, a description such as 'sand with a few fragments of clay' will usually have to be interpreted as 'sand with thin clay layers'. On the other hand, in a thick homogeneous stratum the identification of the soil it contains can, except near the top and bottom of the stratum, be taken as reliable.

Samples cut in the borehole:
The quality of an undisturbed soil sample will depend to a great extent on the quality of the boring crew and on the character and stratification of the soil. Provided that the boring operation is correctly performed, reasonably undisturbed core-type samples are obtainable in fairly stiff clay, whereas this is hardly possible in sand. Such samples cut from the bottom of the hole can, however, constribute

substantially to improving the accuracy in enabling better identification of the soil types to be achieved. Interpretation of the information provided by these samples calls for some caution, as is explained with reference to the Ackermann boring technique (see below).

Application:
This method is still fairly widely used in the Netherlands both for determining the soil profile and for obtaining 'undisturbed' samples.
For the former purpose the Delft Soil Mechanics Laboratory uses, where possible, the 29 mm diameter continuous sampling apparatus which it has developed and with which one continuous soil sample, extending all the way down to the attainable depth, can be extracted, thus providing a completely undisturbed soil profile. Only where greater depths necessitate this, a shell boring (with or without some samples taken from the borehole) or an Ackermann boring is carried out, depending on local conditions and on the purpose of the investigation.
For obtaining undisturbed samples, too, the Delft Soil Mechanics Laboratory prefers to use the large-diameter (66 mm) continuous sampling apparatus instead of the shell boring. With this apparatus not only a completely undisturbed soil profile, but also undisturbed samples of the highest quality are obtained. These continuous boring techniques are described in Sections *f* and *g* (below).

Re c. Bailer borings with continuous sampling (Ackermann boring)



Bailer boring with continuous sampling
(Ackermann boring)

System:
The only difference in relation to the shell boring technique described above is that always *a consecutive series of samples* is obtained. The soil samples are pushed out of the sampling device on the actual site of exploration. A narrower sheet-metal compartment, with a 25 mm x 25 mm square cross-section and a length of 300 mm, is forced into the sample. These soil-filled channel containers are then stored in a box, in their correct sequence, and sent to the laboratory for testing.

Determination of the character of the strata:
This is based on the series of soil samples cut in the borehole.

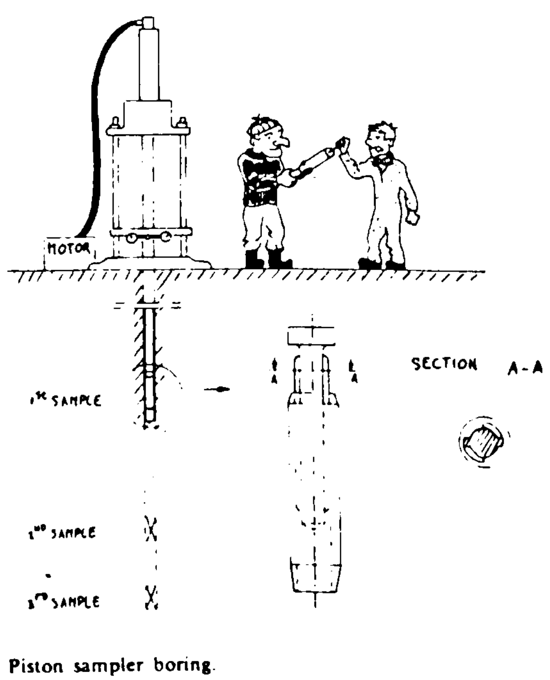
Accuracy:
The accuracy often falls short of expectations. With this method, too, soil will have to be removed from the casing by means of the shell or bailer (namely, soil which remains between the hole from which the sample was cut and the wall of the casing after extraction of a sample). What has been said with reference to this in connection with the shell boring technique is applicable here as well. Besides, the procedure of obtaining the samples in a consecutive series one below the other suffers from disadvantages which have already been discussed in Section I 2 (obtaining undisturbed samples).

These Ackermann samples could at best be rated as unmixed samples, depending on the skill of the boring crew. It will furthermore always have to be borne in mind that the top part of sample taken from the bottom of the borehole may consist of sedimented material. This may occur, for example, on suddenly encountering a homogeneous layer of clay after having penetrated through several metres of sand by shell boring and sampling. During the time it takes to raise the shell to the surface and lower the sampler to the bottom of the hole, a thin layer of sand may have been deposited on the bottom from the water that is present in the hole. Not only will the top few centimetres of the first clay sample then consist of sand, but the same may occur in the second and even in the third sample of clay, though with progressively diminishing thickness of the sand layers.
These effects are likewise dependent on the manner of execution of the work, e.g., adequate flushing of the water in the borehole before taking a sample, accurate measuring, etc. Failure to recognize this problem will entail the risk of wrongly interpreting the upper part of the homogeneous clay stratum in the soil profile as consisting of clay interbedded with a few thin layers of sand. Whether such an error may have any significant consequences will in turn depend on the type of problem under investigation.

'Undisturbed' samples taken from the bottom of the borehole:
With regard to this the reader is referred to what has been said in Section 1.2 concerning the taking of samples one below the other. No 'Ackermann samples' should be taken from a depth of *at least 0.60 m* above the level at which an undisturbed sample is to be obtained in the borehole.

Application:
Ackermann boring is a technique regularly employed in the Netherlands because it yields more and better information than ordinary shell boring does. If at all possible, however, the Delft Soil Mechanics Laboratory prefers to use the continuous sampler (Begemann boring) of 29 mm diameter if undisturbed samples for laboratory testing are not required, and of 66 mm diameter if such samples are required (see under *f* and *g*).

Re d. 1 Inch Piston sampler borings



Piston sampler boring.

System:
A small sampler of 25 mm internal diameter and closable at the bottom by means of a conical piston is pushed, when closed, to the required depth into the ground with the aid of the penetrometer apparatus. The piston, initially locked to the sampler, is released by manipulations which include rotating the extension tubes through half a turn. The soil sample is then taken by forcing the sampler 20 cm deeper into the ground.

After the tubes have been extracted and the sampler brought to the surface, the same procedure can be used for obtaining another sample, at greater depth. For this purpose, the tubes are lowered again into the same hole, pushed further in and again extracted from the hole.

Determination of the character of the strata:
This information can be based only on the samples obtained at the specified depths; no intermediate observations are available. The type of soil and the bulk density of each sample is determined.

Accuracy:
The samples are for the most part reasonably representative of the soil occurring at the sampling depth, provided that they are not taken too close together (see publication [11]). Only a discontinuous set of data for establishing the soil profile is obtained. The extent of the gaps in the profile, and therefore the accuracy of the method, is determined by the number of samples obtained in relation to the total depth of the boring and by the expected degree of heterogeneity of the soil.

'Undisturbed' samples taken from the bottom of the borehole:
Because of the small diameter of the sampler and the method of sampling employed, the samples can be used only for determining the grain size distribution, the Atterberg limits and the bulk density of the soil.

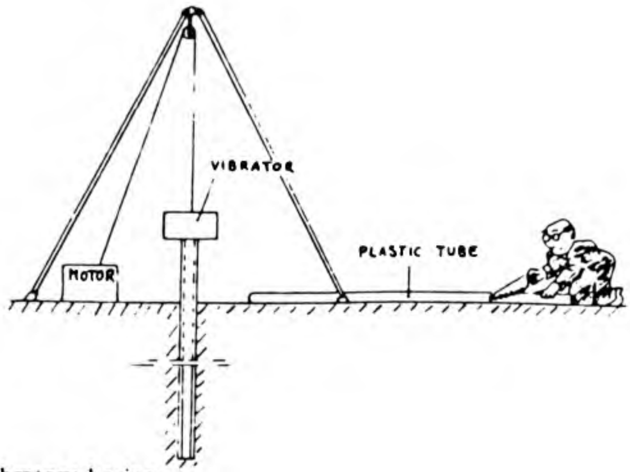
Application:
With the availability of the 29 mm diameter continuous sampler, that technique is, wherever possible and relevant, now always used in preference to the 1 inch piston sampler borings. The latter are, however, still used in cases where merely a few samples are required, e.g., in very shallow exploratory borings or when a sample has to be taken at a depth where a cone penetration test in a sand(y) stratum has revealed a marked decrease in resistance.

The so-called *mud sampler* can also be classed in this type of boring. The apparatus in question consists of a thickwalled plastic tube, generally 3 m in length, in which a close-fitting (watertight and airtight) piston can be moved up and down. To obtain a sample, the plastic tube is placed vertically on the soft surface of the ground, while the piston inside the tube also rests on the surface. By means of a wire the piston is secured to a fixed point, and the sampling tube is then pushed by hand into the 'unconsolidated' layer of silt or mud. When the requisite maximum depth has been reached, the piston is secured to the sampling tube, after which the latter is withdrawn from the ground. Because of the relatively low skin friction and also the suction effect of the piston it is possible to take samples up to 3 m in length by this technique. If the mud is too soft, however, it may run out of the tube while the latter is being withdrawn. On the other hand, if it is too stiff, it will limit the attainable depth of sampling.

Re e. Vibratory borings

System:
A thin-walled sampling tube of 70 mm diameter is vibrated into the ground by means of a vibrating machine and is then withdrawn. The greatest sampling depth, up to 6 m, is attained in sandy soils. *Stiff clay strata may considerably reduce this depth.*

Determination of the character of the strata:
This is based on the soil found to be present in the sampling tube.

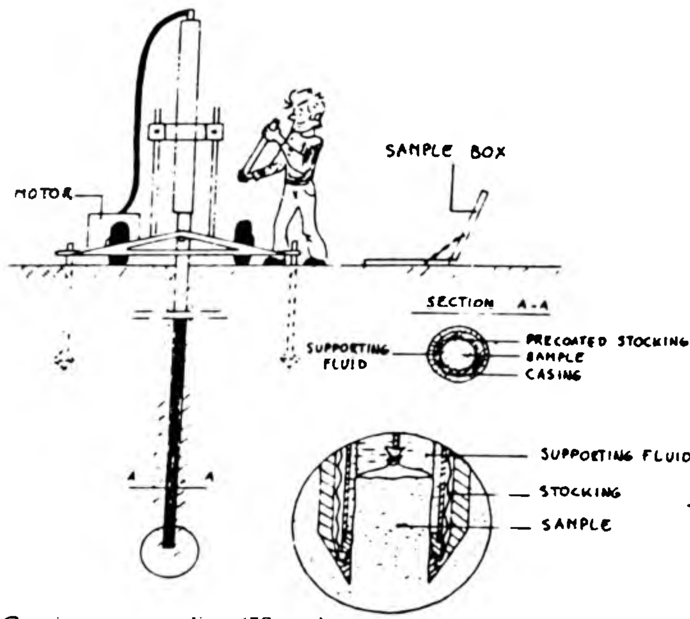


Vibratory boring.

Accuracy:
Reasonable accuracy is achieved in so far as the description of the types of soil encountered are concerned, but the results are liable to be rather less accurate with regard to the location of the strata. The sand samples obtained may be compacted during vibration, so that the length of the sample brought to the surface may be significantly less than its original length as cut in situ. This compaction effect also makes the determination of the density of such sand samples unreliable.

Application:
Most of the available appliances have been developed for underwater sampling in the bed of a river or in the sea bed where water depths are not too great. The sampling apparatus can easily be lowered from a pontoon or boat to the bottom of the water. Under its arrangements for co-operation with the National Geological Department, the Delft Soil Mechanics Laboratory can have such borings carried out by that Department.

Re f. 29 mm diameter continuous borings (Begemann boring)



Continuous sampling (29 mm).

System:
The system developed by the Delft Soil Mechanics Laboratory is based on the principle of obtaining one very long sample, e.g., 20 m in length, in a single operation. This is possible only if the following two conditions are satisfied:
- there must be very little friction between the sample entering the sampling tube and the surrounding wall of the tube;
- during the whole procedure the sample must be adequately supported laterally in order to prevent its collapse.

In this system these conditions are satisfied because the inside diameter of the sampling tube is 8 mm larger than that of the cutting shoe (29 mm) attached to the bottom of the tube. Thus a gap of about 4 mm remains between the soil sample that enters the sampling tube and the surrounding wall of this tube. The gap is constantly kept filled from above with a supporting fluid with a specific gravity of 16 kN/m^3 which provides the necessary horizontal pressure to support the

sample against collapse. In order to achieve complete and rapid transmission of this supporting pressure, the sample is enveloped, directly above the cutting shoe, in a precoated nylon stocking.
Since the sampling tube and the supporting fluid are together pushed into the ground at a speed of about 20 mm/sec. in relation to the (stationary) soil sample, losses of pressure due to flow phenomena may develop in the fluid and thus cause a reduction of the horizontal supporting pressure. To counteract this effect the fluid must have a very low viscosity τ_{u}. When the sampler has reached the desired depth, a closing device at the bottom is automatically actuated when the sampling tube is pulled up vertically.
The sampling equipment is pushed into the ground by the hydraulic driving equipment of the static cone penetrometer apparatus and also withdrawn by means of it. The sample in its nylon stocking is cut off in lengths of 1 m and slid out of the sampling tube into a plastic trough. Samples obtained in this way are sent in flat boxes to the Delft Soil Mechanics Laboratory for further processing. The maximum attainable depth is determined, on the one hand, by the maximum length of the stocking (20 m) and, on the other, by the overall penetration resistance and the available thrusting capacity of the driving equipment.

Determination of the character of the strata:
This is done *in the laboratory* on the basis of a complete, uninterrupted and undisturbed soil sample. The strata boundaries, descriptions of soil types and codings thereof are indicated on the sample cut up into appropriate lengths and the information is then recorded by colour photography (see Fig. 1).

Accuracy:
A high degree of accuracy as regards stratification and structure of the soil is obtained. The drawbacks and inaccuracies mentioned in connection with the boring systems described in points *a*, *b* and *c* do not occur here. It can at all times be checked quite simply whether the sample length obtained does indeed correspond to the sampling depth. Since the sampling tube is topped up with supporting fluid after each extension by a length of 1 m, there will be an overflow of fluid from the tube, this overflow quantity being equal to the volume of sampled soil that enters the bottom of the tube. Under certain circumstances, more particularly when the sampling tube is penetrating through peat strata, a deficiency in sample length may arise in consequence of some compression of the peat during the sampling operation. However, it is known at what depth this occured and to what extent, so that correction of the depth dimensions is possible.

Undisturbed character of the sample:
The samples obtained by this method are to be rated as undisturbed in so far as stratification, structure, bulk densities, gradings and Atterberg limits are concerned. They are not suitable for compression tests, etc. Not only is the sample diameter too small for that purpose, but also – especially in the case of soft soil samples – the horizontal supporting pressures during sampling have been rather high.

Application:
If the object is merely to determine a complete and undisturbed soil profile, this 29 mm continuous boring technique is, where possible, applied by the same mobile equipment used also for the associated static cone penetration tests.
In a case where efficient sealing of the resulting 'borehole' is necessary, it is possible first to withdraw the sample carefully from the tube, in conjunction with continual addition of a slowly stiffening clay-cement slurry. Because of the high bulk density of this slurry (17 kN/m³) the force needed for extracting the sample is very small. When it has thus been removed from the tube (see Fig. 2), the tube itself can be extracted from the ground in conjunction with the adition of more of this stiffening slurry. A good seal is thus ensured. Further information is given in the publications [1], [2] and [3].

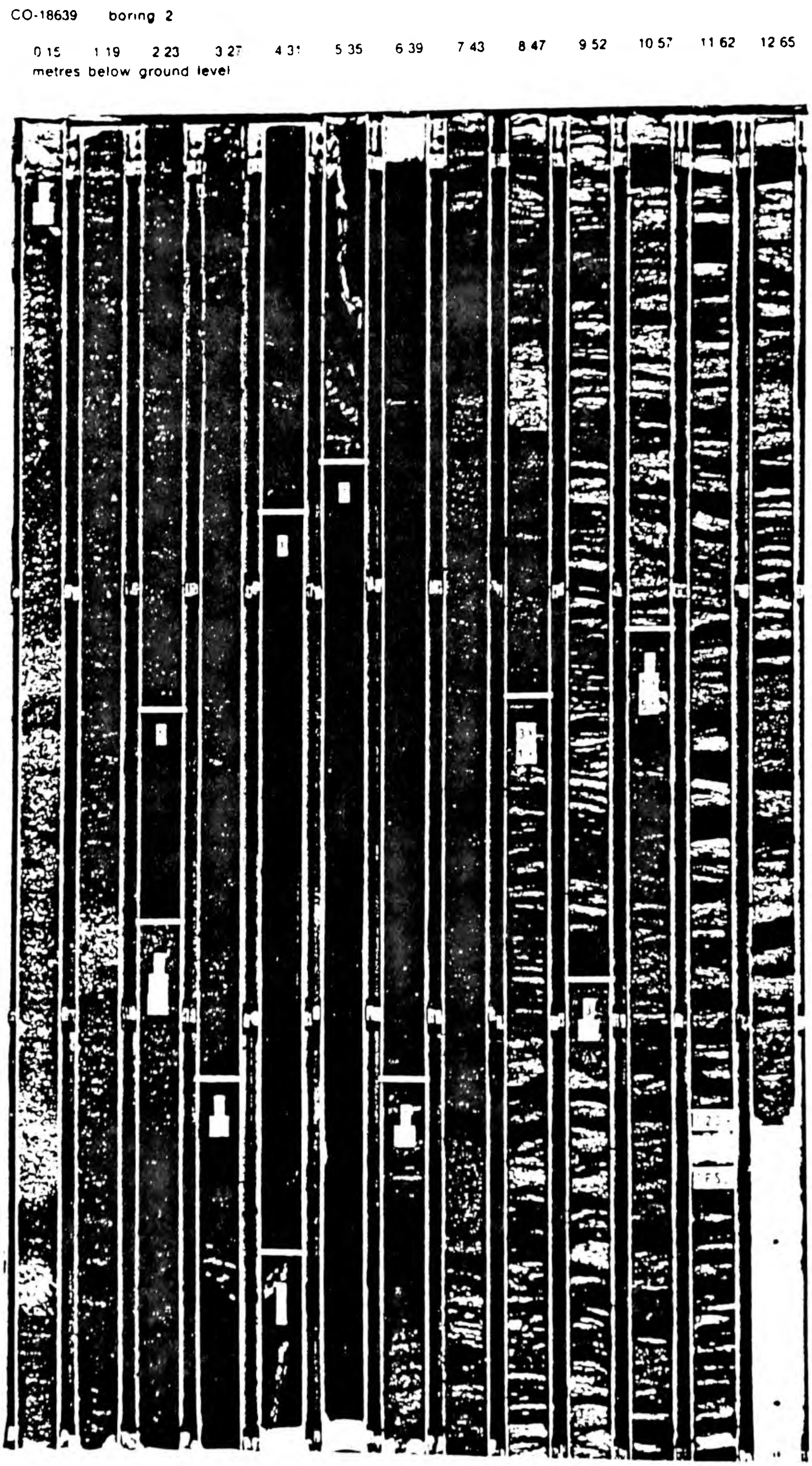


Fig 1 29 mm continuous sample about 13 m long sliced longitudinally

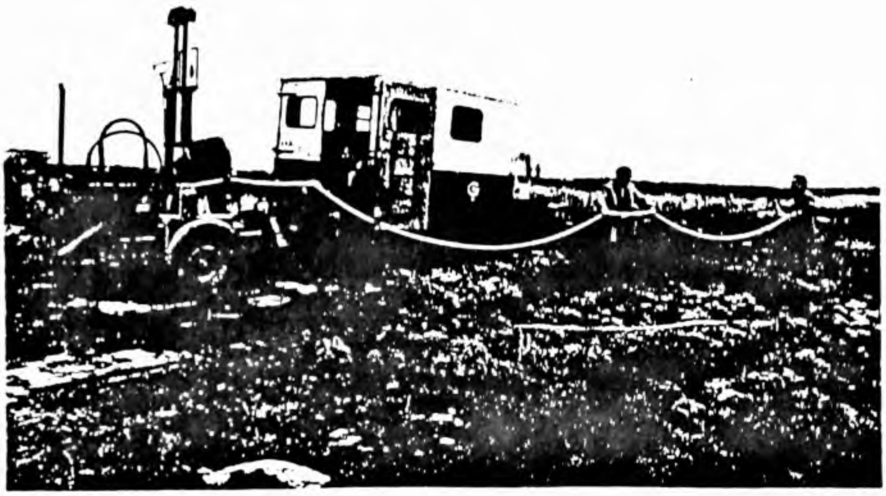


Fig. 2 It is also possible to remove the sample in its entire length (19 m) from the tube.

Re g. 66 mm diameter continuous borings (Begemann boring)

System (see also Annex 1):
The system is similar in principle to that of the 29 mm continuous sampling apparatus, the main difference being, besides the larger diameter, the presence of an extra set of plastic tubes which fairly closely enclose the sample enveloped in the nylon stocking.
A short distance above the cutting shoe the sample enters the nylon stocking and at the same time the plastic tube. At that point the very narrow gap between this tube and the stocking is filled with a heavy fluid which in this case functions as a lubricant. In this arrangement the lateral support for the sample is provided by the plastic tube that closely encloses it. The lubricating and supporting fluid is continually added at the upper end of the boring tube and flows through the gap between the plastic tubes and the steel outer tube (casing) and thus reaches the cutting shoe.
The soil samples are cut up into 1 m lengths while enclosed in the same plastic tubes, which are then sealed airtight at both ends. These samples are sent to the Delft Soil Mechanics Laboratory (see photographs in Annex 1). The tubes are pushed into the ground by means of

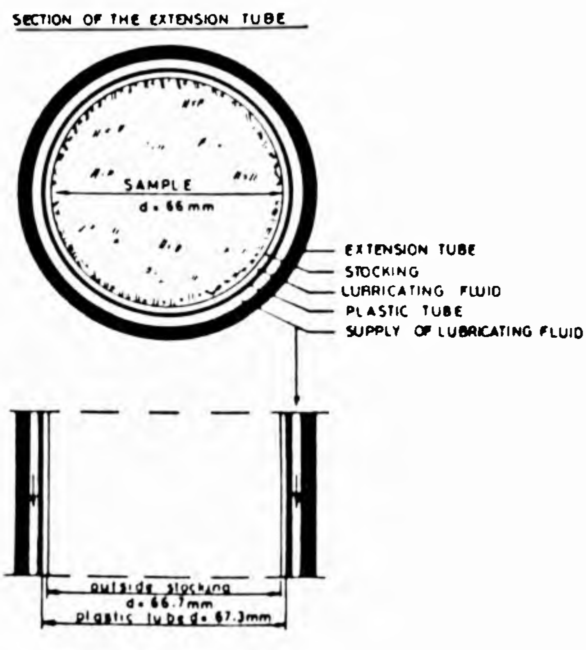


Fig 3 Cross-section through a 66 mm continuous sample.

the 200 kN hydraulic driving equipment of the static cone penetration test (maximum length of sample 19 m).

Determination of the character of the strata:
This can be done in the same way as with the 29 mm continuous sampler on the basis of a complete, uninterrupted and undisturbed sample.

Accuracy:
As regards the soil profile the results are even somewhat more accurate than those obtained with the 29 mm apparatus. Any deficiencies in sampled length are distinctly less with the 66 mm as compared with the 29 mm samples.
From the viewpoint of their undisturbed character in terms of laboratory testing, e.g., compression tests and triaxial tests, these samples are to be rated as being of the highest quality.
An additional advantage is that the representative sample for each of the various strata can be chosen from the overall soil profile.
Further information on this technique is given in Annex 1 and in the publications [3] and [4].

Re h. Core borings

With the aid of additional attachements the heavy penetrometer test apparatus (100- and 200 kN) can be used also for core borings. The core diameter is 19 mm, the boring depth normally being limited to the maximum cone penetration depth attainable with this apparatus. In *the Netherlands* the core boring equipment is most used for boring holes through old foundations, floors, pavements, etc. to enable cone penetration tests to be performed in the underlying soil. The method offers greater scope for application in other countries, where hard cemented soil strata alternating with softer ones are more frequently encountered.

Additional remarks

a. Borings under water
Substantial progress has been achieved in these techniques, too, in recent years. Larger drilling or boring barges are now used, so that the lengths of time during which operations can proceed under workable weather conditions have increased. In principle, any of the boring systems described above, including the continuous borings *f* and *g*, can be applied by working from above water level on these barges or pontoons.
Boring and cone penetration test operations carried out from such craft are fully described in Annex 2.
The possibility of carrying out continuous borings from inside a specially developed diving bell also calls for mention. For further information see Annex 3.

b. Which boring method to choose?
As the reader will have gathered from the foregoing descriptions, the various boring methods differ greatly in quality. The International Group on Soil Sampling is accordingly trying to establish an international classification of methods. In connection with those efforts it soon becomes apparent that at least six classes will have to be introduced.
What quality of boring is needed will depend on many factors, such as:
– is it a preliminary or a definitive investigation?
– how variable is the subsoil (fine or coarse stratification)?
– what demands does the design make upon the subsoil?
– what are the problems to be solved?
Expertise and local experience provide good guarantees for the correct choice. The Delft Soil Mechanics Laboratory will be pleased to advise and take charge of operations.

Reference

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[3] *Dr. ir. H. K. S. Ph. Begemann*
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[4] *Dr. ir. H. K. S. Ph. Begemann*
'Soil Sampler for Taking an Undisturbed Sample 66 mm in Diameter and with a maximum Length of 17 Metres'
IVth Asian Regional Conference on Soil Mechanics and Foundation Engineering, Bangkok, July 1971

1.4 Indirect determination of the soil strata

The following possibilities are available for this:
— by means of the ratio of cone resistance to local friction;
— with the aid of geo-electrical resistivity measurements;
— by other geophysical techniques.

1.4.1 Ratio between cone penetration resistance and local friction

(Dr. Ir. H. K. S. Ph. Begemann)

With the so-called adhesion jacket cone it is possible to carry out cone penetration tests in which not only the cone penetration resistance but also the local friction a short distance above the cone is measured (see Section 2.1.1.2B). On theoretical grounds it can be shown that the ratio between cone penetration resistance and local friction must be much lower in a saturated clay than in a stratum consisting purely of sand. Measurements performed in actual practice confirm this. On the basis of these last-mentioned data a diagram has been plotted (Fig. 4) indicating the relationship between the cone resistance/friction ratio and the type of soil as determined for the mechanical adhesion jacket cone (Begemann cone). (With other cone, different values are obtained, particularly in sand and sandy strata).

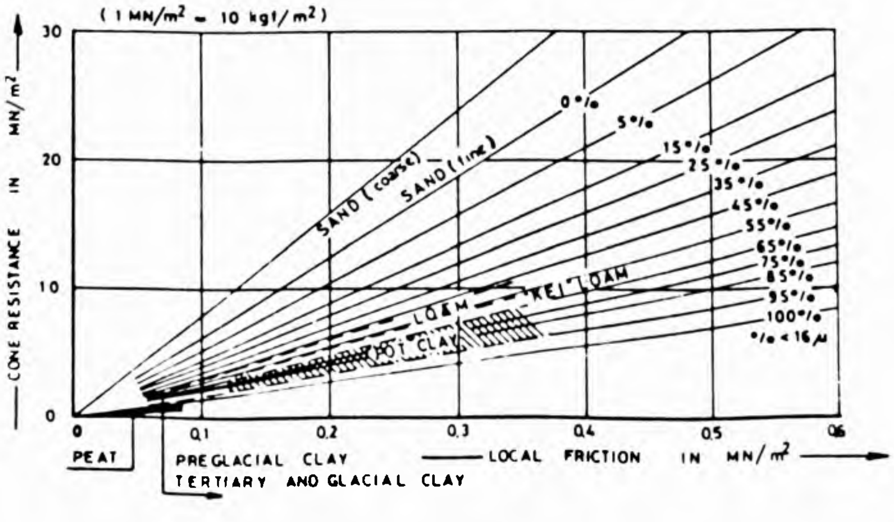

Fig. 4 Information on soil strata provided by the ratio of cone resistance and local friction

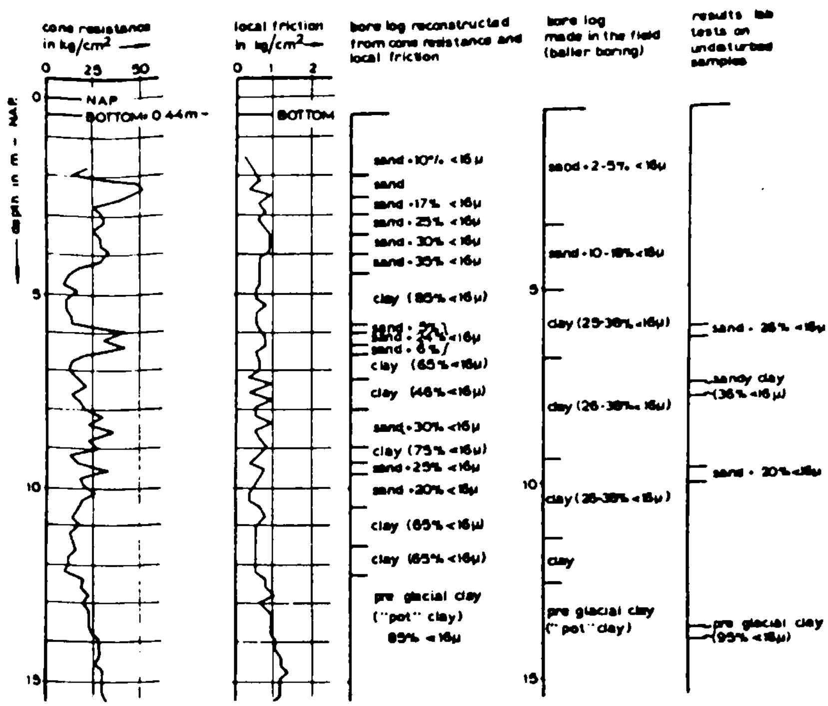

Fig. 5 Comparison of results from borings with indirect method.

It should be noted that the diagram presented in Fig. 4 is *valid only for undisturbed natural sediments situated below ground-water level.* Disturbances due to such causes as excavation work or pile-driving are liable to affect the ratios. This offers the possibility of, for example, detecting the residual influences of previous surcharges. Thus if the cone resistance/friction ratio in a sand stratum is found to be, say, 30 : 1 instead of 60 : 1, it may signify that, in consequence of old surcharges, the horizontal soil stresses are greater than normal. This may be of considerable importance because it has been found in practice that these residual stresses may decrease as a result of vibrations (piling) (see publication [8]).

Fig. 5 present a comparison between a soil profile compiled on the basis of the cone resistance/friction ratio and a soil profile based on a shell boring. The results of grading tests on undisturbed samples are also indicated.

It must again be emphasized that the diagram presented in Fig. 4 is applicable only to the results obtained with the adhesion jacket cone of the Delft Soil Mechanics Laboratory. For the electrical reduced adhesion jacket cone apparatus the ratio in clay soils is equal to that obtained with the mechanical adhesion jacket cone, but in sand the ratio ranges from 100 : 1 to 120 : 1.
Further information is given in the publications [5], [6] and [7].

1.4.2 Geo-electrical resistivity measurement

(Ir. J. G. Bakker)

The electrical resistivity of the subsoil is measured by means of this method. The specific resistivity of a water-saturated soil is determined by, among other factors, the porosity, the grain material, the grain shape, and the electrical conductivity of the pore water. On the assumption that the pore water conductivity is everywhere the same, the specific resistivity can be regarded as characteristic of any particular soil.

In the soil investigation the apparent resistivity is measured It is called 'apparent' because it is, in general, not determined by the specific resistivity of one particular stratum, but by that of several strata. An electric potential field is set up in the ground by means of two current electrodes. The potential difference between two points on the surface of the ground is measured with the aid of two measuring electrodes which are installed between the current electrodes. This measurement is performed with the Bison Earth Resistivity Meter (model 2350 A).
The quotient of the measured potential difference and the current intensity applied, multiplied by a constant depending on the measuring set-up employed, gives the apparent resistivity. In successive measurements, carried out with progressively increasing distance between the (current) electrodes the effect of the deeper-lying strata on the apparent resistivity becomes greater.
The apparent resistivity values determined in this way can be plotted graphically against the corresponding (half) electrode spacing distances. The composition of the soil formations under investigation can be determined by interpretation of this curve with the aid of standard graphs or by calculations. Supplementary information obtained from exploratory borings and/or cone penetration tests are *essential* for proper interpretation.
A less time-consuming procedure consists in performing the measurements with only a few fixed spacings of the electrodes which, after a preliminary investigation, are so chosen that the characteristics of the soil are optimally manifested. These measurements are repeated at points arranged on lines extending over the whole site to be investigated. Then, on the basis of the results obtained, the site can (if possible) be subdivided into evidently more or less homogeneous zones which will have to be further investigated with the aid of cone penetration tests and a few exploratory boreholes.

Geo-electrical resistivity measurement is more particularly a suitable method of determining the depth of transition from cohesive soil to sand, and vice versa. Variations in this depth, if they are less than about 10—15%, will not be revealed by the measurements, however. A prerequisite condition to be satisfied is that the pore water in the soil has a low salt content.
This method of investigation is usually employed by the Delft Soil Mechanics Laboratory as an introductory exploration in cases where relatively little detailed knowledge of the subsoil will (provisionally) serve the purpose, e.g., for establishing road and dyke alignments, establishing possible excavation sites for obtaining sand, or other large-scale assessments of soil conditions, development schemes, siting of recreational areas, etc.
It is not a suitable method for use in regions where the ground-water has a high salt content or shows considerable local variations in salt content. For further information see [9].

1.4.3 Further geophysical exploration

(Ir R. Ch. Visser)

General:
The author of the preceding section has dealt more particularly with electrical methods of geophysical site investigation. In so doing, he has conformed to the subdivision of the subject based on the importance and frequency of application of the method in geotechnical engineering
After the direct methods come the indirect methods, and to conclude the chapter on the determination of the soil strata it will be appropriate for the sake of completeness to add a few words on geophysical exploration in general.
As the term implies, the techniques in question endeavour to distinguish between the strata according to their physical properties.
It is not always the intension to achieve accurate determination of the properties

the investigator's aim may more particularly be to detect contrasts for the purpose of thus distinguishing. If exact measurements of physical properties are indeed required, however, they belong in the next chapter — 'In-situ measurements' — of this publication.

Synopsis:

The possibilities of geotechnical application are in general limited to cases where exploration has to cover a fairly extensive area, such as the detection of seepage, the choice of suitable sites for development as built-up areas, the plotting of alignments of roads or dykes, etc.

The gravimetric survey — usually applied only to the study of very large-scale phenomena — may, under favourable conditions, be utilized for the detection of relatively minor features such as cavities of at least some appreciable size (e.g., caves in limestone formations) and underground workings (such as covered mine shafts).

Seismic methods have for a number of years been available as micro-techniques for refraction measurements, e.g., the Terrascout system of Soiltest and a similar one of Caterpillar for the determination of, among other properties, the 'rippability' of rock riddled with diaclases, i.e., its susceptibility to fragmentation by a tractor-drawn ripper.

Magnetometry can be suitably used for small-scale exploration in special cases.

Geo-electrical surveys — see Section 1.4.2 for direct resistivity measurements — can ascertain relatively minor details such as, for example, the thickness of an overlying layer of clay on sand or the presence of ancient river beds.

Metal detectors occupy a position of their own as a means of pinpointing the position of buried metal pipes, cables and other objects, e.g., the Fisher detectors (inductive method).

Acoustic measurement is related to seismic reflection methods and has been developed for surveys performed from the surface of water, e.g., the Sonia system.

Nuclear methods will be discussed in the next chapter.

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[7] *Prof. J. H. Schmertmann*
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[8] *Dr. ir. H. K. S. Ph. Begemann*
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[9] *A. N. Burton and I. E. Higgenbottem*
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Electrical resistivity, magnetic gravity methods'
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2. IN-SITU MEASUREMENTS

2.1 Measuring specific soilmechanical properties of the various strata in situ

Such measurements comprise not only the direct methods, e.g., permeability measurements or the vane test for determining the apparent cohesion in cohesive soils, but also the indirect ones which are based mainly on correlation, e.g., the Standard Penetration Test (SPT) or the California Bearing Ratio (CBR) test.
The best known and most widely employed in-situ measurements in the Netherlands are those by means of the Cone Penetration Test (CPT), which will accordingly be dealt with first. This will be followed by a discussion of other methods in no particular preference of order.

2.1.1 Cone Penetration Test (CPT)

(Ing. J. Vermeiden)

2.1.1.1 Object

- The primary object was, and still is, to determine by a standardized procedure the *penetration resistance of a cone* as a measure of the consistency or strength (quality) of the soil strata under investigation. The results of the measurements are indicated as *cone resistance in* MN/m^2 ($\approx 10\ kg/cm^2$).
- In 1952 the so-called *adhesion jacket* was introduced as an additional feature, placed as short a distance as possible above the cone and achieving a second object, namely, to measure the longitudinal friction with the surrounding soil ([6] and [12]). The jacket is 133 mm long and has a lateral surface area of 15000 mm^2. The friction measured at this surface is indicated as *local friction in* MN/m^2 ($\approx 10\ kg/cm^2$).

It should be noted that, before the adhesion jacket method had been developed, the overall shear resistance acting along the extension tubes (smooth tubes) was also measured during the penetration operations.
It was found, however, that this 'overall friction' is *not reproducible* and is unserviceable for **general** interpretation ([6] and [12]).

2.1.1.2 Procedure

A. Cone resistance measurement

In order to measure only the cone resistance, it is necessary to eliminate the friction — increasing with depth — of the surrounding soil in contact with the rod or tube by means of which the cone is forced into the ground.

Mechanical cone penetration tests:
For mechanical penetration tests this problem has been solved by mounting the cone under a series of rods and enclosing the latter in a fairly close-fitting casing consisting of a series of tubes (penetration tubes). Two possible procedures are available with such equipment:

- *Discontinuous:* In its retracted condition the cone is first forced into the ground a distance of 100 or 200 mm by application of force to the penetration tubes; then the cone is pushed out 60—70 mm by application of force to the inner rods only, and the magnitude of the force required to achieve this is measured and recorded; then the penetration tubes are forced 100 or 200 mm further into the ground, and a cone penetration measurement is again performed, and so on (see Fig. 6).
- *Continuous:* The outer tubes and inner rods of the penetration testing divice are forced simultaneously, and at the same constant speed, a distance of 1 m into **the ground (see Fig. 7).**

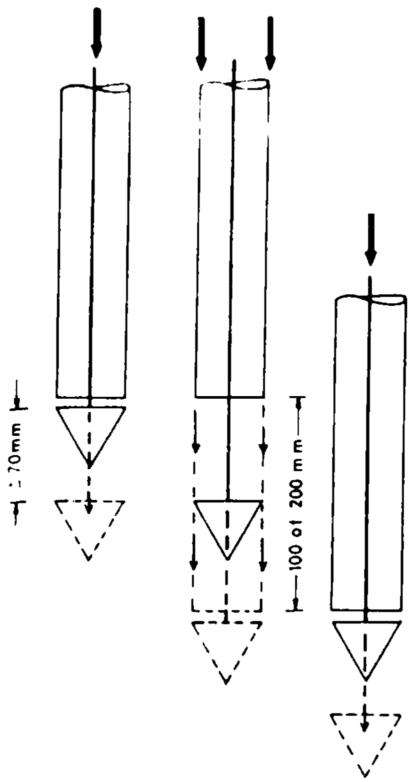


Fig. 6 Mechanical discontinuous penetration testing.

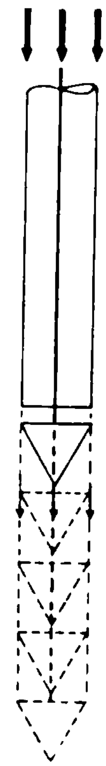


Fig. 7 Mechanical continuous penetration testing.

The force that has to be applied to the rods to achieve this is measured. The cone remains in its extended (pushed-out) condition throughout the measuring operations. It moves in relation to the penetration tubes only in consequence of shortening of the rods when the cone encounters increased resistance or in consequence of elongation of the rods when the cone resistance decreases. This means that the friction encountered by the rods *can change direction* (and can thus affect the result of the measurement either positively or negatively). In view of this drawback, the mechanical continuous penetration technique is only very exceptionally used by the Delft Soil Mechanics Laboratory. One possibility offered by this method is continuous electrical recording of the forces applied to the inner rods. On the other hand, it *cannot* measure local friction.

Electrical cone penetration tests:
In so-called electrical cone penetration tests the cone resistance is measured *directly above the cone* by means of electrical strain gauges which are connected by cables to appropriate recording equipment. For various practical reasons these cone penetration tests are performed *only as continuous cone penetration tests* (i.e., the tubes and cone are forced simultaneously into the ground).
The advantage of this method of measurement is that it dispenses with inner rods and friction effects that are liable to be associated with them. Instead of a series of rods, an electric cable is enclosed within the tubes.

Shape of cone:
The original simple form of cone as illustrated in Fig. 8A (and known as the Barentsen cone: see [10]) was, for practical reasons, replaced around 1947 by the present so-called mantle cone (Fig. 8B and [11]). In the discontinuous penetration test procedure the tubes are thrust down after the cone has been pushed out, so

that any soil which got into the space formed between the base (upper surface) of the cone and the underside of the penetration tube during the cone resistance measurement has to be forced aside. This causes considerable objectionable fouling of the passage of the inner rod through the bottom closure of the penetration tube, resulting in additional friction at this point. The form of cone in Fig. 8B does not suffer from this drawback. It did emerge later on, however, that the constricted part of the jacket just above the cone can nevertheless still encounter considerable skin friction in expansive preloaded clay soils, thus producing a higher cone resistance. This effect has so far not been found to occur in sands and softer clays. In the electrical cone penetration tests, the earliest of which were carried out as long ago as 1951, a cone as shown in Fig. 8C was originally employed.

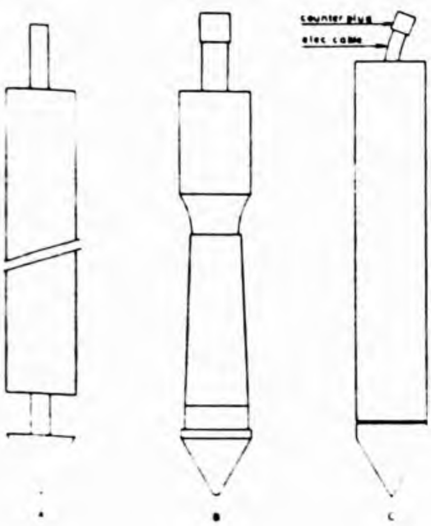


Fig. 8 Cone shapes

Before these electrical cone penetration tests were introduced as a routine procedure, such tests were performed simultaneously and in parallel with mechanical penetration tests in site investigations throughout the Netherlands. It was found that the cone resistances obtained with the two forms of cone in sand may *locally vary considerably*. Since the differences in the measured results were found *locally* to be as much as 80–90%, whereas

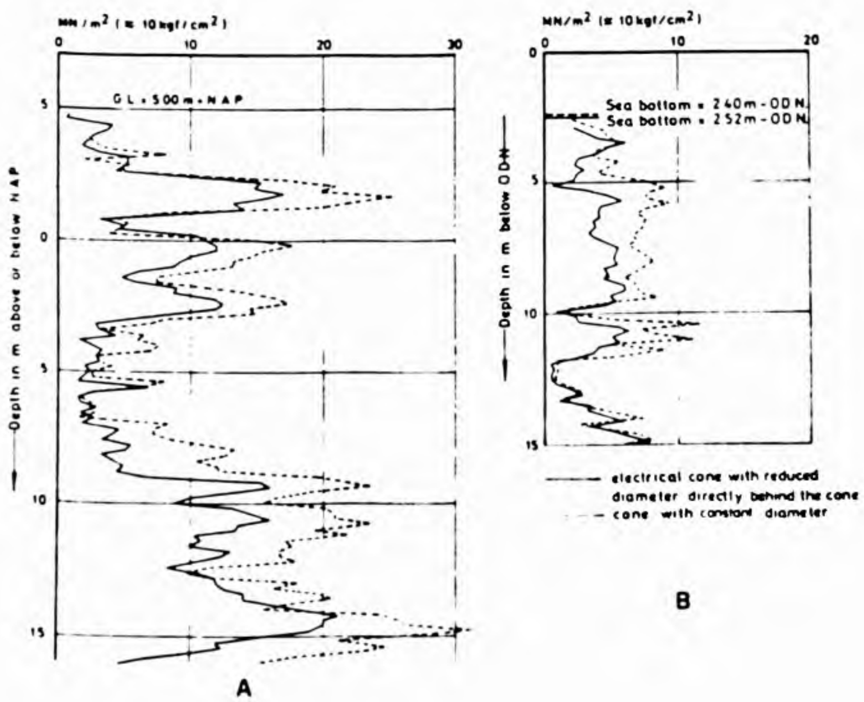


Fig. 9 Comparison of the results obtained with a straight and with a constricted electric cone respectively

Fig. 10 Constricted type of electric cone.

in other places they amounted to 15–20%. it was necessary to undertake a closer investigation of the effect of the cone shape on the cone resistance measured. By way of illustration, two striking examples of cases where the differences were large are presented in Fig. 9.
The examples are self-explanatory. It should be noted that in Fig. 9B there is seen to be a significant difference between the two recordings in the sand stratum extending down to −11.5 m ODN, whereas there is practically no difference between them in the sand stratum from −13 to −15 m ODN. It also emerges that the differences are very small in clay soils.
In further investigations conducted in 1966 a large number of cone penetration tests were performed with various forms of cone. The differences consisted in variations in the depth and length of a constriction just above the actual cone. The type of cone chosen on the basis of these investigations was the one that yielded nearly the same cone resistance values as those obtained with the mechanical jacketed cone. It is shown in Fig. 10. The results of these tests were published by Ir. W. J. Heijnen in a paper presented at the International Conference on Soil Mechanics and Foundation Engineering which was held in Moscow in 1973 [14].
As a result of introducing the cone shown in Fig. 10 it was possible to apply the same rules of calculation and interpretation to the electrical as well as to the mechanical cone penetrometer tests.

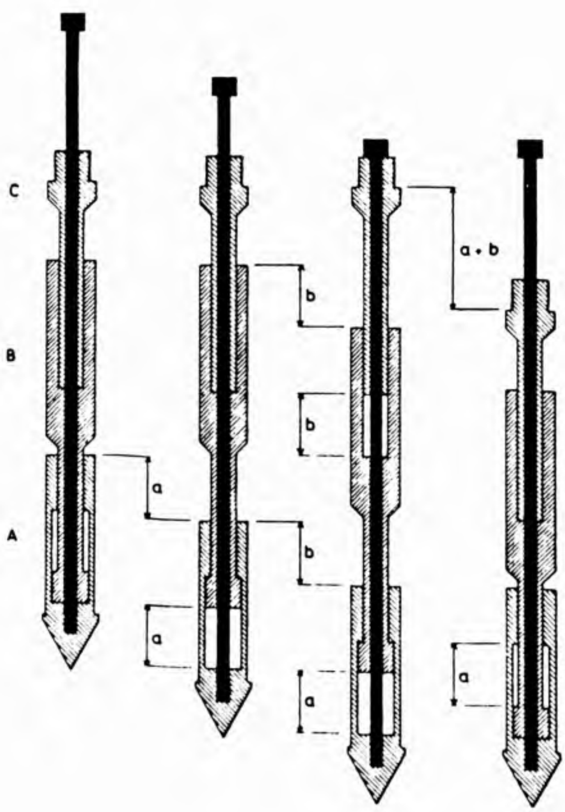
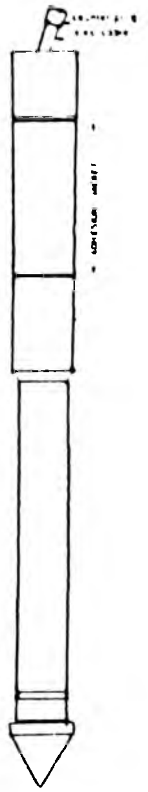


Fig. 11
Mode of operation of the mechanical friction jacket cone.

B. Friction measurements



As already stated in Section 1.4.1, friction is measured locally on a short cylinder mounted just above the cone. In the mechanical apparatus, the cone is alone pushed down for the first 35 mm of its penetration into the ground (in which phase only the actual cone resistance is measured); it is then pushed down a further 35 mm, but now the adhesion jacket goes down with it (so that in this phase cone resistance + friction is measured). The local friction at this depth concerned is now obtained as the difference between the two readings. The shape and manner of operation of this mechanical adhesion jacket cone are illustrated in Fig. 11.
The adhesion jacket is so positioned in relation to the cone that it is outside the range of stress influence of the cone ([6], [12] and [13]).
The adhesion jacket for the electrical cone penetration method is located just above the end of the constriction, where the hole formed by the cone (36 mm dia.) has certainly regained its original diameter. As already noted at the end of Section 1.4.1, in clay the electrical adhesion jacket gives practically the same values as the mechanical adhesion jacket, but in sand the values are only half.

Fig. 12 Constricted electric friction jacket cone.

C. Checking the vertical position of the penetration tubes (Clinograph)

In the electrical cone penetrometer apparatus an electrical clinograph can, if desired, be installed just above the cone or adhesion jacket. With this device it can be checked whether and, if so, by what amount the penetration tubes deviate from the vertical.

D. Water pressure and temperature measurements

Special electrical penetrometer cones are available with which, together with the cone resistance, the water pressure in the subsoil just above the cone can be measured or the temperature in the ground through an insulated cone.

E. Above-ground penetration equipment

The equipment on the surface of the ground has two main functions to perform and accordingly comprises:

- The actual thrusting equipment for forcing the cone with its extension tubes into the ground. The design of this equipment determines its scope of application in connection with site conditions and with regard to attainable penetration depth.
- The measuring and recording equipment for the resistance encountered by the cone and adhesion jacket. The accuracy of the measurements is in part determined by this equipment, which also determines the range of measurement available.

In the Netherlands the penetrometer tests are usually classified into four categories according to the magnitude of the forces and pressures applied, as follows:

a. Manual cone penetration tests
These penetrometer tests are performed with the Barentsen manual cone pentro-

meter apparatus. The penetration tubes are pushed into the ground by manual force (two men). The plunger surface area of the measuring head is 1000 mm², corresponding to the base area of the cone.
The pressure gauge of the measuring head, which can be read to an accuracy of one-tenth of a scale division, ranges up to 1.6 MN/m², corresponding approximately to the weight of two men. The reliability of the readings is very high. It is a convenient and easily portable piece of equipment for use more particularly in very soft ground on sites inaccessible to motor vehicles. The attainable penetration depth is of course limited.

Fig. 13
Barentsen manual cone penetrometer.

b. Medium cone penetration tests
These tests can be performed with portable mechanically or hydraulically powered thrusting appliances capable of developing an overall penetration force of 20 and 30 kN respectively. They are anchored to the ground by means of screw anchors. With these appliances only *mechanical* penetrometer tests are performed generally. The plunger surface area of the hydraulic measuring element is 1000 mm². It is connected to a 0 – 1.6 MN/m² and a 0 – 15 MN/m² pressure gauge. These measuring elements are more accurate than those used with heavier cone penetrometer equipment.
Medium cone penetration tests can also be performed with truck-mounted hydraulic equipment. The advantage is that no special anchorage arrangements are then necessary and that electrical penetration tests can be carried out. For this purpose an electrical cone with a maximum range of either 10 or 30 kN, according to requirements, may be employed. If the truck is fitted up with heavy thrusting equipment (100 kN capacity), the maximum force to be applied is nevertheless limited to 30 kN, and for mechanical penetration tests the measuring element normally used with such equipment is replaced by the more accurate element used for medium cone penetration tests.
This latter modification represents the normal procedure adopted by the Delft Soil Mechanics Laboratory. In many other cases it is applied only on special request.
Finally, it is worth reporting that a track-mounted vehicle for medium-heavy

cone penetration tests on soft ground is to be put into service in the latter half of this year (Fig. 17a).

For sites with very soft surface layers or shallow water depths an 'amfirol' (amphibious vehicle, see Fig. 17b) can be used in co-operation with the drilling firm de Ruyter. The photo's of Figures 14, 15, 16, 17a and 17b give a picture of mentioned penetrometer equipment.

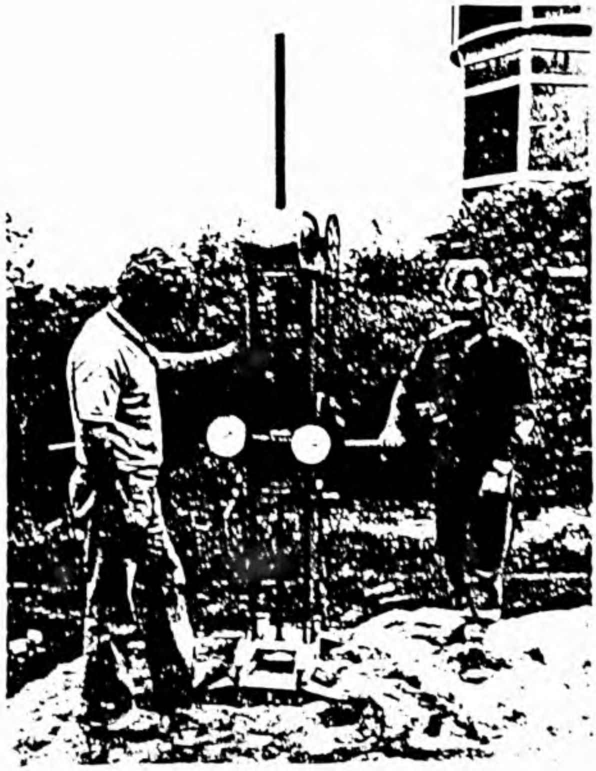


Fig. 14
Hand-operated
medium-heavy
cone penetrometer
(20 – 30 kN).

Fig. 15
Portable hydraulic medium-heavy
penetrometer (30 kN)

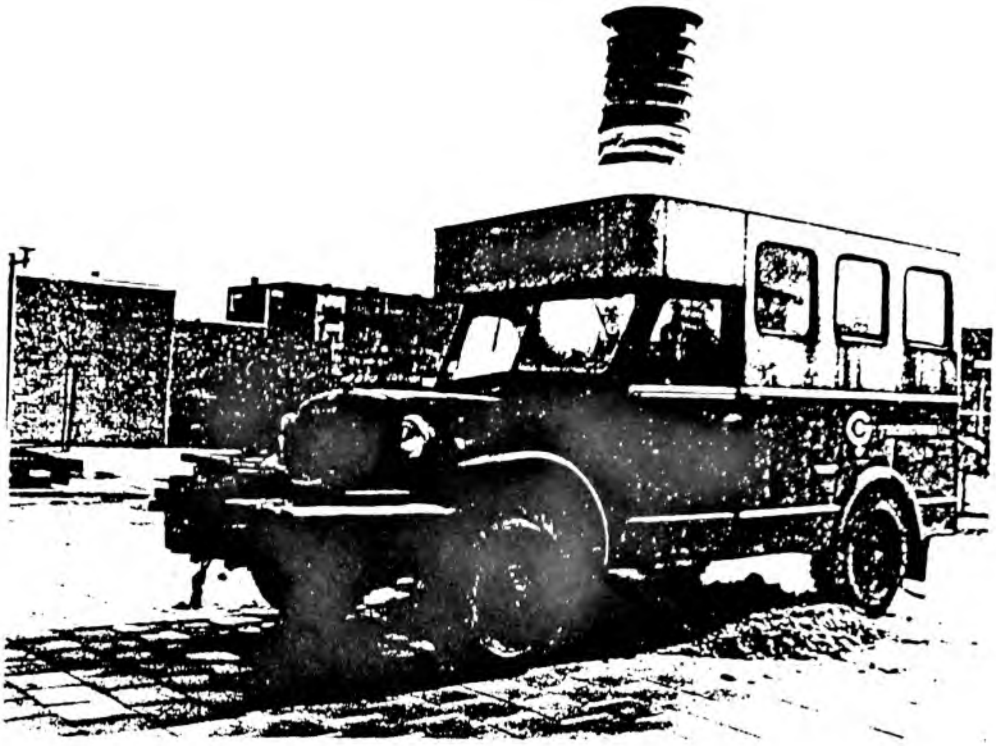


Fig. 16 W-300 truck equipped for medium-heavy penetration testing.

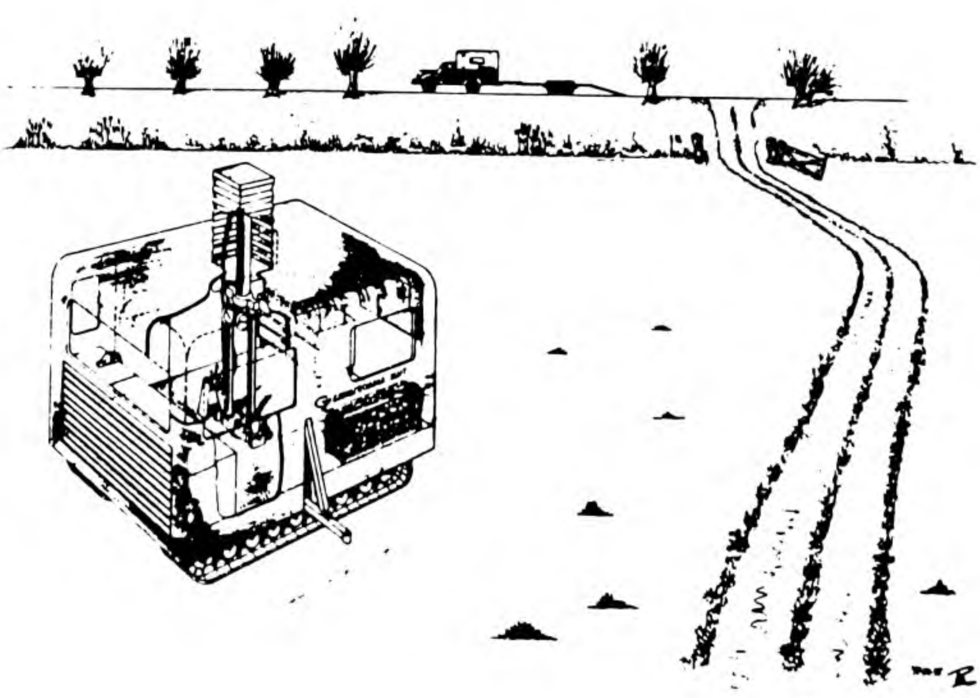


Fig. 17a Track-mounted vehicle for medium-heavy penetration testing.

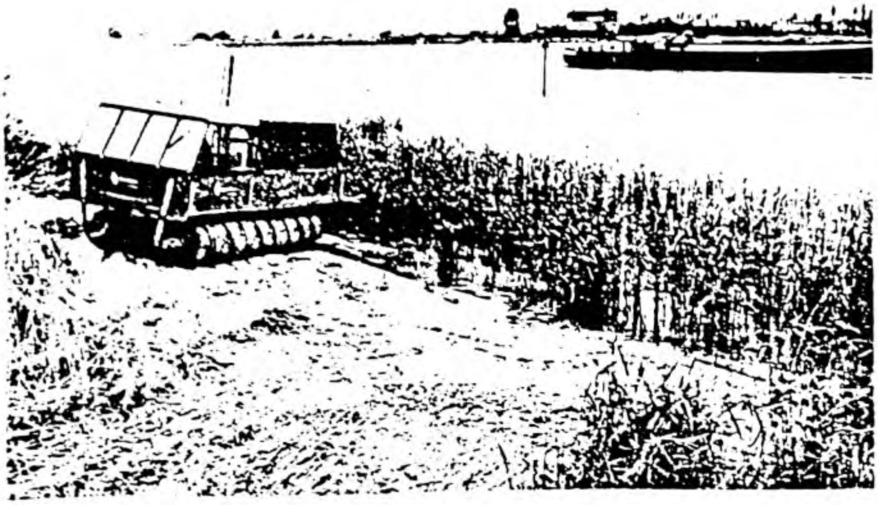


Fig. 17b Amphibious vehicle to perform medium-heavy cone penetration tests.

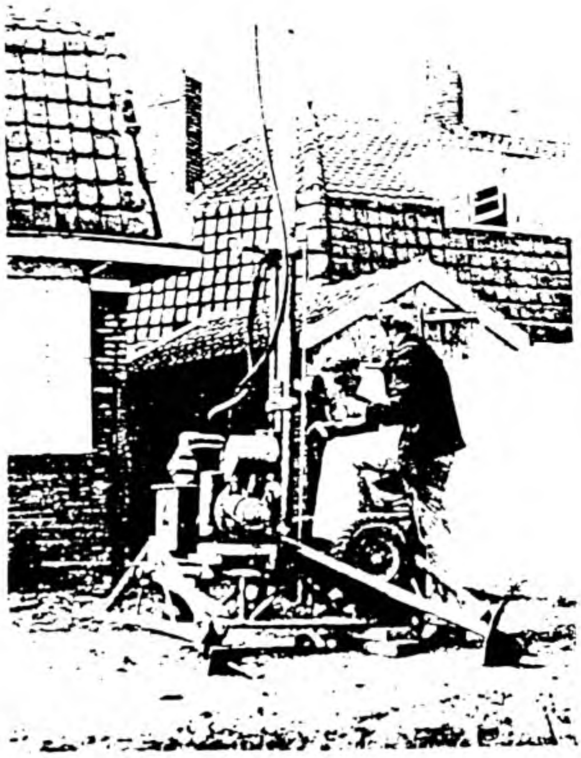


Fig. 18
Trailer mounted
100 kN penetrometer.

c. Heavy penetration tests
Hydraulic thrusting equipment capable of overcoming a total penetration resistance of 100–110 kN has been developed for the purpose.
For mechanical cone penetration tests the hydraulic measuring element has a plunger surface area of 2000 mm², while the two pressure gauges have a range of 0–10 MN/m² and 0–60 MN/m² respectively.
For electrical penetration tests a cone with a maximum measuring range of 70 kN is used.
The Delft Soil Mechanics Laboratory has several 100 kN penetrometers mounted on two wheeled trailers which can be transported by towing behind a Volkswagen mini-bus and be used on poorly accessible sites or in building pits (see Fig. 18). These penetrometers have to be anchored to the ground by means of six or more screw anchors.

Alternatively, some of these hydraulic penetrometers are mounted on Dodge trucks (type W-500) with front-wheel drive (total weight 60 kN). In circumstances where thrusting forces of more than 30 kN have to be applied, the truck is anchored to the ground by means of screw anchors.

Fig. 19
W-500 truck
equipped for heavy
penetration testing.

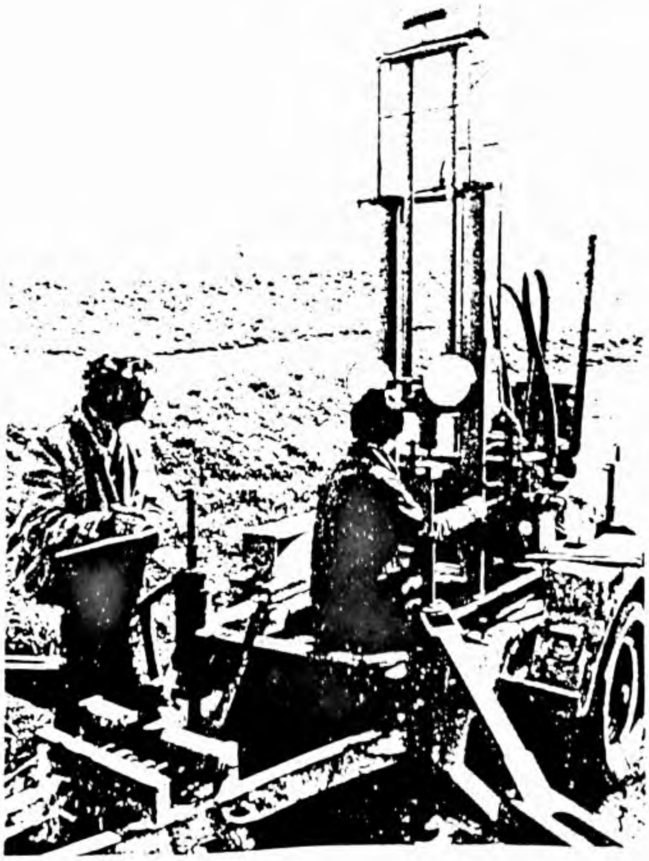


Fig. 20
Trailer mounted 200 kN
penetrometer

Heavy cone penetration tests may also be performed with the aid of so-called 'kentledge trucks'. These vehicles weigh 120–130 kN, enabling such cone penetration tests to be carried out without anchorages.
It should be noted that continuous borings (29 mm diameter) can also be performed by these trucks.

d. Extra-heavy cone penetration tests

Thrusting forces of up to 170 and 200 kN can be exerted by the above mentioned kentledge trucks. Also a one axle device to be towed behind a small truck is available.

For operating on loose upper layers the towed device needs sometimes eight anchors, the 'kentledge truck' only two or three.

These anchors are screwed into the ground with the aid of mechanical power. The apparatus transported by a Volkswagen is also used for operating with the 66 mm diameter continuous boring and sampling equipment.

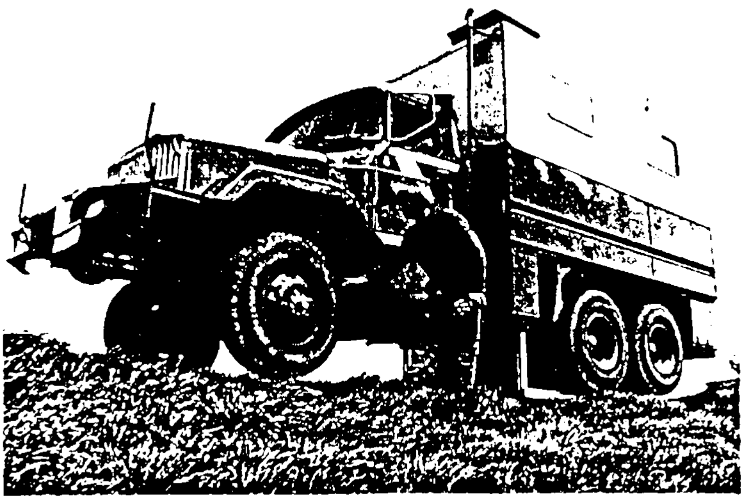


Fig. 21
Kentledge truck
(200 kN).

e. Electrical recording

As a general rule, cone penetration tests on sites that are accessible to, and provide an acceptable riding surface for truck-mounted equipment are performed with the aid of an electrical cone friction meter.

These vehicles are each equipped with a two-pen graphic recorder which draws curves representing the cone resistance and frictional resistance to a suitable scale. Adjustment devices are available for this. The paper recording chart is moved along by a so-called electric shaft which transforms the downward motion of the hydraulic jack into a rotary motion. A stroke length of 1 m of the jack moves the chart a distance of 10 mm, this combination representing the usual depth scale of the penetration record.

To obviate errors in recording the cone penetration results, the equipment is so designed that movement of the chart can occur only if the electrical circuit is completed in three places. More particularly this is effected by:

- a built-in contact in the operating control handle of the hydraulic jack as soon as it is actuated;
- a built-in contact in the thrust element suspended under the hydraulic jack; this contact is closed as soon as the push-rod touches the thrust element;
- a contact fitted to the upper end of a 1 m long rule mounted along one of the columns of the penetrometer apparatus.

Simultaneously with the electrical graphic recording of the cone and frictional resistance these data are also recorded on punched tape, the equipment for which is so adjusted that one observation is recorded every 100 mm, both for the cone resistance and the frictional resistance. By feeding the tape into a computer all the measured data can be compiled in the form of tables, and graphs for these resistances can be plotted.

2.1.1.3 Cone penetration tests from the surface of water

The Delft Soil Mechanics Laboratory has performed a considerable amount of underwater soil exploration not only for the civil engineering works carried out under the Delta Scheme and for the Zuider Zee land reclamation projects, but also regularly performs such investigations in connection with the construction of harbour works, bridges, jetties, etc.
For this purpose the Laboratory has at its disposal two or more cone penetration-

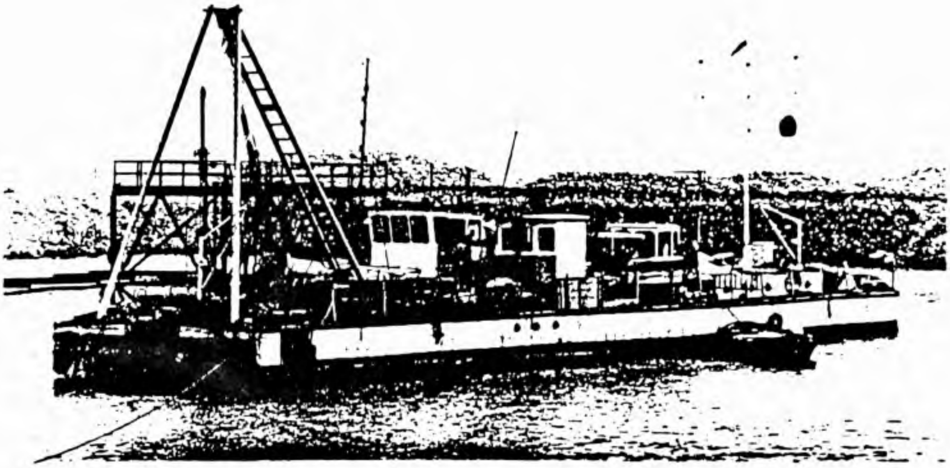


Fig. 22 Drilling pontoon 'Klaas'.

boring pontoons. These are owned by the firm of De Ruiter at Halfweg and are on hire to the Delft Soil Mechanics Laboratory, one of whose expert staff members is in charge of the cone penetration testing (or boring) operations. The pontoon Klaas is shown in Fig. 22.
For soil exploration in connection with the closure of the Eastern Scheldt the Delft Soil Mechanics Laboratory, in co-operation with the contractors' combine called

Fig. 23 DOS pontoon.

Dijksbouw Oosterschelde (DOS), has equipped a heavy pontoon (Fig. 23) with which cone penetration tests, borings, density measurements in situ, etc. can be carried out in rough, deep and fast-flowing water under the responsibility of a number of experts attached to the Delft Soil Mechanics Laboratory.

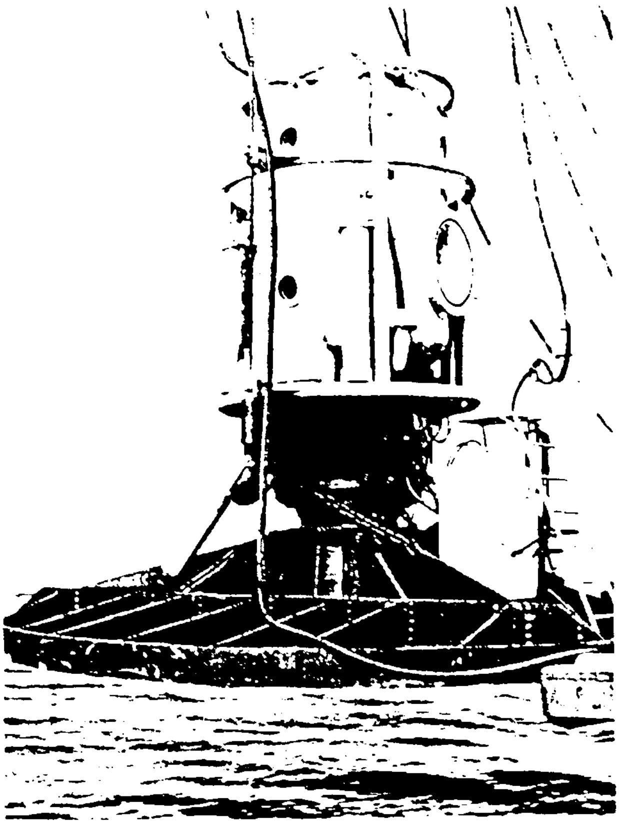


Fig. 24
Diving bell for continuous borings and penetration tests.

Finally, in collaboration with Duikbedrijf Vriens (a diving company), a large *submersible decompression chamber* (diving bell) was designed. With this device it is possible to work directly on the bottom of the water and in thus in principle to carry out all the exploratory operations normally carried out on dry land. In this way cone penetration tests and density measurements can now already be performed in depths of water of up to 200 m (see Fig. 24).
The big (DOS) pontoon and the diving bell are fully described in Annexes 2 and 3. It should finally be noted that facilities have now been created whereby cone penetration tests at extra great depths can quickly be carried out.

2.1.1.4 Possibilities for interpretation

A cone penetation test speedily yields a considerable amount of valuable information:
- When plotted in a graph, the results give a clear (visual) picture of the strata (except very thin ones) of which the subsoil is composed. If a number of cone penetration tests are performed, they will moreover give information on the homogeneity of the soil in the horizontal direction, so that, for example, the original grid of exploration points can speedily be adjusted on the basis of these results or indeed the projected structure more favourably sited.
- In addition, with the adhesion jacket cone it is possible to obtain some preliminary information on the actual nature of various strata (see also Section 1.4.1).
- The measured cone resistance values provide an indication of the permissible maximum point bearing capacity of foundation piles [17].
- Measurement of local side friction may warrant the use of tension piles and provides the basis for calculating the positive or negative adhesion that can be developed.

– If the nature of the soil and the corresponding cone resistance are known, it is possible to estimate some soil parameters such as the value φ, apparent cohesion, and compressibility coefficient or E-value.

For further details the reader is referred to the relevant literature [15], [16], [17] and [18].

2.1.1.5 General remarks

The Cone Penetration Test (CPT) method applied and further developed by the Delft Soil Mechanics Laboratory has, in the past forty years, proved to be a very serviceable and economical method. It can effect very substantial savings in the number of borings to be carried out and in the number of soil samples to be taken and tested. Static cone penetrometer tests are also increasingly being used in other countries.

Execution of the cone penetration tests calls for a well trained team and proper maintenance of the equipment used. As appears from the foregoing account, a number of different techniques have emerged in recent years, however, so that some knowledge of the advantages and disadvantages and of the effect thereof on the interpretation possibilities is indeed necessary. Thus, for instance, in connection with mechanical cone penetration tests it is highly advisable also to measure the local friction. This will not only provide extra information concerning friction along piles [16] and a preliminary indication of the nature of the strata (see Section 1.4.1), but also a check on the measured values for the cone resistance. For example, if the ratio of cone resistance to corresponding local friction in a sand stratum does not conform to that which is normally encountered in sand (namely, between 50 : 1 and 60 : 1), this means that either the friction of the push rods has been too great because they were out-of-plumb (for instance) or the stratum consists of preconsolidated sand [8].

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2.1.2 Density measurements in situ

2.1.2.1 Electrical density measurement

(Ing. A. Vlasblom)

Principle of measurement:
The measuring method is based on the very great difference in electrical conductivity of the pore water in a water-saturated sand mass as compared with that of the practically non-conductive grain material. The specific electrical resistance of the pore water may, however, vary a great deal from one point to another, namely, from 30 ohm cm to 10000 ohm cm. If this specific resistance were known, it would be possible to calculate the amount of water from the measured resistance of a known volume of soil grains + water, if it were permissible to base oneself on the assumption of uniformly distributed electric current conductors ('water paths'). In that case the percentage of pores would be dependent only on $\frac{s_w}{s_{w+k}}$, i.e., the ratio of the specific electrical resistance of the pore water s_w and that of the water-saturated granular mass s_{w+k}. Actually, however, the current conductors in a granular skeleton are of very erratic shape and cross-section. The effect of this can nevertheless be determined by calibration tests on representative soil samples in the laboratory.
For some hundreds of samples the relationship between the pore percentage n and the ratio $\frac{s_w}{s_{w+k}}$ has thus been determined.
It is expressed by

$$n = a + b \cdot \frac{s_w}{s_{w+k}}$$

a and b are constants depending on the grain structure.

Fig. 25
Soil conductivity probe.

It has been found that, for normal sands, fixed values can in general be adopted both for a and for b. For sand with grains of quite unusual shape – such as sand containing remains of sea shells, or with spherical grains or with a high content of silt – the values of a and b should be determined separately by means of calibration tests in the laboratory.

Measurement in situ:
The specific resistance of *water-saturated soil* is measured with a probe specially developed for the purpose and equipped with two combinations of four electrodes, each with a different range of influence. In addition, the lower end of the probe is provided with a cone and a local skin friction measuring device, so that the cone resistance and local friction can be measured at the same time (see Fig. 25).

These probes are forced into the ground by means of the usual thrust machine. In sand strata the measurements are, as a rule, performed at depth intervals of 200 mm and take up little time.

Measurements of the specific resistance of only *the pore water* are performed with a separate probe incorporating a measuring cell and likewise provided with a four electrode combination. The pore water is drawn into the cell through a filter and subsequently, after the specific resistance has been measured, forced out again. This operation is repeated at each desired depth (see Fig. 26). In fine sandy soils these measurements take up some time for filling the measuring cell with water.

Calculation of pore percentage:
The specific resistance measured in situ can be converted to pore percentages by means of the formula $n = a + b \cdot \frac{s_w}{s_{w \cdot k}}$. The results thus obtained are accurate to within ± 1%.

Measuring equipment:
Because of the widely differing geometric features of the soil probe and water probe respectively, the measuring equipment comprises two separate sections. Digital read-out of the results of the measurements can be provided (see Fig. 27). The equipment can be powered by batteries as well as by mains electricity.

Application:
The method described above can be applied only in *saturated sands* of sufficient thickness (not less than about 1.50 m). In the Netherlands it is extensively used for comparing in-situ densities with the critical densities determined in the laboratory for the sands concerned, with the object of assessing the possible risk of the occurrence of flow slides.
In general, these density measurements serve to establish a relationship between in-situ quantities and those determined in the laboratory for the sands concerned.

Fig. 26
Water conductivity probe.

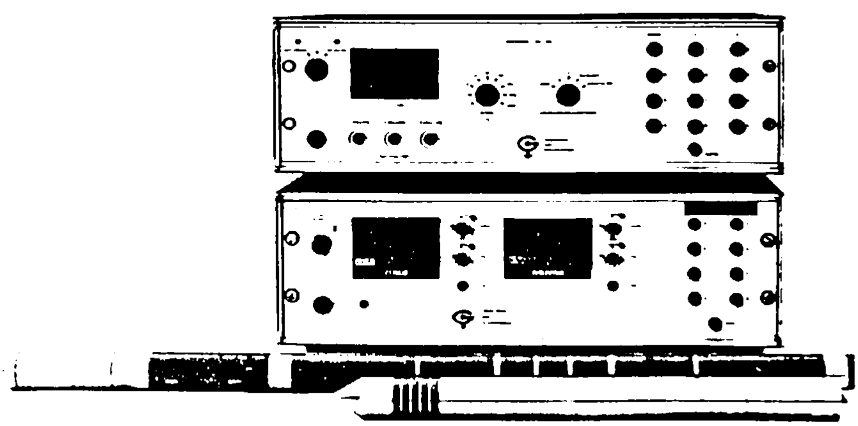

Fig. 27 Measuring equipment.

2.1.2.2. Densitij measurements with the aid of nuclear radiation
(Ir. P. A. Ruygrok)

The nuclear densitometer can provide information on the (wet) bulk density and/or the moisture content of soil strata of varying composition and varying degrees of saturation. If desired, further information on the dry bulk density and pore volume can be derived from this, provided that there is a reasonably reliable indication of the content of organic matter, which must be less than 6% in weight (higher percentages will require appropriate corrections).

Procedure:
In the determination of the wet bulk density the gamma radiation emitted by a suitable source (unstable radioisotope) is attenuated by scattering and/or absorption.

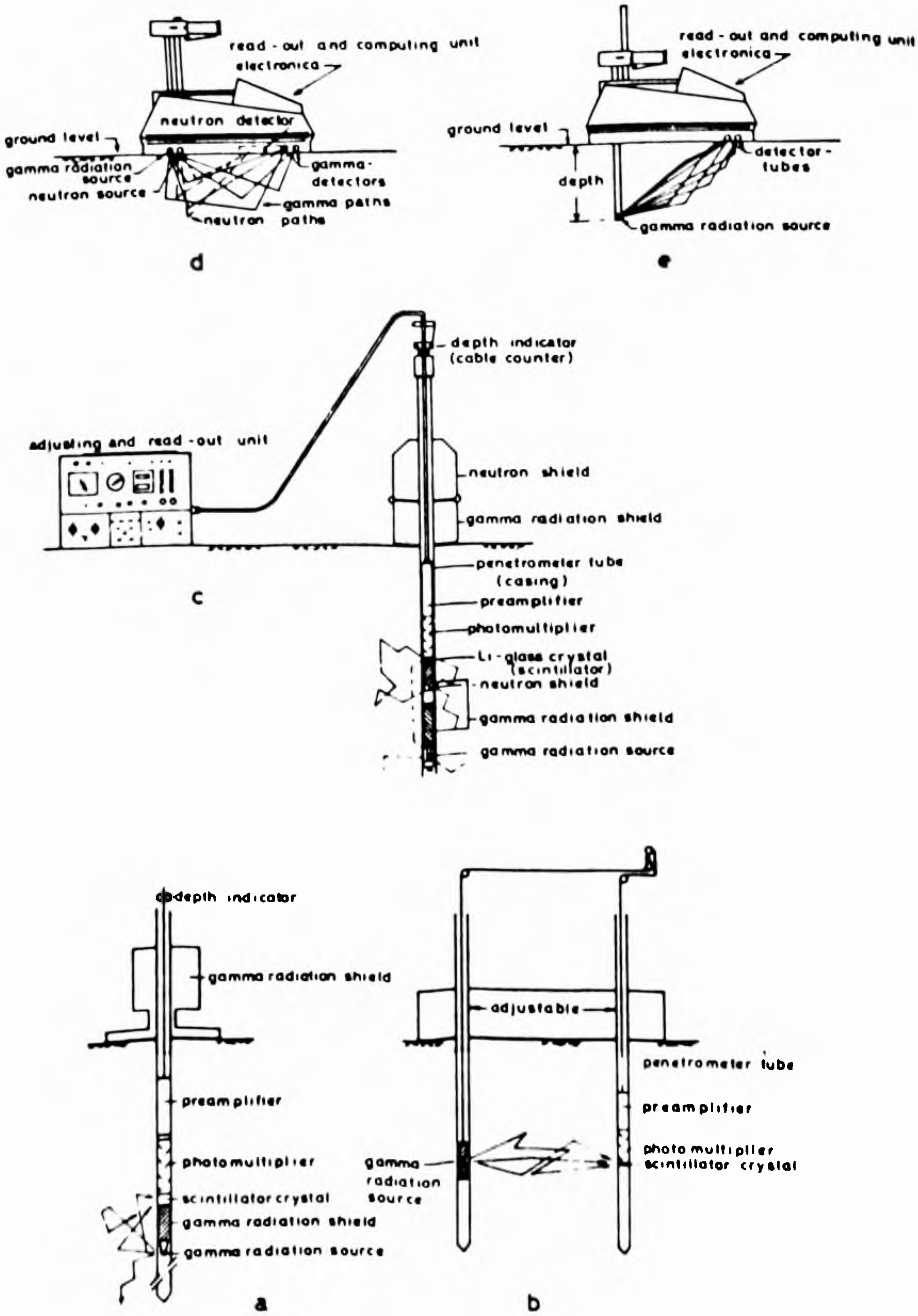

Fig. 28 Possibilities for performing density measurements with the aid of nuclear radiation.

In cases where the source of radiation and the detector, separated by the soil under investigation, are placed facing each other in the ground, the apparatus is called a *transmission probe* (Fig. 28b and e).
If the source and the detector are separated from each other by a radiation shield (i.e., direct transmission of radiation is thus ruled out), the procedure is referred to as the scatter method (Figs. 28a, c and d).

In terms of technique applied in performing the measurements a distinction is to be drawn between surface probes (Fig 28d), sometimes combined with a facility for operating at shallow depths below ground level, in which case only the radiation source penetrates to a maximum depth of 1 m (Fig. 28e), and deep probes (Fig. 28a and c).
Depending on the nature of the subsoil and the degree of saturation, there are various versions of this last-mentioned category of equipment. In saturated mud both the scatter method and the transmission probe can be used, in which circumstances a high-duty detector (high measuring rate, continuous measurement is possible) is often utilized by preference. In saturated dense soil it is at present only possible to employ the scatter method – in which one tube penetrates into the ground – without involving major complications.
In unsaturated soil it is becoming increasingly frequent practice to employ a detector which is sensitive both to gamma radiation and to slow neutrons for moisture content determination (practicable only if the subsoil does not contain too much organic matter). In the determination of moisture content, fast neutrons are greatly slowed down more particularly by hydrogen nuclei and thus provide, in terms of the hydrogen concentration, a measure of the moisture concentration. So far, only the neutron *scatter* technique has proved operationally serviceable for investigations performed in situ (transmission procedures are very awkward to perform).
Since equipment using crystal detectors operates 10–200 times faster than that using gas-filled counting tubes (5–10 minutes measuring time required), the Delft Soil Mechanics Laboratory has adopted the first-mentioned type.
As regards the *applicability* of the deep probe the following can be said.
A distinction must be drawn between penetration probes and measurements in (sometimes semi-permanently) cased boreholes.
In order of decreasing accuracy of the results obtained, the following soils are amenable to in-situ measurement by means of the penetration probe:
- saturated silty mud strata, silty mud deposits } gamma probe only
- saturated clay and clean peat } gamma probe only
- unsaturated soil } combined probe
- densely packed sand } combined probe
- loosely packed sand } combined probe
- ore deposits (gamma probe; neutron probe only if specially calibrated for the purpose).

If a *cased borehole installed with care* (least possible disturbance of the soil) is used, preferably with a plastic or light metal casing, the applicability of the technique will be much enhanced, more particularly when applied in sand, because then only very slight disturbances occur within the active measuring volume. The density measurement may, for example, serve the following purposes:
- monitoring the quality of sand beds and of soil stabilization;
- determining the degree of consolidation, criteria for the dredgeability of silty mud deposits;
- determining the moisture content for optimum compaction;
- approximate estimation of age and weathering of peat strata.

Other aspects concern the relationship between the packing density of granular soil (up to about 20 mm particle diameter) measured in situ and other properties determined in the laboratory or in situ (permeability, angle of internal friction, relative and critical density).

Accuracy:

– *Gamma radiation method:*
For unsaturated soil it is recommended to work with the so-called equivalent mineral density, defined as $\gamma_{eq} = (1 + 0.11\ m_w + 0.12\ m_o)\ \gamma_{wet}$, where m_w and m_o denote the proportions (by mass) of water and organic matter (radiation detection level > 0.15 MeV) respectively
Apart from technical aspects of measurement and calibration (enabling the intrinsic accuracy of the instrument to be kept below 0.01 t/m³), when penetration probe measurements are performed in cohesive soil and densely packed sand, a compaction effect of the order of 0.2 – 0.5 % must be reckoned with. In loose sand this may be as much as 1.5% (in the magnitude of γ_{dry}!). On the other hand, no significant disturbing effect has been found to occur in mud. Other corrections become necessary only if the soil contains more than 6% organic matter or more than 3–5% heavy metal (by weight).

– *Neutron method:*
The accuracy is greatly dependent on the make of the equipment used and on calibration facilities, and it is further limited by the content of bound hydrogen as well as trace elements in ground-water (B, Cl) and by solids (K, Mn, Cd, Fe, Ni), unless special filters (Cd or B4C foil) are employed (which increase the length of time required by the measurements, however).

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2.1.3 Permeability measurements in situ

(Ir. M. A. Viergever)

The most commonly employed methods of determining the permeability of soil strata in situ are based on the 'falling head' principle or on the 'recovery' method. The measurements are carried out in a cased borehole.
In both methods the water level in the borehole casing corresponds to the groundwater level existing in the stratum at the bottom of the hole, i.e., at this stage no water flows into or out of the casing. When the falling head test is applied, water is added so as to raise the level in the casing, resulting in outflow of water from the casing into the surrounding soil. In the recovery test the water level in the casing is lowered, so that water flows into it from the surrounding soil. The rate at which the water flows out of or into the borehole casing is a measure of the permeability of the soil.
Since a cased borehole has a fairly large diameter, a substantial quantity of water has to flow in or out. The above-mentioned methods can therefore suitably be used only in reasonably permeable soils such as sand or very sandy strata.
Drawbacks of these methods are the many possible disturbing influences associated with the manner of execution, e.g., disturbance of the strata around the borehole casing, leakages along the casing, silt or clay deposits at the bottom of the borehole, and 'boils' associated with the inflow of water into the casing.
It is essential that the soil in the casing is carefully removed by means of a shell (or bailer) and that the water levels inside and outside the casing are maintained as nearly equal as possible while it is being installed at the required depth in the ground. The casing must certainly *not* have a thickened edge, as is sometimes employed in order to reduce friction on the outer face of the casing.

The Delft Soil Mechanics Laboratory has devoted a good deal of attention to the execution of permeability tests. This has resulted in the development of methods

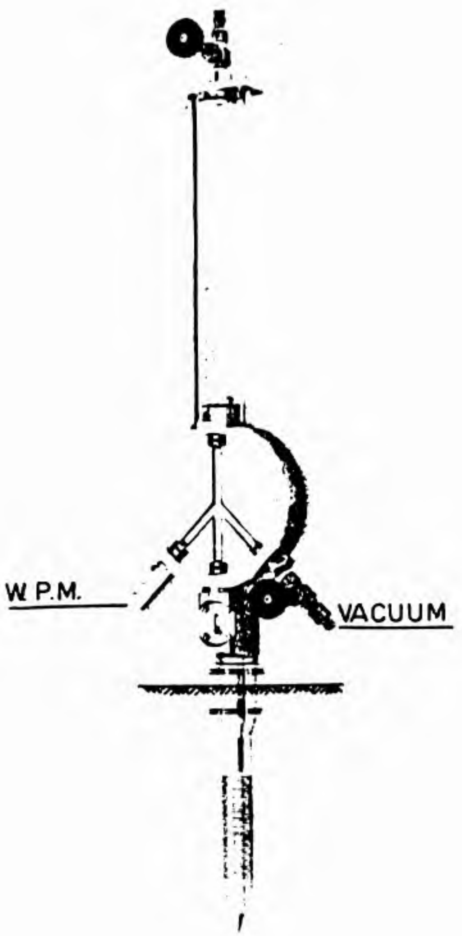


Fig. 29 In-situ permeability measuring equipment for cohesive soils.

for measuring in very poorly permeable strata such as clay and to the improvement of methods for measuring the permeability of highly permeable soils.

Measurements in soils of low permeability are performed with the aid of an apparatus as illustrated in Fig. 29. It comprises a probe which can be forced into the ground and which is provided with a filter composed of rings with gaps that widen inwards in order to minimize the risk of blockage. At the top the apparatus can be sealed off from the external air and is connected to a water pressure gauge and a vacuum vessel. When the probe has been forced into the ground, the apparatus is completely filled with water and sealed off from the external air. Some of the water will flow out of the apparatus into the ground and thus produce a vacuum inside the top part of the apparatus. After a time a state of equilibrium develops, which can be read on the water pressure gauge (which thus indicates the existing water pressure). Next, the connection from the filter probe to the rest of the apparatus is closed, and a certain quantity of air is then introduced into the top part of the latter at such low pressure that, when the connection to the filter is opened again, water will flow in from the surrounding soil. The rate of inflow of this water, which can be measured with the aid of the water pressure gauge and a stop-watch, will depend on the geometry of the filter, the volume flexibility of the enclosed air, and the permeability of the soil around the filter. According to the size of the enclose air volume, more water will have to flow into the apparatus in order to cancel the negative pressure. In this way, by appropriate choice of the volume of air enclosed in the apparatus, a value of the permeability coefficient k can quickly be determined even in poorly permeable clay soils.

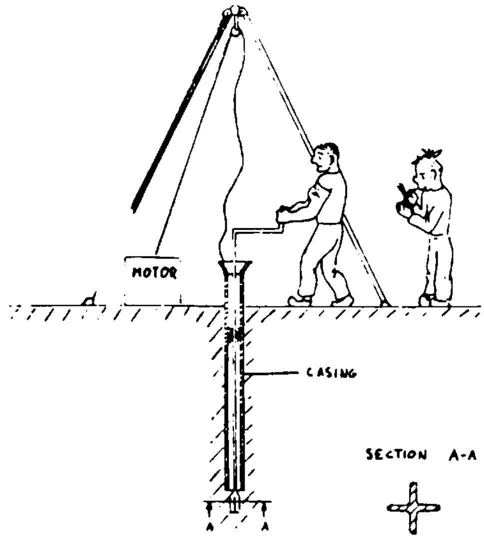
The constant head test is used for permeability measurements in sand. In this procedure the permeability coefficient k is determined under conditions of steady-state flow from the flow rate and the magnitude of the negative pressure applied in relation to the existing water pressure.

The measurement is performed in a carefully made borehole and proceeds by working from the bottom upwards. An impervious plug is formed at the bottom of the hole into which a filter is lowered. The space between the filter and the hole is backfilled with fine gravel. Then the casing is pulled up a distance corresponding to the height of the filter and the casing is closed above the filter and gravel with an inflatable seal. At the top of the suction tube the water is drawn up by suction into a transparant standpipe in a volume-measuring cell. The negative (suction) pressure at which the water just does not flow out over the pipe is determined, and then the negative pressure at which a certain rate of flow emerges from the pipe into the volume-measuring cell. With the aid of refined measuring techniques it is possible to determine the flow rate and negative pressure with considerably accuracy even when measurements are performed in highly permeable sands.

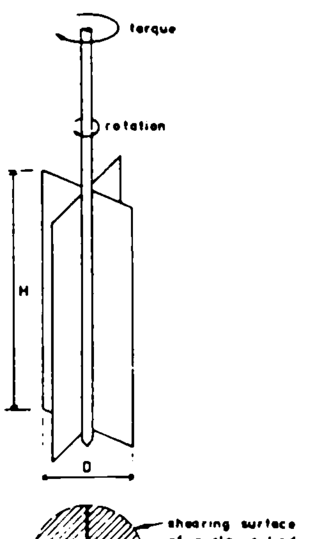
2.1.4 Vane test

(Ir. E. Hoogkamer)

Object:
The object of the vane test is to determine the shear strength (apparent cohesion) of saturated cohesive soils by means of a cylindrical rotary shearing test.



Vane test.



The vane test:
A cruciform (four-bladed) vane is carefully forced into the undisturbed soil and then rotated about its vertical axis, causing the cylindrical mass of soil within the vane to shear off. The torque required to do this is measured. Fig. 30 illustrates the principle of the test.
The height of the vane is usually equal to twice its diameter. A larger diameter is used in softer soils than in stiffer ones.

Fig. 30 Vane test.

Interpretation:
If testing is done in a saturated cohesive soil for which – in view of the speed with which the test is performed – the apparent φ can be taken as zero, so that only an apparent cohesion is acting on the shearing surfaces, interpretation of the results is a simple matter. For this purpose the cylindrical mass of soil is assumed to have a radius and a height equal to those of the vane.
In that case the apparent cohesion acts upon the vertical cylindrical surface and on the top and underside of the cylinder. The moments (resisting torque) developed by these forces in relation to the vertical axis are simple to calculate. The apparent cohesion values obtained in this way are, according to various investigators, such as Dr. L. Bjerrum [23], on the high side.
According to Bjerrum the correct value may vary between 100 and 70 % of the measured value depending on the plasticity index. A percentage of approx. 70 %

is in good agreement with the values measured by means of the adhesion jacket cone using the mechanical penetrometer.
The interpretation of the results of a vane measurement involving a non-zero apparent φ becomes more difficult and far less accurate because in such cases it is necessary to make an *assumption* as to the *state of stress* around the vane. This test is indeed not to be recommended for such soils.
The *accuracy* of the test is largely dependent on the *manner of execution*. In principle, there are two possible procedures:
(1) the vane is lowered into a borehole and pushed down into the soil at the bottom of the hole;
(2) the vane and its extension rods, enclosed within a casing (set of tubes), is forced into the ground to just above the required testing depth, after which the vane is pushed further down beyond the lower end of the casing into the as yet undisturbed soil.
These two possibilities are indicated schematically in Fig. 31.

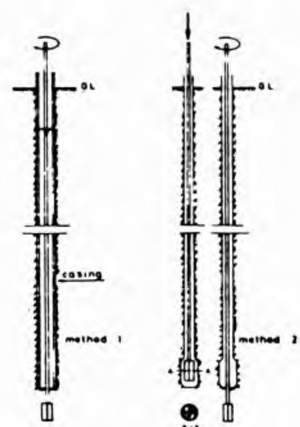


Fig. 31 Procedure for performing the vane test.

Method (1) (vane test in a borehole) has the advantage that, when an exploratory boring is carried out, the test can be performed, at little extra cost, at many different depths during the boring operation and also at great depths underground. There are, however, two major drawbacks:
(a) the drilling or boring method and the supervision of boring operations can very greatly affect the degree of disturbance, or absence of disturbance, of the *soil just below the bottom of the borehole;* with regard to this problem the reader is referred to what has been said about boreholes and sampling in Sections 1.2 and 1.3;
(b) when working at greater depths and with insufficient lateral restraint against buckling of the extension rods of the vane the subsoil may be remoulded as a result of forcing the vane into it.
Method (2) has the advantage of offering the best guarantee that the soil to be tested is undisturbed. Against this is the disadvantage that it is suitable only for relatively soft soils. If a sand stratum of any significant thickness is encountered, it soon becomes virtually impossible to force the vane further in.
Although method (2) is used by preference wherever possible, both methods can of course be applied by the Delft Soil Mechanics Laboratory.

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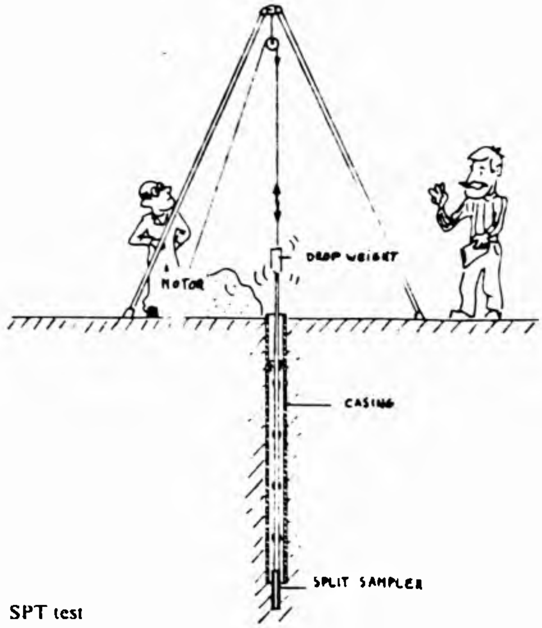
2.1.5 Standard Penetration Test (SPT)

(Dr. Ir. H. K. S. Ph. Begemann)



SPT test

System:
A soil sampler attached to extension tubes is lowered to the bottom of a borehole. The sampler is then driven into the subsoil by blows delivered by a drop weight. All the dimensions of the sampler have been specified by Terzaghi and Peck (ASTM Standards designation D 1586-67), including its outside diameter of 50 mm and its length of approx. 500 mm; the weight is 0.63 kN and its height of drop is 750 mm.
The number of blows N required to achieve 300 mm penetration of the sampler into the subsoil is stated as the result of the test.

Object of the test:
The object is to obtain soil parameters deduced from the number of blows N, having due regard also to the character of the soil (soil sample) in which the test was performed. At the same time, the test provides the required sample of the soil.

Accuracy:
The care exercised in forming the borehole is a major factor in determining the accuracy of the test. If the water in the hole is kept too low, a decrease of the density is liable to occur in sand and sandy soils in consequence of 'boils' at the bottom of the hole. In that case the value obtained for N will be too low. If the borehole casing has not been completely cleared of soil down to its lower edge, the first part of the penetration of the sampler under the action of the blows will occur inside the casing. In such circumstances there is, in sandy soils, considerable risk of obtaining excessively high values of N because of the lateral restraint and locking action of the sand in the bottom part of the borehole casing.
Since the blows for driving the sampler into the subsoil are applied above ground level, the length and horizontal rigidity of the extension rods to which the sampler is attached play an important part. When working at relatively great depths a large proportion of the impact energy may be absorbed by horizontal vibration and thus be lost to the sampler.
The test itself mainly provides a measurement of friction on the outside and inside of the sampler.
Results of cone penetration tests with the friction sleeve have clearly shown that the ratio between cone resistance and local friction depends on the composition of

the soil (see 1.4.1). The fineness of the sand also plays a part in this connection. Attempts to establish a direct correlation between N and cone resistance for cohesive and non-cohesive soils can therefore not yield reliable data. A closer approximation will be possible only if the composition of the soil (granulometric grading) is included in the investigation.

The SPT cannot be regarded as a refined and reliable test. It merely provides preliminary indications as to consistency and density of the various strata. SPT results are only approximately comparable with soil mechanical parameters in the subsoil.

More detailed comments are contained in the General Report for Central and Western Europe of the European Symposium on Penetration Testing which was held at Stockholm in 1974 [17].

Reference

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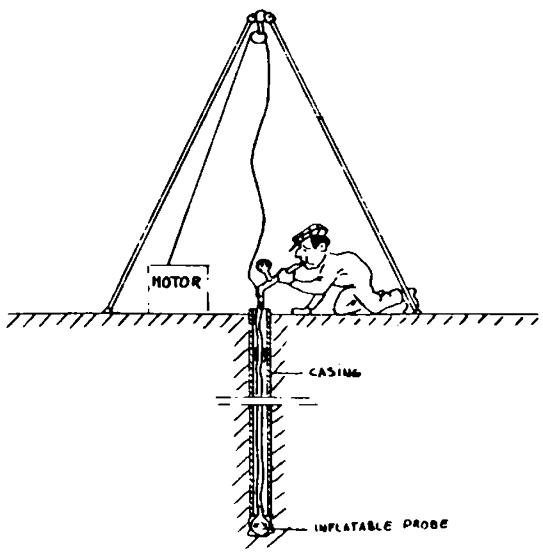
Proceedings of the European Symposium on Penetration Testing, Stockholm, 1974

2.1.6 Pressuremeter test

(Ir. J. Kruizinga and Ing. H. C. van de Graaf)

Object:
The object of the pressuremeter test is to determine the strength-deformation characteristics of the soil in situ. A number of tests can be performed on any given vertical line (e.g., at intervals of 1 metre; 0.60 m is the minimum spacing). The number and choice of subsurface levels at which testing is to be done will depend on the soil profile and on the nature of the project.



Pressuremeter test

Principle of the test:
In principle, the test consists in introducing into the ground a probe which is radially deformable in the horizontal direction. When the desired subsurface depth has been reached, the pressure in the probe is increased step by step, each step being maintained for a certain length of time. At the same time the horizontal volume changes of the probe are measured. The predicated plane strain condition is considered to be achieved by providing a pressurized guard cell above and below the measuring cell in the probe (see Fig. 32). The result obtained is shown in very generalized graphical form in Fig. 33 (measured volume plotted as a function of the pressure applied).

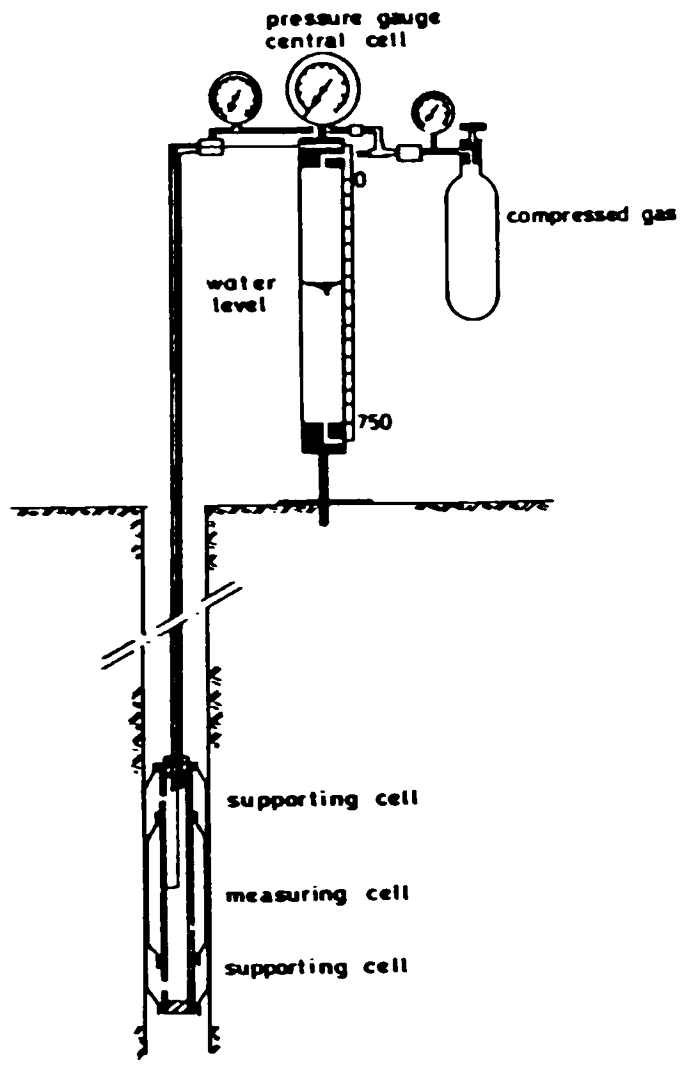


Fig. 32 Pressuremeter test set-up.

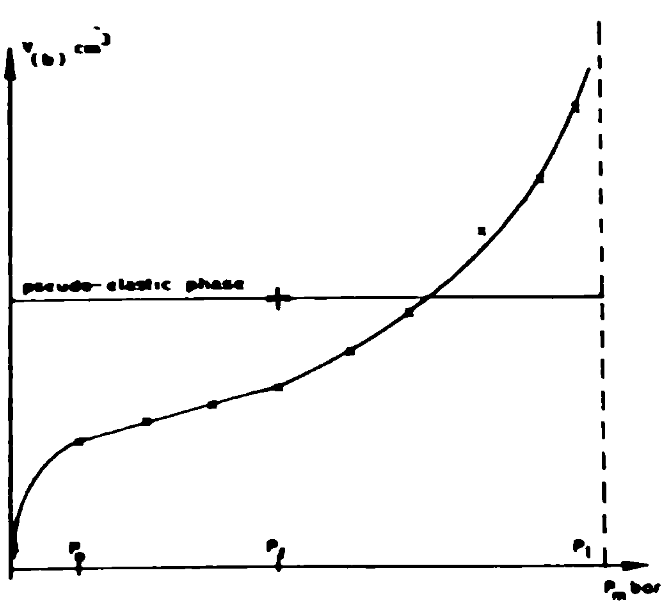


Fig. 33 Result of pressuremeter test (uncorrected curve).

Execution of the test:
The following procedures may be applied; all are based on the principle that there must be good contact between the probe and the soil:

- By sinking a borehole by rotary mud flush *boring*, the sides of the hole being supported by a fluid of high specific gravity over a height of, say, 3 to 5 m. The probe is then inserted and the test performed, on completion of which the probe is lowered to the depth of the next test (e.g., 1 or 2 m deeper).
  After the tests have been performed all the way down to the bottom of the borehole, the probe is removed and the hole bored to a greater depth. The reason for thus sinking the hole in successive stages is that, because of relaxation of the soil surrounding the hole, the length of time between boring and testing must not be too long.
  This method is widely used in sandy soils, hard clays and rock.
- By *driving* a steel tube, containing the probe, into the ground. This tube is provided with longitudinal slots and thus has low rigidity in the radial direction. On completion of the test, the tube is driven further into the ground until it reaches the required depth for the next test. If the penetration resistance encountered by the tube becomes too high after 2–4 m, the tube with the probe in it is pulled out of the ground. A cased borehole can then be formed – by means of a shell, for example – down to the level of the previous last test, after which the tube containing the probe can be re-inserted and driven further into the ground. This method is used in sandy soils and soft strata.
- By the so-called *retrojet* method. This method provides qualitatively the best contact between the measuring cell and the surrounding soil because the latter undergoes the least disturbance with this technique. The cells are enclosed in a thin-walled steel tube which is open at its lower end and is forced into the ground by lightly applying pressure to it. The soil that enters the tube is carried away up the tube by a jet of fluid directed obliquely upwards. About 1 m above the measuring cell the tube tapers and from here onwards the material is flushed along the outside of the extension tubes on its upward journey. The carrier fluid used in the apparatus is a very thin bentonite slurry which is discharged in spurts at intervals of 2 seconds, in very small amounts, at a pressure of 100 atm. from the injection holes at the bottom of the tube.
  This method is used in sandy soils as well as in soft strata. It is be noted that the execution of these tests is somewhat time-consuming and therefore tends to make them more expensive.

Soil mechanical parameters that can be obtained:
(a) *Directly calculable parameters*
The following can be determined from the pressuremeter curve corrected with reference to a calibration curve:

1. The '*pression limite*' P_l (= limit pressure) and the associated '*pression fluage*' P_f (= yield pressure = end of pseudo-elastic zone).
2. The '*module pressiométrique*' E_p (= deformation modulus = the 'slope' of the pressuremeter curve in the pseudo-elastic zone).
3. The *horizontal earth pressure at rest* P_o (= start of the pseudo-elastic zone).

The 'pression limite' P_l gives an idea of the strength, while E_p is a measure of the rigidity of the soil.

(b) *Derived parameters*
By introducing one or more *empirical factors* as given by Ménard it is possible to calculate, inter alia, the *horizontal coefficient of soil reaction*. There is considerable divergence of opinion on these empirical factors, however, and in France, too, their country of origin, they are still a controversal subject.

Application:
In the Netherlands the Delft Soil Mechanics Laboratory has been studying this

in-situ testing method in the last few years, more particularly in connection with large and special construction projects.
In such cases the object has chiefly been to investigate restraint (fixity) conditions and earth pressures in connection with the supporting towers for the cableway used for dumping stones in the dam closing the Eastern Scheldt, the 'semi-metro' railway viaducts at The Hague, and a cofferdam at Den Helder.
In anticipation that further possibilities for applying this technique to soil investigations under Netherlands conditions will emerge, e.g., determinations of K_0 (the horizontal effective overburden stress), the Delft Soil Mechanics Laboratory has procured complete equipment for performing the various possible modes of this test.

Interpretation of the (standard) pressuremeter test:
The interpretation of a standard pressuremeter test consists essentially in determining P_l, P_f, P_0, and E_p from the pressuremeter curve after it has been duly corrected (with the aid of the calibration curve).

$E_p = K \frac{\Delta P}{\Delta V}$, where:

K = compression coefficient of the probe employed

$\frac{\Delta P}{\Delta V}$ = the inverse of the slope of the 'straight' portion of the pressuremeter curve (in the pseudo-elastic zone)

$K = 2(1 + \nu) \cdot (V_0 + v_m)$, where:

ν = Poisson's ratio = 0.33 (assumed)

V_0 = volume of the measuring cell at rest

v_m = volume of the liquid in the measuring cell, corresponding to the mean pressure P_m $(= \frac{P_0 + P_f}{2})$ applied in the pseudo-elastic zone.

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2.1.7 Camkometer test

(Ir. J. J. Broeze)

The Delft Soil Mechanics Laboratory has recently gained its first experience with the device called the camkometer for determining the ratio between horizontal and vertical overburden stress. Developed at Cambridge and deriving its name from that town ('Cambridge K_0-meter'), it consists of a thick-walled hollow cylinder provided on its lateral surface with four load cells for measuring the horizontal pressure of the soil. The cylinder is jacked into the ground; the soil entering it is

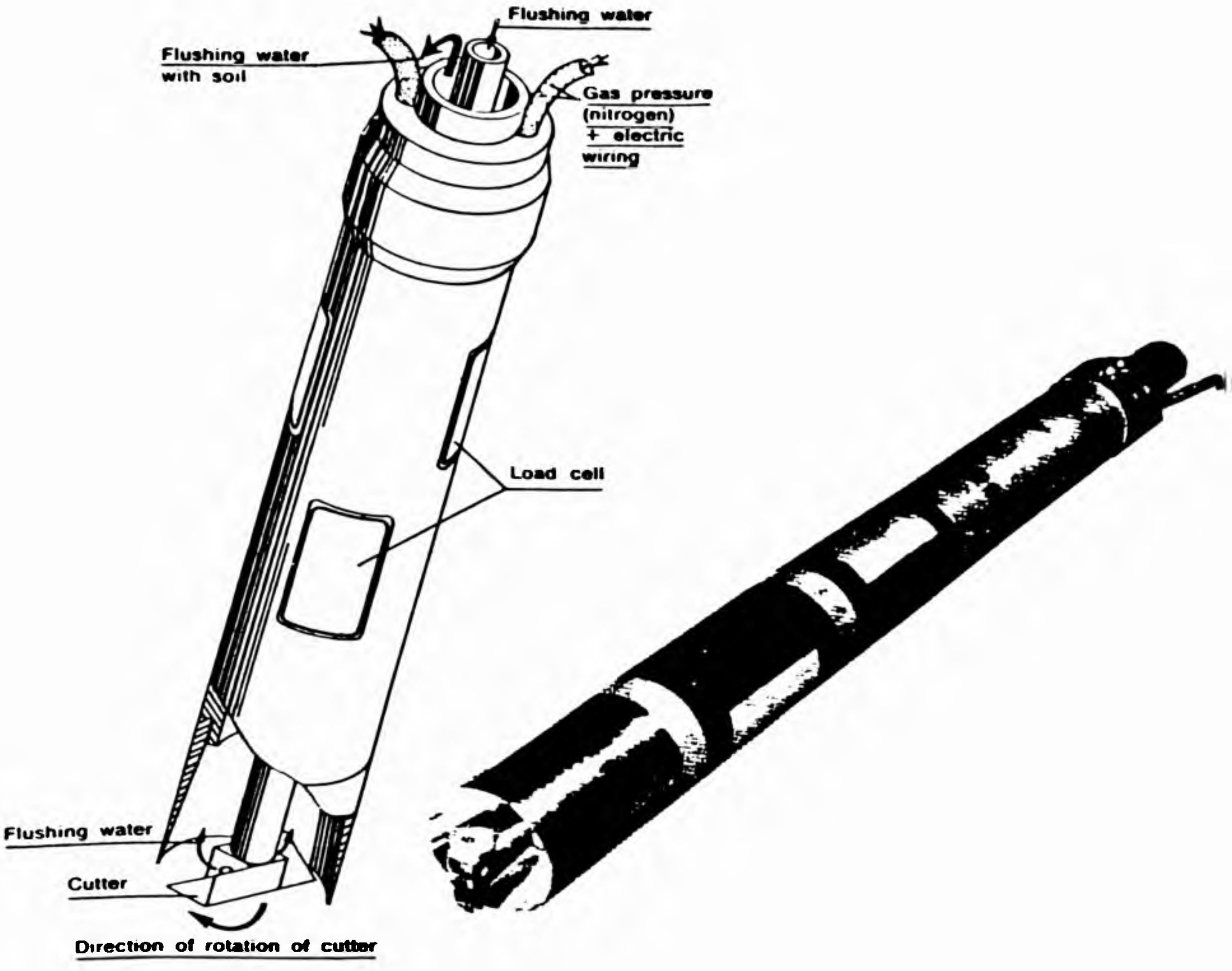

Fig. 34 Camkometer

brought to the surface with the aid of a cutter and water flushing, so as to form an undisturbed borehole (see Fig. 34).
The cutter is driven by a hollow shaft through which water flows for carrying the dislodged soil upward through the space between the cutter shaft and the inner surface of the cylinder. Each load cell for measuring the horizontal pressure of the soil on the cylinder consists of a rectangular plate cut out of the cylinder wall and connected at its corners to the latter by means of four strips provided with electrical resistance strain gauges.
When the camkometer has been introduced into the ground in the manner described, the load cells are subjected to loading by the surrounding soil. This loading on the outside is compensated by the application of gas pressure on the inside of the load cell. By varying the gas pressure it is possible to determine that value of the pressure which corresponds to the zero reading of the strain gauges. The K_0-value is then obtained as the quotient of the measured horizontal and vertical overburden stress. This information on the initial state of stress in the subsoil is of importance in connection with analytical and numerical stress calculations.
At the present time it is not yet possible to say much about the accuracy of the measurements because only a small number of tests has so far been carried out.

2.1.8 In-situ California Bearing Ratio (CBR) test
(Ing. W. F. Heins)

Object:
The object of the test is to determine the so-called CBR value of undisturbed upper layers of the soil. It is a standarized test in which the resistance encountered by a plunger penetrating into the top layer of the soil is measured and derives its name from the California Division of Highways, which devised it. The results of these tests are correlated with the behaviour of motor roads with pavements of flexible construction. Utilizing the experience gained in this way a design method for flexible pavements was established, based on the CBR value of the undisturbed subgrade and the CBR values of the pavement layers to be installed.

Execution of the test:
Although it was originally designed as a laboratory test, the CBR test is also applied to in-situ measurements. The procedure is the same in both cases.
A plunger of 50 mm diameter is pushed down at a constant penetration rate of 1.25 mm per minute into the top layer of soil to be tested until an overall penetration depth of 12.5 mm has been reached. The forces that have to be applied to the plunger in order to reach depths of 2.5, 5.0, 7.5, 10.0 and 12.5 mm are noted. These values are compared with, and expressed as percentages of, corresponding values obtained with a standard sample of well-compacted crushed stone (100%). These percentages (CBR values) usually decrease with increasing penetration depth, but in some materials they increase.
In the former case the CBR value associated with 2.5 mm penetration of the plunger is adopted as the design value for the layer concerned. In the latter case the CBR value associated with a penetration of 5 mm is adopted.
The test is performed with a specified surcharge acting on the layer around the plunger. The surcharge is applied by means of a steel plate of specified dimensions and with a cylindrical hole in the middle through which the plunger can move freely.

The penetration depths are measured with the aid of a dial gauge or a device called a Linear Voltage Differential Transformer (LVDT).
For carrying out the test in situ the weight of a motor truck provides the dead weight to resist the jacking reaction. A small hydraulic jack is placed under the front of the vehicle and applies its force through a dynamometer ring to the plunger of the CBR test apparatus. The dial gauge is mounted on a measuring beam of such length as not to influence the displacement measurement. The test set-up is illustrated in Fig. 35.

Fig. 35
Set-up for CBR test in situ.

Application:
As already mentioned, the results obtained are used for the design of flexible pavements. Design charts are available for motorways and for airfield runways. Such charts give the relationship between the CBR value obtained for a particular layer, the wheel load and the pavement structure needed above that layer. In this way it is possible to achieve a more balanced design for pavements by ensuring that the CBR values of the constituent layers progressively increase from the bottom of the pavement upwards. For further information the reader is referred to the literature [30].

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2.1.9 Plate bearing test

(Ing. W. F. Heins)

This in-situ test consists in applying a test load enabling the load-deformation relationship of the subsoil (road subgrade or fill material) or of the sub-base or of the pavement as a whole to be determined. These measured data can be used for, f.i., the design of flexible as well as rigid pavements and the checking of existing ones.
A check may be necessary, for example, in a case where the existing pavement is subjected to heavier working loads, which frequently occurs on lower-order airfields from which, after a time, heavier aircraft than originally anticipated have to operate. This is especially likely to occur on military airfields.
The plate bearing test is performed not only for pavements, but also for obtaining data for the design of raft and spread foundations (modules of subgrade reaction). In this case the test can be regarded as a simple in-situ test.

Execution of the test:
A circular steel plate is used. Its diameter depends on the depth at which the test is performed and on the dimensions of the actual load in the ultimate situation.
For wheel loads the circular shape of the plate is the simplest simulation of the contact area of the wheel and is accordingly chosen. The plates employed must be rigid; permissible deflections of these plates are to be found in the literature.
The plate diameter should be not less than 0.30 m and will be very seldom larger than 0.75 m because of the magnitude of the load that has to be applied. The plate diameter will furthermore depend, inter alia, on the grain size of the material to be tested.
A hydraulic jack and an electric load cell are placed on the plate. The load cell should enable the applied force to be measured accurately (with an accuracy better than 1% of the measuring range); its output signal may moreover be used for electrically controlling the hydraulic oil pump of the jack, but only for *force-controlled* tests. It is necessary to use an electric load cell on account of the friction occurring in the jack. This friction not only depends to a great extent on the quality of the jack, but also on the oil pressure applied.
In cases where the load to be applied is not too great, the reaction of the jack is resisted by the dead weight of a heavy vehicle, more particularly one used for cone penetrometer tests (see Fig. 36).
For plate bearing tests which have to simulate very heavy loads, such as those due to aircraft, container transport vehicles or heavy industrial loads (as may occur on the yards and hard-standings of engineering works, raw material processing plants,

Fig. 36 Plate loading test.

etc.) a specially designed 'ballast truck' is employed for the purpose. This vehicle can also be used for carring out the so-called rolling test (see Section 3.5.2).
Measurement of the deflection (downward movement) of the plate is normally done by means of three electrical displacement transducers disposed around the perimeter, providing three readings which can be averaged to take account of possible tilting of the plate. The accuracy of these instruments is about 0.1% of the measuring range. In addition, the measuring signal from the transducers can be used for controlling the system if a *displacement-controlled* test is required. The transducers should be attached to a measuring beam whose supports are located sufficiently far from the loading test plate that the downward displacement of the latter will not affect the measurements by causing the beam supports also to undergo some downward movement. Obviously, this 'sphere of influence' of the plate will depend, inter alia, on the rigidity of the layer to be tested and on the magnitude of the loads applied to it.

Test procedure:
The procedure applied in carrying out the plate bearing test varies quite a lot from one country to another, as does the procedure for determining the strain modulus and modulus of subgrade reaction (k-value) from the measured data.
The Delft Soil Mechanics Laboratory has already for some considerable time followed a fixed procedure. Just as in most other countries, a pre-load of 0.02 MN/m^2 is applied to the plate before the start of the test. The object of this pre-load is to eliminate any play in the system and furthermore to press the plate into firm contact with the layer to be tested.
In carrying out the test the pressure is then increased step by step – 0.02, 0.05, 0.1, 0.15 MN/m^2, etc. – until the maximum requisite test load, appropriate to the maximum actual load that the layer will have to carry, has been reached. After a loading period of not less than half an hour and not more than one hour, each loading step is repeated five times, the load in each case being reduced, not to zero, but to the pre-load value of 0.02 MN/m^2. In this way the overall deformation can be separated into plastic and elastic deformations.
Of course, it is desirable to have a standardized testing procedure for the sake of obtaining results that are comparable with one another.

Interpretation:
With the aid of the measured pressures and the measured deformations resulting from these pressures it is possible to calculate the so-called strain modulus E_v (known also as the M_E-value). In many cases the modulus of subgrade reaction (k-value) is calculated from the measured results.

The strain modulus is determined from: $E_v = f \cdot r \cdot \frac{\Delta P}{\Delta S}$

where: f = factor 1.5 or 2
r = radius of the plate
ΔP = increase in pressure (or stress)
ΔS = increase in deflection associated with ΔP

E_v therefore has the dimension of a stress.
The k-value is the pressure (or stress) on the soil that produces a deflection of 10 mm and is therefore expressed in terms of stress per unit length.
It should finally be noted that the plate loading test equipment described here can be used not only for static but also, if so desired, for dynamic testing.

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2.2 Determining the ground-water pressures in the various strata

(Ing. H. C. van de Graaf)

Depending on the permeability of the stratum concerned and on the period of time within which changes in the ground-water pressure occur, the pressure is determined with the aid of an open standpipe or with a certain type of water pressure gauge.

2.2.1 Standpipes

Mode of operation:
A standpipe consists of a filter which is installed in the stratum concerned and is extended upwards by a pipe to a little above ground level. Since the pipe is open at the top, the water level inside it will correspond to the head (= pressure) of the ground-water in the stratum. If the ground-water pressure changes, the water level in the standpipe will correspondingly change. For this to happen, however, a fairly substantial quantity of water has to flow through the filter into or out of the pipe. In a permeable stratum (sand and gravel) the change in water level in the standpipe will be accomplished within a reasonably short time (ranging from a few minutes to several hours). In poorly permeable soil (peat, clay), however, it could take many days for the change in water level to be completed, and in highly impermeable soil it could indeed take weeks. The time that elapses before the standpipe indicates the new (i.e., altered) ground-water pressure is called the *adjustment time*. In general, the adjustment time should be much shorter than the length of time within which the change in ground-water pressure takes place.
If the adjustment time of a standpipe is too long, a water pressure gauge will have to be used instead (2.2.2 to 2.2.5). Such a device has a much lower *water consump-*

tion, i.e., the quantity of water that has to flow through the filter into or out of the measuring device as a function of the change in the water pressure to be recorded. (In all water pressure measuring devices it is necessary for water to flow in or out through the filter in order to enable a change in pressure to be measured).

Installing procedure:
According to the method by which they are installed, two categories of standpipes are to be distinguished:
- standpipes that are forced into the ground;
- standpipes that are inserted into boreholes.

Standpipes forced into the ground:
A standpipe of this type consists of a series of 1" seamless steam pipe lengths (similar to gas piping, but with a thicker wall) in which the part just above the closed bottom end is provided with small holes, usually over a height of 200 mm, and is enclosed with a copper gauze filter. Depending on the equipment used for forcing the standpipe into the ground, the lengths of piping range from 1 to 3 m; they are joined to one another by means of external socket joints. The screw-threaded ends are packed with Teflon (PTFE) tape or with Hesorite and hemp. To ensure a good seal between the pipe and the surrounding soil the lowest socket is always at least 2 - 3 m above the filter. Depending on the soil strata, additional measures may be necessary in order to prevent communication between the various strata in consequence of the socket joints employed. This is a problem that requires particular attention in a case where standpipes to obtain pressure measurements at several different levels in the subsoil have to be installed in close proximity to one another.
In order to protect the filter from being choked with soil penetrating into it during the operation of forcing the standpipe into the ground, the pipe is kept entirely filled with water during this operation, so as to maintain an excess pressure inside it. On reaching the desired depth the water in the pipe is topped up in order to observe whether the filter is sufficiently permeable. The maximum attainable depth at which the filter can be installed by this method will depend on the compactness of the subsoil. If the soil is very compact, it will be necessary to install the standpipe in a borehole.

Standpipes inserted into boreholes:
These usually consist of 1" pipes provided with a 1 m long filter made of PVC, which are installed in the borehole formed by shell boring or Ackermann boring. The standpipe is installed in conjunction with the extraction of the casing from the borehole.
Fine filter gravel is deposited around the filter, and a good seal must be formed above the gravel. Sealing should be done expertly and carefully, especially in cases where two or three standpipes with their respective filters are to be installed in one and the same borehole. The connection to the standpipes as well as to the poorly permeable intermediate strata has to be 'leakproof', otherwise the measurements in the two or three different groundwater regimes may affect one another and their results thus be inaccurate. Fig. 37 illustrates this situation.
There are various methods of forming the seal. The simplest is to throw some of the soil extracted from the borehole – the 'clayiest' part of it – back into the hole in the form of little lumps. This procedure gives *no guarantee* that the seal will be formed in the right place and that no segregation of the soil will occur on its way down the hole.
Clay-bentonite pellets are now commercially available for the purpose. They are supplied in the dry state in bags. It is important that these clay pellets should have the right properties to provide adequate assurance that a 'leakproof' seal will indeed be formed.
One of the requirements is that the pellets soften quickly enough so that they will have formed a homogeneous sealing layer already before the next filter layer is

placed. Tests have shown that so long as they continue to exist as recognizably individual pellets in the sealing layer, the filter sand deposited on top of them can penetrate in between the pellets. It is therefore desirable to carry out a preliminary investigation of their properties.
In the more complex cases, such as those where two or three standpipes are installed in one borehole, the Delft Soil Mechanics Laboratory may have recourse to using a seal formed with a special *stiffening clay-cement mixture*, which is introduced through a tube reaching down to the desired depth. The fluidity and homogenity of this mixture offers the best guarantee for a 'leakproof' seal.

Although the cost involved is higher, the standpipe installed in a borehole offers the advantage of having a shorter adjustment time than that of a standpipe which is forced into the ground, because:
- there is no risk of the filter becoming clogged up while passing through clay strata which may be present above the level at which the filter is to be installed;
- the diameter of the filter is larger;
- the hight of the filter can be larger.

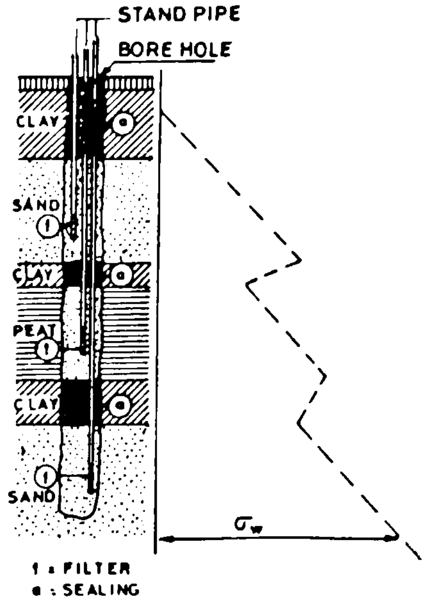

Fig. 37 Installing several standpipes in one borehole.

Observations in standpipes:
The following methods are to be distinguished:
a. manual readings;
b. float recorder;
c. water level scanner.

Re a
Periodical measurement of a change in water level in a standpipe is often done by hand. A special sounding probe attached to a thin string is lowered into the standpipe. When the probe comes into contact with the surface of the water, a lapping noise is heard, this being due to the concave shape of the underside of the probe. If there is a high background sound level in the vicinity of the standpipe and/or if the water is very deep down in the pipe, the lapping sound is inaudible at the top of the pipe. In such cases an electric probe is used instead. As soon as this device touches the water, electrical contact is made, causing a small lamp to light up at the end of the measuring tape. Provided that the water is not more than a few metres below the top of the standpipe, the accuracy of manual measurements is approximately 10 mm.

Re b
The float recorder is used in cases where continuous water level records over a fairly long period of time are required, e.g., for the determination of the effects of pumping or tidal motions. On the water in the standpipe is a float attached to a thin steel wire that passes round the pulley of the recording device (see Fig. 38). The accuracy of such measurements is approximately 10 mm.
On account of the diameter of the float, the standpipe should be of suitably enlarged diameter, e.g., 2.5" to 3", at least down to the lowest ground-water level that can be expected to occur.

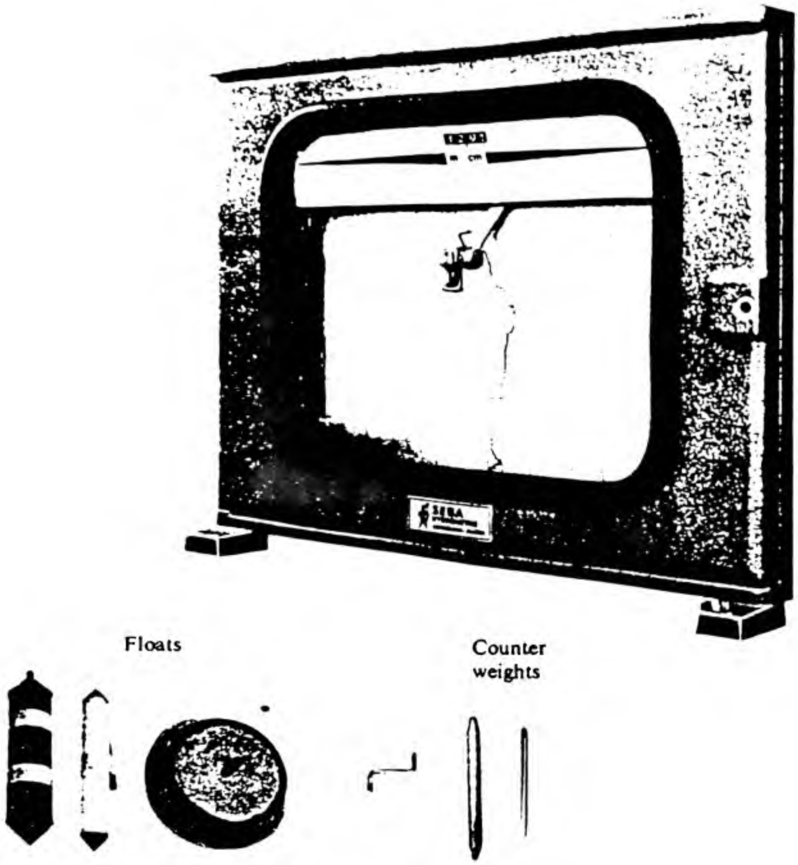

Fig. 38 Float recorder (Seba recorder).

Re c

The water level scanner is so equipped that remote recordings, i.e., at some distance away from the standpipe, are possible. Thus, when special tests with standpjpes installed in a number of places are carried out, the results of the measurements can be read and recorded at a central point. An electrode in the form of a probe suspended from a wire wound round a drum is lowered into the standpipe and closes an electrical circuit on coming into contact with the water in the pipe. As soon as this happens, a reversing relay in the circuit causes the drum to rotate in the opposite direction and thus raise the probe. As soon as the probe breaks contact with the water, the drum again reverses its direction and lowers the probe, which thus performs a continuous scanning motion (see Fig. 39).

The accuracy is approximately 7 mm. An advantage of this method is that the adjustment time is shorter because a standpipe of smaller diameter is used.

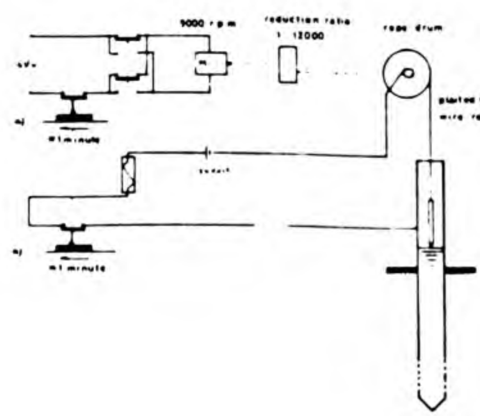

Fig 39 Water level scanner (schematic).

2.2.2 Bourdon water pressure gauges

A device of this type is merely a 19 mm standpipe with filter (see 2.2.1) which is forced into the ground and is connected to a pressure gauge. The pipe, which is closed at the top, is completely filled with water (closed system). In order to check this the upper part of the pipe consists of a so-called extension piece which is provided with a water level gauge glass (see Fig. 40) and with a filler cap at the top.

The Bourdon pressure gauge is connected to a point just below the gauge glass and has a measuring range from -100 to $+50$ kN/m^2.

The head of the water in the stratum under investigation (in which the filter is installed) is therefore equal to the level of the Bourdon gauge connection plus the reading given by this gauge.

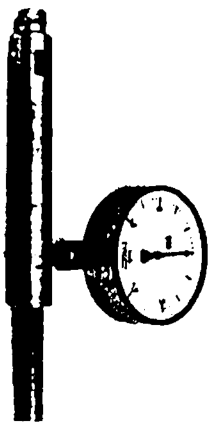

Fig. 40 Bourdon water pressure gauge.

However, if the water level in the standpipe is lower than the level at which the Bourdon gauge is mounted, this rule no longer applies, and it will then be necessary to top up the system with water. The *adjustment time* of this type of water pressure gauge ranges from a few hours in clayey sand to several days in clay. These fairly long times are due to the fact that the pressure gauge has a relatively high water consumption.

Every time the system is topped up, a further adjustment time has to elapse. This topping up is necessary because air or gas from the ground-water can rise through the filter and collects at the top of the pipe. And of course, in cases where the pipes have to be extended when the ground surface level is raised by filling, it will also be necessary to top up the water.

The Bourdon water pressure gauge is sensitive to temperature influences. This is because, for a given head, a change in temperature will bring about a change in the pressure gauge reading due to the difference in thermal expansion coefficient between the pipe itself and the water (and possibly air) in it. This effect is greater in proportion as the permeability of the soil in which the filter is installed is lower. In order to reduce this effect as much as possible, a protective case is placed over the pipe and preferably embedded in a small earth embankment thrown up around it. To safeguard the extension piece from fracturing due to freezing of the water in winter, the pipe is filled with turpentine (specific gravity 0.8) to a depth of 1 metre below the level of the pressure gauge. This affects the reading obtained, to which a correction of -0.2 m w.g. will then have to be applied.

Another kind of error in the water pressure measurement may occur when, in the event of subsidence of the ground level, negative skin friction acting on the extension tubes causes the tip with the filter to penetrate deeper into the stratum concerned, thus giving rise to an excess water pressure. Precautions against this eventuality can, however, be taken in such cases.

Despite the above-mentioned drawbacks, the accuracy of the measurements obtained with a correctly installed and properly maintained Bourdon water pressure gauge can in general be between 0.2 and 0.3 m w.g. An advantage with regard to checking the accuracy of the reading is that the measuring appliance is above ground level and can therefore be easily changed if a fault should develop.

On the other hand, the long adjustment time makes this equipment unsuitable for detecting changes in water pressure that occur within a few hours or indeed, in

some cases, within several days. All the same, because of the relatively low cost involved, this method has come into widespread use.
Depending on the permeability of the compressive strata and the filling rate of the site, this type of water pressure gauge can be used for determining the increase in ground-water pressure in consequence of raising the level of a site or for other similar purposes. It is thus possible to assess the stability of the raised site and to make an estimate of the settlement that is likely to occur. Such measurements are indeed often indispensable for making settlement prognoses.
A drawback of this type of water pressure gauges is that if they are installed at a site which is subsequently to be raised, the tubes have to be progressively extended, with the result that the temperature sensitivity may greatly increase. Besides, under such circumstances the gauges are liable to be damaged by the vehicles transporting the fill to the site. Also, such gauges are awkward to install under permanent structures such as tanks.

2.2.3 TPD water pressure gauges

This type of electric water pressure gauge derives its name from the fact that it has been developed exclusively for the Delft Soil Mechanics Laboratory by the Institute of Applied Physics of the TNO organization and the Delft Technical University. It functions on the inductive principle. Above the filter is a bellows unit to which a soft iron core is attached which is in a potential field. Any change in the water pressure causes the bellows with the core to move, resulting in a change in the output signal (Fig. 41).

The tube containing the transducer has an external diameter of only 32 mm, as also have the extension tubes, which are each 1 m in length and internally threaded, thus obviating the drawback associated with the local protrusions due to the sockets on the tubes used with the Bourdon water pressure gauge. Also, these tubes have a greater wall thickness, enabling greater force to be applied to them than to the Bourdon tubes.
The head of the ground-water in the stratum in which the filter is installed can be calculated by adding to the level of the filter the direct reading obtained at the measuring unit. As with the Bourdon gauge, the reading is independent of the barometric pressure. Since the *water consumption* of the transducer is substantially less than that of the Bourdon gauge, the adjustment time is considerably shorter.
Another phenomenon to be reckoned with in working with any type of water pressure gauge is that when it is forced into a poorly permeable stratum, an excess water pressure is created in this stratum around the tip and filter. In such cases the deciding factor is not the adjustment time of water pressure gauge, but that of the surrounding *soil*. Depending on the type of soil and the diameter of the gauge, this adjustment time may me anything up to several days.

Fig. 41 TPD electric water pressure gauge (transparent model)

The readings are obtained with the aid of a battery-fed electrical measuring unit. The range of measurement is 20 m w.g., the overall accuracy being about 0.2 m w.g. Alternatively, the readings can be recorded with the aid of a recording instrument.

On completion of the measurements, the filter (along with the transducer) is — in contrast with the Bourdon procedure — extracted from the ground and the zero reading is checked again. In addition to the range of application covered by the Bourdon water pressure gauge, the TPD gauge can be used, inter alia, for determining the effect of tides on the water pressures in dykes or investigating damage attributable to the effects of pumping.

2.2.4 Pneumatic water pressure gauges

The transducer consists of a metal disc comprising two small vertical pipes to which flexible tubes are connected. The pipes communicate respectively with an annular gap formed in the underside of the disc and with a small vertical hole at the centre of the disc. The gap and hole are both closed underneath by a rubber membrane. Under the latter is a filter, so that the prevailing water pressure in the soil presses the membrane against the disc.
The flexible tubes pass upwards through the extension tubes of the pressure gauge. Readings are taken by applying air pressure to one of the flexible tubes. As soon as this pressure just exceeds the ground-water pressure, the membrane is pushed down, so that communication is established between the annular gap and the hole in the plate, with the result that air comes back through the other flexible tube. This air pressure less the air pressure that has to be applied when the water pressure is zero indicates the ground-water pressure existing at the filter. The head is then determined in the same way as with the TPD water pressure gauge. The transducer is forced into the ground with tubes similar to those used with the TPD gauge.
Air is passed through the transducer at a constant rate, irrespective of the water pressure. The adjustment time of the transducer is determined by the fact that at the start of taking readings the membrane is pressed downward, so that water has to flow out of the filter. In clay this may take some hours. Once this condition has been attained, any change in water pressure will manifest itself within a few minutes. The accuracy of the measurements is 0.02 — 0.05 m w.g., for a measuring range of 20 m w.g. Checking is possible to the same extent as with the TPD gauge.
Readings are obtained with a precision pressure gauge (Thommen type). Alternatively, the results can be continuously recorded by means of a pressure balance compensator (DBCM) powered by a battery.
Fairly substantial amounts of compressed air are consumed in obtaining the readings, and for this reason a (semi-)permanent measuring installation is required. As a result, application of this method is confined to more or less special cases, such as those where an accuracy better than 0.10 m w.g. is desired, e.g., in investigating the effects of pumping upon the water pressure in impermeable strata and tidal influences on the water pressure in dykes. For this reason the readings must, in principle, always be taken only by the Laboratory's own personnel.

2.2.5 Dynamic water pressure gauges

(Ing. A. Vlasblom and Ing. H. C. van de Graaf)

Changes in water pressure, i.e., changes that occur within a period of a few seconds or indeed of a few hundredths of a second, can be measured by means of this equipment.
The under-mentioned two types of transducer, both equipped with a ceramic filter and having an external diameter of 36 mm, are used for the purpose.

a. Piezo-resistive transducers
This type comprises a silicone diaphragm to which are affixed four electrical resistance strain gauges arranged in a bridge circuit. The diaphragm and strain gauges form a single diffusion-bonded unit. The volume deformation is less than 0.01 mm^3, so that this type of appliance is especially suitable for measuring dynamic phenomena. The constant-current principle is applied, making calibration independent of the length of the cable.
The standard range is 500 kN/m^2, the accuracy being of the order of 1 kN/m^2.

b Strain gauge diaphragm transducers

The measuring element in this type of transducer is a stainless steel diaphragm, possibly in the form of a small load cell, with four electrical resistance strain gauges arranged in a bridge circuit (with a gauge in each of the four arms of the bridge). The functional behaviour depends on the thickness and diameter of the diaphragm. In general the frequency range is smaller than that of the equipment described in point (a).

The calibration is affected by the length of the cable (resistance). The standard range is 400 kN/m^2, the accuracy is of the order of $1 - 2$ kN/m^2.

The transducers are forced into the ground with the aid of 36 mm diameter penetrometer tubes. It is important that the ceramic filter should remain saturated with water while this is taking place, otherwise only a damped-out water pressure will be measured.

The following equipment is available for recording the water pressures:

- light-beam oscillograph (visicorder) for frequencies up to 1000 Hz; a current amplifier must be connected on the output side of each transducer to provide the necessary control current of the galvanometers;
- multi-channel pen recorder, suitable for the recording of semi-static phenomena up to a frequency of 1 Hz.

Dynamic water pressure gauges are widely used for determining the decrease in intergranular pressure resulting from, for example, pile-driving vibrations or soil compaction, or for estimating the excess water pressures caused by rolling loads (e.g., trains or other traffic) or cyclic loads (impact forces due to waves); such excess pressures are important because they may cause softening of the soil. In this way it is possible to assess the stability of a structure under such conditions.

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3. PLANNING AND DESIGN OF A DREDGING PROJECT

This section includes two papers. One is the lecture, entitled "The design of a dredging project", presented by Mr. W.G. Borst, F.C. de Weger International B.V. and the Netherlands Dredging Consultants. The lecture is reproduced in full. The other paper is a summary of research undertaken and facilities available in the Netherlands in the field of planning of river dredging. This is in fact an excerpt from Hydro Delft No.71, August 1985, a special issue on navigation in restricted waters.

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3.1 THE DESIGN OF A DREDGING PROJECT

By Ir. W.G. Borst, F.C. de Weger International B.V. and the Netherlands Dredging Consultants.

I. INTRODUCTION

In this chapter, the design of a dredging project will be discussed by a (dredging) consultant.

DEMONSTRATION

The design process will be demonstrated by means of a case study i.e. a recently executed project in Indonesia, the "Cilacap Harbour and Shore Protection Development Project".

ASPECTS

First some important aspects of the design of a dredging project will be discussed in general, such as:

- Dimensions of a project.
- The need for dredging.
- The effects of dredging.
- Dredging methods.
- Types of projects.
- Local circumstances.

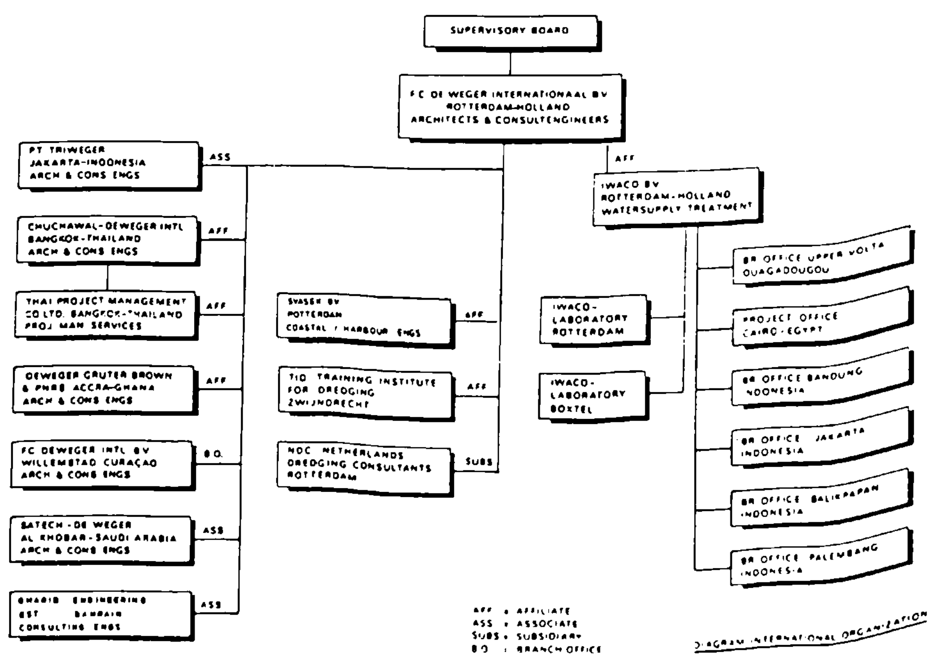


Figure 1 Organization of F.C. de Weger Internationaal B.V.

ILLUSTRATIONS

Most of the illustrations in the first part of this chapter are taken from the technical journals on hydraulics and dredging, listed in chapter VIII.

II. DIMENSIONS OF A PROJECT

QUANTITIES

Expressed in quantities of soil to be moved, a dredging project can range from several dozens to many millions of m^3, depending on the nature of the project.

EXAMPLES

Examples of projects are:

- Construction and maintenance of ponds, lakes, ditches and canals (figs. 2 and 3).
- Deepening of an existing harbour basin.
- Dredging of new harbour basins.
- Deepening of lengthy entrance channels in sea, or river deltas.
- Construction of a completely new harbour (figs. 4 and 5).
- Coastal extentions, beachnourishment, reclamation works etc.
- Artificial islands.

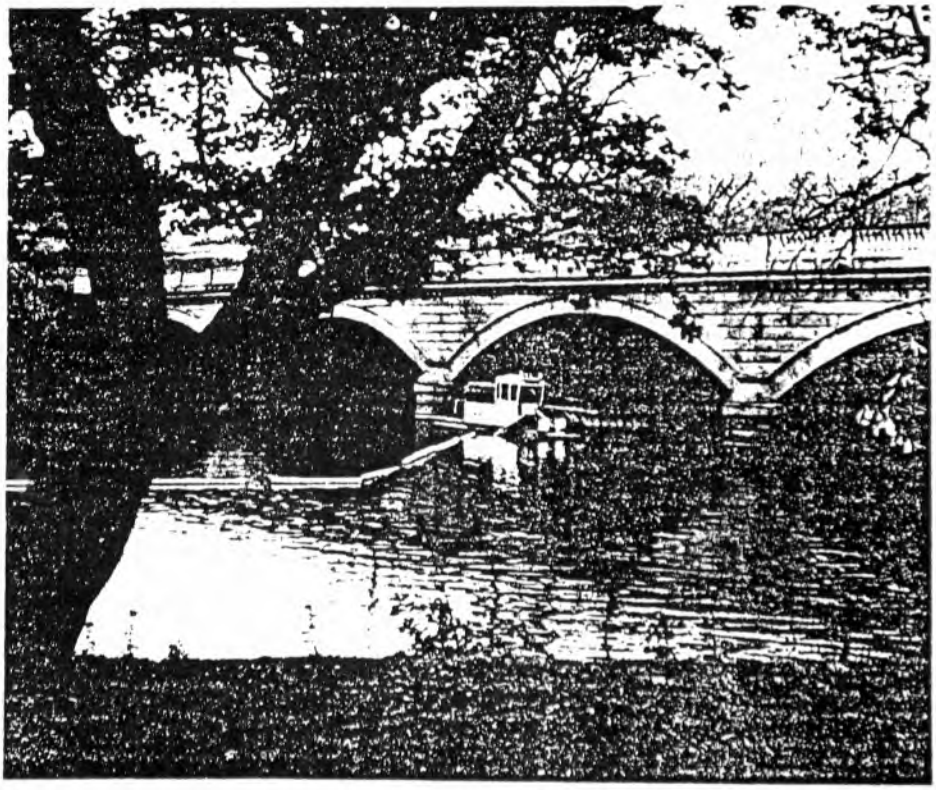


Figure 2 Maintenance of a pond

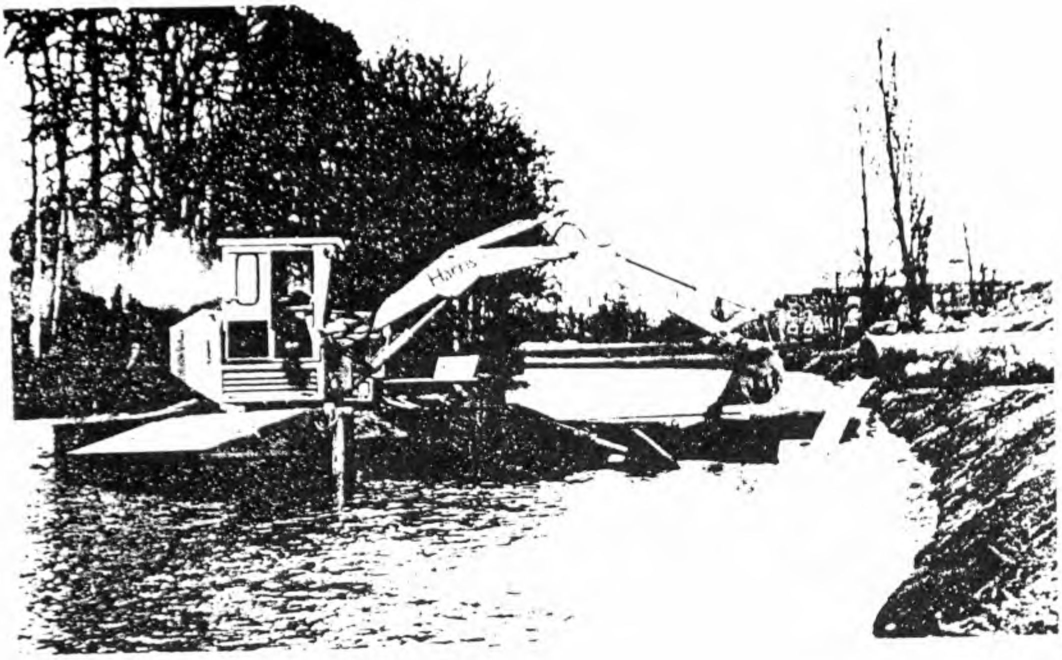


Figure 3 Maintenance of a canal

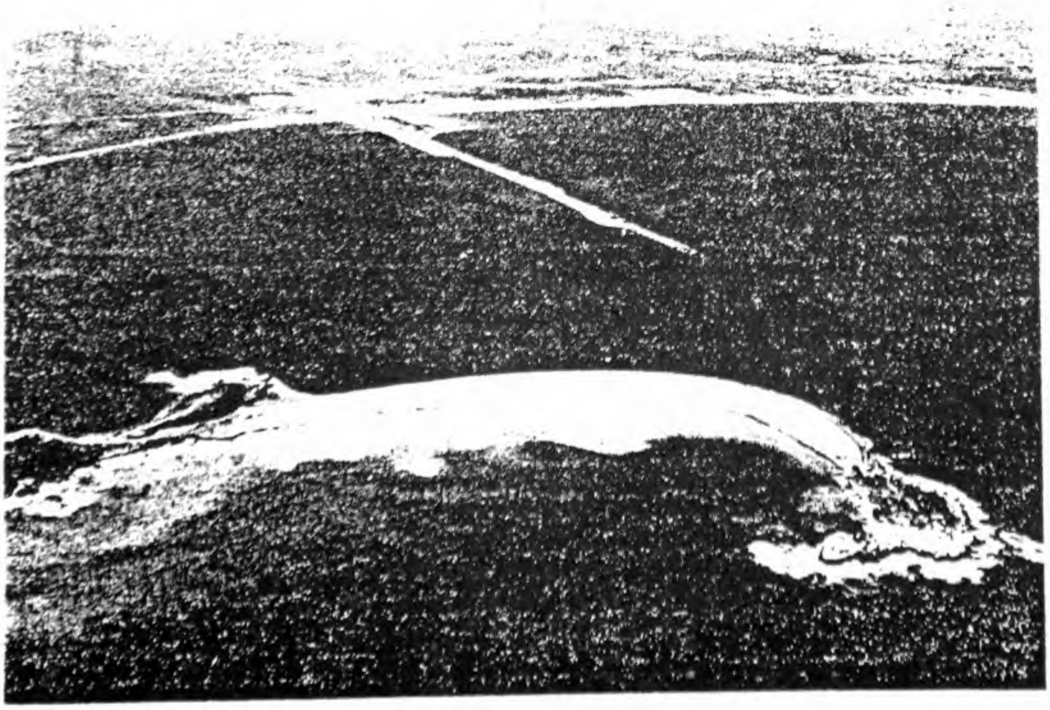


Figure 4 Construction of a new harbour installation

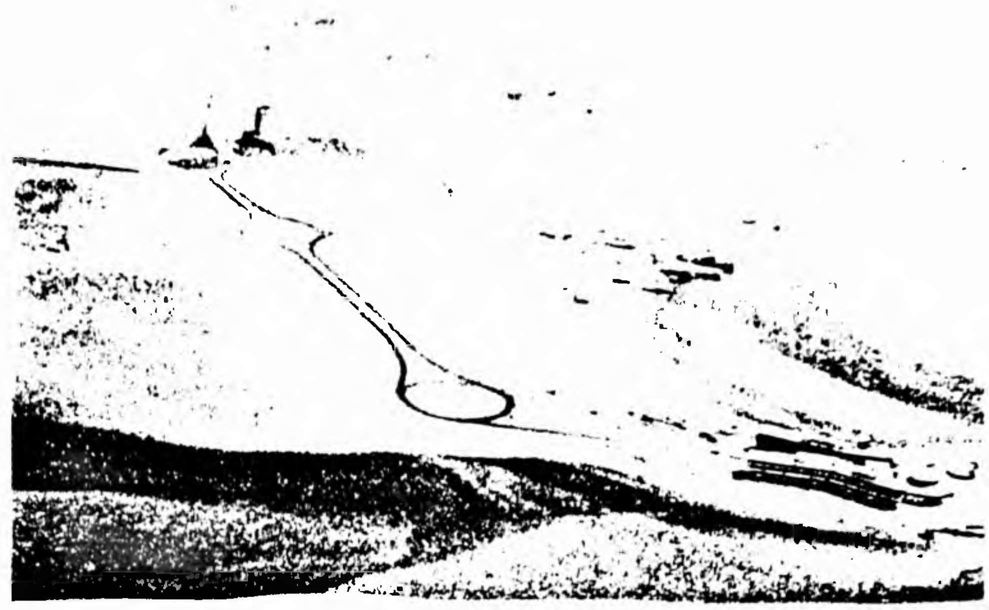


Figure 5 Construction of a new harbour and airport

PART

Mostly dredging is only part of a far greater infrastructural project. Especially in case of a harbour located at the sea coast or in a river estuary a number of other parts and disciplines besides dredging are of importance, whether seen from an overall design point of view or not.

INFRASTRUCTURAL NATURE

Most of these parts are of an infrastructural nature such as roads, railways, bridges, docks, quays, Ro-Ro-berthing facilities storage yards, buildings, and safety and environmental provisions (tanker cleaning, etc.). Consider, for instance, fig. 5 showing the construction of a new harbour and airport complex in the Middle East.

INVESTMENTS

To be able to evaluate the efficiency of the required investments, economic feasibility studies have to be made, which require as input the estimated (phased) costs of all parts together with the amounts for depreciations and proceeds.

TASK

Here lies an important part of the task of a dredging consultant as in the feasibility phase he will execute the project on paper for his employer.

This implies that the dredging consultant needs a thorough knowledge of the dredging scene both from the angle of dredging methods and possible productions as well as from the angle of associated costs.

DISCIPLINES

Disciplines the dredging consultant is concerned with are:

- Geodesy (positioning).
- Communication/data logging (computers).
- Navigation.
- (Dynamic) soil mechanics (dredgeability, production).
- Oceanography.
- Hydraulics (physical-mathematical model research).
- Morphology, sedimentology (physical-mathematical modelling).
- Legislation (permissions, concessions, duties, contracts, etc.).
- Surveying (on-site investigation, supervision).
- Reporting.
- Administering.

LIFE CYCLE

In fig. 6 this is shown by means of the life cycle of a dredging project.

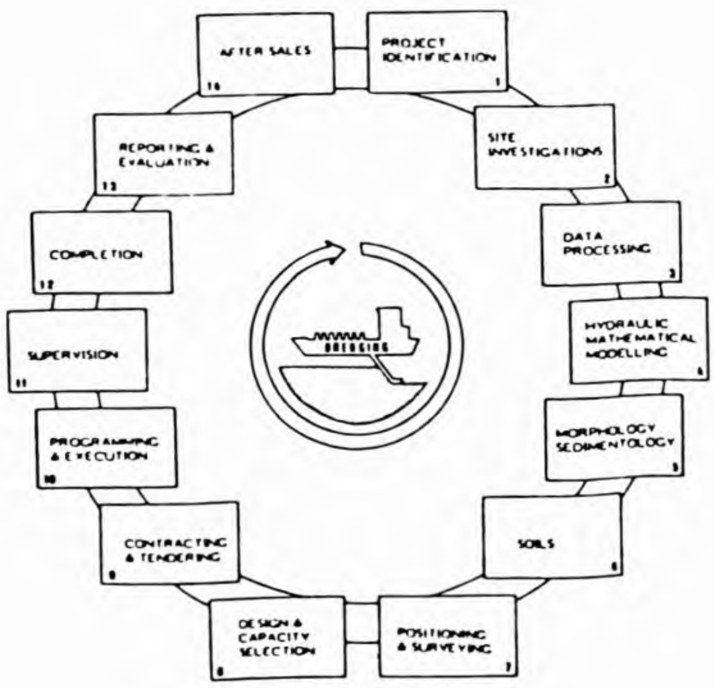


Figure 6 Life cycle of a dredging project

DEFINITION CONSULTANT

This leads us to the question of what exactly is a "dredging consultant". The definition of a consultant is:

> An independant advisor, specialized or otherwise, who as a trusted representative, acts in the widest sense in the interest of this employer in technical, financial and contractual matters.

The position of the consultant in relation to his employer and the tasks of the consultant are schematically shown in fig. 7 and fig. 8.

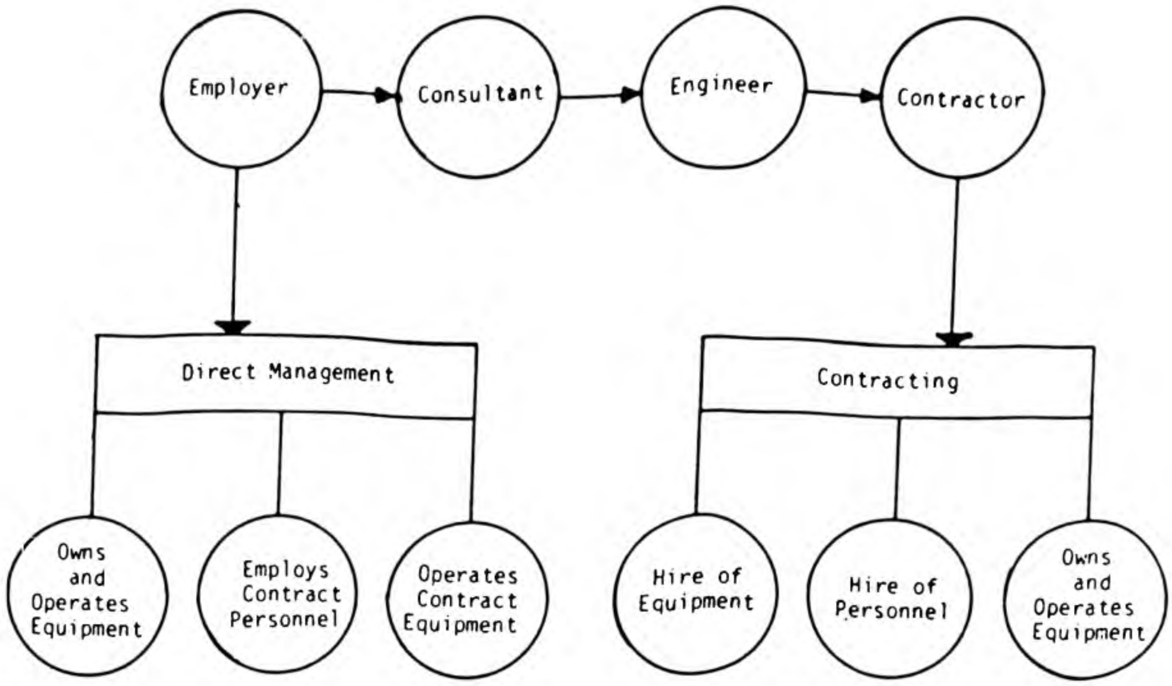


Figure 7 Position of the consultant in relation to his employer and the contractor

NORMAL PROCEEDINGS

Preparatory phase	Tendering	Execution phase
- detailed design - drawings - techn. specifications - budgets - financing arrangements - estimating of execution-period	- study of tender documents - estimate of costs and price - selection of suppliers, subcontractors - site investigations - alternative(s)	- start-up (licences, permits) - mobilisation - execution - completion - testing/inspection - maintenance - clearance of site/demobilisation - handing-over
Tender documents	Offer from contractor	Final certificate of completion

Figure 8 Tasks of a consultant

A dredging consultant is in the light of the preceeding definition, a consultant specialized in dredging projects. Previously the possible disciplines related to a dredging project have been discussed, the relative importance of which is determined by the nature and type of the dredging project (i.e. capital vs. maintenance dredging).

Apart from the technical requirements, particularly the contract form determines the price level and the flexibility of a dredging project.

''ES OF CONTRACTS

In figs. 9 and 10 some of the more common types of contracts are shown together with a table showing the advantages and disadvantages for employer and contractor of several types of contracts.

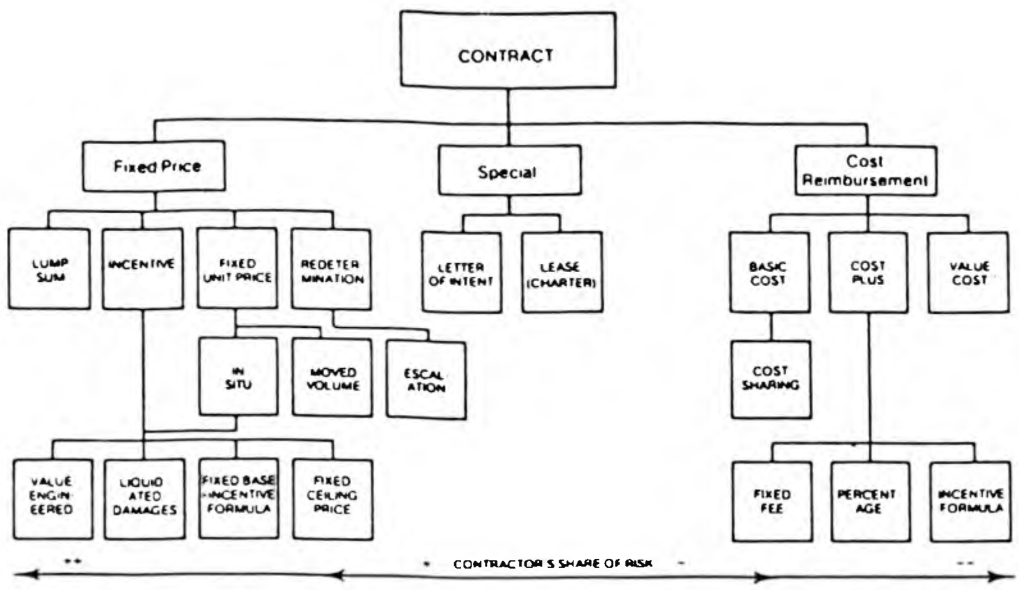


Figure 9 Some of the more common types of contracts

type of selection	advantage for		disadvantage for	
	employer	contractor	employer	contractor
open Public tender	Competitive and capable bidders Strong position of employer	Feed back from market	If system requires award to lowest bidder	Weak position versus employer – tender specs – tender costs – soil data
restricted Tender by invitation	Known bidders	Better chance (negotiation)	Less competition no new blood	Invitation through subjective judgement by employer Politics
direct Private or negotiated tender	Contractor knows local situation	Relationship with client		
direct labour	Control	None	Less quality Non competitive	Less demand

Figure 10 Some advantages and disadvantages for employer and contractor of several types of contracts

In the Netherlands dredging knowledge is concentrated in the hands of several private companies and government agencies (Rijkswaterstaat).

SELECT CONSULTANT

A client with the above knowledge and knowing the kind of problems related to this project, will be able to select the best consultant for his specific project.

Furthermore, it will be clear, that for extensive projects most consultants will hire external expertise to be able to tackle the complete project.

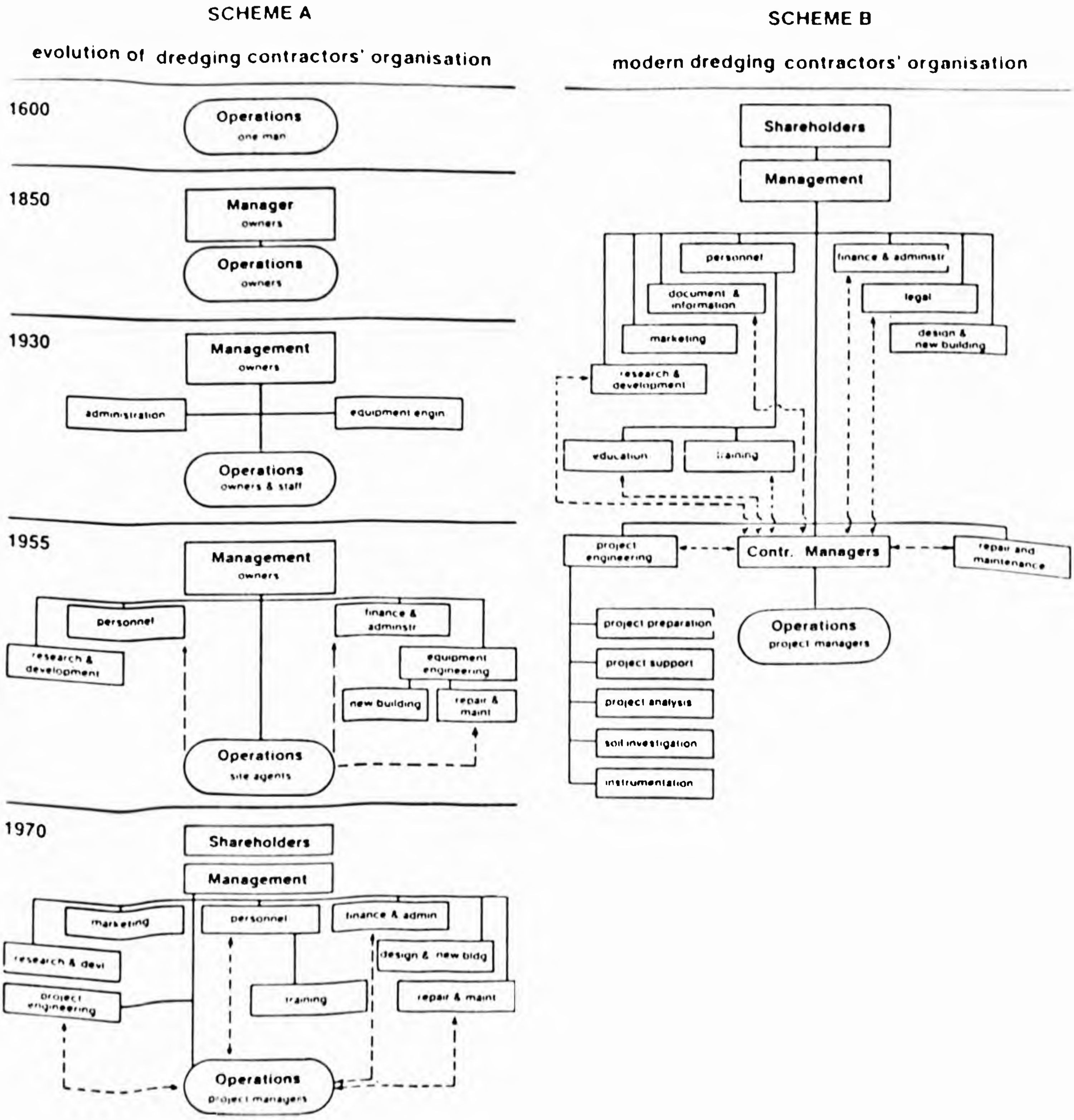


Figure 11 Evolution of dredging contractor's organization

aspects	navigation	aviation	dredging
capital investment level	HIGH	HIGH	HIGH
capital cost	> 50%	• 33%	> 50%
operating cost			
foreign currency	high	high	high
labour requirem	HIGH, BUT REDUCING	HIGH, BUT REDUCING	LOW
skill	high		high
quality	high	high	high
technology	HIGH	HIGH	HIGH
demand			
regular	line service	line service	maint dredg
irregular	tramp service	charter service	cptl dredg
capacity			
inelasticity	high	high	high
equipment			
versatility	low	low	low
employer			
regular	usually private	public and private	usually public
irregular	private	private	private and public

Figure 12 Developments in several high technology areas

DEVELOPMENT

In the past dredging was a pure craft, today in general a scientific approach is used (technics, electronics, computers, etc.). This development started in the fifties. The dredging contractors' organization has evolved accordingly, all the more so because of the size of foreign dredging projects.

In figs. 11 and 12 the evolution of dredging contractors' organization and this evolution compared to other high technology areas are shown.

Figure 13 Fishing harbour of Scheveningen, the Netherlands. Example of a consultancy project of the Hydraulics laboratory

III. THE NEED FOR DREDGING

The need for dredging may be caused by many different factors, depending on the nature of the project or problem. A distinction has to be made between capital and maintenance dredging.

Capital dredging is the result of a policy decision to make or do something, such as:

Construction of a harbour	: infrastructural reasons.
Deepening of a harbour entrance	: nautical and economical reasons.
Deepening of a harbour basin	: nautical and economical reasons.
Enlarging turning circles	: nautical and economical reasons.
A silt trap (pit)	: reduction maintenance frequency.
Tidal closure in estuary	: safety reasons.
The construction of a dike body	: safety and economical reasons.
Extending land areas into the sea	: safety and economical reasons, house building, recreation, industry.
Raising existing sites by reclamation	: safety and economical reasons, house building, recreation, industry.
Production of materials	: sand, gravel, tin, manganese, etc.
Artificial islands	: oil production, LNG-LPG storage.
Changing of the coast line	: economical and environmental reasons, recreation.

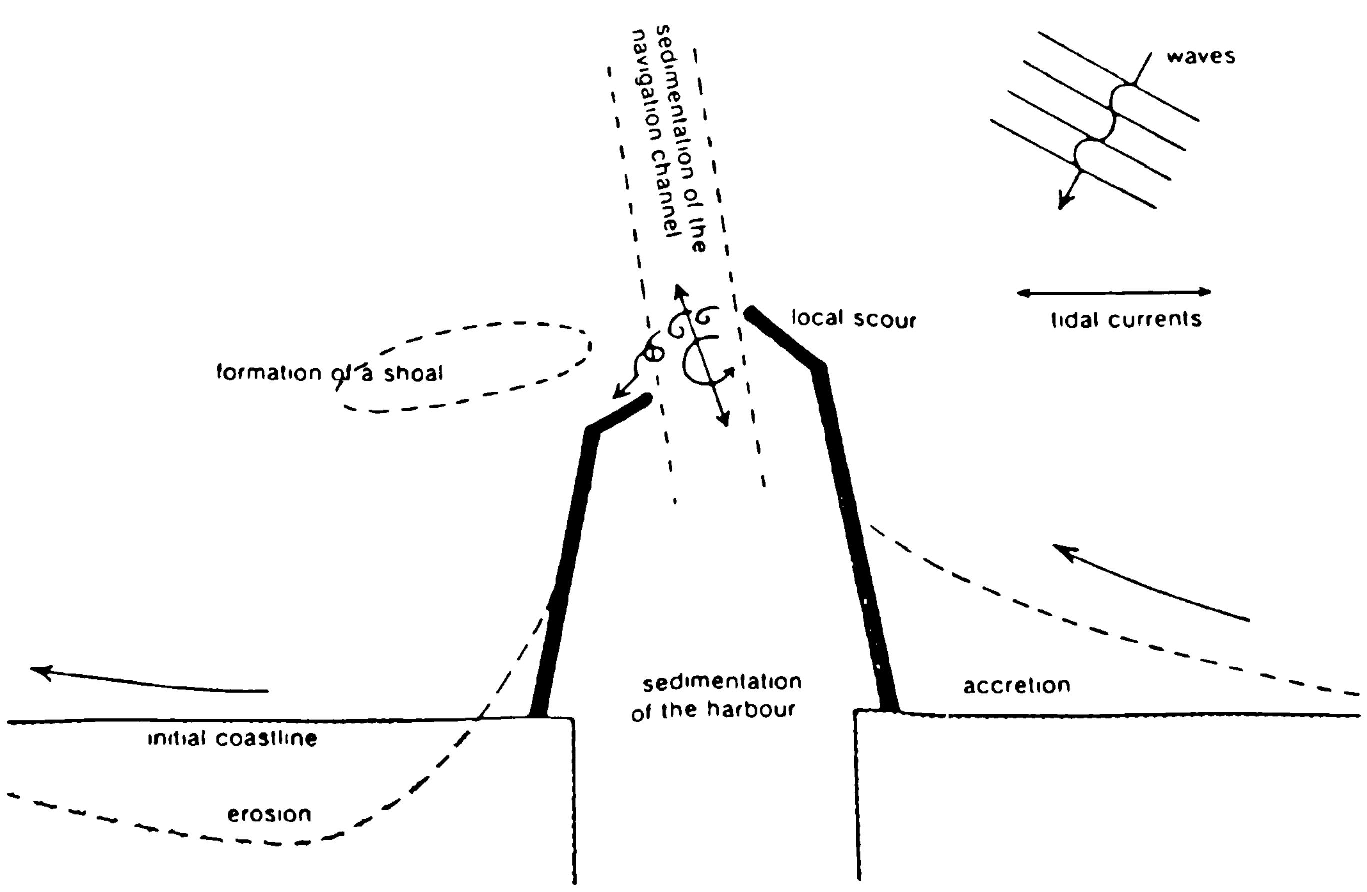


Figure 14 Need for dredging (harbour of Scheveningen)

1. To maintain and deepen the existing navigable waterways and harbours and the approaches to them, inland as well as offshore (maintenance dredging as well as capital dredging).
2. To develop and create ports and harbours, basins, canals, channels, marinas and other waterways.
3. To improve and/or maintain river discharge capabilities by deepening natural waterdepths or by watercourse realignment for such purposes as improving water quality, flood control and navigation facilities (partly maintenance dredging, partly capital dredging).
4. To provide landfills to raise the level of lowlands and to reclaim swampy and marshy lands, so creating new land areas for different purposes (habitation, industries, agriculture and improvement of environmental conditions).
5. To dig out trenches through areas with bad soil conditions and to provide landfills for the construction of roads, dams, causeways and foundations of engineering works.
6. To extend land areas into the sea and to construct artificial islands for various purposes.
7. To construct control or protective structures for waterways and coastal areas such as dikes, levees, groins, jetties and breakwaters.
8. To provide fill materials for beach protection and nourishment including protective dune construction.
9. To excavate underwater areas for foundations for construction purposes and underwater trenches for pipelines and cables and to provide fill materials to cover up underwater trenches for the protection of pipelines.
10. To recover subaqueous deposits like sand, gravel, shell and clay for construction purposes and furthermore minerals, precious metals and fertilizers, *i.e.* wet mining operations.

Figure 15 Aim of dredging operation

MAINTENANCE DREDGING

Maintenance dredging is a reaction to a cause, changing of an existing safe situation into an unsafe or economically unacceptable situation. Examples of these are siltation of an entrance channel, harbour basin or turning circle, siltation of a silt trap, sand suppletion for an eroding beach, and pollution of a river, canal or ditch.

Sometimes the need for dredging and/or filling-up can be proven with the help of physical/mathematical models, for instance in case of remedial measures to improve a river's stream/flow pattern.

In fig. 14 this is schematically represented, while in fig. 15 the aims of dredging are summed up.

IV. THE EFFECTS OF DREDGING

DIRECT EFFECT

The direct effect of dredging is the realisation of a project or the discontinuation of an undesired situation. The degree of satisfaction over this depends on the accuracy of the execution of the works and whether the dredging activities have in effect the desired success, for instance no mentionable maintenance after capital dredging, in other words: whether the results are permanent. An underestimated subject was/is the quantity of maintenance dredging caused by the intervention in the local (dynamic) equilibrium between bed, flow profile and flow velocity.

MAINTENANCE DREDGING

Quotation from a dredging journal: Maritime Asian, April, 1983 "Countries do not always understand, that dredging takes one day to learn and ten years to master. They may find they have created a future load of maintenance dredging, by taking the capital work on themselves.".

DIFFERENCES

In this framework the big differences can be pointed out in the approach and production of government dredging organizations and private contractors.

In figure 16 these aspects are represented schematically for a number of countries, with the situation of their harbours as criteria.

country	executed by	condition of port
U.S.A.	Government employing Government-owned equipment	Inefficient
Indonesia	As U.S.A.	Inefficient
Sri Lanka	As U.S.A	Inefficient
Ivory Coast	Government employing Government-owned equipment inside (cutters) only; maintenance of approach channels (trailers) executed by contractor through tender by invigation	Inefficient
Cameroon	As Ivory Coast	Inefficient
Germany	Government executes through chartered contractors equipment	Efficient
The Netherlands	Contractor executes for Government on long-term contracts through tender	Efficient
Belgium	As Netherlands	Efficient
Nigeria	Government-owned equipment operated by contractor through management and manning contract	Developing
Argentina	As Nigeria	Developing *New*: concessionary terminals
United Kingdom	Contractor executes for Authority through tender *N.B.* Ports Authorities have done away with their own dredging equipment	Efficient
France	Generally by contractor through tender	Efficient
Japan	As France	Efficient

Figure 16 Schematic representation of dredging work with as criteria the situation of harbours

ALTERATIONS

All alterations influencing the transport capacity of a stream being an exponential function of the local current near the bottom, lead to changes in the degree of sedimentation or erosion (see e.g. the Hjulstrom-diagram or the Shields-curve).

Employers are confronted with these problems afterwards when soundings show that sedimentation occurs to a more or less extent than planned.

ECONOMIC FEASIBILITY

The economic feasibility may depend largely on the extent of maintenance dredging, all the more so if the soil to be dredged is polluted in which environmental aspects play an exceedingly important role.

Formerly one could only employ physical scale models to examine hydraulic and morphologic processes and to give advise in erosion, sedimentation, soil removal and wave penetration.

At present, the dredging consultant has other and sometimes better tools to tackle this kind of problems, in particular with regard to non-cohesive sedimentations.

MATHEMATICAL MODELS

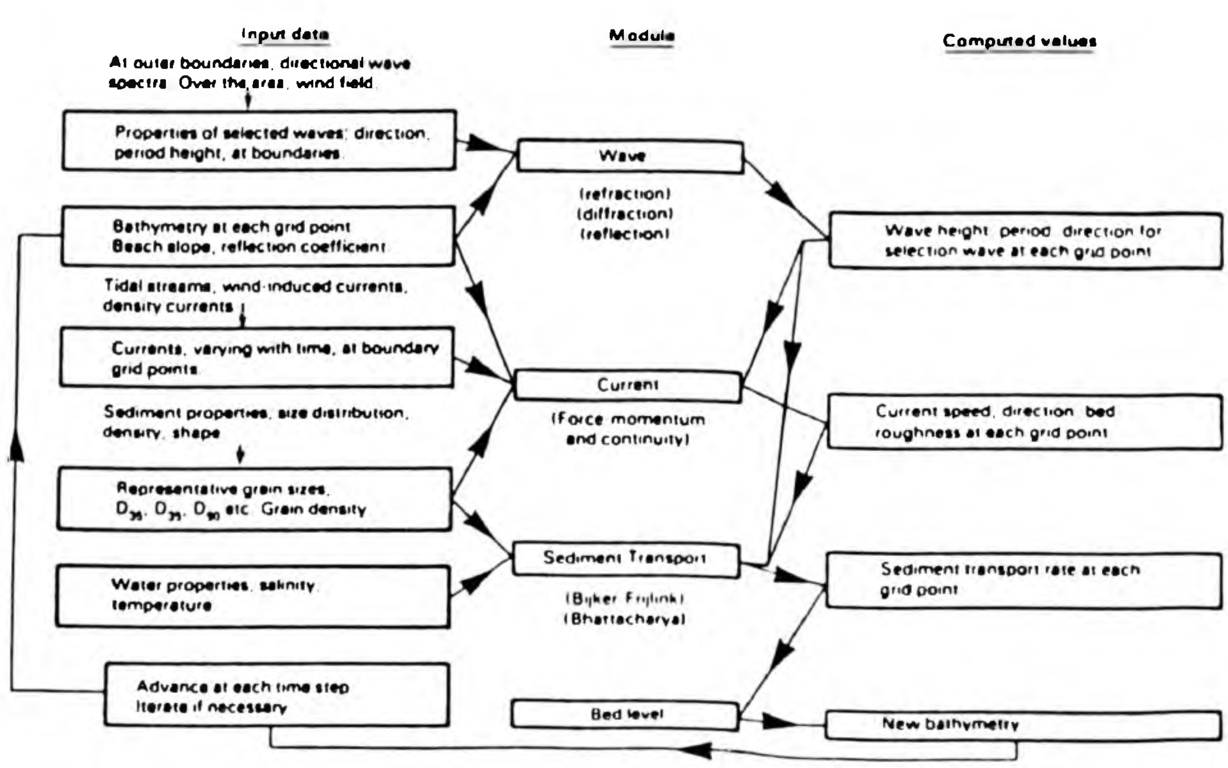
The present-day generation computers, the physical understanding of hydraulic problems and the developments in numerical analysis open up and make applicable the reproduction of two and three dimensional mathematical current models.

FEEDBACK

Besides the running of mathematical models, showing the sensitivities, a feedback to the prototype situation is always necessary. That means that measurements in nature (prototype) have to be taken to calibrate the model such as measurements of current and tide. Only after calibration the model can be used for prediction purposes.

SCHEME

Fig. 17 schematically represents a model of sediment transport.



<u>Figure 17</u> Schematic representation of a sediment transport model

One should always remember that the degree of schematisation (simplification) together with the input decide the end result, which in some cases does not need to be better than a simple calculation by hand. (The latter is always necessary as a check in the order or magnitude on the results of the model.)

In case of cohesive sediments, the modelling is more complicated. Physical models usually fail here also due to scaling effects.

COMBINATION

A nowadays often used combination is the preparation of numerical models, together with a fullscale test to deliver the necessary input for the models.

Example: Cilacap slope stability test

ENVIRONMENTAL EFFECTS

Other direct or indirect effects of dredging are the environmental effects: the interaction of the dredging process on the natural habitats of the water and the bottom. For instance coral (very sensitive to turbidity), the breeding places of fish and shrimps, etc. This interaction is twofold; first the direct removal of the natural habitat in case of capital dredging and second the possible pollution of the water. It is no rule that dredging activities are always harmful to the environment. Several examples of dumping areas are known which after some time became favourite spots for fish and crustaceans, to the satisfaction of local fishermen.

NOT ALWAYS HARMFUL

V. DREDGING METHODS

Dredging methods are among other things determined by:

- the size of the project : quantity in m³.
- the character of the soil : hard, soft, cohese, non-cohesive, sensitivity to liquifaction.
- the parameters of the location: flow velocities, direction, tide waves, shipping frequency, ice, etc.
- the dumping area : distance to location.
- execution aspects : making "work with work".
- obstacles : hidden objects in or on the bottom, such as old scrap iron, ship wrecks, ammunition, etc.
- environmental aspects : legislation, pressure groups.
- the necessary accuracy : cm, dm, m.
- the available equipment : possible modes of operation.

OTHER ASPECTS

Besides the already mentioned aspects, contract conditions, ways of settlement, the available time and the equipment available in the market play an important role. The contractor will eventually only offer what HE can do with HIS own equipment, or look for suitable joint-venture-partners if the work (and the risk) is too extensive. This making tenders different among themselves and hard to compare by consultant/employer.

ASSUMPTIONS

In the feasibility phase of a project, the dredging consultant has to make several assumptions, for instance concerning possible production rates, necessary time, risk related to the work, etc.

Furthermore the consultant has to estimate the work to evaluate the economical feasibility of the project, to be able to take the decision to carry it out.

The pressure on the dredging market, nowadays, makes it difficult for a consultant to set the "correct" price even if the best method has been selected.

A "wrong" choice of equipment can show itself during contracting as an extra economization or as extra costs, influencing either positively or negatively the feasibility of the project.

Rock Soil Type	Excavation Characteristics						Suitable as reclamation material	Suitability to pipeline transportation	Often observed bulk density before excavation
	Dipper dredger	Bucket dredger	Suction dredger	Cutter dredger	Trailer dredger	Grab dredger			
ROCK*									
I Igneous	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	2.6 -2.8
II Sedimentary	Possible in soft rock but difficult	Possible in soft rock but difficult	N.A.	Difficult to fair in softer rocks	N.A.	Possible in softer rocks but very difficult	Very good	Fair, large fragments may block pipes	1.9 -2.5
III Metamorphic	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	2.0 -2.8
* Weathering of rocks will alter form and strength considerably and may allow direct dredging without blasting, etc.									
Boulders	Fair	Very slow, may require slinging	N.A.	N.A.	N.A.	Difficult but large units cope	Not acceptable	N.A.	N.A.
Cobbles or Cobbles with gravel	Fair	Fair	Difficult	Difficult	Difficult	Fair	Bad to Good	Poor	N.A.
Gravel	Easy	Fair	Difficult to Fair	Fair	Difficult to Fair	Fair	Good	Fair	1.75-2.2
Sandy gravel	Easy	Fair to Easy	Fair	Fair to Easy	Fair to Easy	Fair to Easy	Very good	Fair to good	2.0 -2.3
Medium sand Fine sand Extra Fine Sand Silty Fine Sand	Easy but low production	Easy	Easy Fair	Easy	Fair to Easy but high over-flow losses likely	Easy	Very good Good	Good, Very good	1.7 -2.3
Cemented fine sand	Fair	Fair	N.A.	Fair to Easy	Difficult	Difficult	Good	Bad to good	1.7 -2.3
Silt	N.A.	Easy	Difficult to Fair	Easy	Fair to Easy but high overflow losses	Fair	Bad	Very good	1.6 -2.0
Firm or stiff gravelly or sandy clays (i.e. boulder clays)	Fair	Difficult to Fair	N.A.	Difficult to Fair	N.A.	Difficult to Fair	Good	Only possible after disintegration	1.8 -2.4
Soft silty clays (i.e. alluvial clays)	N.A.	Fair to Easy	N.A.	Easy	Fair	Easy	Bad	Fair	1.2 -1.8 (fresh harbour sediment 1.15-1.6)
Firm or stiff Silty clays	Fair to Easy	Easy	N.A.	Fair to Easy	Difficult to Fair	Fair	Bad to fair	Only possible after disintegration	1.5 2.1
Peats	N.A.	Easy	N.A.	Easy if no gas encountered	Fair	Easy	Unacceptable	Very good	0.9 -1.1

Figure 18 Comparison of soil types suitable for different types of dredgers

INATIONS

As there are many dredging methods with numerous combinations of equipment such as trailing suction hopper dredgers, cutter dredgers, stationary suction dredgers, wheel dredgers, bucket dredgers, grab dredgers, backhoe dredgers, airlift systems, pneumapumps, agitation systems, etc., we will not go into this any further.

TERATURE

For more detailed information regarding production chains we refer to literature.

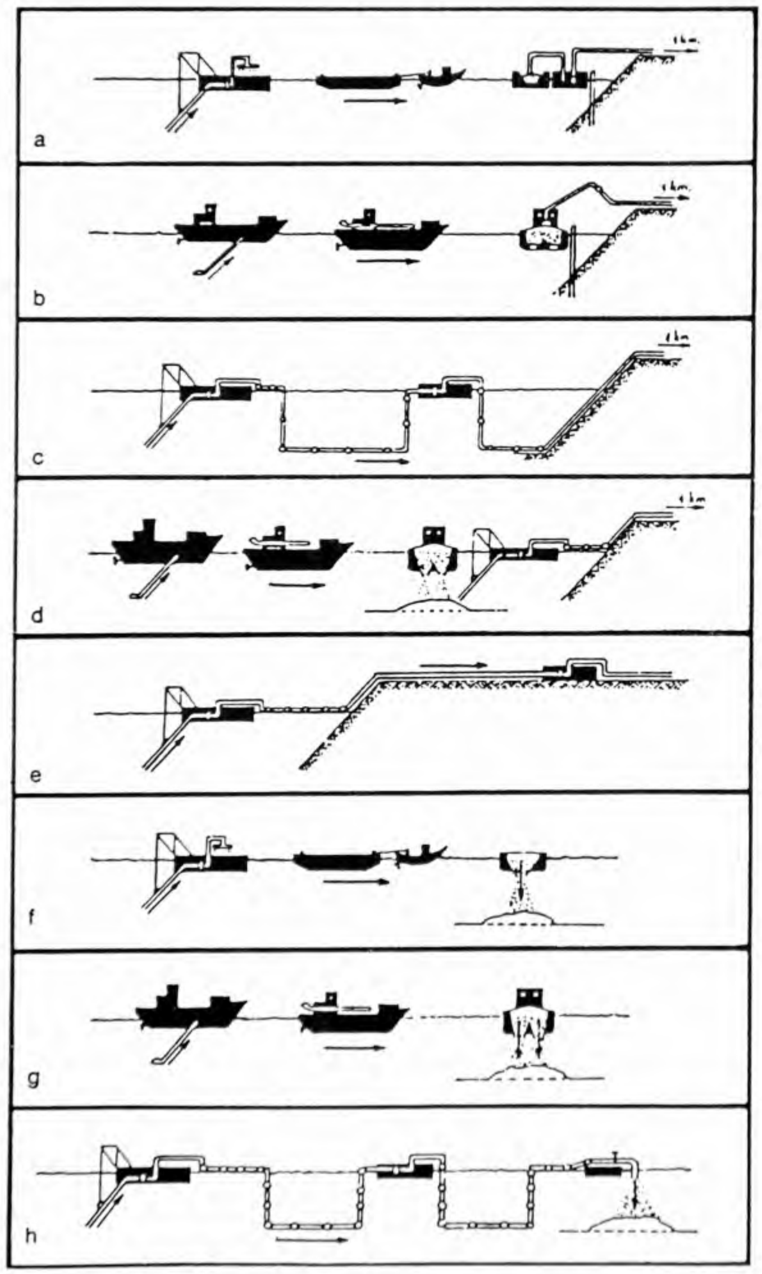


Figure 19 Eight hydraulic modes of operation

FIRST ESTIMATION

As an illustration some tables and figures are presented which are often used in a first rough estimation for the selection of a working method, workability, and expected downtime.

ACCURATE PARAMETERS

After this first selection, more detailed calculations are made. These, however, require more accurate parameters of the environmental circumstances on site as wind, current, waves, types of soil, etc.

TERM	Uniaxial Compressive Strength MN/m²	lbs/in²	kg/cm²
Very weak	< 1.25	< 182.5	< 12.8
Weak	1.25 to 5	182.5 to 730	12.8 to 51
Moderately weak	5 to 12.5	730 to 1825	51 to 128
Moderately strong	12.5 to 50	1825 to 7300	128 to 510
Strong	50 to 100	7300 to 14600	510 to 1020
Very strong	100 tó 200	14600 to 29200	1020 to 2040
Extremely strong	> 200	> 29200	> 2040

Figure 20 Classification of rock strength

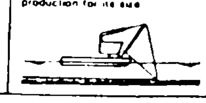
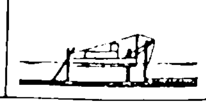
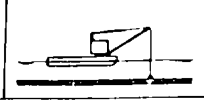
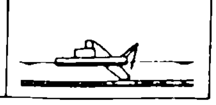
Dredger type (1)	Dragline on barge (2)	Dipper dredger (3)	Clamshell or orange peel bucket dredger (4)	Endless chain bucket dredger (5)
Dredging principle	Scrapes off material by pulling single bucket over it toward stationary crane. Lifts bucket and deposits dredged material in a conveyance or on a bank	Breaks off material by forcing cutting edge of single shovel into it while dredger is stationary. Lifts shovel and deposits dredged material in a conveyance or on a bank	Removes material by forcing opposing bucket edges into it while dredger is stationary. Lifts bucket and deposits dredged material in a conveyance or on a bank	Removes material by forcing single cutting edge of successive buckets into material while dredger is slowly moved between anchors. Lifts buckets and deposits dredged material in a barge or own hopper
Horizontal working force on dredger	Medium intermittent force toward bucket	High very intermittent force away from bucket	No forces.	Medium constant force away from bucket
Anchoring while working	Dragline crane can be on shore or on barge. If on barge latter can be secured with spuds or anchors	Several heavy spuds	Several spuds or anchors	Several anchors
Effect of swells and waves	Can work up to moderate swells and waves	Very sensitive to swells and waves	Can work up to moderate swells and waves	Very sensitive to swells and waves
Material transport	Transport occurs in barges, trucks or cars. Crane does not transport material. Material disposal occurs in many ways	Transport occurs in barges, trucks or cars; dredger does not transport material. Material disposal occurs in many ways	Transport occurs in barges, trucks or cars; dredger does not transport material. Material disposal occurs in many ways	Transport normally occurs in barges. Dredgers equipped with hoppers are limited to material disposal by bottom dumping
Dredged material density	Approaches in-place density in mud and silt. Approaches dry density in coarser material	Approaches in place density in mud and silt. Approaches dry density in coarser material	Approaches in place density in mud and silt. Approaches dry density in coarser material	Approaches in place density in mud and silt. Approaches dry density in coarser material
Comments	The Term dredger is questionable for this machine, since it is not exclusively built for underwater excavation and is frequently used for material removal above water. It is suitable for all but the hardest material and has a low production for its size	Special hard material dredger of simple principle. Rudimentary machine can be assembled for temporary service by placing power shovel on spud barge. Low production for size of plant and investment	This machine is simple in principle. It can be assembled in rudimentary form for temporary service by placing a crane on a barge. It is suitable for all but the hardest materials and has a low production for its size	Highly developed machine. Not used in United States (other than as part of mining plant) but used extensively in other countries. It is suitable for all but the hardest materials and has a high production for its size
Silhouetted outline				

Figure 21 Mechanical dredgers

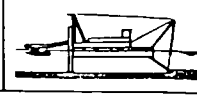
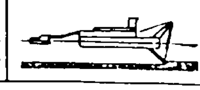
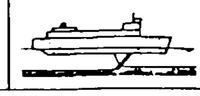
Dredger type (1)	Cutterhead dredger (2)	Dustpan dredger (3)	Hopper dredger (4)	Sidecasting dredger (5)
Dredging principle	Material is removed with a rotary cutter (or plain suction inlet in light material) picked up with dilution water by the suction pipe and transported through the pump and the discharge line. While working dredger swings around spud toward an anchor.	Material is removed with water jets picked up by a wide but shallow suction opening and transported through the pump and the discharge line. While working dredger is slowly pulled toward two anchored spuds or anchors.	Material is removed and picked up together with dilution water by draghead sliding over bottom (or stationary) and flows through suction piping, pump and discharge piping into hoppers of vessel.	Material is removed and picked up together with dilution water by draghead sliding over bottom and flows through suction piping, pump and discharge arm over side of vessel back into the water.
Horizontal working force on dredger	Medium intermittent force opposing swing to side.	Medium constant force opposing forward movement	Slight constant force opposing forward movement	Slight constant force opposing forward movement
Anchoring while working	Two spuds and two swing anchors (one working spud and one walking spud).	Two spuds or anchors secured upstream while working	Dredger moves under own power to dig a channel or is anchored to dig a hole.	Dredger moves under own power to dig a channel
Effect of swells and waves	Very sensitive to swells and waves.	Very sensitive to swells and waves	Little affected by swells and waves	Little affected by swells and waves
Material transport	Transport occurs in pipeline. Length of discharge line depends on available power, but can be extended with booster pump units to a total length of several miles.	Transport occurs in pontoon supported pipeline to side of dredger. Spoil discharges into water. Booster pump units are not used with the plant.	After material is in hoppers transport is over any suitable waterway. Material can be bottom dumped or pumped out (if so equipped). Pumpout is similar to pipeline dredger operation.	Transport occurs in pipeline on discharge boom over side of dredger. Material discharges into adjacent water.
Dredged material density	Diluted to an average of 1 200 g/L	Diluted to an average of 1 200 g/l	Diluted to an average of 1 200 g/l	Diluted to an average of 1 200 g/l
Comments	Highly developed machine with intricate horizontal moving procedure used throughout the world. Suitable for all but very hard materials. High production for size of plant.	Special sand dredger used only in United States in Mississippi River. Floating line is positioned with rudder in discharge stream. High production for size of plant.	Highly developed machine used throughout the world. Suitable for all but very hard materials. Production depends on traveling time to dump and mode of discharge.	Special sand dredger. Sand transport is limited to length of discharge boom. Used in coastal inlets or where material discharge into water is not objectionable. High production for size of plant.
Silhouetted outline				

Figure 22 Hydraulic dredgers

DREDGER	DREDGER CAPACITY	ROCK				NON COHESIVE SOIL						COHESIVE SOIL						ORGANIC SOIL		FACTOR PER M TIDAL RANGE	FACTOR CROSS CURRENT	FACTOR SWELL	
		FRACTURED ROCK		WEATHERED SOFT ROCK		STONES		GRAVEL		SAND		SILT/SAND		STIFF CLAY		SOFT CLAY		PEAT					
		T_H	T_V	T_H	T_V	T_H	T_V	T_H	T_V	T_H	T_V	T_H	T_V	T_H	T_V	T_H	T_V	T_H	T_V	T_V	T_H	T_H	T_V
BUCKET DREDGER	BUCKET CAPACITY																						
	50 - 200 liter	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	50	20	100	30	75	15	50	10	35	15	75	25	5 40	50	25	15
	200 - 500 "	150	30	100	20	?	?	75	25	150	50	125	25	75	15	125	25	100	35	5	75	50	25
	500 - 800 "	N.A.	N.A.	N.A.	N.A.	?	*	100	35	200	60	150	30	100	20	150	30	175	65	5	100	75	15
DIPPER	0.5 - 2 m3 2 - 5 "																						
GRAB	0.5 - 2 m3	100	50	100	25	*	*	25	50	100	25	N.A.	N.A.	N.A.	N.A.	50	30	75	40	5	25	[illegible]	15
	2 - 4 "	200	75	200	50	?	?	150	75	200	50	N.A.	N.A.	N.A.	N.A.	150	75	150	75	5	50	[illegible]	25
	4 - 7 "	250	100	250	75	?	*	200	100	300	75	N.A.	N.A.	N.A.	N.A.	250	100	250	125	5	75	[illegible]	[illegible]
CUTTER	CUTTER Ø																						
	0.75 - 1.50	N.A.	N.A.	N.A.	N.A.	N.A.		150	50	200	40	150	30	75	15	100	25	100	30	5	50	25	[illegible]
	1.50 - 2.50	75	75	50	20	N.A.		225	75	250	50	200	40	100	20	150	40	125	40	5	75	[illegible]	25
	2.50 - 3.50	100	50	75	25	N.A.		300	100	300	60	250	50	150	30	200	50	175	60	5	100	[illegible]	[illegible]
	500 - 2.000	N.T.		N.T.		N.T.		500	150	1500	500	N.T.	N.T.	N.T.	N.T.	N.T.	N.T.	N.T.	N.T.	-	-	-	
	2.000 - 5.000	N.T.		N.T.		N.T.		1000	250	2000	750	N.T.	N.T.	N.T.	N.T.	N.T.	N.T.	N.T.	N.T.	-	-	-	
TRAILING HOPPER DREDGERS	HOPPER CAPACITY IN TONS																						
	500 - 3.000 ton	1000	75	N.A.		N.A.		1000		1000	75	1000	50	N.A.	N.A.	1000	50	N.A.	N.A.	5	250	125	[illegible]
	3.000 - 6.000 ton	1500	100	N.A.		N.A.		1500		1500	50	1500	50	N.A.	N.A.	1500	75	N.A.	N.A.	5	500	[illegible]	3
	6.000 - 10.000 ton	1500	100	N.A.		N.A.		1500		1500	75	1500	50	N.A.	N.A.	1500	100	N.A.	N.A.	5	500	[illegible]	3

T_H - Horizontal tolerance in cm

T_V - Vertical tolerance in cm

Slopes : If the slope angle is steeper than $tg\ \alpha = \frac{T_V}{T_H}$ then the horizontal tolerance is binding

If the slope angle is $< tg\ \alpha = \frac{T_V}{T_H}$ then the vertical tolerance is binding

Figure 23 Tolerances in dredgework

VI. TYPES OF PROJECTS

Dredging projects differ among themselves in size and in nature of the dredging process. Among other things this is caused by the strong variations in the character of the soil (cohesive/ non-cohesive, hard/soft no synonime!), the location of the work, the existing water depth and the quantities to be dredged It also makes an important difference whether capital or maintenance dredging is concerned.

To a consultant, a project is almost never strictly a dredging project. Dredging is usually part of an overall project where such parts as navigation, harbour facilities, beaconage and buoyancy together with the infrastructure of harbour basins are as important or even more so.

With the help of the tables in figs. 24 and 25 a broad division is made of different types of dredging projects and possible equipment.

	TYPE OF WORK	LOCATION			EQUIPMENT								AGITATION	QUANTITIES
	capital	sea	est.	inl.	trailing suction	cutter suction	stationary suction	bucket dredger	grab dredger	bock hoc	springer	pneum. air lift		
Entrance channels	V	x	x		o	o		o			o		o	+,++ up to 10^8
Harbour entrances	V	x	x		o	o							o	+, ++
Harbour basins	V	x	x	x	o	o		o	o	o	o		o	+
Turning circles	V		x	x	o	o							o	+
Local deepening sand/silt traps temp. anchor places	V	x	x	x	o	o							o	- (≈ 0.2 · [illegible])
Sand closures	V		x		o	o	o							+, ++ (peak capacity)
Sand suppletion	V	x	x		o	o	o							+
Raising of:	V				o	o								+, ++
- roads				x										
- dikes			x	x										
- land				x										
- offshore islands		x		x										
Soil improvement	V		x	x		o		o	o	o				-, +
Production of materials:	V	x	x	x	o	o	o	o	o	o	o	o		+, ++
- sand					o	o	o	o	o					
- gravel						o	o	o	o					
- manganese						o	o		o					
- tin									o	•		o		
River works/canals	V			x	o		o	o	o	o		o		-, +
Ditches/canals/ponts	V			x				o	o	o				-

- = small
+ = large
++ = extremely large

Figure 24 Types of dredging work I

	PARTICULARS	MAINTENANCE	EQUIPMENT					QUANTITIES	REMARKS
			trailing suction	cutter suction	grab	agitation	pneum. air lift		
Entrance channels	depending on type of soil	V	o	o		o		-, +, ++	maintenance depends on the frequency of dredging, over/under dredging etc
Harbour entrances	construction depths	V	o	[illegible]		o		-, +	
Harbour basins	"work with work"	V	o	o	o	o	o	-, +	
Turning circles	combinations of equipment are often necessary	V	o	o	o	o	o	-, +	
Local deepening sand/silt traps temp. anchor places		V	o	o		o	o	-, +	
Sand closures									
Sand suppletion		V						depends on storms and necessary safety	
Raising of roads - dikes - land offshore islands									
Soil improvement									
Production of materials sand gravel manganese tin									
River works/canals		V	o		o	o	o	-, +	
Ditches/canals/ponds		V		o	o			-	mostly dead water

Figure 25 Types of dredging work II

VII. LOCAL CIRCUMSTANCES

With regard to local circumstances influencing the dredging process have to be considered (among others):

LOCATION

- Location of the project:
  - The Netherlands.
  - Europe.
  - Middle-East.
  - Asia.
  - The Arabic.
  - South Africa.
  - Africa.

CIRCUMSTANCES

- Depending on the location it is possible to differentiate in:
  - climate : wet/dry season.
  - temperature : warm/cold (extremes: ice?).
  - percipitation : little/much, period.
  - wind : little/much.
  - waves : significant height, direction, frequency, distribution.
  - current : extent and direction.
  - tide : type and daily variation.

ACCESSIBILITY

- Accessibility of the site:
  - by water (not all projects are at the coast).
  - by road/railroad.
  - by air.
  - traffic or other restrictions during execution.

FACILITIES

- Bunker and repair facilities:
  - spare parts.

The herefore mentioned aspects are only part of the local circumstances influencing a dredging project. On these and other grounds a dredging consultant will make a choice with regard to equipment and methodology to be used. Whether contractors agree with this choice will show from the presented tenders and from the price level. Sometimes extra alternatives will be handed in, specificly based on contractors equipment and cheaper than the requested offer in agreement with the specifications. Whether an alternative is really cheaper, has to be evaluated thoroughly by means of the criteria set by the original tender documents.

VIII. LITERATURE

- Terra et Aqua, International Journal on Public Works, Ports and Waterways Development
  P.O. Box 80 521
  2508 GM The Hague
  I.A.D.C. (free of charge)

- Dredging & Port Construction
  Queensway House
  Queensway, Redhill
  Surrey RH1 1QS
  United Kingdom

- Hydro Delft
  Quarterly publication Delft Hydraulics Laboratory
  P.O. Box 177
  2600 MH Delft
  The Netherlands

- Ports and Dredging
  Quarterly publication by IHC Holland
  P.O. Box 208
  3350 AE Papendrecht
  The Netherlands

- World Dredging & Marine Construction
  P.O. Box 17 479
  Irvine
  California 92714
  U.S.A.

IX. CASE-STUDY CILACAP

The illustrations in this part are a selection of the illustrations used in the lecture on this subject. The illustrations speak for themselves and are given without further comments.

The Cilacap project started out as the design of a safe berthing place for Pertamina at Cilacap, Java in Indonesia. The project was undertaken by the C.I.B. group, consisting of:

- Sumber Tjipta Jaya : pipeline, logistics, etc.
- Royal Netherlands Harbour Works: jetties, berth, assistance, pipeline.
- Dredging Company Breejenbout : dredging work.

After the start of the contract a technical and economical feasibility study was tendered related to the nautical safety of the project. (The original contract consisted of 1 berthing place.) This study was won by Svasek B.V. in August, 1981.

The total study took 9 months and was followed by several supplementary studies:

- Slope stability test	1982
- Detail calculations shore protection	1982/83
- Study rock outcrops in channel (nautical consequences)	1982
- Training captains and pilots	1982

The berthing place was meant for 135 000 dwt tankers:

- Length (b.p.): 300 m.
- Beam : 43 m.
- Draught : 14 m (partially loaded to 100 000 dwt).

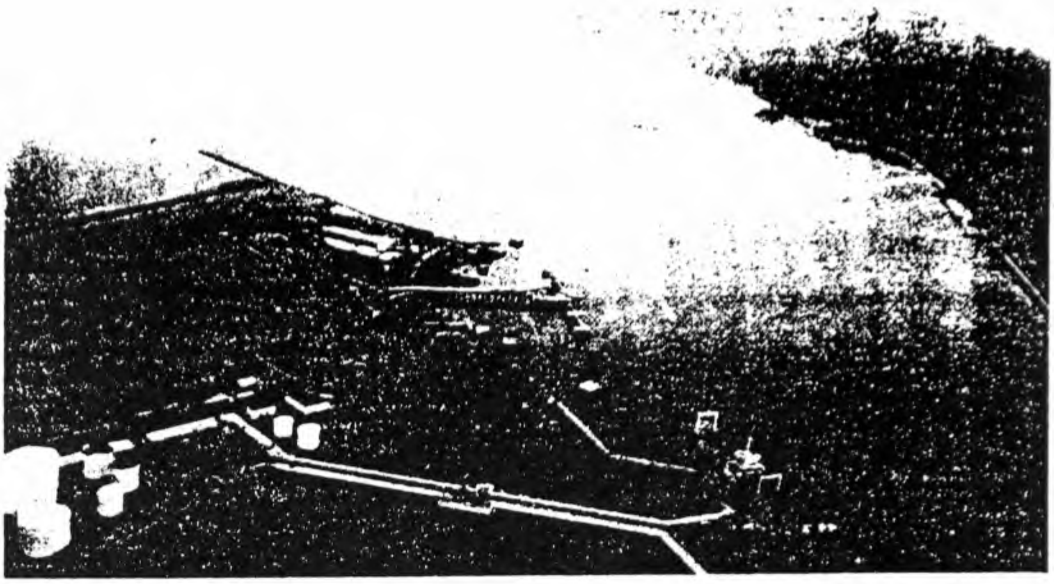


Figure 26 Cilacap project

The initial design had the following dimensions:

- Width of channel : 200 m.
- Depth : -17.00/-16.00/-14.50 m LLWS.
- Berthing place : -17.00 m LLWS.
- Turning circle : 480 m, 2 levels, -14.50/-9.50 m LLWS.
- Quantity to be dredged: appr. 6.0 million m^3.

The recommended layout after the study became:

- Width of channel : 250 m.
- Depth : -16.80/-16.50/-15.50 m LLWS.
- Berthing place : -17.00 m LLWS.
- Turning circle : 600 m/-15.50 m LLWS.
- Nett keel clearance : 20, 15, 10 %.
- Quantity to be dredged: 9.6 million m^3.

The quantity of maintenance dredging was estimated to be 400 000 m^3 ± 50 % per year, 100 000 m^3 of which from the river and approximately 300 000 m^3 over the sand bank (waves, current).

The shore protection project consisted of sand suppletion of 800 000 m^3 (1982/83) together with 8 double rows of concrete piles with different centre to centre distances.

Cilacap harbour development and shore protection study Cilacap, Java, Indonesia

In 1981 Svasek bv was engaged by Pertamina, Jakarta, Indonesia, for the economical and technical feasibility study of Cilacap, Java, Indonesia.

The study consists of the economical and technical appraisal of the investment concerned with the enlargement of the existing Cilacap harbour in order to accommodate oil tankers, up till 135.000 tdw.
In the present situation the largest ships calling at Cilacap harbour are 35 000 tdw tankers.

The study included the following items:

- hydrological field surveys
- geotechnical field survey and laboratory testing
- slope stability geotechnical advise dredged slopes (as steep as possible)
- evaluation of wave, current and wind data
- capital dredging: quantities, methods and costs involved
- mathematical modelling of river branches and entrance channel
- tidal and sedimentological computations
- evaluation and prognosis on rate of siltation/maintenance dredging
- maintenance dredging, quantities, methods, costs involved
- navigation and nautical safety
- real time simulation tests on ship simulator
- economical evaluation of all costs involved in order to obtain the optimal solution for Cilacap harbour i.e. for all solutions with the same level of safety (the investments required versus pay off).

Svasek bv engaged for this study two local Indonesian consultants (1 & 2) and four Dutch consultants (3 to 6) i.e.

1. Janhydros. Indonesion naval oceanographic service, Jakarta, Indonesia
2. Geomarindex. Geotechnical consultants and surveyors, Jakarta, Indonesia.
3. IGF: Institute for Geotechnics and foundation engineering
4. NSMB. Netherland Ship Model Basin
5. Port of Rotterdam, economist and master pilot
6. IMDC. International Marine and Dredging Consultants
7. Individual experts through Seal S.A.

Figure 27 Short description of the project, the scope of the study and the engaged expertise

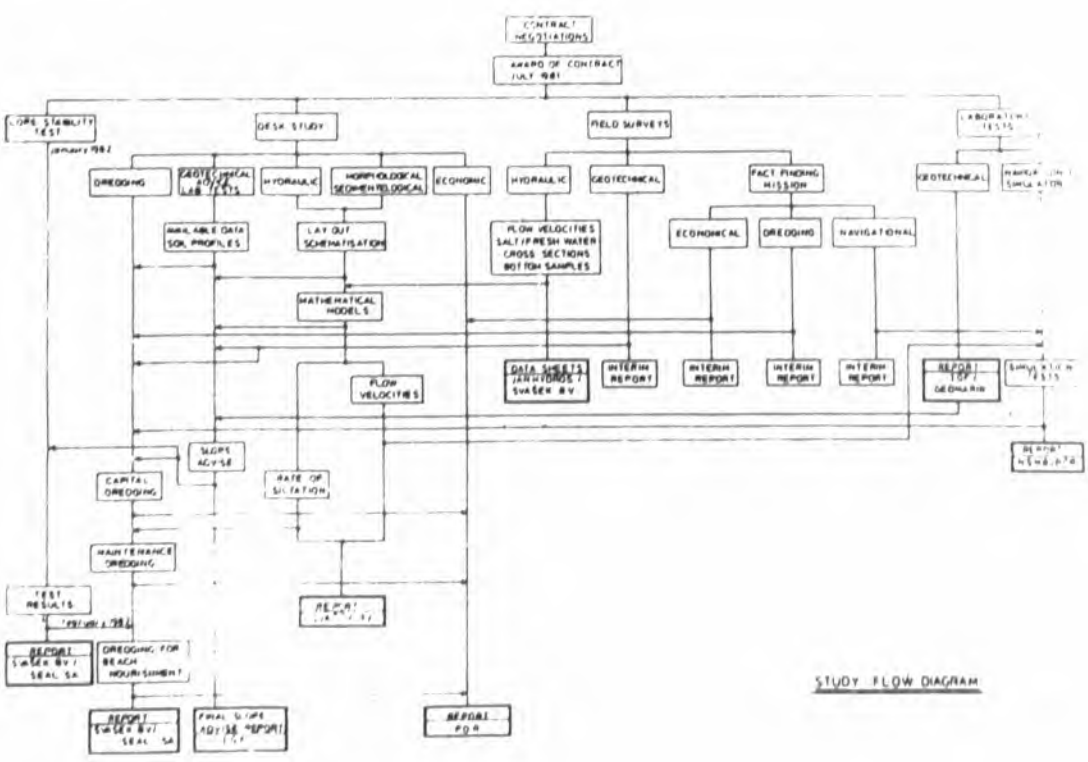


Figure 28 Study flow diagram

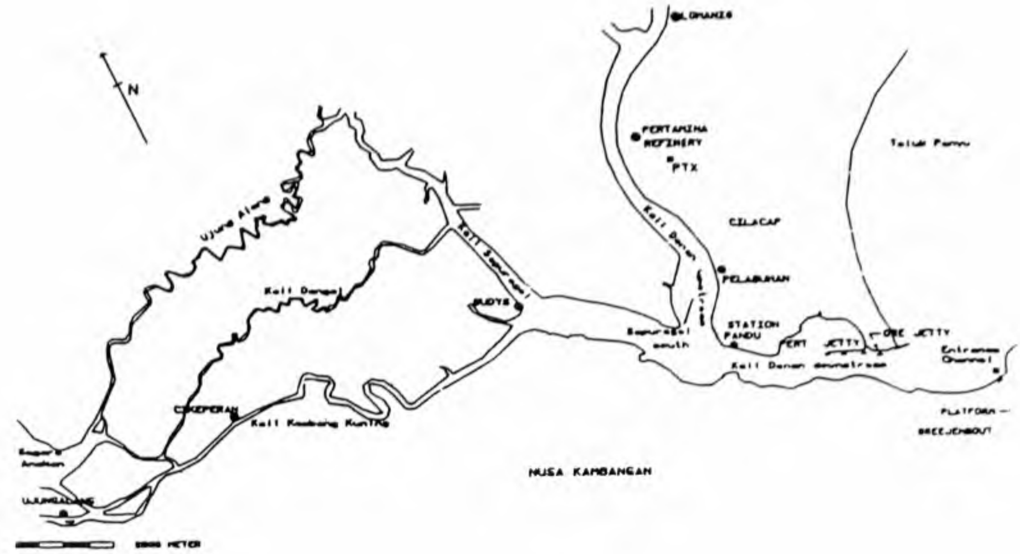


Figure 29 Study area

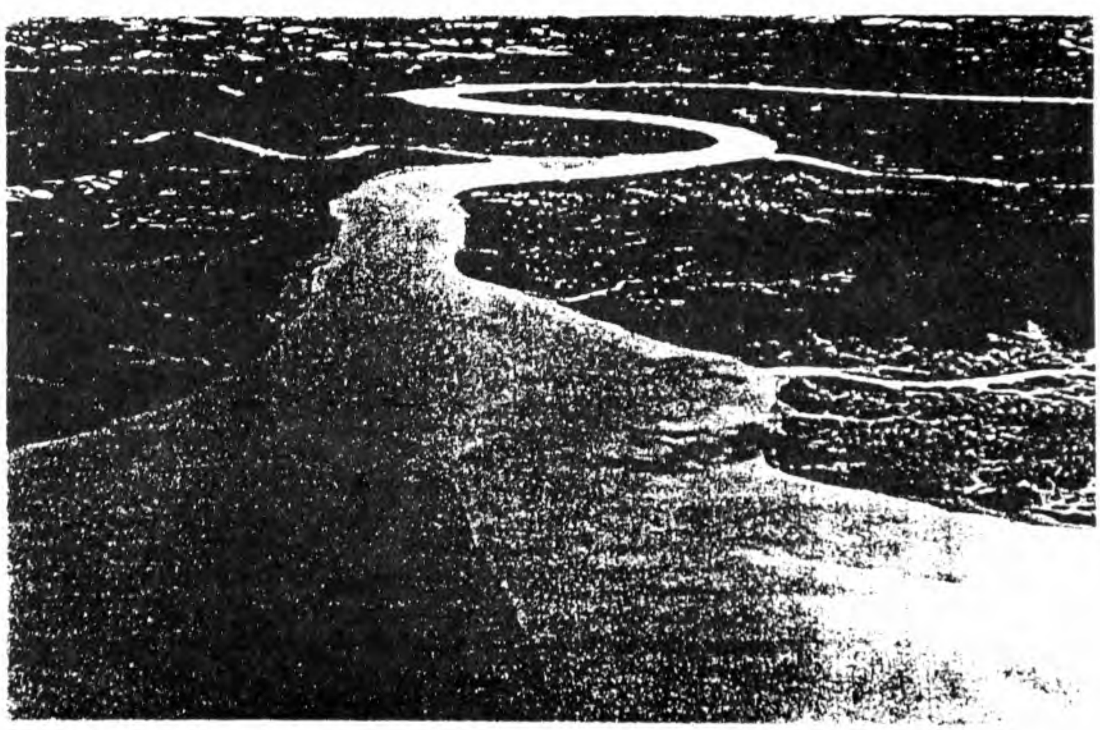


Figure 30 Air photo of the study area

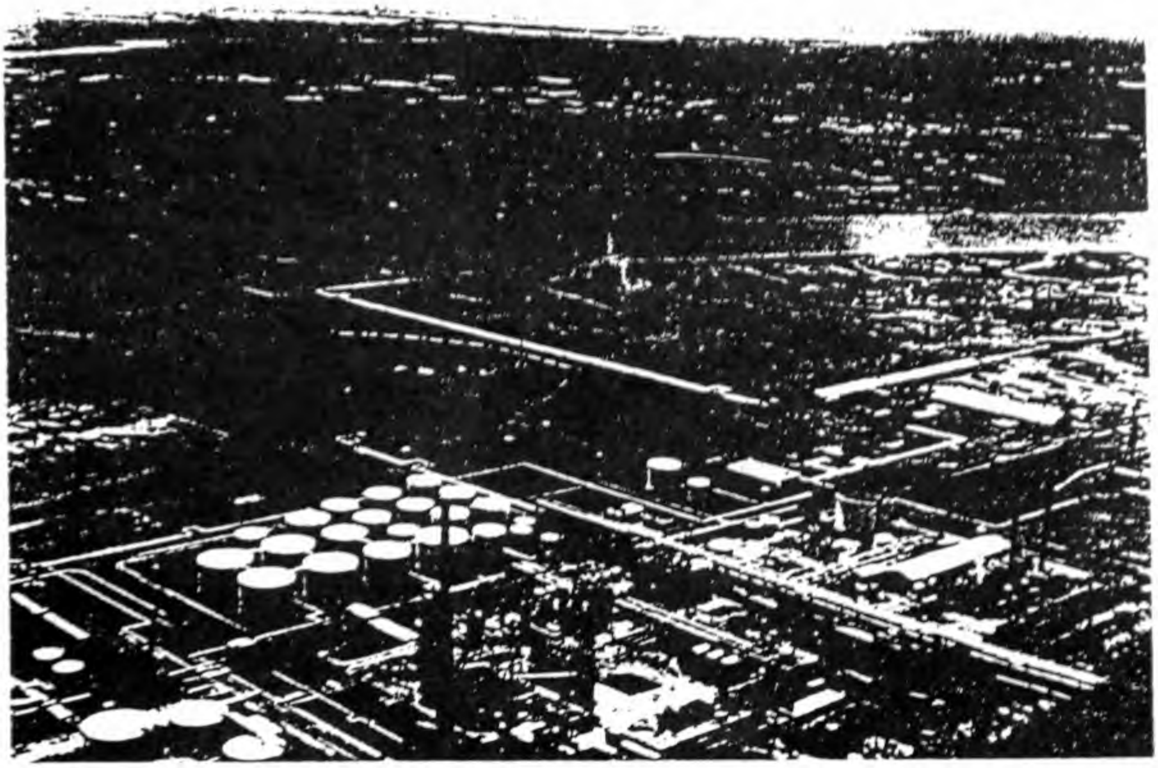


Figure 31 The Kali Donan near the refinery

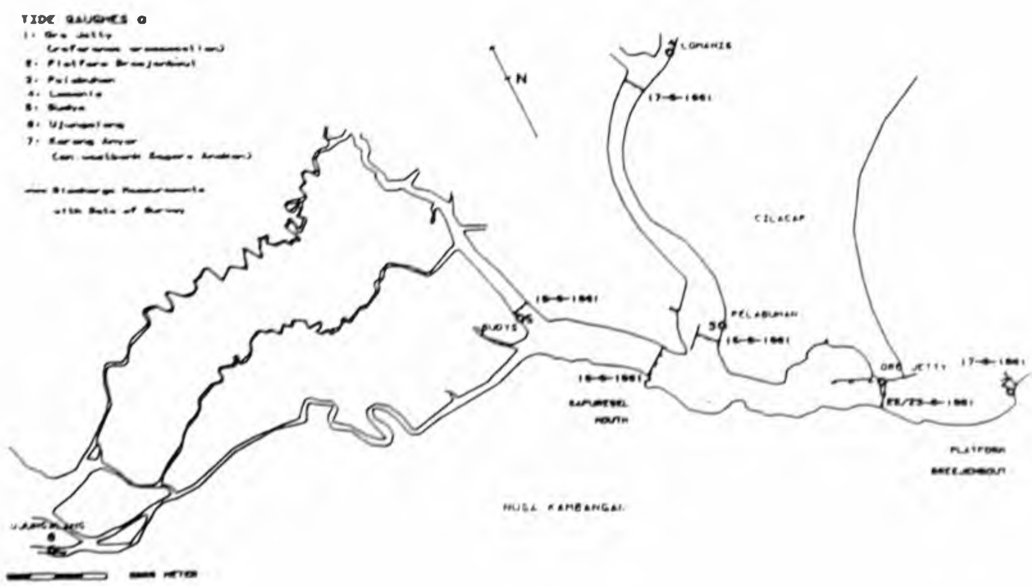


Figure 32 Location of tide gauges and discharge measurements

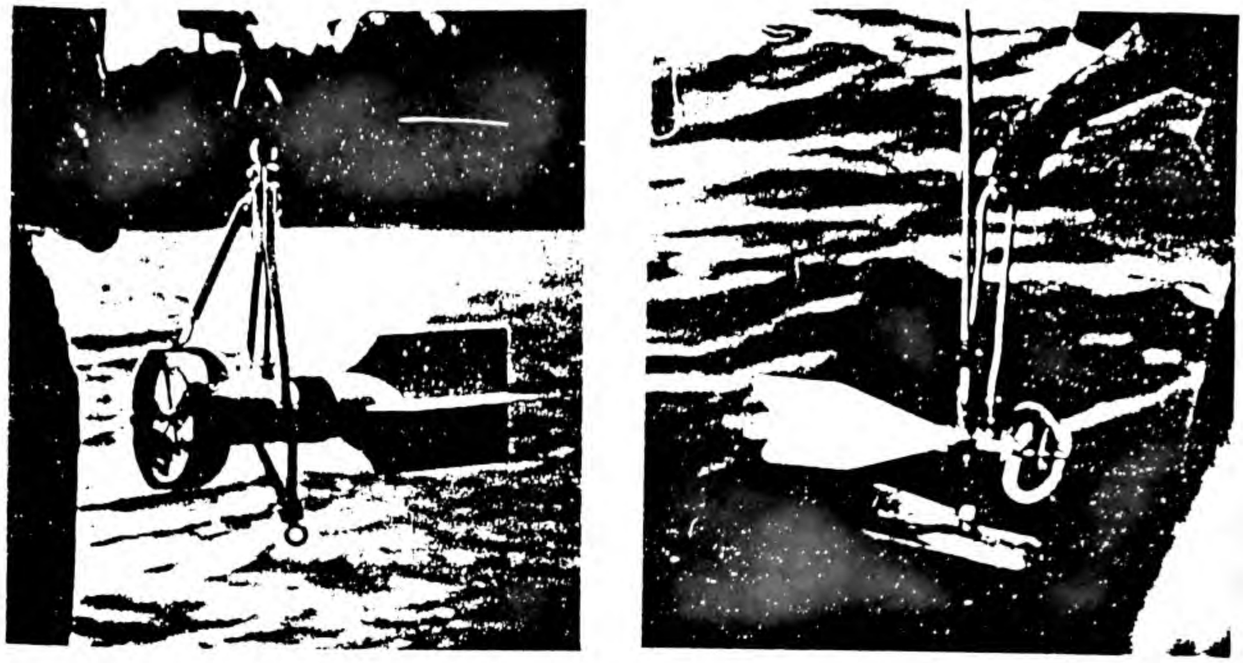


Figure 33 Detail photo's of the used measurement equipment

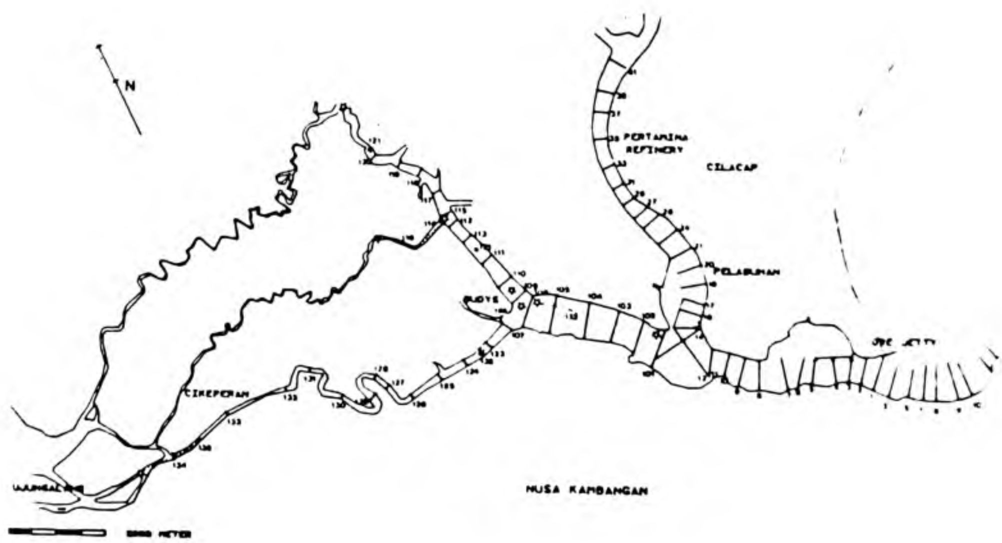


Figure 34 Location of cross-sections

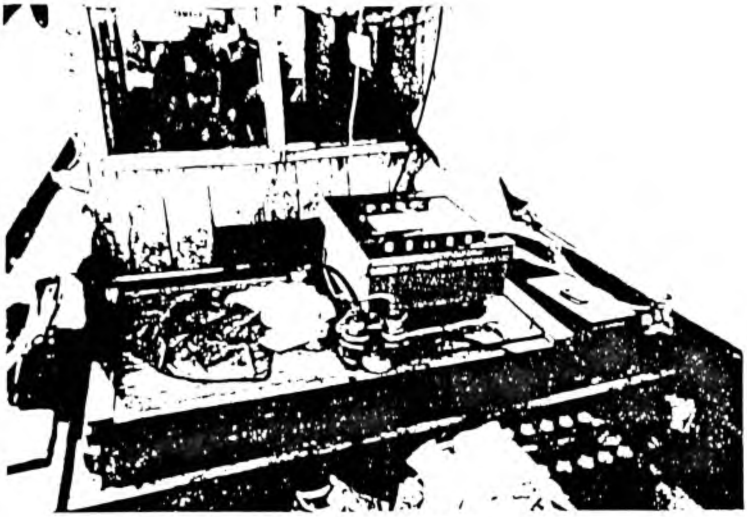


Figure 35 Used measuring equipment

Figure 36 Local circumstances

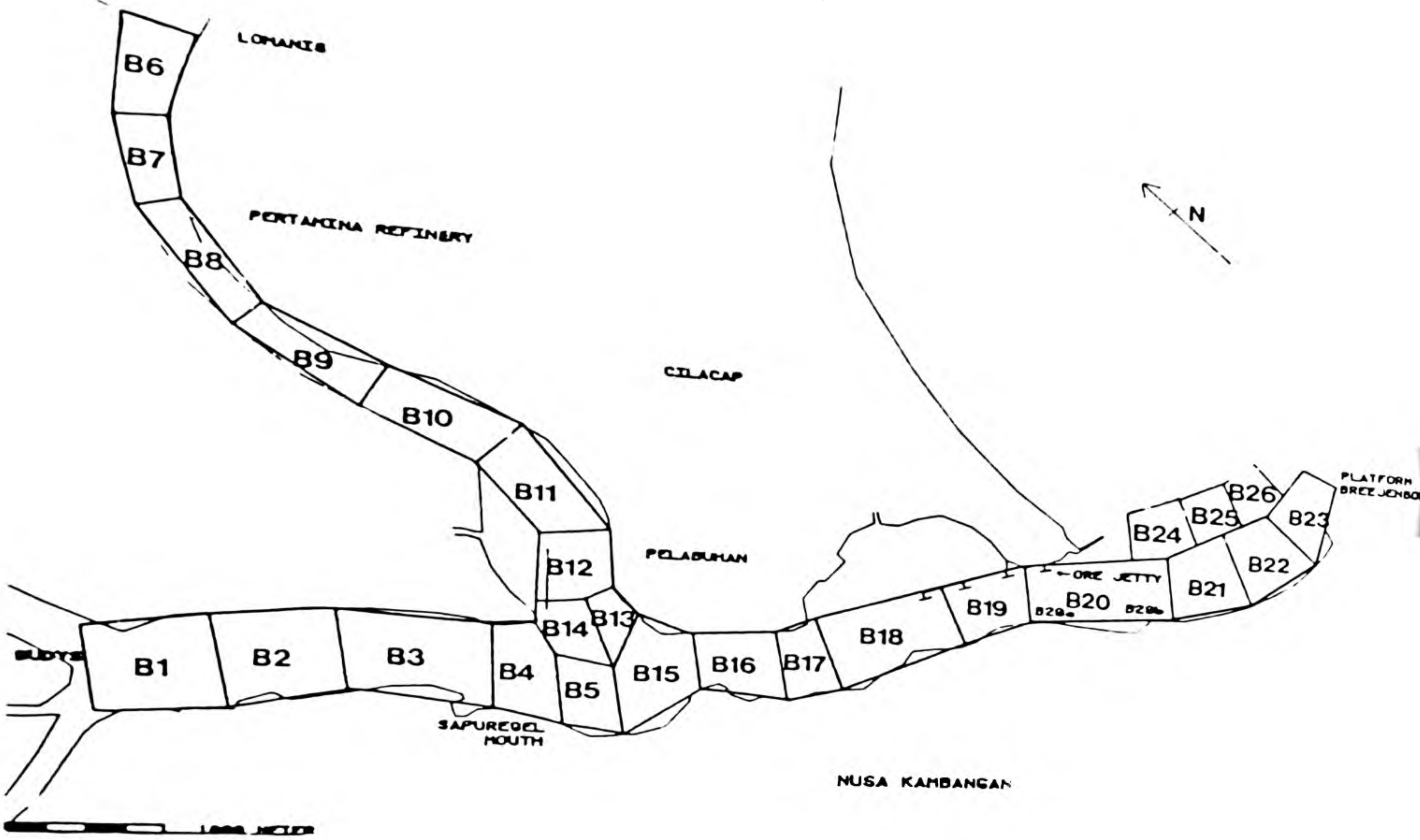


Figure 37 Branch set schematisation

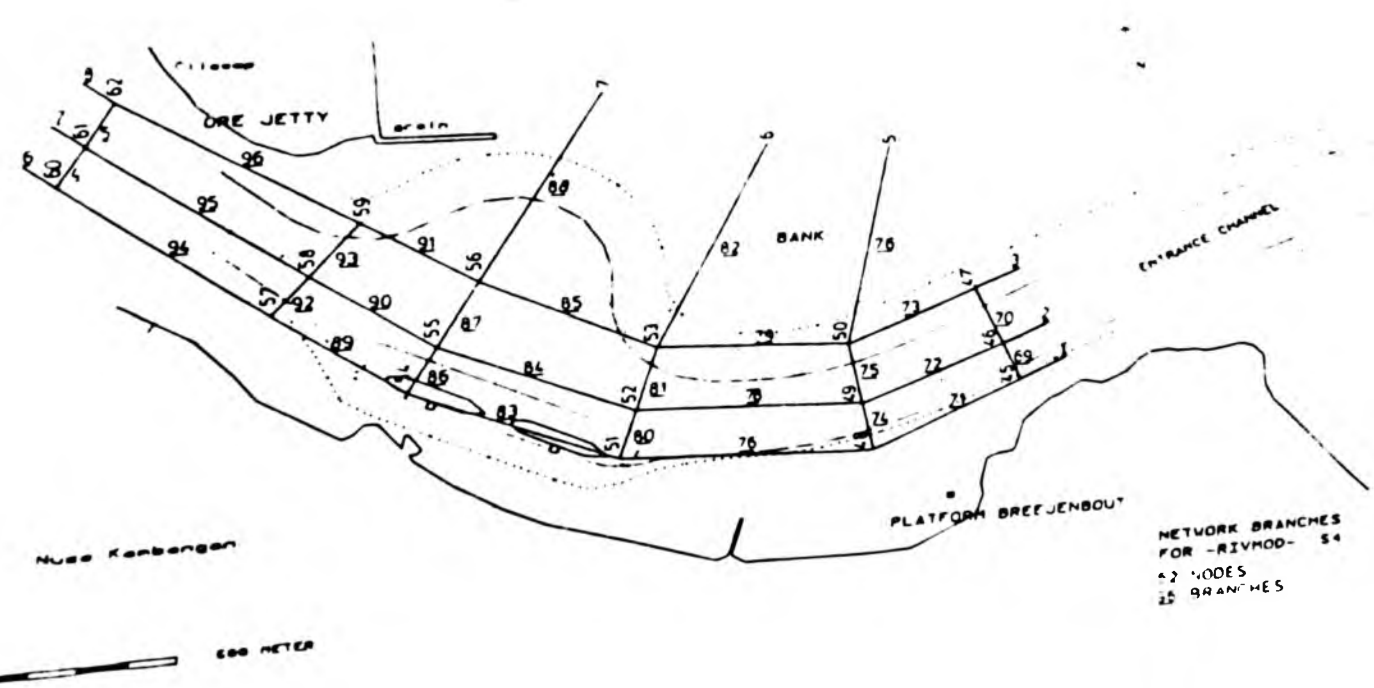


Figure 38 Schematization network for river mound

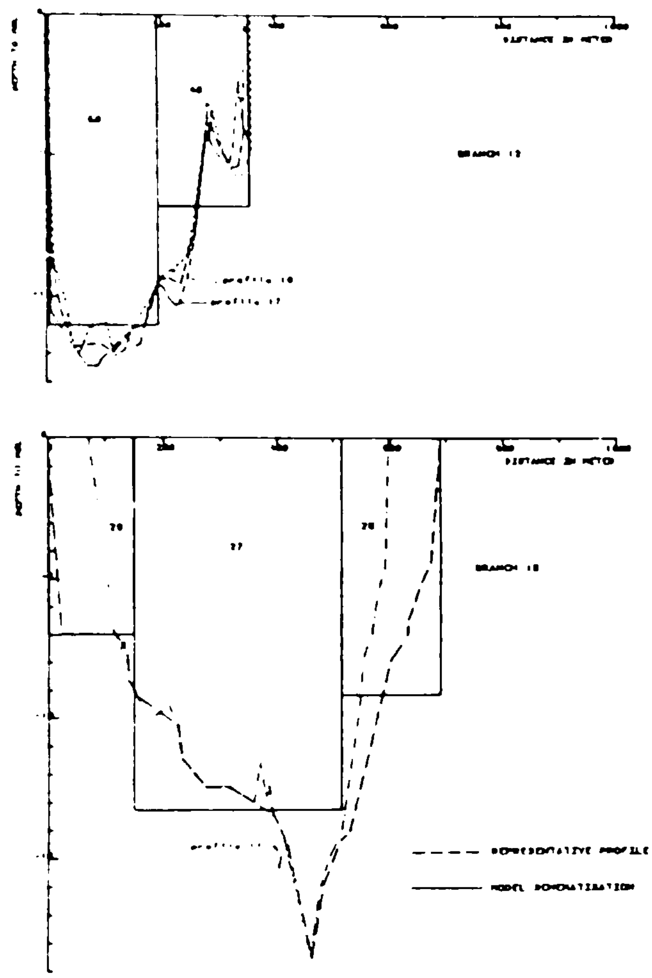


Figure 39 Profiles used for branch schematisation

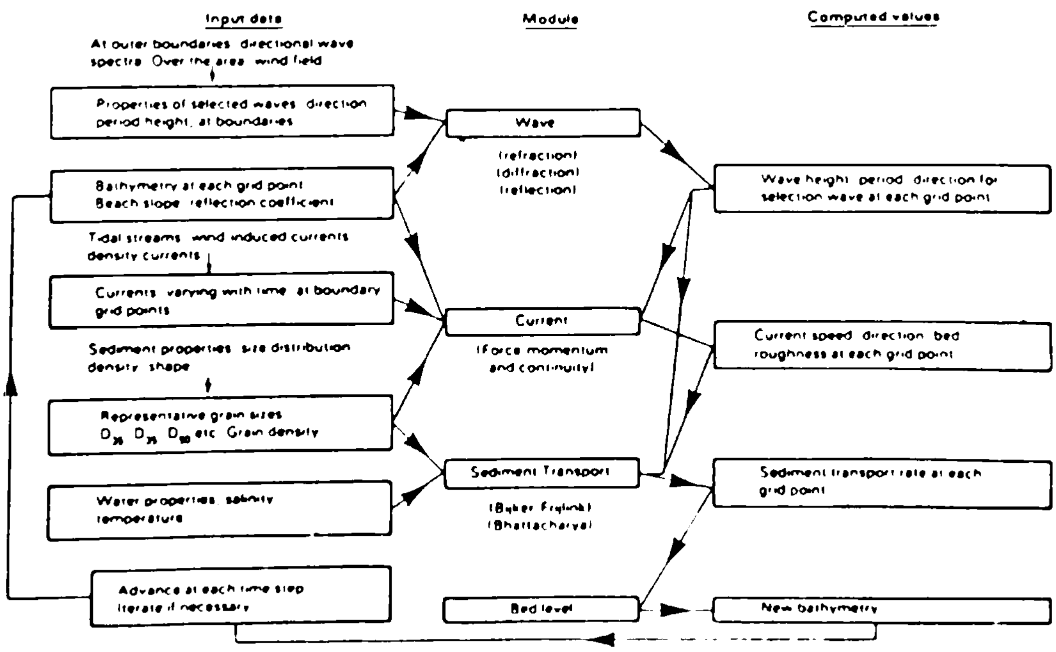


Figure 40 Numerical analysis of sediment transport coastal engineering problems

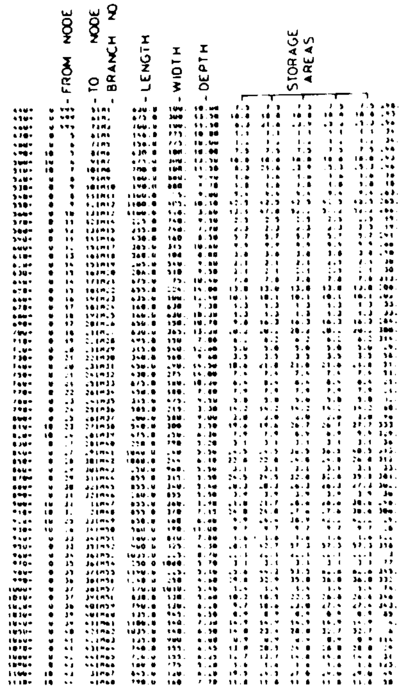


Figure 41 Computer input for mathematical model

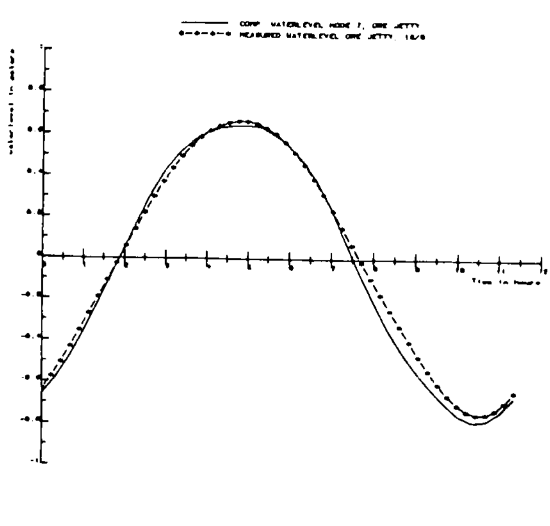


Figure 42 Calibration run calculated versus measured water levels

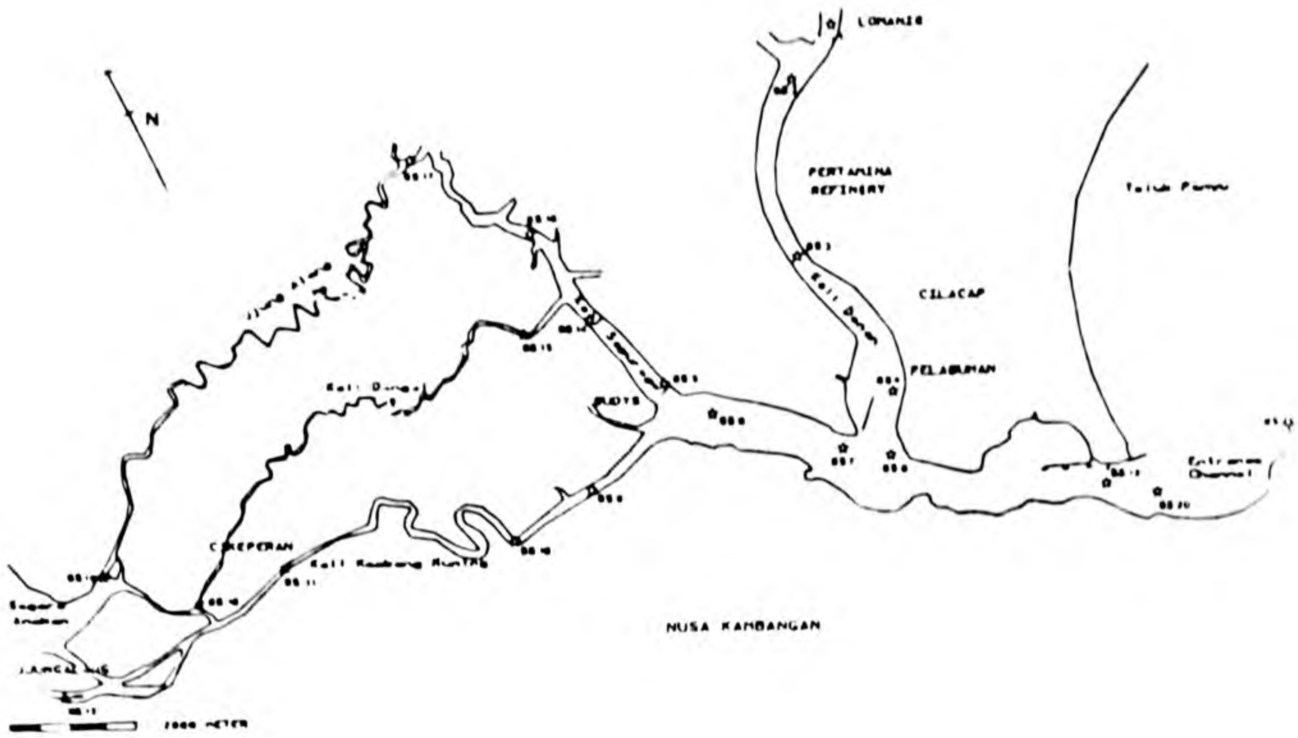


Figure 43 Location of bottom samples in study area

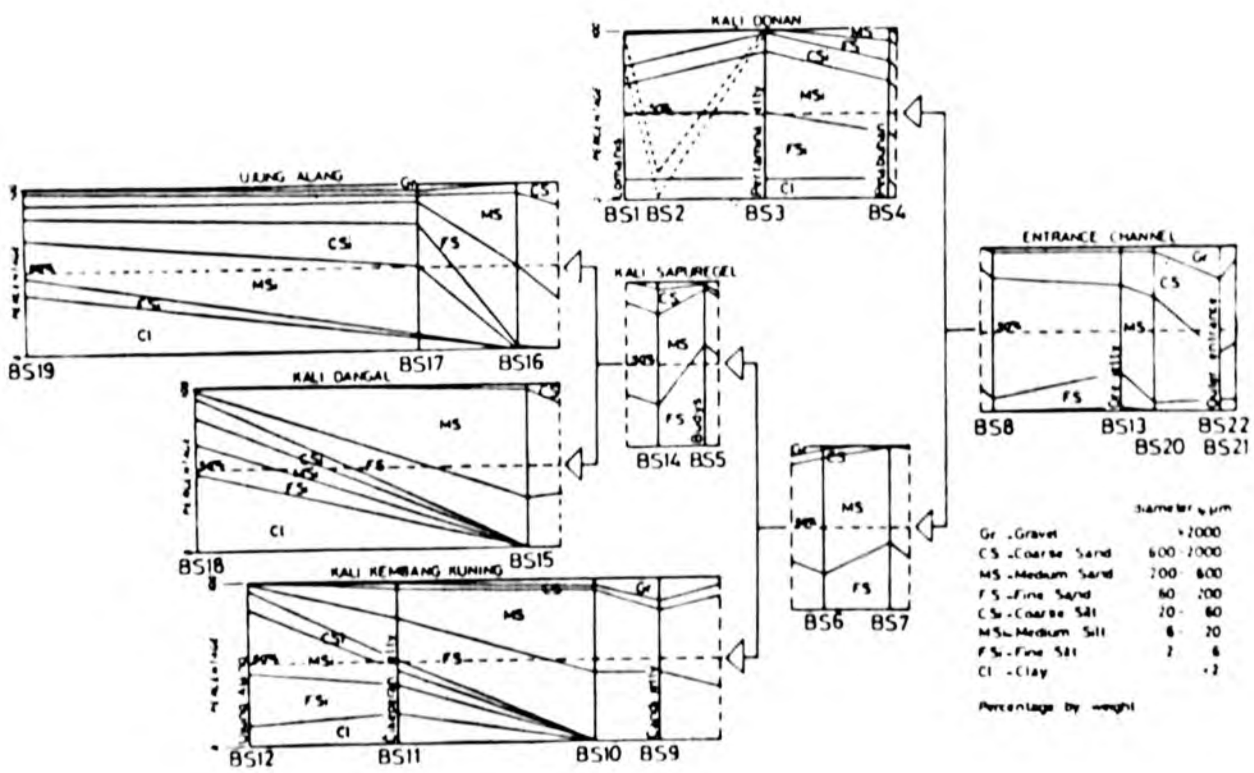


Figure 44 Graphic representation of grain size characteristics of rivers in study area

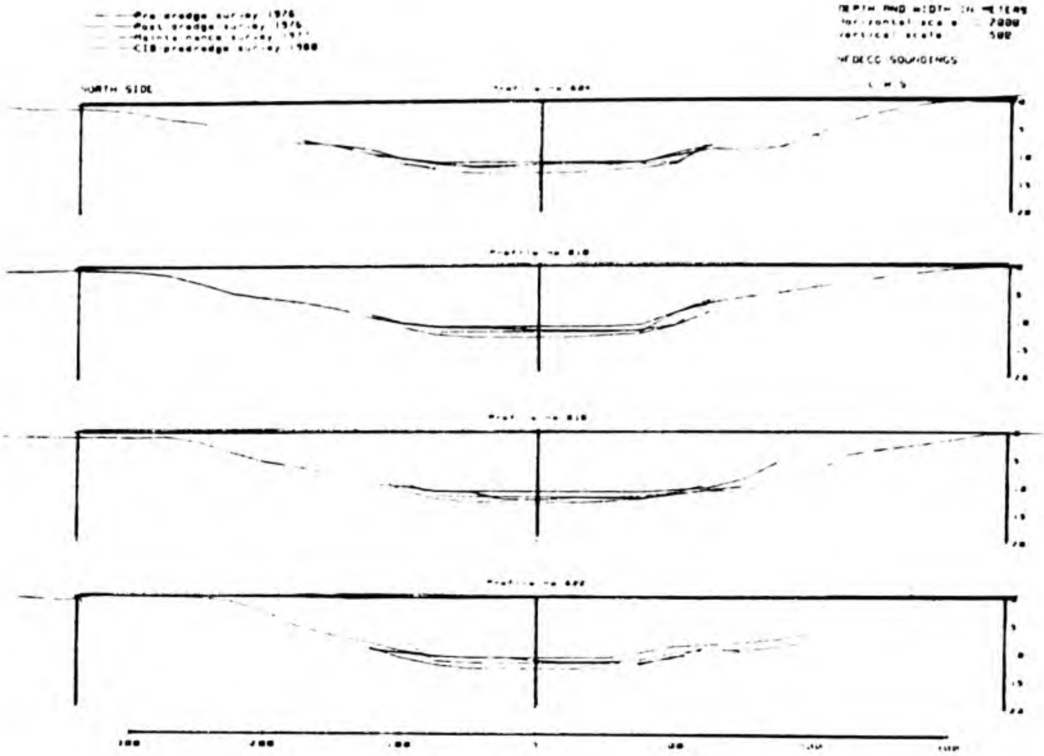


Figure 45 Comparison of bed level in time as a measure for sedimentation and erosion

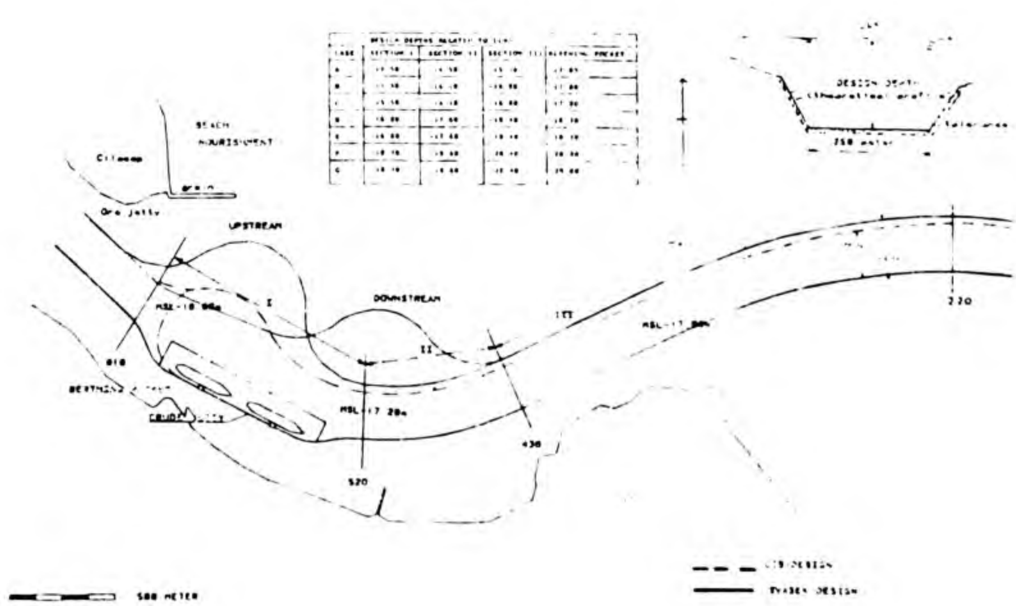


Figure 46 General layout of the alternatives; variable: location turning circle and channel depth

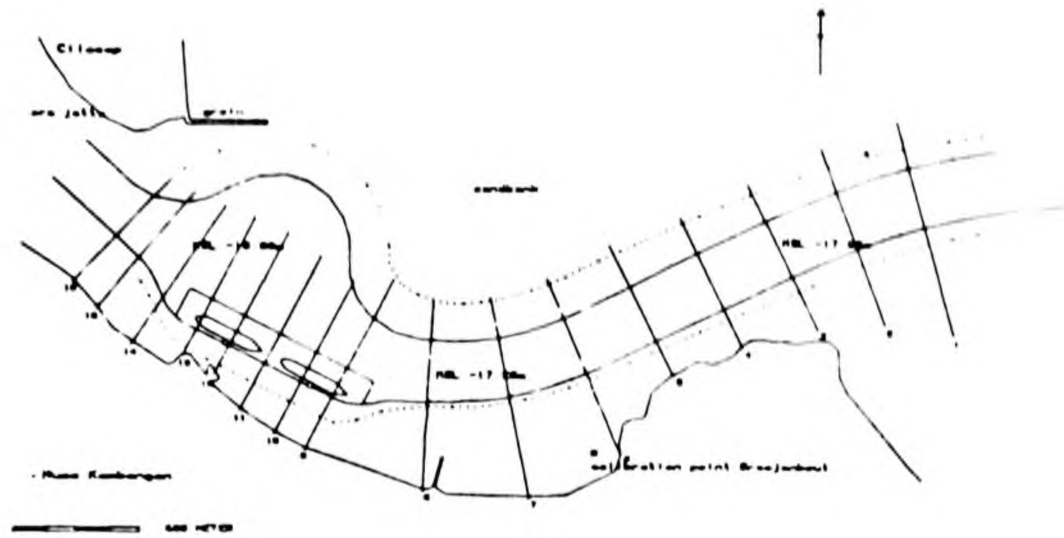


Figure 47 Entrance channel alternative I with location of cross-sections, used in streamline corpulation

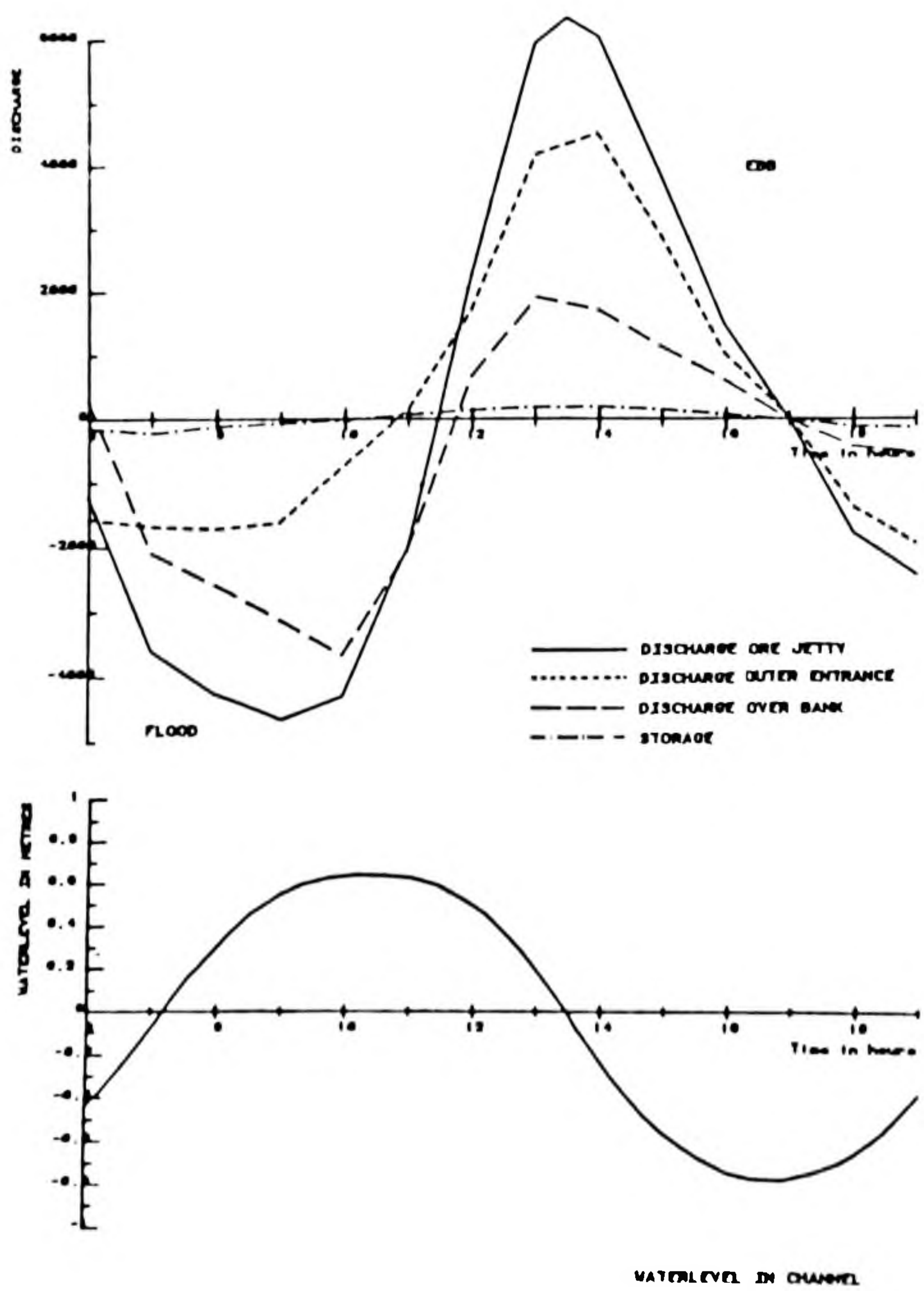


Figure 48 Discharge and water level in entrance Kali Donan

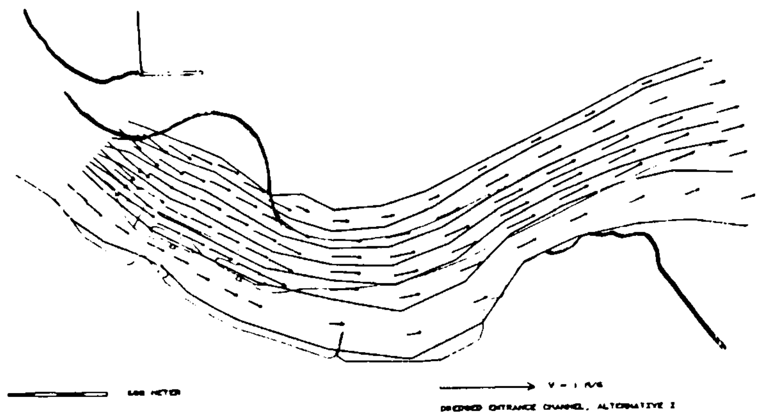


Figure 49 Streamlines and velocities ebb flow

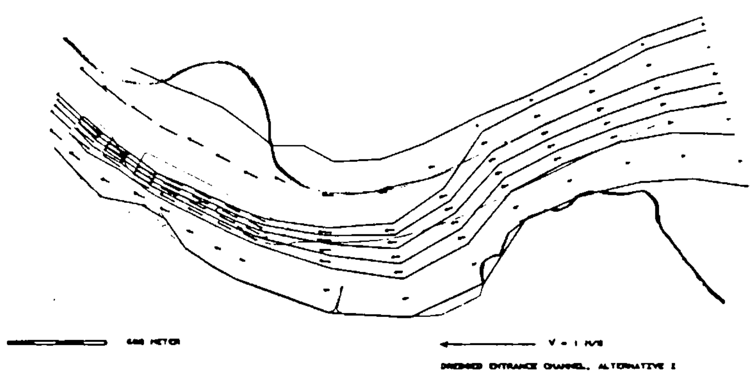


Figure 50 Streamlines and velocities flood flow

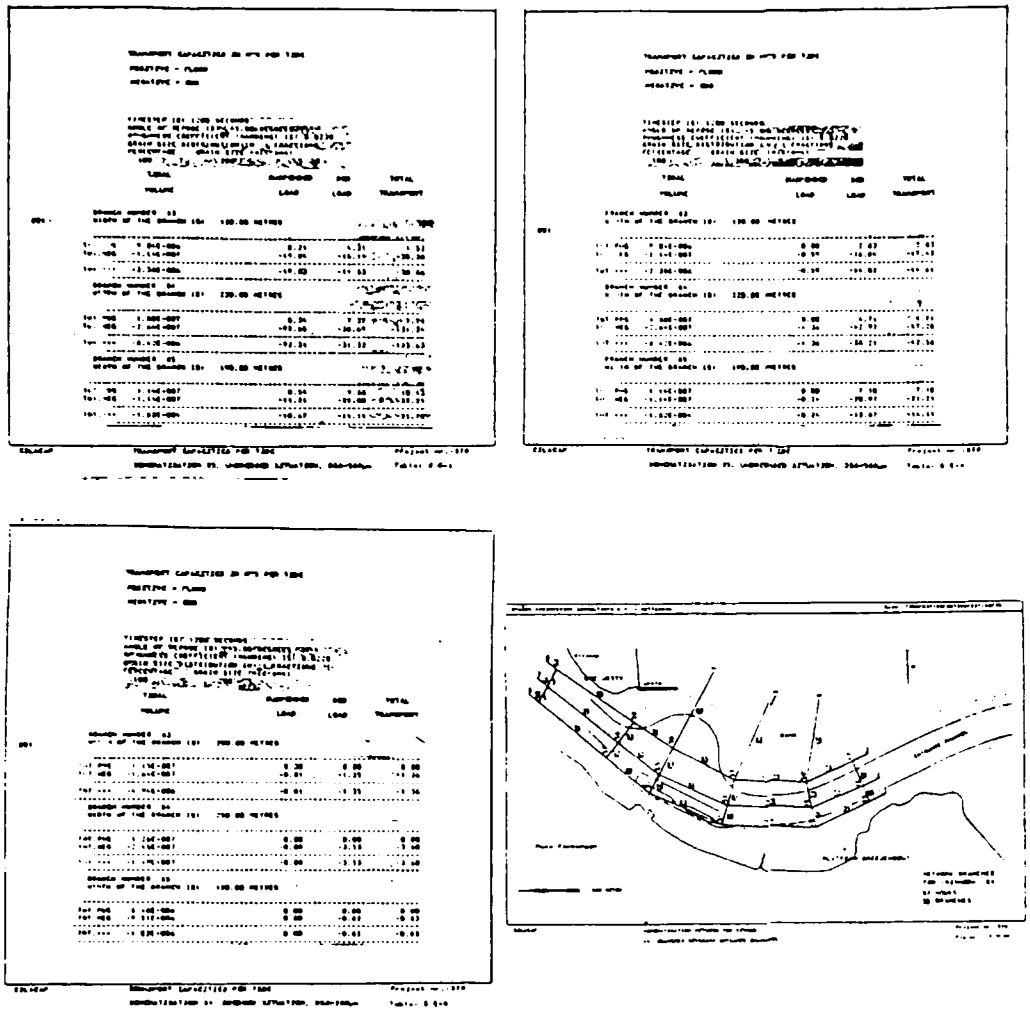


Figure 51 Results sensitivity analysis sedimentation in study area

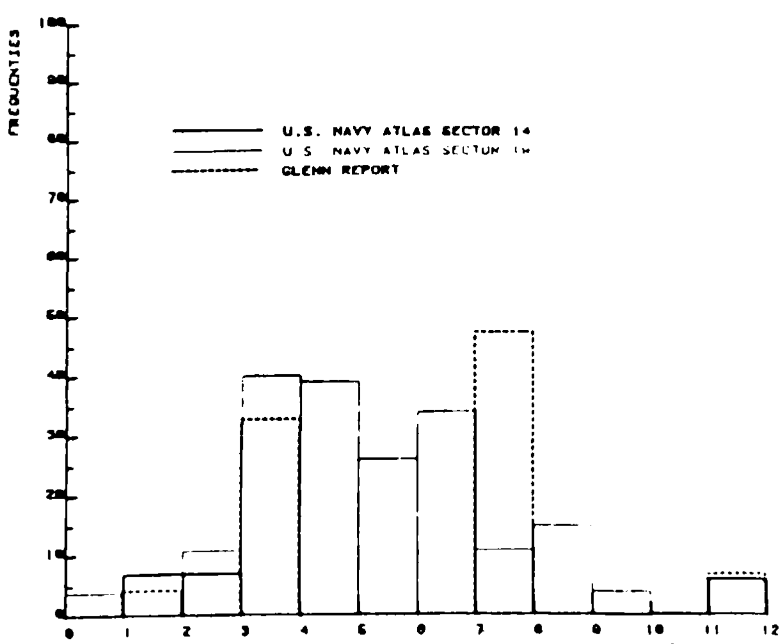


Figure 52 Variations in wind data in study area

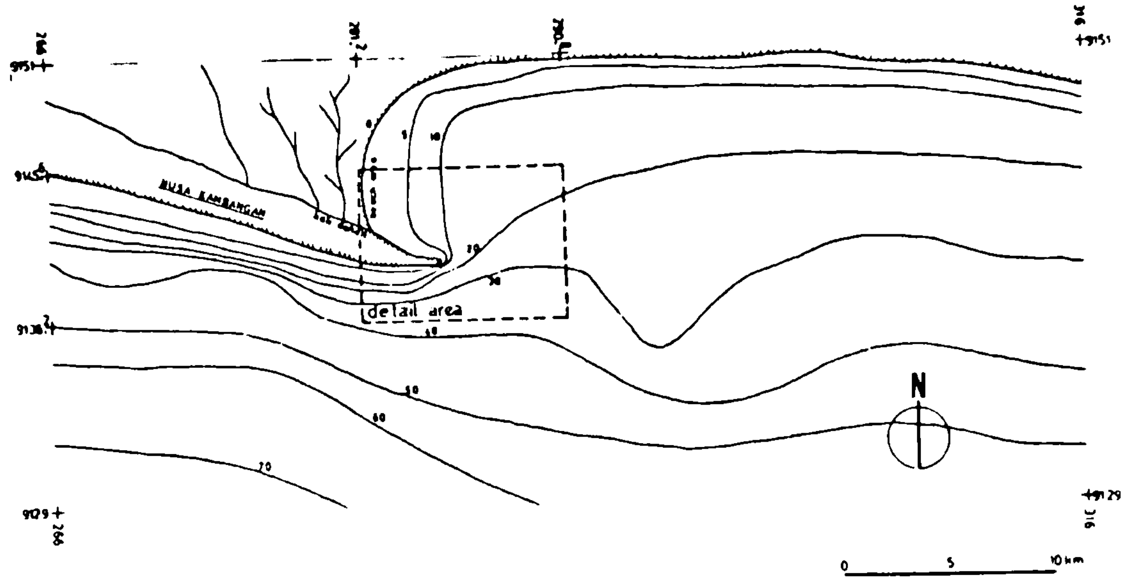


Figure 53 Depth contours main area used in refraction calculations

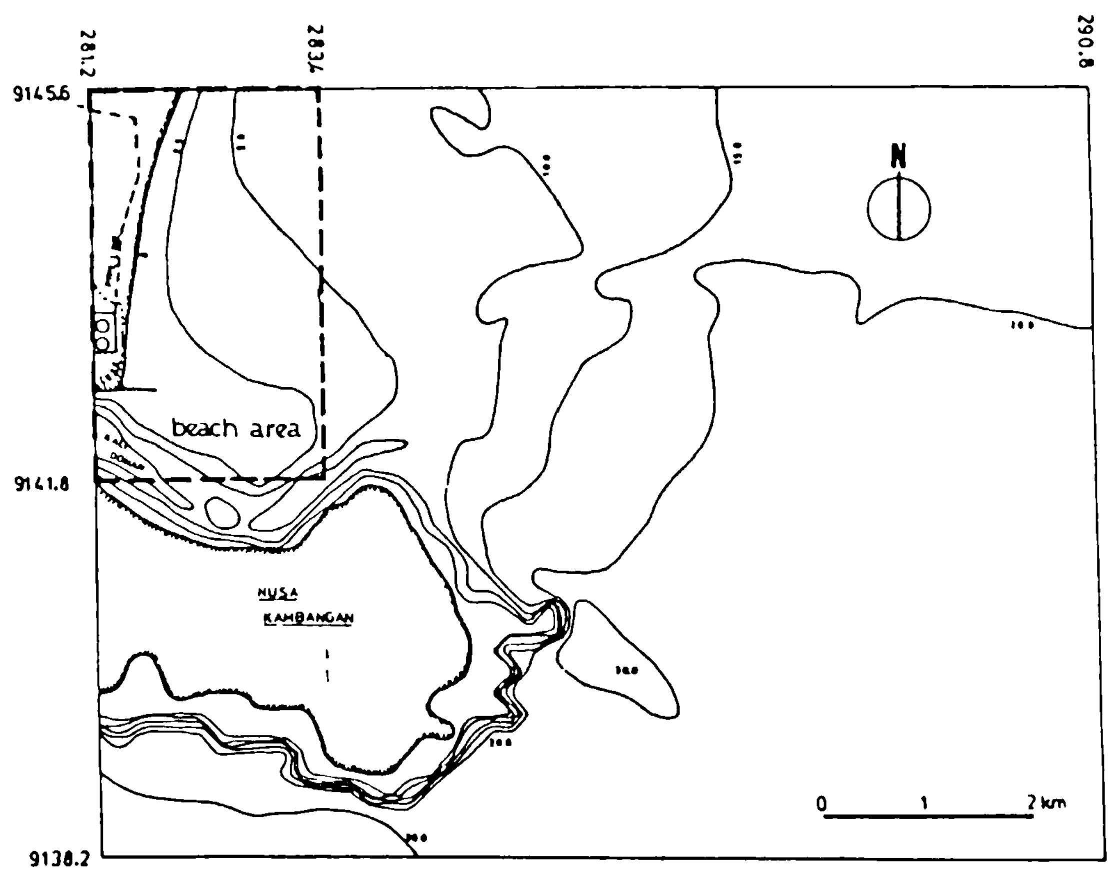


Figure 54 Depth contours detail area with beach area used in refraction calculations

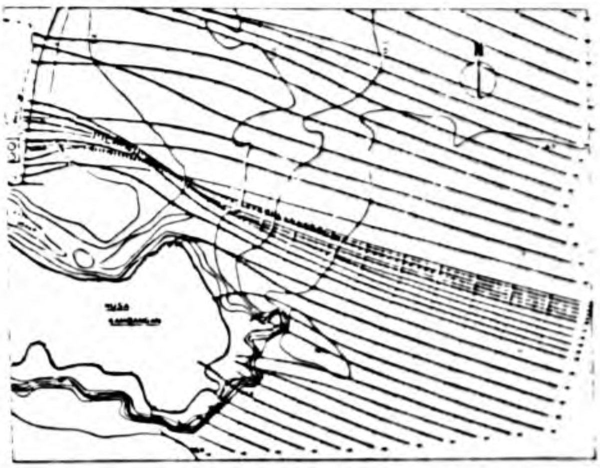


Figure 55 Refraction pattern detail area wave direction east

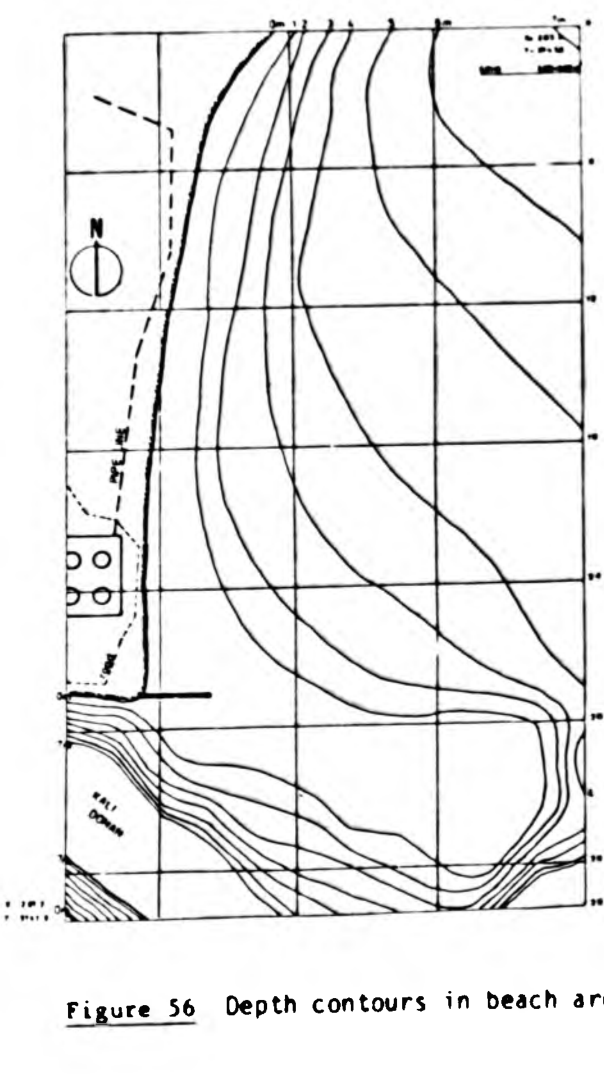


Figure 56 Depth contours in beach area

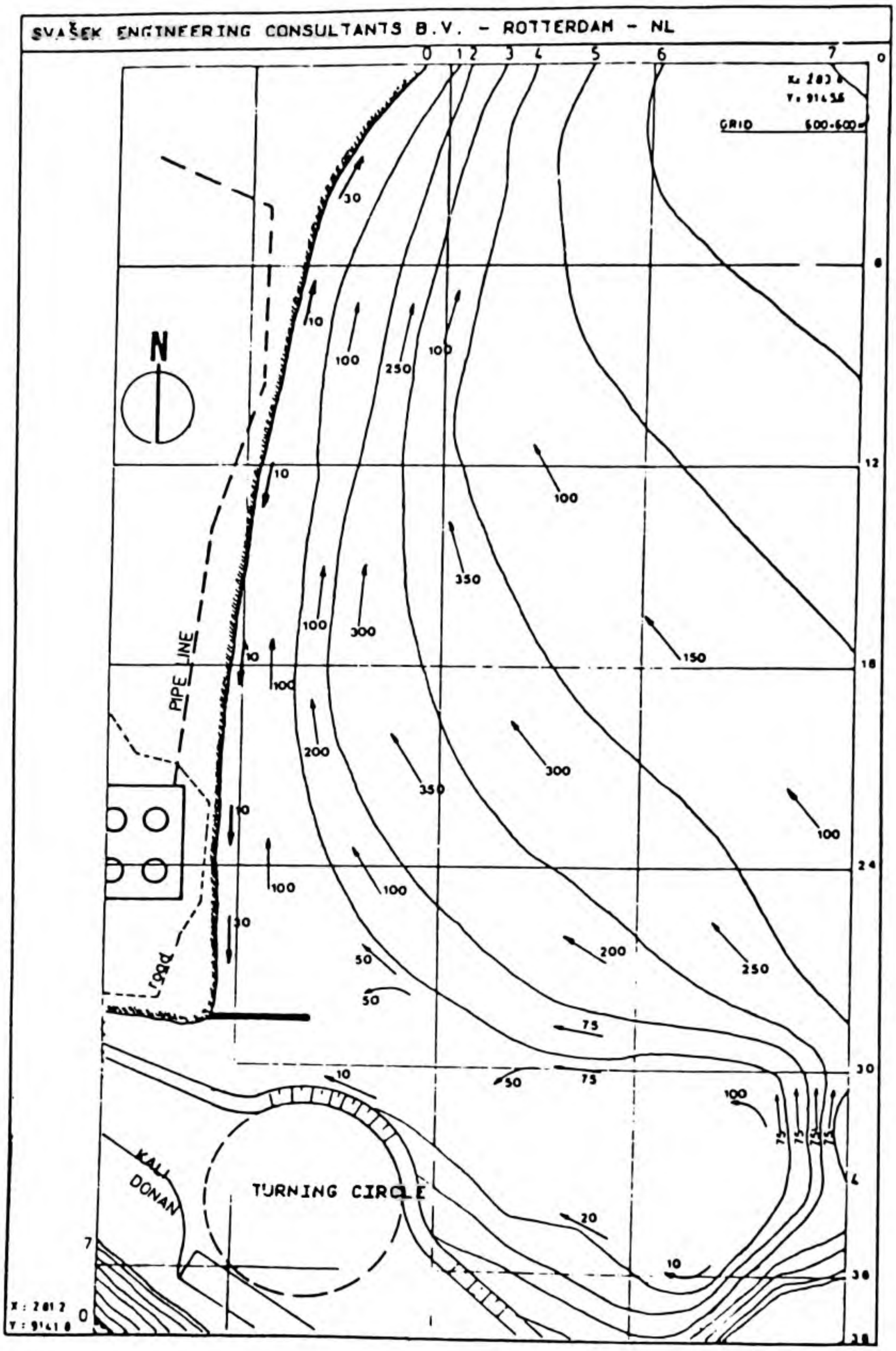


Figure 57 Transport capacity (1000 m³/6 months) combination of waves and tide in dredged situation

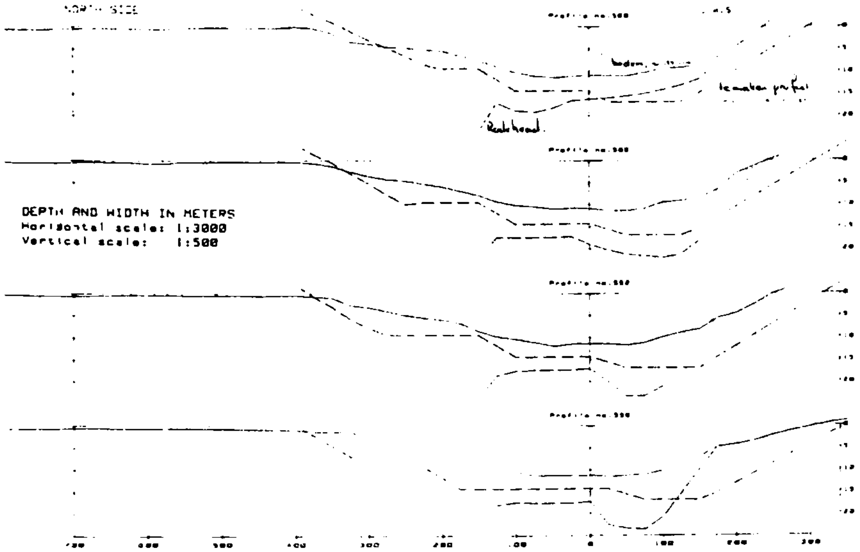


Figure 58 Position of existing bottom, to be made profile and rockhead in several profiles

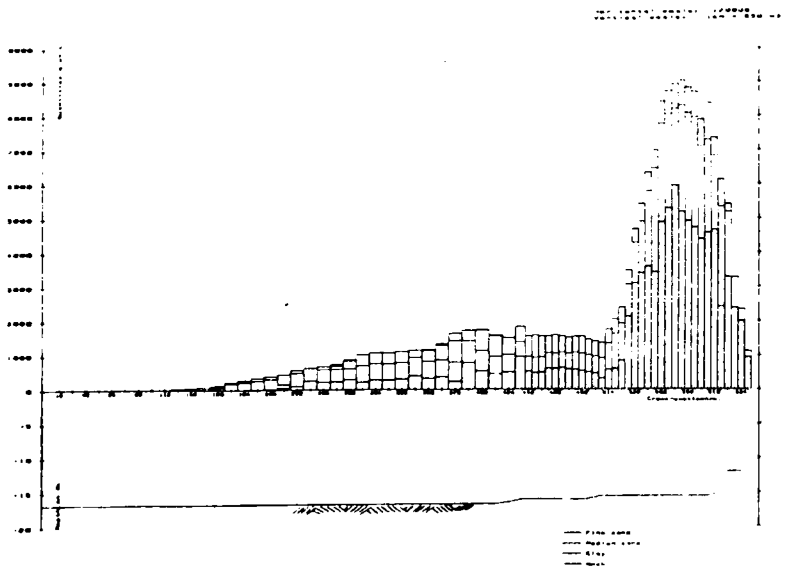


Figure 59 Picasso of dredged quantities set against the length axis of the channel to be dredged

DESIGN		SOFT SEDIMENT			TOTAL SOFT	HARD SEDIMENT	TOTAL
	SLOPE	FINE SAND	MEDIUM SAND	CLAY		ROCK	
A	1:10	-	625	-	625	-	625
B	1:5	3800	3800	1864	9464	90	9554
	1:10	5600	4100	1764	11464	90	11554
C	1:5	3600	3500	2164	9264	90	9354
	1:10	5100	3900	1964	10964	90	11054
D	1:5	3800	3800	4050	11650	350	12000
	1:10	5600	4100	5950	15650	350	16000
E	1:5	3600	3500	4545	11645	355	12000
	1:10	5100	3900	6145	15145	355	15500
F	1:5	3800	3800	8637	16237	863	17100
	1:10	5600	4100	11581	21281	1090	22371
G	1:5	3600	3500	8824	15924	867	16791
	1:10	5100	3900	11754	20754	1095	21849

All Quantities in 1000 m^3

Figure 60 To be dredged quantities in different alternatives

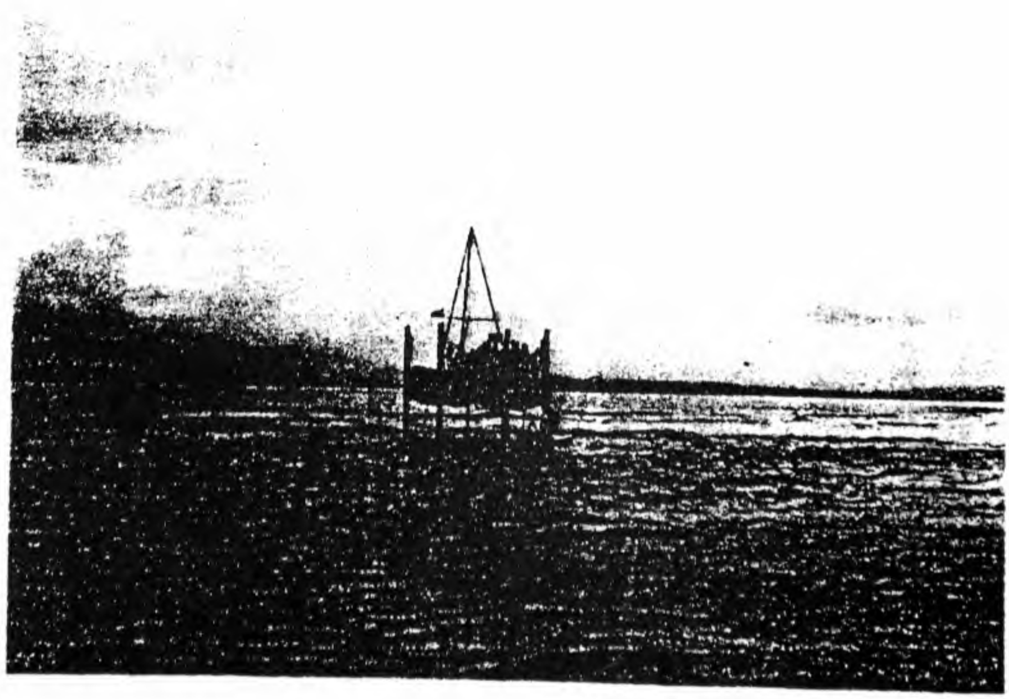


Figure 61 Jack up pontoon, used for the soil survey of the sand bank north of the entrance channel

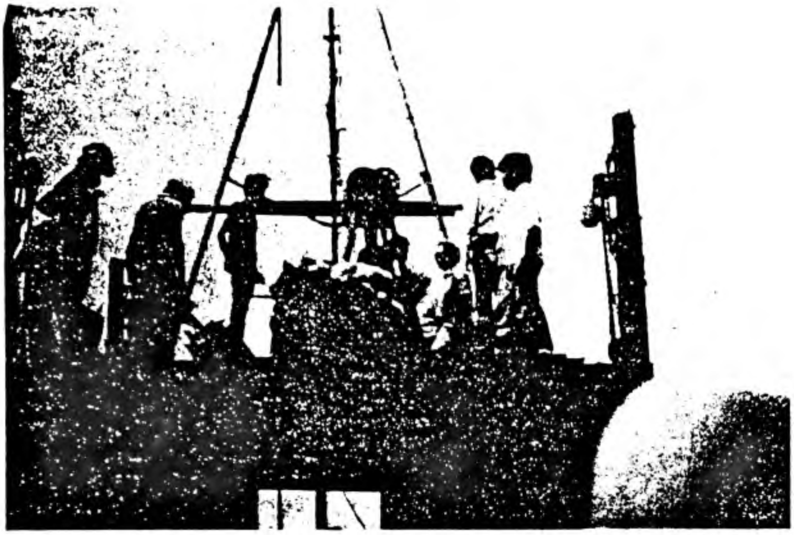


Figure 62 Detail picture of pontoon and equipment supervision by Dutch expert (IGF)

Figure 63 Detail picture of electronic equipment on board survey vessel "de Vliestroom" of Dredging Company Breejenbout

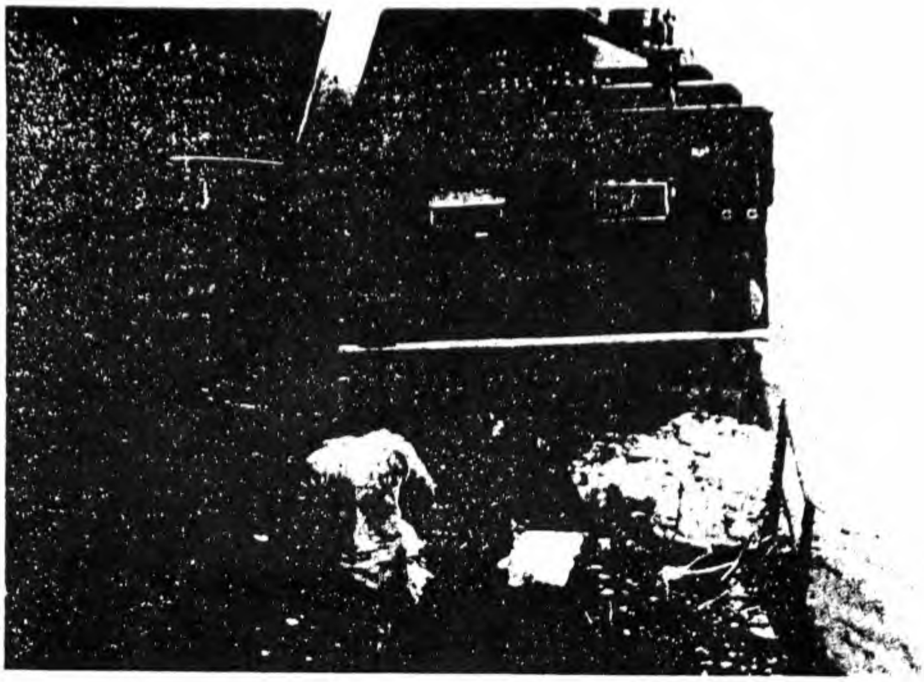


Figure 64 Delay during trailing caused by hard soil (conglomerate: soft rock) blocking the draghead inlet

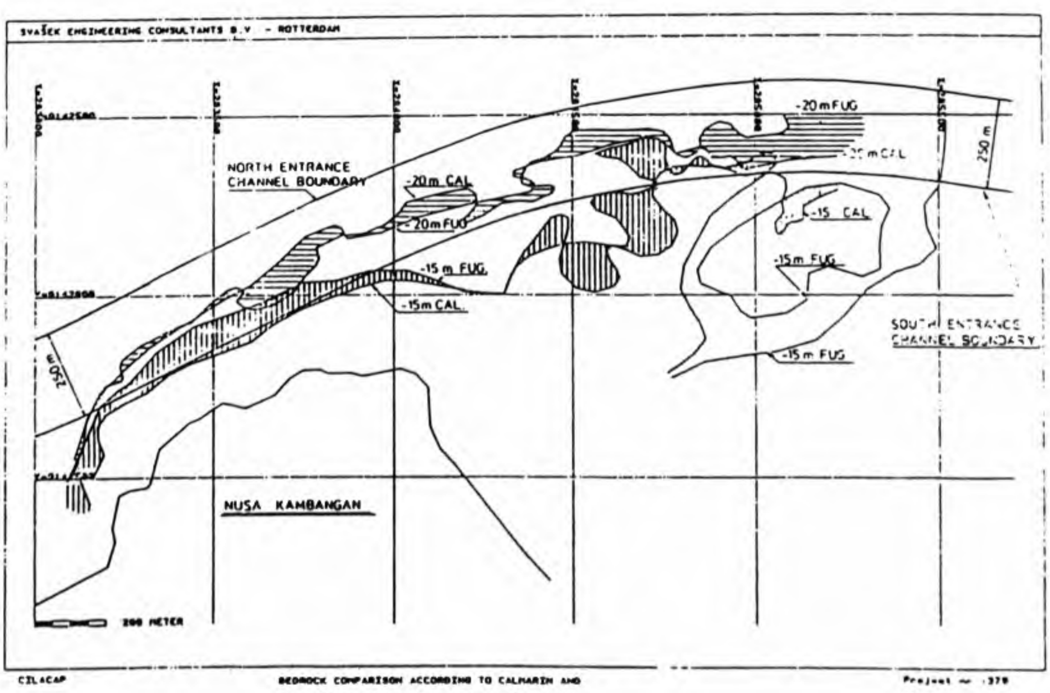


Figure 65 Horizontal accuracy surveys

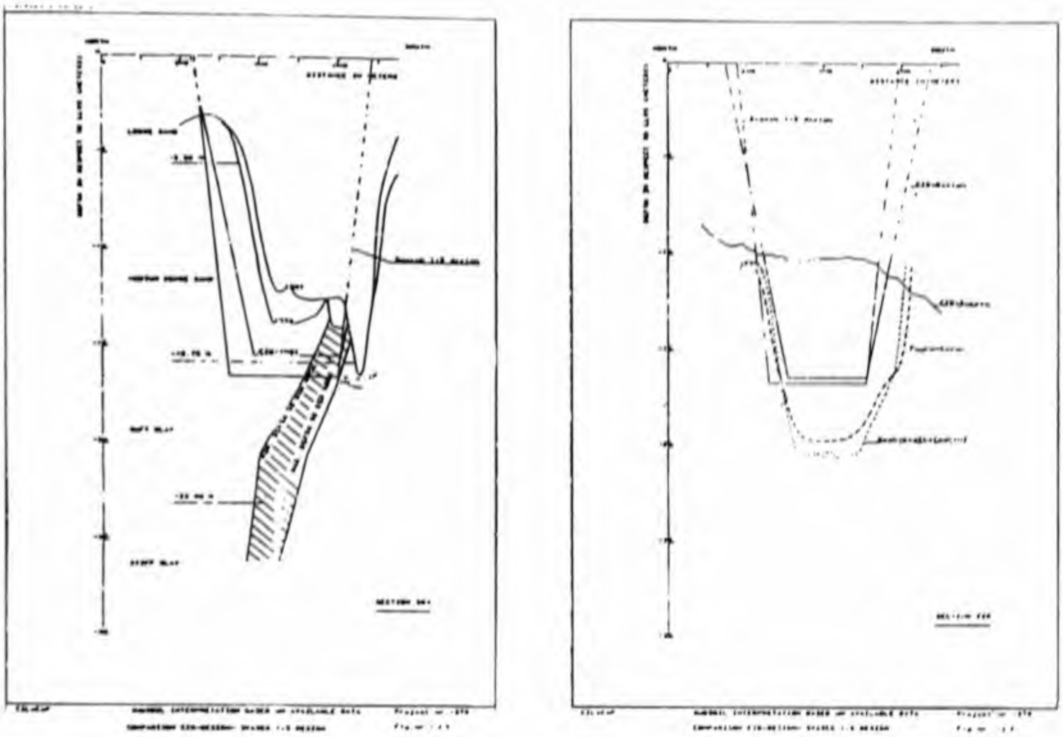


Figure 66 Vertical accuracy surveys

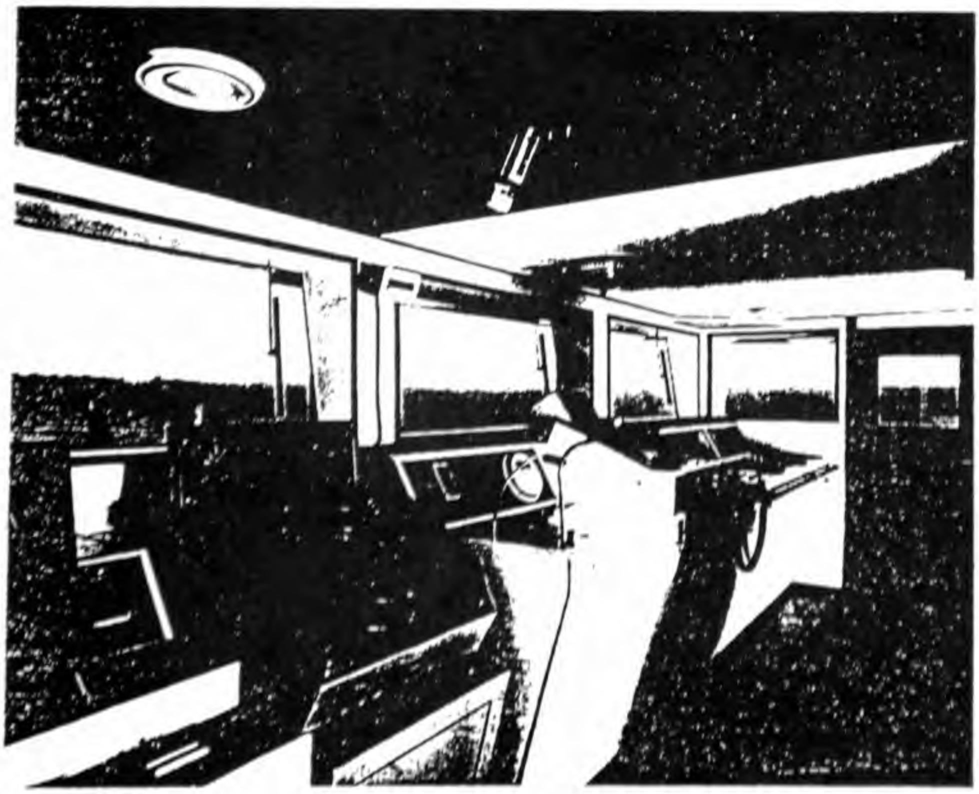


Figure 67 Tanker bridge of real-time simulation model with representation of outside world

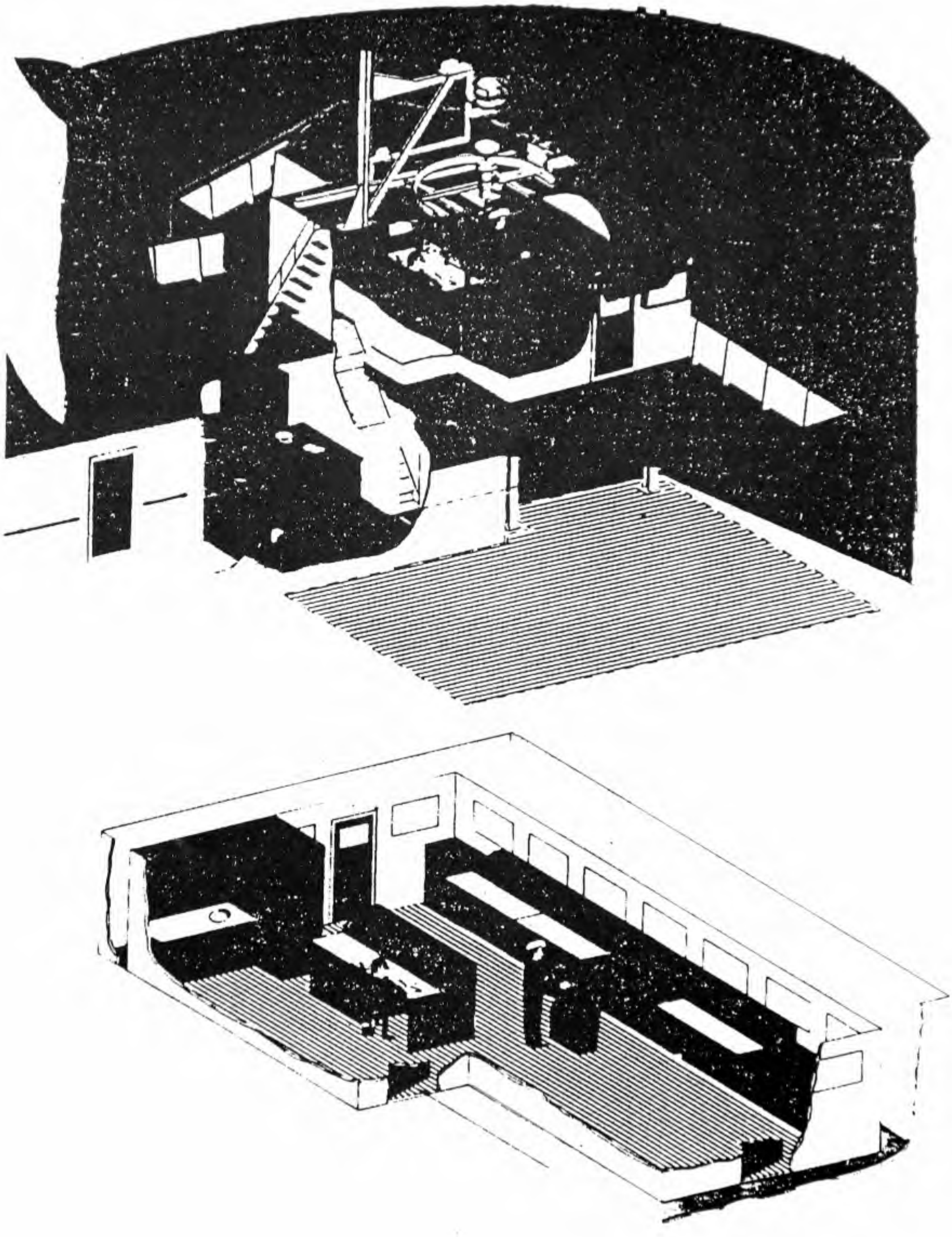


Figure 68 Schematic view of simulator

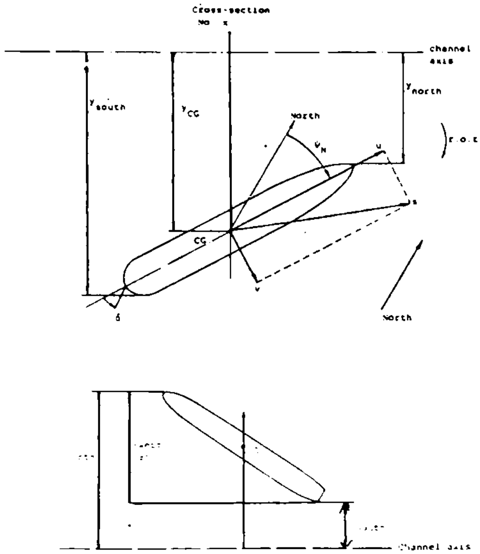


Figure 69 Some of the variables registered

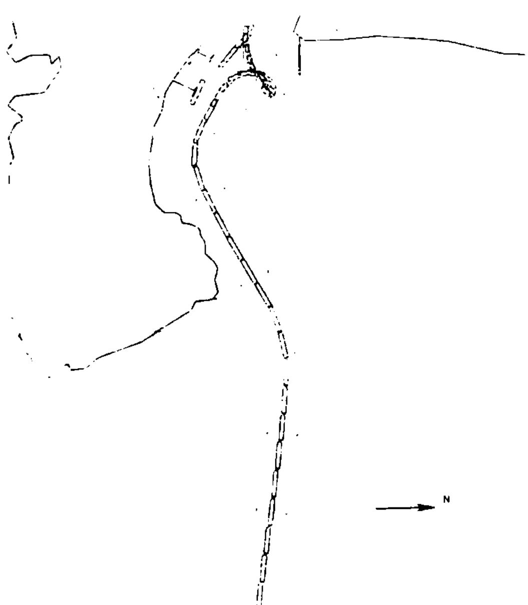


Figure 70 Example of manoeuvres during entering and berthing on real-time simulator

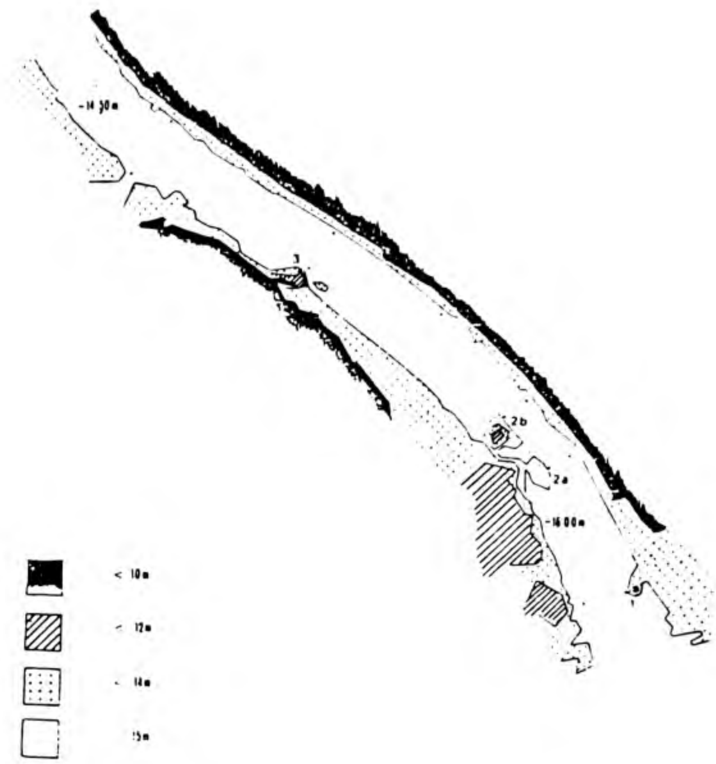


Figure 71 Locations of the rock outcrops in the channel

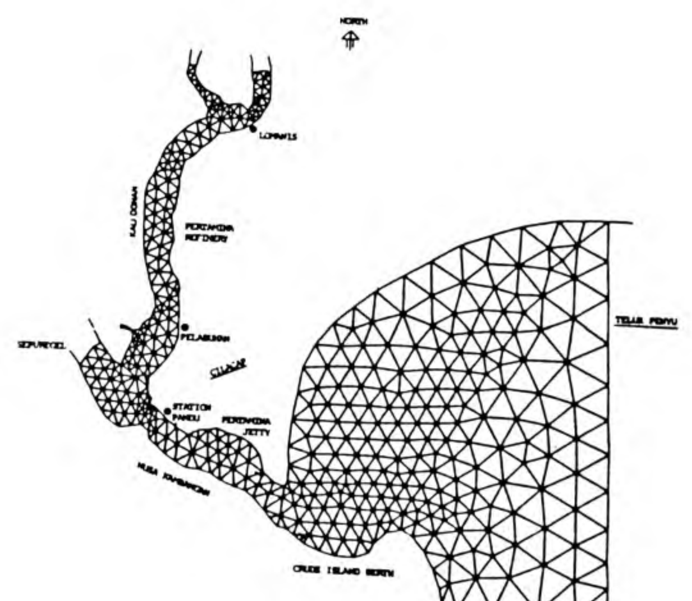


Figure 72 Two dimensional (finite elements method) flow model to get a more accurate flow pattern to be used in a simulation model including the rock outcrops (risk analysis)

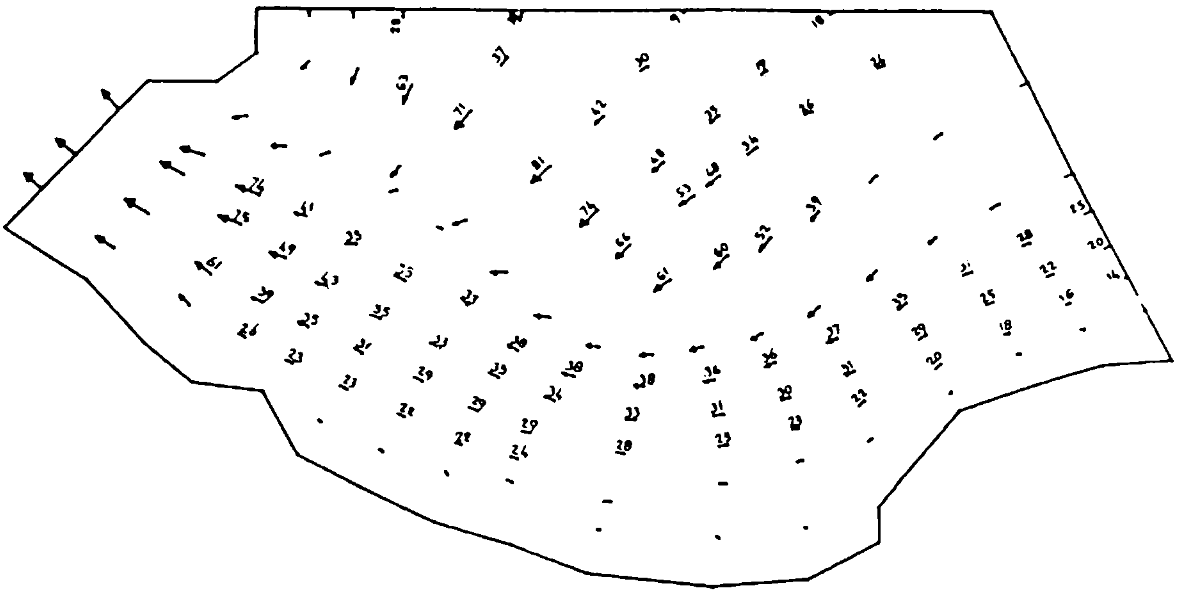


Figure 73 Example of calculated flow pattern

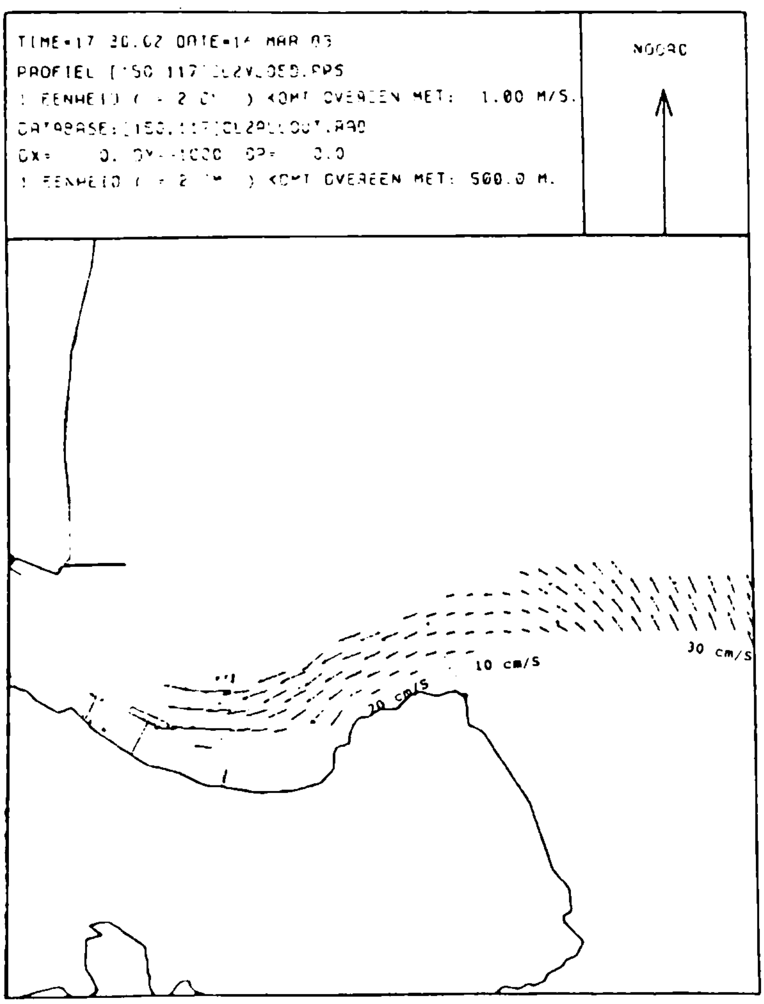


Figure 74 Example of use made of flow pattern in the simulation

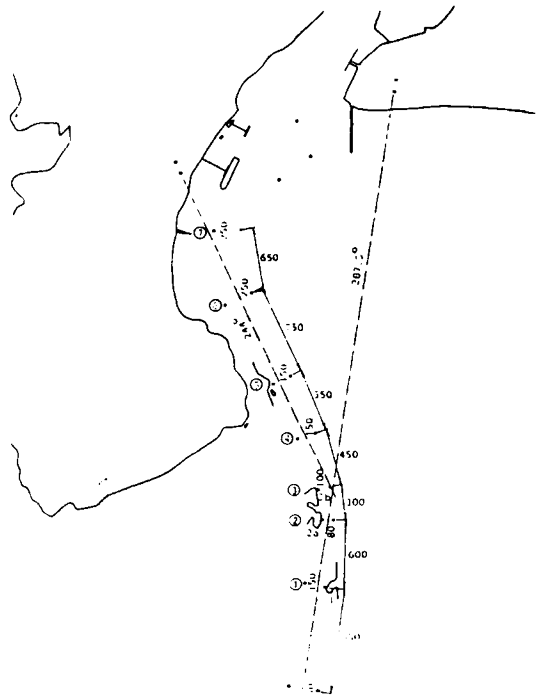


Figure 75 Pilot instruction with leading lines and configuration of buoys with all rock outcrops in the channel used in simulating the navigability of the channel

Figure 76 One of the simulation runs

IRUNNR 2021 TIME 10.02 DATE 23-MAR-83

	T MIN	YDW M	Y1 M	Y2 M	RPM	RUD DEGR	PSI DEGR	BETA DEGR.	UGR M/S	VGR M/S	SGR M/S	R.O.T DEGR/S	DPT M	DSD M	DPBOW M	DPAFT M
1	0.	0.	23.	-23.	0	0	273.7	4.8	3.08	0.26	3.09	0.002	82	70	7.3	7.3
2	0.	0.	24	-24.	33	-35	272.9	5.2	3.09	0.28	3.10	-0.039	81	68	7.3	7.3
3	1.	-2.	26	-30.	59	-35	270.8	5.4	3.10	0.29	3.12	-0.079	76.	66	7.3	7.3
4	1.	-8.	22.	-38	57	-35	269.5	4.8	3.17	0.26	3.18	0.004	67.	70	7.2	7.3
5	2.	-15.	15.	-46.	31.	-35.	269.3	5.1	3.19	0.28	3.21	-0.038	60	76	6.9	7.3
6	2.	-24.	10.	-58.	74.	-35	267.3	4.7	3.22	0.27	3.23	-0.032	48	81	6.8	7.2
7	3.	-37.	-9.	-65.	65.	-35.	268.9	3.6	3.34	0.21	3.35	0.156	39	96	6.8	6.9
8	3.	-39.	-13.	-65.	41.	-35.	270.2	3.5	3.36	0.20	3.37	0.172	38	100.	6.8	6.8
9	3.	-40.	-16.	-64.	40.	-35.	271.4	3.5	3.37	0.20	3.37	0.169	38	104	6.8	6.8
10	3.	-41.	-19.	-62.	29	-35.	272.7	3.5	3.37	0.20	3.38	0.162	39	107	6.8	6.8
11	3.	-41.	-21.	-61.	29	-35.	273.8	3.5	3.38	0.21	3.38	0.149	40	110.	6.8	6.8
12	3.	-40	-22.	-58.	22.	-35.	274.9	3.6	3.38	0.21	3.38	0.129	47.	112.	6.7	6.7
13	3.	-40	-23.	-56.	0.	-35.	275.7	3.6	3.38	0.21	3.39	0.107	52.	113.	6.8	6.8
14	4.	-38.	-23.	-54.	0.	-35	276.4	3.8	3.38	0.22	3.39	0.074	52.	114	6.8	6.8
15	4.	-34.	-14.	-54	0.	-35.	276.8	3.8	3.38	0.23	3.39	0.045	52.	109	6.7	6.7
16	4.	-21.	-2.	-40.	40.	-35	276.3	4.0	3.37	0.24	3.38	-0.058	57	92.	6.8	6.8
17	5.	-7.	18.	-32.	74.	-35.	274.6	3.1	3.42	0.19	3.42	0.022	80	81.	6.8	6.8
18	5.	9.	39.	-21.	70.	-35.	277.6	1.7	3.52	0.11	3.52	0.217	89	58.	6.4	6.8
19	6.	36.	80.	-8.	0.	35.	283.4	1.5	3.53	0.09	3.53	0.167	102.	18.	6.5	6.8
20	6.	45.	90.	-1.	30.	35.	284.4	1.5	3.53	0.09	3.53	0.143	107	7.	6.6	6.8
21	6.	55.	102.	7.	54	35.	285.3	1.7	3.52	0.10	3.52	0.093	114	-5.	6.7	6.7
22	6.	64.	111.	16.	74.	35.	285.7	2.0	3.53	0.12	3.54	0.016	120.	-15.	6.7	6.4
23	6.	74.	122.	27.	74.	35.	285.4	2.4	3.55	0.15	3.56	-0.096	130.	-26.	5.5	6.4
24	6.	84.	136.	33.	74.	35	284.3	2.6	3.57	0.16	3.57	-0.190	140.	-35	4.6	6.4
25	6.	95.	144.	46.	74	35.	282.7	2.8	3.58	0.18	3.59	-0.272	153.	-42	3.9	6.4
26	6.	106.	151.	61.	74	35.	280.1	3.1	3.60	0.19	3.60	-0.345	168	-48	3.2	6.6
27	7.	115.	156.	74.	70	25.	277.5	3.2	3.61	0.20	3.61	-0.395	180	-54	2.5	6.7
28	7.	123.	159	86.	20	1.	274.7	3.1	3.61	0.20	3.61	-0.372	192.	-59.	2.0	6.7
29	7.	129	161.	97.	0	-1	272.1	3.0	3.58	0.19	3.59	-0.343	203	-63	1.6	5.7
30	7.	134	163	106	0	-1	269.7	3.0	3.56	0.18	3.57	-0.332	212	-66	1.3	4.8
31	7.	139.	163	115.	0	-1	267.3	2.9	3.54	0.18	3.54	-0.320	220	-68	1.1	4.1
32	7.	142.	162.	122.	0.	-1.	265.0	2.9	3.52	0.18	3.52	-0.312	227	-69.	1.0	3.3
33	7	144	161	128	0	-1.	262.7	2.9	3.49	0.18	3.50	-0.307	233	-69	0.9	2.7
34	7.	146.	162	129	0	-13.	260.5	2.9	3.47	0.17	3.48	-0.305	237	-69	0.9	2.2
35	8	147.	163	132.	0	-34	253.3	2.9	3.45	0.17	3.46	-0.305	237	-67	0.9	1.6
36	8	145	175	115.	0	-35	248.8	2.9	3.36	0.17	3.36	-0.296	226	-80	2.2	0.0
37	9.	127.	166	89	74	-35	239.0	2.4	3.26	0.14	3.27	-0.231	197.	-74	5.1	0.0
38	9.	95.	146.	44.	51.	-35.	231.3	2.1	3.17	0.12	3.18	-0.201	151.	-48	5.8	2.1
39	10.	45.	92.	-2.	74.	-35.	228.4	0.6	3.20	0.03	3.20	0.092	101.	-1.	5.9	5.8
40	11.	9.	40.	-22.	23.	-11.	238.3	-0.5	3.21	-0.03	3.21	0.287	83.	63	5.8	5.8
41	11.	0.	17.	-18	71.	34.	245.7	0.3	3.14	0.02	3.14	0.124	86	79	5.8	5.8
42	11.	1.	19.	-17.	74	34.	246.3	1.0	3.16	0.05	3.16	0.009	88.	78	5.7	5.8
43	11.	3.	20.	-15	74.	30.	245.8	1.6	3.17	0.09	3.18	-0.115	89	77	5.6	5.8
44	12.	4.	20.	-11.	34.	3.	244.6	1.7	3.19	0.10	3.19	-0.177	88	76.	5.5	5.8
45	12.	5.	21.	-12.	0.	-28	242.8	1.6	3.17	0.09	3.17	-0.197	86	73.	5.2	5.8
46	12.	5.	24.	-15	42.	-35	240.9	1.5	3.15	0.08	3.15	-0.201	93	71	4.9	5.6
47	12	3.	26.	-19	69	-35.	239.2	1.2	3.13	0.07	3.14	-0.165	79	69	4.7	5.8
48	12	1.	26.	-24	74	-35	237.9	0.7	3.14	0.04	3.14	-0.093	74	70	4.6	5.8
49	12	-2	24	-28	65	-35.	237.3	0.3	3.15	0.02	3.15	-0.020	70	73	4.4	5.7
50	12	-5.	21.	-31	35	-35	237.3	0.2	3.15	0.01	3.15	0.013	66	77	4.5	5.6
51	13.	-8.	18	-34.	23	-35	237.4	0.4	3.13	0.02	3.13	0.005	63	81	4.7	5.5
52	13.	-11.	15.	-37	44.	-35	237.4	0.4	3.11	0.02	3.11	0.002	60	84	4.8	5.2
53	13.	-15.	11.	-40	74	-35	237.6	0.2	3.11	0.01	3.11	0.048	57	89	4.8	4.9
54	14.	-24	-5	-42.	20.	-20.	241.7	0.0	3.07	0.00	3.07	0.101	53.	107.	4.8	4.5
55	14.	-25	-10	-40	0	-22.	243.8	0.5	2.99	0.02	2.99	0.012	55	113.	4.8	4.8
56	15.	-25	-8	-42.	59	-34	242.5	0.4	2.94	0.02	2.94	-0.024	52	111	4.8	4.8
57	15.	-28	-13	-43	-10	-34	244.5	-0.9	2.95	-0.05	2.95	0.083	51	117	4.8	4.8
58	16	-31	-10.	-52.	74	-34	245.3	-1.3	2.91	-0.07	2.91	0.042	49	115	4.8	4.8
59	17.	-37	-18	-57	0	-34	251.9	-2.5	2.94	-0.13	2.94	0.203	40	116	4.8	4.8
60	17.	-30.	2.	-62	-74	0	259.2	-1.9	2.73	-0.09	2.73	0.159	42.	101	4.8	4.9
61	18	-14	6	-35	-74	21	265.6	-1.7	2.42	-0.07	2.42	0.136	54	85	4.8	4.8

15 RUDDER ORDERS MEAN (RUDDER) = -21.1
47 RPM ORDERS VAR (RUDDER) = 543.6
1 V H F ORDERS

Figure 77 Some characteristics of the simulation run

		4+6+8 Bft	4+6 Bft	4 Bft	6 Bft	N	CSC	S	SSW	
... tanks 35,000 ... hp	starboard	51.6147	49.6021	50.3536	48.0643	55.0416	66.5245	72.1330	41.0836	36.9268
	port	29.4273	19.6838	16.6256	23.1730	41.6449	15.1679	22.8027	41.2689	34.9562
... tanks 45,000 ... hp	starboard	29.7296	23.1287	25.7867	21.0603	36.4691	27.5969	55.8634	2.5514	18.7611
	port	6.9014	1.1337	0.3351	2.4643	20.4516	2.1660	14.5105	7.7412	3.7696

Table 8: Maximum probabilities of exceedance (in percentages) at port and starboard side near rock-outcrop No. 2a for two alternatives and the different external conditions (reference values +100 (starboard) and +20 (port)).

Figure 78 Result of the simulation

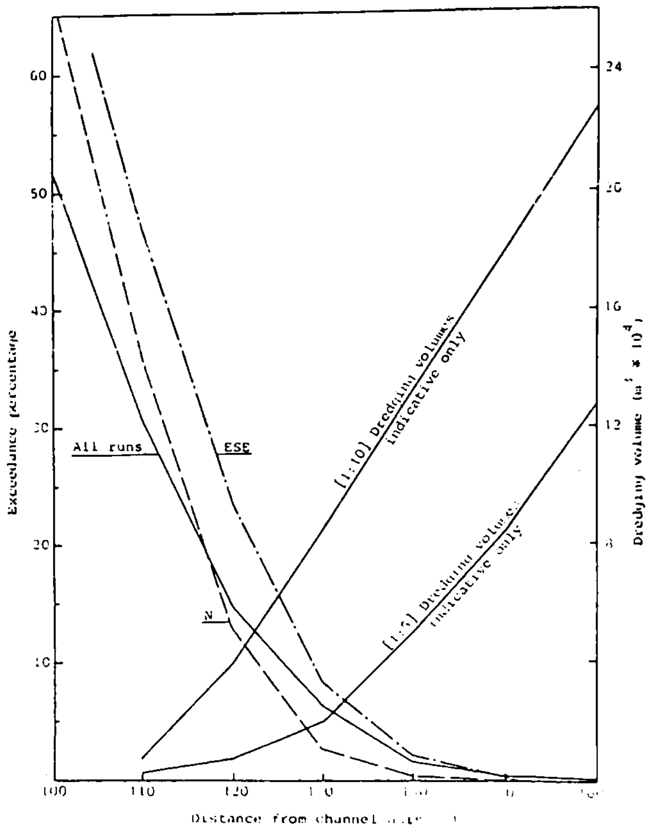


Figure 79 Extend of the risk as a result of temporary dredging work (widening the bend) pending the final clearance of the obstacles in the real channel

3.2 PLANNING OF RIVER DREDGING

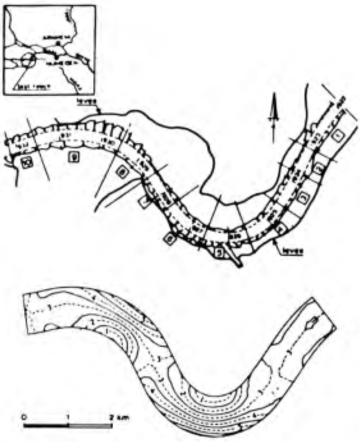
Considerable research has been done in the field of navigation in restricted waters in the Netherlands. One of the subjects dealt with is planning of river dredging.

Waterways can be distinguished in natural water courses, of which especially the rivers are of importance and artificial waterways, of which canals and lakes have to be mentioned. Throughout history, rivers have been used as natural transport routes. In the case of an easily navigable river, no capital investment and no maintenance is required. However, with increasing sizes of ships such rivers become an exception and show many defects in certain reaches and/or during certain periods of the year. River engineering deals with the improvement of waterways. Canals connect river systems to form a network of waterways and they go beyond the reach of natural water courses.

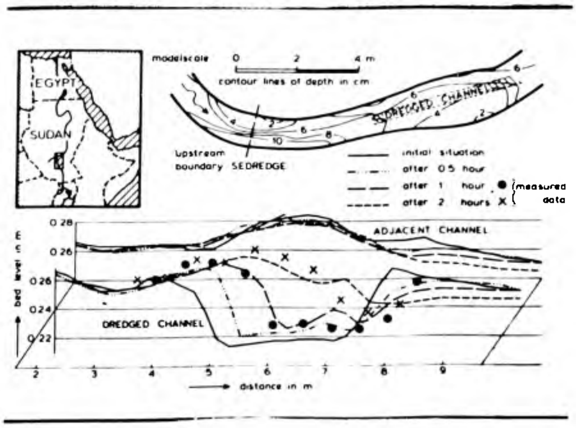
River improvement studies have to be based on the knowledge of the river characteristics. Available data have to be collected and analyzed and generally, additional river surveys have to be carried out. For the processing of these data computer programs are used.

The dominant factors affecting navigation are the least available depth (LAD), and the width of the navigable channel between the river banks. For the determination of the factors as a function of time and place, it is important to predict the trend of the hydrograph after a flood season. A highly predictable hydrograph presents a great advantage to navigation and the other way around. Based on hydrologic, hydraulic and topographic data, this problem is solved by using computer programs for the assessment of probability curves of hydrographs and water-level profiles along the river. After that, the bottlenecks in the waterway can be located and specified.

A first step in the improvement of rivers for navigation is often, due to its flexibility, the repeated dredging of channels through shallow reaches. An important aspect of these operations is that sedimentation in the dredged channels determines the efficiency. The sedimentation can be estimated from computations with 1-D and 2-D mathematical models describing the time-dependent bed level changes. Together with, the predicted trend of the hydrograph, the feasibility and/or optimal dredging strategy can be assessed.



Example of simulation with SEDIBO



Simulation with SEDREDGE compared with observations

More structural improvement can be achieved by permanent river-training works, such as:

- construction of wide river reaches, for instance by building groynes (the most extreme case is the width normalisator);
- river bend cut-offs;
- raising the water level by the construction of weirs combined with ship locks (canalization), backing up the water during dry periods;
- regulation of the discharge by the construction of dams with locks.

These works, especially the last two types, are seldom feasible in the case they are not combined with other purposes, such as irrigation, water power, flood control, etc. The response of the river (hydraulically and morphologically) to these works can be estimated from computations with 1-D mathematical models which can cover large areas.

More detailed information can be obtained from computations with 2-D mathematical models and scale models with a movable bed.

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4. DREDGING CONTRACTING

It is well known that the most widely used standard contract condiriona for civil engineering works are those contained in the Conditions of Contract (International) for Work of Civil Engineering Construction with Forms of Tender and Agreement, 3rd edition published by Fédération Internationale des Ingéniurs-Conseils (FIDIC) in March 1977. A copy of these conditions is reprinted here.

This standard Contract form contains three parts. Apart from the General Conditions and the Conditions of Particular Application, there is a third part, dealing with the conditions of Particular Application to Dredging and Reclamation Work.

A presentation on "Experience of Dredging Contracting" was made by Mr. Jack H. Hulscher, Volker Stevin Dredging, in which he commented on certain specific contractual issues, mainly from the viewpoint of the contractor.

4.1 EXPERIENCE OF DREDGING CONTRACTING

By Mr. Jack H. Hulscher, Volker Stevin Dredging.

The standard contract form falls into three parts. A part from the General Conditions and the Conditions of Particular Application, the third part deals with the conditions of Particular Application to Dredging and Reclamation Work.

Particular attention is drawn to a few of these special conditions. The necessity of applying such special conditions to dredging and reclamation works is explained in the Introduction to Part III, which reads:

" **Introduction**

In Dredging and Reclamation Work the Contractor is not normally held responsible for the maintenance of the Works after takeover; the Works are usually taken over in sections as they are completed; the Contractor can only work economically if he is allowed to work continuously by day and by night; the incidence of Plant Costs (mobilisation, supply and demobilisation) forms a much higher proportion of total cost in the case of a dredging contract than is generally the case with construction contracts; as plant supplied by the Contractor almost invariably includes ships and at times includes ships taken on charter by the Contractor he cannot give to the Employer the unrestricted right to sell such plant. The Employer may find cover against the risks of non-completion by an increase of the amount of the performance bond.

Quantities included in the tender documents must necessarily be estimates the accuracy of which is inherently less than normally experienced on construction contracts."

A very important condition is Clause 11, which replaces Clause 11 of the General Conditions. In this clause it is found that the Employer is under the obligation to provide the Tenderer, in his tender documents, with such data on soil specifications and hydraulic conditions as shall have been obtained by and on behalf of the Employer and data on navigation conditions, environmental conditions, dumping places and the Tender shall be deemed to have been based on such data. Clause 11 of the Condition of Particular Application to Dredging and Reclamation Work reads:

" **Clause 11**

The Employer shall have made available to the Contractor with the Tender documents such data on soil specifications and hydraulic conditions as shall have been obtained by or on behalf of the Employer from investigations undertaken relevant to the Works and furthermore depending on the nature and situation of the Works such additional data necessary in connection with the execution of the Works like navigation conditions, environmental conditions, dumping places and such particular data and the Tender shall be deemed to have been based on such data, but the Contractor shall be responsible for his own interpretation thereof. The Contractor shall also be deemed to have inspected and examined the Site and its surroundings and information available in connection therewith and to have satisfied himself, so far as is practicable, before submitting his Tender, as to the form and nature thereof, but he shall not normally be called upon to satisfy himself as to the quantities of materials to be dredged more accurately than he can deduce from the Tender documents and inspection of the Site only."

The importance of this Clause lies in the fact that the Contractor, during the tender stage, is not or almost never in a position to carry out his own site investigations including boring and sampling/tests of soil samples. Moreover, such investigation, which is quite expensive if done properly, would have to be done by all tenderers.

It is obvious that it is much more practicable for the Employer to have an extensive site/soil investigation programme carried out prior to final design of the Works.

Thus, the consulting engineer, who normally is responsible for the design of the Project, will avail of the results of the soil investigations and can take these into account in his final design. An even more important factor is, however, that the Employer, giving the same information to all tenderers, places these tenderers on exactly the same footing and this enables himself to properly evaluate the various tenders afterwards. It is equally beneficial to the contractors to be provided with sufficient and accurate soil data. They know that their competitors will be able to assess such data, and will also not underestimate the situation at the site.

As generally known, both the output (expressed in cubic metres/dredging hour) and the wear and tear of the pumps, pipes, boosters etc. are highly depending on the characteristics of the dredged material. Consequently, the costs per week of the dredging operations and thus the costs per cubic metre can vary substantially depending on the characteristics of the material to be dredged.

As might be noticed, the Employer is only under the obligation to make available the data obtained from investigations relevant to the Works.

It will probably be appreciated that this is a somewhat cryptical description. It is clear that, if the Employer has not undertaken any investigation at all, there is no obligation to provide any data. Therefore, the I A D C, being the International Association of Dredging Companies, is presently preparing recommendations to FIDIC in respect of redrafting this Clause 11.

Basically what they want, is that the Employer is equally responsible for providing the Contractors with soil data and the accuracy and sufficiency of such information as he is for the design of the Works. (As it might be known, under FIDIC, normally the responsibility for errors and omissions in the design of the Works, rests witht the Employer).

One last remark in this respect: It happens more and more that the Employer in the tender documents disclaims any responsibility for the correctness of data supplied in the tender documents. In other words, if during the execution of the works the actual sub-soil conditions turn out to be different, the Employer will not be responsible for the additional costs resulting therefrom. This cannot be considered as a fair position, because, as already mentioned, tenderers normally do not have the time to carry out an extensive soil investigation and consequently they have to rely on the correctness of information provided by the Employer.

Apart from this practical aspect, there is also a legal question arising here. In many legal systems, the general disclaimer of responsibility will not always be honoured in court on in arbitration; if it is found that information provided is indeed incorrect, which means not representative for the actual situation, the judge or arbitrators are likely to establish that this would constitute a mis-representation for which the Employer is responsible the Employer shall not be allowed to hide behind the erroneous disclaimer of responsibilities.

Another important provision is found in Clause 21.

In Clause 21 of the General Conditions it is found that the Contractor shall insure against loss of or damage to the Works (the so-called CAR-insurance). In Clause 21 of the Conditions of Particular Application to Dredging and Reclamation Works, this obligation is limited to an insurance against damage to the constructional Plant:

" **Clause 21**

The Contractor's obligation to insure under this Clause shall be limited, unless otherwise specially agreed, to the insurance against normal marine risks of all Plant (including ships) supplied by the Contractor for use on the Works whether owned or taken on charter by the Contractor. Such insurance shall be effected with an insurer and in terms approved by the Employer (which approval shall not be unreasonably withheld). "

The reason is that dredging works in itself are always excluded from a CAR policy, since it is not possible to insure what is popularly mentioned a hole in the ground.

Naturally, it is possible to insure against damages to the reclamation works.

The dredging industry is to a very large extent a capital intensive industry. The costs of a dredging project therefore are depending directly on the financial costs of the dredging plant and in very many cases over 50% of the costs per cubic metre are costs directly related to the choice of the dredging equipment to be used for the execution of such project.

Consequently, the Dredging Contractor, who has the most suitable equipment available for the execution of the works as described in the drawings and specifications, can offer the lowest price. This very specific feature of dredging contracts is recognized by the drafters of part III (Conditions of Particular Application to Dredging and Reclamation Work) of the FIDIC conditions, when considering the implication of the Engineer's contractual possibilities to impose variation orders.

Clause 51 of the General Conditions stipulates that the Engineer shall, if it is in his opinion desirable, have the power to order the Contractor to (i.a):

- increase or decrease the quantity of any work included in contract.
- change the character or quantity or kind of any such work.
- change the levels, lines position and dimensions of any part of the work

Among international construction lawyers a never ending discussion is continuing as to what extent the Engineer is reasonably entitled to demand from a contractor under this Clause 51; it is recognized that the Engineer's possibilities are, although not unlimited, in any event rather far stretching.

In view of what has already been said in respect of the direct relationship between the efficiency of the execution of the dredging works (and thus: the costs thereof) on the one hand, and the choice of the optimum equipment of the Contractor on the other hand, it will be easy to understand that an amendment to the works cannot always be effected with the equipment which the Contractor has brought to the work site.

This was very well appreciated at the time Part III was drafted and Clause 51 of Part III says that "the alterations, additions and omissions provided in Clause 51 (of the General Conditions) shall be imposed upon the Contractor only insofar as they can be executed by means of the Plant used or intended to be used in the execution of the Works, as originally specified by the Contractor in his tender documents".

At this stage it may be remarked that in many cases the Plant, used or intended to be used, may not be the most suitable or efficient plant for the execution of alterations in the Works, but that, no doubt such alterations can be executed by that plant.

In such an event the Contractor shall, in principle, be under the obligation to execute such altered works. However, it shall then be alleged that the altered works cannot be executed at the unit rates, mentioned in the Contract for the originally defined works.

Reference is then made to Clause 52 of the General Conditions and it can be argued that "the Contract does not contain rates or prices applicable to the extra or additional work" and that, consequently, suitable rates or prices shall be agreed upon between the Engineer and the Contractor.

The last provision of Part III to which attention is drawn here is Clause 63, sub-Clause (1).

In the General Conditions it is found that the Employer has the right to sell "any of the Constructional Plant" in the event Contractor should become bankrupt or is (i.a.) "persistently or flagrantly neglecting to carry out his obligations under the Contract". In Clause 63 (1) of Part III such right is denied to the Employer.

The reason for this is twofold. In the first place, it may very well be that the Contractor is not the registered owner of the dredge (vessels are registered goods), but that he charters the dredge from an affiliated company.

In such a case the Contractor is not entitled to sell or alienate the ownership of the dredge.

The other reason is that even if the Contractor is indeed the registered owner of the dredge, he is prohibited to sell or alienate the ownership of the dredge by his financers.

As said before, the dredging industry is very capital intensive. A dredge may very well cost 20 to 30 million US dollars. Such an investment will be financed for a substantial part by a bankloan and the bank will no doubt require the dredge as a collateral for such loan. In many cases a bank will have a mortgage or other type of lien on the dredge and one of the principle conditions of such lien is of course that the owner will not sell the dredge without the prior approval of the financers.

One final remark shall be made about the FIDIC conditions which are originating from the English I.C.E. conditions.

In these conditions are defined the traditional functions and role of the typical English institute of the independent "Engineer", who, although paid by the Employer, and acting as an agent of the Employer, has the obligation to fairly and equitably distribute the rights and obligations of the Employer and the Contractor under the Contract.

Such Engineer has his own legal obligation to act as an expert and as a referee, or as a "quasi-arbitrator" as lawyers prefer to formulate.

Today, many contracts state that the Employer appoints one of his qualified employees as the Engineer under the Contract. This may very well place the employee in the position that one day he may face a situation where he, as an expert or referee, may in all reasonability have to take a decision which is in the interest of the Contractor, rather than in the interest of his Employer. It is hoped that this session has given some background information on the position of a Contractor and that it will be taken into account when required to take such expert decisions.

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CONDITIONS OF CONTRACT
(INTERNATIONAL)
FOR WORKS OF
CIVIL ENGINEERING
CONSTRUCTION

with forms of tender and agreement

MARCH 1977

Approved by the following Organisations:

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THE ASSOCIATED GENERAL CONTRACTORS OF AMERICA
1957 E Street N. W., Washington, D. C. 20006, U.S.A.

3rd EDITION

CONDITIONS OF CONTRACT
(INTERNATIONAL)
FOR
WORKS OF
CIVIL ENGINEERING CONSTRUCTION

WITH FORMS OF TENDER AND AGREEMENT

MARCH 1977

Prints may be obtained from

FÉDÉRATION INTERNATIONALE DES INGENIEURS-CONSEILS
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or

From the Organisations listed herein.

CONDITIONS OF CONTRACT
(INTERNATIONAL)
FOR WORKS OF
CIVIL ENGINEERING CONSTRUCTION

EXPLANATORY MEMORANDUM

In the preparation of the Conditions it was recognised that while there were numerous Clauses which would be universally applicable there were some Clauses which must necessarily vary to take account of the circumstances and locality of the Works. The Clauses of universal application have been grouped together and are referred to as Part I—General Conditions. They have been printed in a form which will facilitate inclusion (without further reproduction) in the contract documents normally prepared.

The General Conditions are linked with the Conditions of Particular Application, referred to as Part II, by the consecutive numbering of the Clauses, so that Parts I and II together comprise the conditions governing the rights and obligations of the parties.

The Clauses in Part II must be specially drafted to suit each particular Contract and to assist those entrusted with their preparation Notes intended as an aide-memoire in relation to the matters which should be covered by the variable Clauses have for convenience been included in the document. These Notes should be detached from the document when inviting tenders.

There is also included under Part III the Conditions of Particular Application to Dredging and Reclamation Work.

It is recommended that Bills of Quantities should be supplied in duplicate to Contractors by Employers when inviting tenders. Only one copy of the Bills of Quantities should be returned with the tender; the Contractor should be permitted to purchase further copies.

TABLE OF CONTENTS

		Page
Table of Contents—General Conditions ...	...	i
Index —General Conditions ...	...	iv
PART I.	General Conditions	1
PART II.	Conditions of Particular Application ...	22
PART III.	Conditions of Particular Application to Dredging and Reclamation Work ...	24
Form of Tender ...	... ...	26
Form of Agreement	... ...	28

Membership of F.I.D.I.C.	... ...	29
Membership of F.I.E.C., I.F.A.W.P.C.A. and F.I.I.C....	...	30

GENERAL CONDITIONS—Table of Contents

Clause		Page
	DEFINITIONS AND INTERPRETATION	
1 (1)	Definitions	1
(2)	Singular and Plural	1
(3)	Headings or Notes	1
(4)	Cost	1
	ENGINEER AND ENGINEER'S REPRESENTATIVE	
2	Duties and Powers of Engineer and Engineer's Representative	1 & 2
	ASSIGNMENT AND SUB-LETTING	
3	Assignment	2
4	Sub-letting	2
	CONTRACT DOCUMENTS	
5 (1)	Language/s and Law	2
(2)	Documents Mutually Explanatory	2
6 (1)	Custody of Drawings	2
(2)	One Copy of Drawings to be kept on Site	2
(3)	Disruption of Progress	2
(4)	Delays and Cost of Delay of Drawings	3
7	Further Drawings and Instructions	3
	GENERAL OBLIGATIONS	
8	Contractor's General Responsibilities	3
9	Contract Agreement	3
10	Performance Bond	3
11	Inspection of Site	3
12	Sufficiency of Tender—Adverse Physical Conditions and Artificial Obstructions	3
13	Work to be to the Satisfaction of Engineer	4
14	Programme to be Furnished	4
15	Contractor's Superintendence	4
16	Contractor's Employees	4
17	Setting Out	4
18	Boreholes and Exploratory Excavation	4
19	Watching and Lighting	5
20 (1)	Care of Works	5
(2)	Excepted Risks	5
21	Insurance of Works, etc	5
22 (1)	Damage to Persons and Property	5
(2)	Indemnity by Employer	6
23 (1)	Third Party Insurance	6
(2)	Minimum Amount of Third Party Insurance	6
(3)	Provision to Indemnify Employer	6
24 (1)	Accident or Injury to Workmen	6
(2)	Insurance against Accident, etc., to Workmen	6
25	Remedy on Contractor's Failure to Insure	6
26 (1)	Giving of Notices and Payment of Fees	6
(2)	Compliance with Statutes, Regulations, etc.	6
27	Fossils, etc.	6
28	Patent Rights and Royalties	7
29	Interference with Traffic and Adjoining Properties	7
30 (1)	Extraordinary Traffic	7
(2)	Special Loads	7
(3)	Settlement of Extraordinary Traffic Claims	7
(4)	Waterborne Traffic	7
31	Opportunities for Other Contractors	7
32	Contractor to keep Site Clear	7
33	Clearance of Site on Completion	7

General Conditions—Table of Contents—*continued*

Clause			Page
		LABOUR	
34	(1)	Engagement of Labour	8
	(2)	Supply of Water	8
	(3)	Alcoholic Liquor or Drugs	8
	(4)	Arms and Ammunition	8
	(5)	Festivals and Religious Customs	8
	(6)	Epidemics	8
	(7)	Disorderly Conduct, etc.	8
	(8)	Observance by Sub-Contractors	8
	(9)	Other Conditions affecting Labour and Wages	8
35		Returns of Labour, etc.	8
		MATERIALS AND WORKMANSHIP	
36	(1)	Quality of Materials and Workmanship and Tests	8
	(2)	Cost of Samples	8
	(3)	Cost of Tests	8
	(4)	Cost of Tests not Provided for, etc.	8
37		Inspection of Operations	8
38	(1)	Examination of Work before Covering up	9
	(2)	Uncovering and Making Openings	9
39	(1)	Removal of Improper Work and Materials	9
	(2)	Default of Contractor in Compliance	9
40	(1)	Suspension of Work	9
	(2)	Suspension Lasting more than 90 days	9
		COMMENCEMENT TIME AND DELAYS	
41		Commencement of Works	9
42	(1)	Possession of Site	10
	(2)	Wayleaves, etc.	10
43		Time for Completion	10
44		Extension of Time for Completion	10
45		No Night or Sunday Work	10
46		Rate of Progress	10
47	(1)	Liquidated Damages for Delay	10
	(2)	Reduction of Liquidated Damages	11
	(3)	Bonus for Completion	11
48	(1)	Certification of Completion of Works	11
	(2)	Certification of Completion by Stages	11
		MAINTENANCE AND DEFECTS	
49	(1)	Definition of Period of Maintenance	11
	(2)	Execution of Work of Repair, etc.	11
	(3)	Cost of Execution of Work of Repair, etc.	11
	(4)	Remedy on Contractor's Failure to Carry Out Work Required	11
50		Contractor to Search	12
		ALTERATIONS, ADDITIONS AND OMISSIONS	
51	(1)	Variations	12
	(2)	Orders for Variations to be in Writing	12
52	(1)	Valuation of Variations	12
	(2)	Power of Engineer to Fix Rates	12
	(3)	Variations exceeding 10 per cent	12
	(4)	Daywork	13
	(5)	Claims	13
		PLANT, TEMPORARY WORKS AND MATERIALS	
53	(1)	Plant, etc., Exclusive Use for the Works	13
	(2)	Removal of Plant, etc.	13
	(3)	Employer not liable for Damage to Plant, etc.	13
	(4)	Re-export of Plant	13
	(5)	Customs Clearance	13
	(6)	Other Conditions affecting Plant, Temporary Works and Materials	13
54		Approval of Materials, etc., not implied	13

General Conditions—Table of Contents—*continued*

Clause			Page
		MEASUREMENT	
55		Quantities	13
56		Works to be Measured	14
57		Method of Measurement	14
		PROVISIONAL SUMS	
58	(1)	Definition of Provisional Sums	14
	(2)	Use of Provisional Sums	14
	(3)	Production of Vouchers, etc.	14
		NOMINATED SUB-CONTRACTORS	
59	(1)	Definition of Nominated Sub-Contractors	14
	(2)	Nominated Sub-Contractors, Objection to Nomination	14
	(3)	Design Requirements to be Expressly Stated	15
	(4)	Payments to Nominated Sub-Contractors	15
	(5)	Certification of Payments to Nominated Sub-Contractors	15
	(6)	Assignment of Nominated Sub-Contractors' Obligations	15
		CERTIFICATES AND PAYMENT	
60	(1)	Certificates and Payment	15
	(2)	Advances on Constructional Plant and Materials	15
	(3)	Payment in Foreign Currencies	15
61		Approval only by Maintenance Certificate	15
62	(1)	Maintenance Certificate	15
	(2)	Cessation of Employer's Liability	16
	(3)	Unfulfilled Obligations	16
		REMEDIES AND POWERS	
63	(1)	Default of Contractor	16
	(2)	Valuation at Date of Forfeiture	16
	(3)	Payment after Forfeiture	16
64		Urgent Repairs	17
		SPECIAL RISKS	
65	(1)	No Liability for War, etc., Risks	17
	(2)	Damage to Works, etc., by Special Risks	17
	(3)	Projectile, Missile, etc.	17
	(4)	Increased Costs arising from Special Risks	17
	(5)	Special Risks	17
	(6)	Outbreak of War	17
	(7)	Removal of Plant on Termination	18
	(8)	Payment if Contract Terminated	18
		FRUSTRATION	
66		Payment in Event of Frustration	18
		SETTLEMENT OF DISPUTES	
67		Settlement of Disputes—Arbitration	18
		NOTICES	
68	(1)	Service of Notices on Contractor	19
	(2)	Service of Notices on Employer or Engineer	19
	(3)	Change of Address	19
		DEFAULT OF EMPLOYER	
69		Default of Employer	19
		CHANGES IN COSTS AND LEGISLATION	
70	(1)	Increase or Decrease of Costs	19
	(2)	Subsequent Legislation	19
		CURRENCY AND RATES OF EXCHANGE	
71		Currency Restrictions	19
72		Rates of Exchange	20

GENERAL CONDITIONS—INDEX

	Clause	Page
Access, to Works	37	8
Access, Contractor to satisfy himself	11	3
Accident or Injury to Workmen—Insurance against	24 (2)	6
Accident or Injury to Workmen—Liability for	24 (1)	6
Accommodation outside the Site—Contractor to provide	42 (2)	10
Address, change of	68 (3)	19
Adjustment of Contract Price if variations exceed 10 per cent of Tender Sum	52 (3)	12
Advances on Constructional Plant and Materials	60 (2)	15
Adverse Physical Conditions and Artificial Obstructions	12	3
Agent of Contractor	15	4
Agreement	9	3
Alcoholic Liquor or Drugs	34 (3)	8
Alterations, Additions and Omissions	51 & 52	12
Ambiguities in Contract Documents	5 (2)	2
Approval of Materials, etc., not implied	54	13
Approval only by Maintenance Certificate	61	15
Arbitration	67	18
Arms and Ammunition	34 (4)	8
Assignment of Contract	3	2
Assignment of Nominated Sub-Contractors' obligations	59 (6)	15
Bankruptcy of Contractor	63 (1)	16
Bills of Quantities—estimated only	55	13
Bond, Performance	10	3
Bonus for Completion	47 (3)	11
Boreholes and Exploratory Excavation	18	4
Care of Works	8 & 20 (1)	3 & 5
Certificate, Maintenance	61 & 62	15
Certificates and Payment	60 (1)	15
Certification of Completion of Works	48 (1)	11
Certification of Completion by Stages	48 (2)	11
Claims for Extra or Additional Work or Expense	52 (5)	13
Clearance of Site	32 & 33	7
Commencement of Works	41	9
Completion of Works, Bonus for	47 (3)	11
Completion of Works, Time for	43	10
Completion of Works, Time for, Extension of	43 & 44	10
Compliance with Statutes, Regulations, etc.	26	6
Constructional Plant, Insurance of	21	5
Contingencies, provisions for	58 (1)	14
Contract Agreement	9	3
Contractor's general responsibilities	8	3
Contractor's Superintendence	15	4
Contractor's Employees	16	4
Cost	1 (4)	1
Costs, Increase or Decrease of	70	19
Covering up Work, Examination before	38 (1)	9
Currencies, Payment in Foreign	60 (3) & 72	15 & 20
Currencies, Rates of Exchange	72	20
Currency Restrictions	71	19
Customs Clearance	53 (5)	13

Index to General Conditions—*continued*

	Clause	Page
Damage to Persons and Property	22 (1)	5
Damage to Works	20 (1) & 65 (2)	5 & 17
Damages, Liquidated	47	10
Daywork	52 (4)	13
Decrease or Increase of Costs	70 (1)	19
Default of Contractor	63 (1)	16
Default of Employer	69	19
Defective Materials and Work	39 & 49 (2) & (3)	9 & 11
Defects, Contractor to Search for, if Required	50	12
Definitions	1	1
Delay, Liquidated Damages for	47	10
Delays and Cost on Delivery of Drawings	6 (4)	3
Design by Nominated Sub-Contractors	59 (3)	15
Discrepancies in Documents	5 (2)	2
Dismissal of Contractor's Employees	16 (2)	4
Disorderly Conduct, etc.	34 (7)	8
Documents Mutually Explanatory	5 (2)	2
Drawings	6 & 7	2 & 3
Drawings delay in issue	6 (3)	2
Drugs or Alcoholic Liquor	34 (3)	8
Employer not liable for Damage to Plant, etc.	53 (3)	13
Employer's liability, cessation of	62 (2)	16
Engagement of Labour	34 (1)	8
Engineer and Engineer's Representatives, Duties and Powers of ...	2	1 & 2
Epidemics	34 (6)	8
Errors in Setting-Out	17	4
Examination of Work before Covering up	38 (1)	9
Excepted Risks	20 (2)	5
Exchange, Rates of	72	20
Extension of Time, due to Employer's Failure to give Possession of Site ...	42 (1)	10
Extension of Time for Completion	44	10
Extraordinary Traffic	30	7
Faulty Work, Removal of	39 (1)	9
Fees and Notices...	26	6
Fencing, Watching, Lighting, etc.	19	5
Festivals and Religious Customs	34 (5)	8
Foreign Currencies, Payment in	60 (3) & 72	15 & 20
Fossils, etc.	27	6
Foundations, Examination of	38 (1)	9
Frustration	66	18
Giving of Notices—Payment of Fees	26	6
Guarantee of Insurance Company or Bank	10	3
Improper Work and Materials	39	9
Increase or Decrease of Costs	70	19
Indemnity by Contractor	22 (1) & 24 (1)	5 & 6
Indemnity by Employer	22 (2) & 65 (1)	6 & 17
Injury to Persons—Damage to Property	22	5
Inspection and Testing of Materials and Workmanship	36 & 37	8

Index to General Conditions—*continued*

	Clause	Page
Inspection of Foundations, etc.	38 (1)	9
Inspection of Site by Contractor	11	3
Instructions of Engineer	13	4
Insurance—of Works, etc....	21	5
Insurance—remedy on failure to insure	25	6
Insurance—Third Party	23	6
Insurance—Workmen	24 (2)	6
Interference with Traffic and Adjoining Properties	29	7
Labour, Engagement of	34 (1)	8
Labour, Other Conditions affecting Labour and Wages	34 (9)	8
Language/s	5 (1)	2
Law to which contract subject	5 (1)	2
Legislation, Subsequent	70 (2)	19
Lighting, Fencing, Watching, etc.	19	5
Liquidated Damages for Delay	47	10
Maintenance	49	11
Maintenance Certificate	61 & 62	15
Materials, Advances on Constructional Plant and	60 (2)	15
Materials—Approval of, etc., not implied	54	13
Materials—Improper, Removal of	39	9
Materials—Quality of	36 (1)	8
Materials—supply of	8	3
Measurement by Engineer	56	14
Measurement, Method of	57	14
Measurement, Quantities Estimated Only	55	13
Night and Sunday Work	45	10
Nominated Sub-Contractors, Assignment of Obligations of	59 (6)	15
Nominated Sub-Contractors, Certification of Payments to	59 (5)	15
Nominated Sub-Contractors, Definition	59 (1)	14
Nominated Sub-Contractors, Design by	59 (3)	15
Nominated Sub-Contractors, Objection to Nomination	59 (2)	14
Nominated Sub-Contractors, Payment to	59 (4)	15
Notices, Service of	68	19
Notices and Fees, Payment of	26	6
Omissions, Alterations and Additions	51	12
Openings, Uncovering and Making	38 (2)	9
Operations, Inspection of	37	8
Order of Work, Contractor to Furnish Programme	14	4
Other Contractors, Opportunities for	31	7
Patent Rights and Royalties	28	7
Payment if Contract terminated	65 (8)	18
Payment in Foreign Currencies	60 (3)	15
Performance Bond	10	3
Period of Maintenance	49	11
Plant, Advances in respect of Materials and	60 (2)	15
Plant, Customs Clearance	53 (5)	13

Index to General Conditions—*continued*

	Clause	Page
Plant, Employer not liable for Damage to, etc.	53 (3)	13
Plant, etc., Exclusive Use for the Works	53 (1)	13
Plant, Other Conditions affecting	53 (6)	13
Plant, Re-export of	53 (4)	13
Plant, Removal of, etc.	53 (2) & 65 (7)	13 & 18
Plant, Supply of	8	3
Possession of Site	42 (1)	10
Power of Engineer to fix Rates	52 (2)	12
Programme to be Furnished	14	4
Progress, Rate of	46	10
Provision to Indemnify Contractor	22 (2) & 65 (1)	6 & 17
Provision to Indemnify Employer	23 (3)	6
Provisional Sums, Definition	58 (1)	14
Provisional Sums, Use of	58 (2)	14
Quality of Materials and Workmanship	36 (1)	8
Quantities	55	13
Rate of Progress	46	10
Rates of Exchange	72	20
Rates, Power of Engineer to fix	52 (2)	12
Re-export of Plant	53 (4)	13
Regulations, Statutes, etc., Compliance with	26 (2)	6
Religious Customs and Festivals	34 (5)	8
Removal of Improper Work and Materials	39	9
Removal of Contractor's Employees	16 (2)	4
Removal of Plant, etc.	53 (2) & 65 (7)	13 & 18
Returns of Labour, etc.	35	8
Risks, Excepted	20 (2)	5
Risks, Special	65	17
Roads, etc., Damage by Extraordinary Traffic	30	7
Roads, Interference with Access to	29	7
Royalties and Patent Rights	28	7
Safety of Site Operations	8 (2)	3
Samples, cost of	36 (2)	8
Setting-Out	17	4
Shift working	45	10
Site, Clearance of	32 & 33	7
Site, Possession of	42 (1)	10
Special Risks	65	17
Statutes, Regulations, etc., Compliance with	26	6
Sub-Contractors, Nominated	59	14 & 15
Sub-Contractors, Responsibility of the Contractor for Acts and Default of	4	2
Sub-Contractors, Observance by	34 (8)	8
Sub-letting	4	2
Subsequent Legislation	70 (2)	19
Sufficiency of Tender	12	3
Sunday and Night Work	45	10
Supply of Plant, Materials and Labour	8	3
Supply of Water	34 (2)	8
Suspension of Work	40	9

Index to General Conditions—*continued*

	Clause	Page
Tender documents	11	3
Tender, Sufficiency of	12	3
Termination of Contract	65 & 69	17, 18 & 19
Tests	36	8
Third Party Insurance	23	6
Time for Completion	43	10
Time for Completion, Extension of	44	10
Traffic, Extraordinary	30	7
Traffic, Interference with	29	7
Uncovering Work and Making Openings	38 (2)	9
Unfulfilled Oblilgations	49 (3) & 62 (3)	11 & 16
Urgent Repairs	64	17
Variations	51	12
Variations, Valuation of	52	12
Variations exceeding 10 per cent	52 (3)	12
Vouchers, Production of	58 (3)	14
War, Outbreak of	65 (6)	17
Watching and Lighting, etc.	19	4
Water, Supply of	34 (2)	8
Wayleaves, etc.	42 (2)	10
Work, Examination of before Covering up	38 (1)	9
Work, Improper, Removal of	39	9
Work, Suspension of	40	9
Work to be to Satisfaction of Engineer	13	4
Workmanship, Quality of	36	8
Works, Care of	20 (1)	5
Works, Completion of (Maintenance Certificate)	62 (1)	15
Works, Commencement of	41	9
Works, Insurance of	21	5
Works, Repair of	49	11
Works, Time for Completion of	43	10
Works to be measured	56	14

Conditions of Contract

PART 1—GENERAL CONDITIONS

DEFINITIONS AND INTERPRETATION

Definitions.

1. (1) In the Contract, as hereinafter defined, the following words and expressions shall have the meanings hereby assigned to them, except where the context otherwise requires:—

(a) "Employer" means the party named in Part II who will employ the Contractor and the legal successors in title to the Employer, but not, except with the consent of the Contractor, any assignee of the Employer.

(b) "Contractor" means the person or persons, firm or company whose tender has been accepted by the Employer and includes the Contractor's personal representatives, successors and permitted assigns.

(c) "Engineer" means the Engineer designated as such in Part II, or other the Engineer appointed from time to time by the Employer and notified in writing to the Contractor to act as Engineer for the purposes of the Contract in place of the Engineer so designated.

(d) "Engineer's Representative" means any resident engineer or assistant of the Engineer, or any clerk of works appointed from time to time by the Employer or the Engineer to perform the duties set forth in Clause 2 hereof, whose authority shall be notified in writing to the Contractor by the Engineer.

(e) "Works" shall include both Permanent Works and Temporary Works.

(f) "Contract" means the Conditions of Contract, Specification, Drawings, priced Bill of Quantities, Schedule of Rates and Prices, if any, Tender, Letter of Acceptance and the Contract Agreement, if completed.

(g) "Contract Price" means the sum named in the Letter of Acceptance, subject to such additions thereto or deductions therefrom as may be made under the provisions hereinafter contained.

(h) "Constructional Plant" means all appliances or things of whatsoever nature required in or about the execution or maintenance of the Works but does not include materials or other things intended to form or forming part of the Permanent Works.

(i) "Temporary Works" means all temporary works of every kind required in or about the execution or maintenance of the Works.

(j) "Permanent Works" means the permanent works to be executed and maintained in accordance with the Contract.

(k) "Specification" means the specification referred to in the Tender and any modification thereof or addition thereto as may from time to time be furnished or approved in writing by the Engineer.

(l) "Drawings" means the drawings referred to in the Specification and any modification of such drawings approved in writing by the Engineer and such other drawings as may from time to time be furnished or approved in writing by the Engineer.

(m) "Site" means the land and other places on, under, in or through which the Permanent Works or Temporary Works designed by the Engineer are to be executed and any other lands and places provided by the Employer for working space or any other purpose as may be specifically designated in the Contract as forming part of the Site.

(n) "Approved" means approved in writing, including subsequent written confirmation of previous verbal approval and "approval" means approval in writing, including as aforesaid.

Singular and Plural.

(2) Words importing the singular only also include the plural and *vice versa* where the context requires.

Headings or Notes.

(3) The headings and marginal notes in these Conditions of Contract shall not be deemed to be part thereof or be taken into consideration in the interpretation or construction thereof or of the Contract.

Cost.

(4) The word "cost" shall be deemed to include overhead costs whether on or off the Site.

ENGINEER AND ENGINEER'S REPRESENTATIVE

Duties and Powers of Engineer and Engineer's Representative.

2. (1) The Engineer shall carry out such duties in issuing decisions, certificates and orders as are specified in the Contract. In the event of the Engineer being required in terms of his appointment by the Employer to obtain the specific approval of the Employer for the execution of any part of these duties, this shall be set out in Part II of these Conditions.

(2) The Engineer's Representative shall be responsible to the Engineer and his duties are to watch and supervise the Works and to test and examine any materials to be used or workmanship employed in connection with the Works. He shall have no authority to relieve the Contractor of any of his duties or obligations under the Contract nor, except as expressly provided hereunder or elsewhere in the Contract, to order any work involving delay or any extra payment by the Employer, nor to make any variation of or in the Works.

The Engineer may from time to time in writing delegate to the Engineer's Representative any of the powers and authorities vested in the Engineer and shall furnish to the Contractor and to the Employer a copy of all such written delegations of powers and authorities. Any written instruction or approval given by the Engineer's Representative to the Contractor within the terms of such delegation, but not otherwise, shall bind the Contractor and the Employer as though it had been given by the Engineer. Provided always as follows:—

(a) Failure of the Engineer's Representative to disapprove any work or materials shall not prejudice the power of the Engineer thereafter to disapprove such work or materials and to order the pulling down, removal or breaking up thereof.

(b) If the Contractor shall be dissatisfied by reason of any decision of the Engineer's Representative he shall be entitled to refer the matter to the Engineer, who shall thereupon confirm, reverse or vary such decision.

ASSIGNMENT AND SUB-LETTING

Assignment.

3. The Contractor shall not assign the Contract or any part thereof, or any benefit or interest therein or thereunder, otherwise than by a charge in favour of the Contractor's bankers of any monies due or to become due under this Contract, without the prior written consent of the Employer.

Sub-letting.

4. The Contractor shall not sub-let the whole of the Works. Except where otherwise provided by the Contract, the Contractor shall not sub-let any part of the Works without the prior written consent of the Engineer, which shall not be unreasonably withheld, and such consent, if given, shall not relieve the Contractor from any liability or obligation under the Contract and he shall be responsible for the acts, defaults and neglects of any sub-contractor, his agents, servants or workmen as fully as if they were the acts, defaults or neglects of the Contractor, his agents, servants or workmen. Provided always that the provision of labour on a piecework basis shall not be deemed to be a sub-letting under this Clause.

CONTRACT DOCUMENTS

Language/s and Law.

5. (1) There shall be stated in Part II of these Conditions:—

(a) the language or languages in which the Contract documents shall be drawn up and

(b) the country or state, the law of which is to apply to the Contract and according to which the Contract is to be construed.

If the said documents are written in more than one language, the language according to which the Contract is to be construed and interpreted shall also be designated in Part II, being therein designated the "Ruling Language".

Documents Mutually Explanatory.

(2) Except if and to the extent otherwise provided by the Contract, the provisions of the Conditions of Contract Parts I and II shall prevail over those of any other document forming part of the Contract. Subject to the foregoing, the several documents forming the Contract are to be taken as mutually explanatory of one another, but in case of ambiguities or discrepancies the same shall be explained and adjusted by the Engineer who shall thereupon issue to the Contractor instructions thereon. Provided always that if, in the opinion of the Engineer, compliance with any such instructions shall involve the Contractor in any cost, which by reason of any such ambiguity or discrepancy could not reasonably have been foreseen by the Contractor, the Engineer shall certify and the Employer shall pay such additional sum as may be reasonable to cover such costs.

Custody of Drawings.

6. (1) The Drawings shall remain in the sole custody of the Engineer, but two copies thereof shall be furnished to the Contractor free of charge. The Contractor shall provide and make at his own expense any further copies required by him. At the completion of the Contract the Contractor shall return to the Engineer all Drawings provided under the Contract.

One Copy of Drawings to be Kept on Site.

(2) One copy of the Drawings, furnished to the Contractor as aforesaid, shall be kept by the Contractor on the Site and the same shall at all reasonable times be available for inspection and use by the Engineer and the Engineer's Representative and by any other person authorised by the Engineer in writing.

Disruption of Progress.

(3) The Contractor shall give written notice to the Engineer whenever planning or progress of the Works is likely to be delayed or disrupted unless any further drawing or order, including a direction, instruction or approval, is issued by the Engineer within a reasonable time. The notice shall include details of the drawing or order required and of why and by when it is required and of any delay or disruption likely to be suffered if it is late.

Delays and cost of delay of Drawings

(4) If, by reason of any failure or inability of the Engineer to issue within a time reasonable in all the circumstances any drawing or order requested by the Contractor in accordance with sub-clause (3) of this Clause, the Contractor suffers delay and/or incurs costs then the Engineer shall take such delay into account in determining any extension of time to which the Contractor is entitled under Clause 44 hereof and the Contractor shall be paid the amount of such cost as shall be reasonable.

Further Drawings and Instructions.

7. The Engineer shall have full power and authority to supply to the Contractor from time to time, during the progress of the Works, such further drawings and instructions as shall be necessary for the purpose of the proper and adequate execution and maintenance of the Works. The Contractor shall carry out and be bound by the same.

GENERAL OBLIGATIONS

Contractor's General Responsibilities.

8. (1) The Contractor shall, subject to the provisions of the Contract, and with due care and diligence, execute and maintain the Works and provide all labour, including the supervision thereof, materials, Constructional Plant and all other things, whether of a temporary or permanent nature, required in and for such execution and maintenance, so far as the necessity for providing the same is specified in or is reasonably to be inferred from the Contract.

(2) The Contractor shall take full responsibility for the adequacy stability and safety of all site operations and methods of construction, provided that the Contractor shall not be responsible, except as may be expressly provided in the Contract, for the design or specification of the Permanent Works, or for the design or specification of any Temporary Works prepared by the Engineer.

Contract Agreement

9. The Contractor shall when called upon so to do enter into and execute a Contract Agreement, to be prepared and completed at the cost of the Employer, in the form annexed with such modification as may be necessary.

Performance Bond.

10. If, for the due performance of the Contract, the Tender shall contain an undertaking by the Contractor to obtain, when required, a bond or guarantee of an insurance company or bank, or other approved sureties to be jointly and severally bound with the Contractor to the Employer, in a sum not exceeding that stated in the Letter of Acceptance for such bond or guarantee, the said insurance company or bank or sureties and the terms of the said bond or guarantee shall be such as shall be approved by the Employer. The obtaining of such bond or guarantee or the provision of such sureties and the cost of the bond or guarantee to be so entered into shall be at the expense in all respects of the Contractor, unless the Contract otherwise provides.

Inspection of Site.

11. The Employer shall have made available to the Contractor with the Tender documents such data on hydrological and sub-surface conditions as shall have been obtained by or on behalf of the Employer from investigations undertaken relevant to the Works and the Tender shall be deemed to have been based on such data, but the Contractor shall be responsible for his own interpretation thereof.

The Contractor shall also be deemed to have inspected and examined the Site and its surroundings and information available in connection therewith and to have satisfied himself, so far as is practicable, before submitting his Tender, as to the form and nature thereof, including the sub-surface conditions, the hydrological and climatic conditions, the extent and nature of work and materials necessary for the completion of the Works, the means of access to the Site and the accommodation he may require and, in general, shall be deemed to have obtained all necessary information, subject as above mentioned, as to risks, contingencies and all other circumstances which may influence or affect his Tender.

Sufficiency of Tender.

12. The Contractor shall be deemed to have satisfied himself before tendering as to the correctness and sufficiency of his Tender for the Works and of the rates and prices stated in the priced Bill of Quantities and the Schedule of Rates and Prices, if any, which Tender rates and prices shall, except insofar as it is otherwise provided in the Contract, cover all his obligations under the Contract and all matters and things necessary for the proper execution and maintenance of the Works.

Adverse Physical Conditions and Artificial Obstructions.

If, however, during the execution of the Works the Contractor shall encounter physical conditions, other than climatic conditions on the Site, or artificial obstructions, which conditions or obstructions could, in his opinion, not have been reasonably foreseen by an experienced contractor, the Contractor shall forthwith give written notice thereof to the Engineer's Representative and if, in the opinion of the Engineer, such conditions or artificial obstructions could not have been reasonably foreseen by an experienced contractor, then the Engineer shall certify and the Employer shall pay the additional cost to which the Contractor shall have been put by reason of such conditions, including the proper and reasonable cost

(a) of complying with any instruction which the Engineer may issue to the Contractor in connection therewith, and

(b) of any proper and reasonable measures approved by the Engineer which the Contractor may take in the absence of specific instructions from the Engineer,

as a result of such conditions or obstructions being encountered.

13. Save insofar as it is legally or physically impossible, the Contractor shall execute and maintain the Works in strict accordance with the Contract to the satisfaction of the Engineer and shall comply with and adhere strictly to the Engineer's instructions and directions on any matter whether mentioned in the Contract or not, touching or concerning the Works. The Contractor shall take instructions and directions only from the Engineer or, subject to the limitations referred to in Clause 2 hereof, from the Engineer's Representative. **Work to be to the Satisf of Engineer.**

14. (1) Within the time stated in Part II of these Conditions, the Contractor shall, after the acceptance of his Tender, submit to the Engineer for his approval a programme showing the order of procedure in which he proposes to carry out the Works. The Contractor shall whenever required by the Engineer or Engineers' Representative, also provide in writing for his information a general description of the arrangements and methods which the Contractor proposes to adopt for the execution of the Works. **Programme to be Furnished.**

(2) If at any time it should appear to the Engineer that the actual progress of the Works does not conform to the approved programme referred to in sub-clause (1) of this Clause, the Contractor shall produce, at the request of the Engineer, a revised programme showing the modifications to the approved programme necessary to ensure completion of the Works within the time for completion as defined in Clause 43 hereof.

(3) The submission to and approval by the Engineer or Engineer's Representative of such programmes or the furnishing of such particulars shall not relieve the Contractor of any of his duties or responsibilities under the Contract.

15. The Contractor shall give or provide all necessary superintendence during the execution of the Works and as long thereafter as the Engineer may consider necessary for the proper fulfilling of the Contractor's obligations under the Contract. The Contractor, or a competent and authorised agent or representative approved of in writing by the Engineer, which approval may at any time be withdrawn, is to be constantly on the Works and shall give his whole time to the superintendence of the same. If such approval shall be withdrawn by the Engineer, the Contractor shall, as soon as is practicable, having regard to the requirement of replacing him as hereinafter mentioned, after receiving written notice of such withdrawal, remove the agent from the Works and shall not thereafter employ him again on the Works in any capacity and shall replace him by another agent approved by the Engineer. Such authorised agent or representative shall receive, on behalf of the Contractor, directions and instructions from the Engineer or, subject to the limitations of Clause 2 hereof, the Engineer's Representative. **Contractor's Superintend**

16. (1) The Contractor shall provide and employ on the Site in connection with the execution and maintenance of the Works **Contractor's Employees.**

(a) only such technical assistants as are skilled and experienced in their respective callings and such sub-agents, foremen and leading hands as are competent to give proper supervision to the work they are required to supervise, and

(b) such skilled, semi-skilled and unskilled labour as is necessary for the proper and timely execution and maintenance of the Works.

(2) The Engineer shall be at liberty to object to and require the Contractor to remove forthwith from the Works any person employed by the Contractor in or about the execution or maintenance of the Works who, in the opinion of the Engineer, misconducts himself, or is incompetent or negligent in the proper performance of his duties, or whose employment is otherwise considered by the Engineer to be undesirable and such person shall not be again employed upon the Works without the written permission of the Engineer. Any person so removed from the Works shall be replaced as soon as possible by a competent substitute approved by the Engineer.

17. The Contractor shall be responsible for the true and proper setting-out of the Works in relation to original points, lines and levels of reference given by the Engineer in writing and for the correctness, subject as above mentioned, of the position, levels, dimensions and alignment of all parts of the Works and for the provision of all necessary instruments, appliances and labour in connection therewith. If, at any time during the progress of the Works, any error shall appear or arise in the position, levels, dimensions or alignment of any part of the Works, the Contractor, on being required so to do by the Engineer or the Engineer's Representative, shall, at his own cost, rectify such error to the satisfaction of the Engineer or the Engineer's Representative, unless such error is based on incorrect data supplied in writing by the Engineer or the Engineer's Representative, in which case the expense of rectifying the same shall be borne by the Employer. The checking of any setting-out or of any line or level by the Engineer or the Engineer's Representative shall not in any way relieve the Contractor of his responsibility for the correctness thereof and the Contractor shall carefully protect and preserve all bench-marks, sight-rails, pegs and other things used in setting-out the Works. **Setting-out.**

18. If, at any time during the execution of the Works, the Engineer shall require the Contractor to make boreholes or to carry out exploratory excavation, such requirement shall be ordered in writing and shall be deemed to be an addition ordered under the provisions of Clause 51 hereof, unless a provisional sum in respect of such anticipated work shall have been included in the Bill of Quantities. **Boreholes and Exploratory Excavation.**

Watching and Lighting.

19. The Contractor shall in connection with the Works provide and maintain at his own cost all lights, guards, fencing and watching when and where necessary or required by the Engineer or the Engineer's Representative, or by any duly constituted authority, for the protection of the Works, or for the safety and convenience of the public or others.

Care of Works.

20. (1) From the commencement of the Works until the date stated in the Certificate of Completion for the whole of the Works pursuant to Clause 48 hereof the Contractor shall take full responsibility for the care thereof. Provided that if the Engineer shall issue a Certificate of Completion in respect of any part of the Permanent Works the Contractor shall cease to be liable for the care of that part of the Permanent Works from the date stated in the Certificate of Completion in respect of that part and the responsibility for the care of that part shall pass to the Employer. Provided further that the Contractor shall take full responsibility for the care of any outstanding work which he shall have undertaken to finish during the Period of Maintenance until such outstanding work is completed. In case any damage, loss or injury shall happen to the Works, or to any part thereof, from any cause whatsoever, save and except the excepted risks as defined in sub-clause (2) of this Clause, while the Contractor shall be responsible for the care thereof the Contractor shall, at his own cost, repair and make good the same, so that at completion the Permanent Works shall be in good order and condition and in conformity in every respect with the requirements of the Contract and the Engineer's instructions. In the event of any such damage, loss or injury happening from any of the excepted risks, the Contractor shall, if and to the extent required by the Engineer and subject always to the provisions of Clause 65 hereof, repair and make good the same as aforesaid at the cost of the Employer. The Contractor shall also be liable for any damage to the Works occasioned by him in the course of any operations carried out by him for the purpose of completing any outstanding work or complying with his obligations under Clauses 49 or 50 hereof.

Excepted Risks.

(2) The "excepted risks" are war, hostilities (whether war be declared or not), invasion, act of foreign enemies, rebellion, revolution, insurrection or military or usurped power, civil war, or unless solely restricted to employees of the Contractor or of his sub-contractors and arising from the conduct of the Works, riot, commotion or disorder, or use or occupation by the Employer of any part of the Permanent Works, or a cause solely due to the Engineer's design of the Works, or ionising radiations or contamination by radio-activity from any nuclear fuel or from any nuclear waste from the combustion of nuclear fuel, radio-active toxic explosive, or other hazardous properties of any explosive, nuclear assembly or nuclear component thereof, pressure waves caused by aircraft or other aerial devices travelling at sonic or supersonic speeds, or any such operation of the forces of nature as an experienced contractor could not foresee, or reasonably make provision for or insure against all of which are herein collectively referred to as "the excepted risks".

Insurance of Works, etc.

21. Without limiting his obligations and responsibilities under Clause 20 hereof, the Contractor shall insure in the joint names of the Employer and the Contractor against all loss or damage from whatever cause arising, other than the excepted risks, for which he is responsible under the terms of the Contract and in such manner that the Employer and Contractor are covered for the period stipulated in Clause 20(1) hereof and are also covered during the Period of Maintenance for loss or damage arising from a cause, occurring prior to the commencement of the Period of Maintenance, and for any loss or damage occasioned by the Contractor in the course of any operations carried out by him for the purpose of complying with his obligations under Clauses 49 and 50 hereof:—

(a) The Works for the time being executed to the estimated current contract value thereof, or such additional sum as may be specified in Part II in the Clause numbered 21, together with the materials for incorporation in the Works at their replacement value.

(b) The Constructional Plant and other things brought on to the Site by the Contractor to the replacement value of such Constructional Plant and other things.

Such insurance shall be effected with an insurer and in terms approved by the Employer, which approval shall not be unreasonably withheld, and the Contractor shall, whenever required, produce to the Engineer or the Engineer's Representative the policy or policies of insurance and the receipts for payment of the current premiums.

Damage to Persons and Property.

22. (1) The Contractor shall, except if and so far as the Contract provides otherwise, indemnify the Employer against all losses and claims in respect of injuries or damage to any person or material or physical damage to any property whatsoever which may arise out of or in consequence of the execution and maintenance of the Works and against all claims, proceedings, damages, costs, charges and expenses whatsoever in respect of or in relation thereto except any compensation or damages for or with respect to:—

(a) The permanent use or occupation of land by the Works or any part thereof.

(b) The right of the Employer to execute the Works or any part thereof on, over, under, in or through any land.

(c) Injuries or damage to persons or property which are the unavoidable result of the execution or maintenance of the Works in accordance with the Contract.

(d) Injuries or damage to persons or property resulting from any act or neglect of the Employer, his agents, servants or other contractors, not being employed by the Contractor, or for or in respect of any claims, proceedings, damages, costs, charges and expenses in respect thereof or in relation thereto or where the injury or damage was contributed to by the Contractor, his servants or agents such part of the compensation as may be just and equitable having regard to the extent of the responsibility of the Employer, his servants or agents or other contractors for the damage or injury.

(2) The Employer shall indemnify the Contractor against all claims, proceedings, damages, costs, charges and expenses in respect of the matters referred to in the proviso to sub-clause (1) of this Clause. **Indemnity by Employer.**

23. (1) Before commencing the execution of the Works the Contractor, but without limiting his obligations and responsibilities under Clause 22 hereof, shall insure against his liability for any material or physical damage, loss or injury which may occur to any property, including that of the Employer, or to any person, including any employee of the Employer, by or arising out of the execution of the Works or in the carrying out of the Contract, otherwise than due to the matters referred to in the proviso to Clause 22 (1) hereof. **Third Party Insurance.**

(2) Such insurance shall be effected with an insurer and in terms approved by the Employer, which approval shall not be unreasonably withheld, and for at least the amount stated in the Appendix to the Tender. The Contractor shall, whenever required, produce to the Engineer or the Engineer's Representative the policy or policies of insurance and the receipts for payment of the current premiums. **Minimum Amount of Third Party Insurance.**

(3) The terms shall include a provision whereby, in the event of any claim in respect of which the Contractor would be entitled to receive indemnity under the policy being brought or made against the Employer, the insurer will indemnify the Employer against such claims and any costs, charges and expenses in respect thereof. **Provision to Indemnify Employer.**

24. (1) The Employer shall not be liable for or in respect of any damages or compensation payable at law in respect or in consequence of any accident or injury to any workman or other person in the employment of the Contractor or any sub-contractor, save and except an accident or injury resulting from any act or default of the Employer, his agents, or servants. The Contractor shall indemnify and keep indemnified the Employer against all such damages and compensation, save and except as aforesaid, and against all claims, proceedings, costs, charges and expenses whatsoever in respect thereof or in relation thereto. **Accident or Injury to Workmen.**

(2) The Contractor shall insure against such liability with an insurer approved by the Employer, which approval shall not be unreasonably withheld, and shall continue such insurance during the whole of the time that any persons are employed by him on the Works and shall, when required, produce to the Engineer or the Engineer's Representative such policy of insurance and the receipt for payment of the current premium. Provided always that, in respect of any persons employed by any sub-contractor, the Contractor's obligation to insure as aforesaid under this sub-clause shall be satisfied if the sub-contractor shall have insured against the liability in respect of such persons in such manner that the Employer is indemnified under the policy, but the Contractor shall require such sub-contractor to produce to the Engineer or the Engineer's Representative, when required, such policy of insurance and the receipt for the payment of the current premium. **Insurance against Accident, etc., to Workmen.**

25. If the Contractor shall fail to effect and keep in force the insurances referred to in Clauses 21, 23 and 24 hereof, or any other insurance which he may be required to effect under the terms of the Contract, then and in any such case the Employer may effect and keep in force any such insurance and pay such premium or premiums as may be necessary for that purpose and from time to time deduct the amount so paid by the Employer as aforesaid from any monies due or which may become due to the Contractor, or recover the same as a debt due from the Contractor. **Remedy on Contractor's Failure to Insure.**

26. (1) The Contractor shall give all notices and pay all fees required to be given or paid by any National or State Statute, Ordinance, or other Law, or any regulation, or bye-law of any local or other duly constituted authority in relation to the execution of the Works and by the rules and regulations of all public bodies and companies whose property or rights are affected or may be affected in any way by the Works. **Giving of Notices and Payment of Fees.**

(2) The Contractor shall conform in all respects with the provisions of any such Statute, Ordinance or Law as aforesaid and the regulations or bye-laws of any local or other duly constituted authority which may be applicable to the Works and with such rules and regulations of public bodies and companies as aforesaid and shall keep the Employer indemnified against all penalties and liability of every kind for breach of any such Statute, Ordinance or Law, regulation or bye-law. **Compliance with Statutes, Regulations, etc.**

(3) The Employer will repay or allow to the Contractor all such sums as the Engineer shall certify to have been properly payable and paid by the Contractor in respect of such fees.

27. All fossils, coins, articles of value or antiquity and structures and other remains or things of geological or archaeological interest discovered on the site of the Works shall as between the Employer and the Contractor be deemed to be the absolute property of the Employer. The Contractor shall take reasonable precautions to prevent his workmen or any other persons from removing or damaging any such article or thing and shall immediately upon discovery thereof and, before removal, acquaint the Engineer's Representative of such discovery and carry out, at the expense of the Employer, the Engineer's Representative's orders as to the disposal of the same. **Fossils, etc.**

Patent Rights and Royalties.

28. The Contractor shall save harmless and indemnify the Employer from and against all claims and proceedings for or on account of infringement of any patent rights, design trademark or name or other protected rights in respect of any Constructional Plant, machine work, or material used for or in connection with the Works or any of them and from and against all claims, proceedings. damages, costs, charges and expenses whatsoever in respect thereof or in relation thereto. Except where otherwise specified, the Contractor shall pay all tonnage and other royalties, rent and other payments or compensation, if any, for getting stone, sand, gravel, clay or other materials required for the Works or any of them.

Interference with Traffic and Adjoining Properties.

29. All operations necessary for the execution of the Works shall, so far as compliance with the requirements of the Contract permits, be carried on so as not to interfere unnecessarily or improperly with the convenience of the public, or the access to, use and occupation of public or private roads and footpaths to or of properties whether in the possession of the Employer or of any other person. The Contractor shall save harmless and indemnify the Employer in respect of all claims, proceedings, damages, costs, charges and expenses whatsoever arising out of, or in relation to, any such matters in so far as the Contractor is responsible therefor.

Extraordinary Traffic.

30. (1) The Contractor shall use every reasonable means to prevent any of the highways or bridges communicating with or on the routes to the Site from being damaged or injured by any traffic of the Contractor or any of his sub-contractors and, in particular, shall select routes, choose and use vehicles and restrict and distribute loads so that any such extraordinary traffic as will inevitably arise from the moving of plant and material from and to the Site shall be limited, as far as reasonably possible, and so that no unnecessary damage or injury may be occasioned to such highways and bridges.

Special Loads.

(2) Should it be found necessary for the Contractor to move one or more loads of Constructional Plant, machinery or pre-constructed units or parts of units of work over part of a highway or bridge, the moving whereof is likely to damage any highway or bridge unless special protection or strengthening is carried out, then the Contractor shall before moving the load on to such highway or bridge give notice to the Engineer or Engineer's Representative of the weight and other particulars of the load to be moved and his proposals for protecting or strengthening the said highway or bridge. Unless within fourteen days of the receipt of such notice the Engineer shall by counter-notice direct that such protection or strengthening is unnecessary, then the Contractor will carry out such proposals or any modification thereof that the Engineer shall require and, unless there is an item or are items in the Bill of Quantities for pricing by the Contractor of the necessary works for the protection or strengthening aforesaid, the costs thereof shall be paid by the Employer to the Contractor.

Settlement of Extraordinary Traffic Claims.

(3) If during the execution of the Works or at any time thereafter the Contractor shall receive any claim arising out of the execution of the Works in respect of damage or injury to highways or bridges he shall immediately report the same to the Engineer and thereafter the Employer shall negotiate the settlement of and pay all sums due in respect of such claim and shall indemnify the Contractor in respect thereof and in respect of all claims, proceedings, damages, costs, charges and expenses in relation thereto. Provided always that if and so far as any such claims or part thereof shall in the opinion of the Engineer be due to any failure on the part of the Contractor to observe and perform his obligations under sub-clauses (1) and (2) of this Clause, then the amount certified by the Engineer to be due to such failure shall be paid by the Contractor to the Employer.

Waterborne Traffic.

(4) Where the nature of the Works is such as to require the use by the Contractor of waterborne transport the foregoing provisions of this Clause shall be construed as though "highway" included a lock, dock, sea wall or other structure related to a waterway and "vehicle" included craft, and shall have effect accordingly.

Opportunities for other Contractors.

31. The Contractor shall, in accordance with the requirements of the Engineer, afford all reasonable opportunities for carrying out their work to any other contractors employed by the Employer and their workmen and to the workmen of the Employer and of any other duly constituted authorities who may be employed in the execution on or near the Site of any work not included in the Contract or of any contract which the Employer may enter into in connection with or ancillary to the Works. If, however, the Contractor shall, on the written request of the Engineer or the Engineer's Representative, make available to any such other contractor, or to the Employer or any such authority, any roads or ways for the maintenance of which the Contractor is responsible, or permit the use by any such of the Contractor's scaffolding or other plant on the Site, or provide any other service of whatsoever nature for any such, the Employer shall pay to the Contractor in respect of such use or service such sum or sums as shall, in the opinion of the Engineer, be reasonable.

Contractor to Keep Site Clear.

32. During the progress of the Works the Contractor shall keep the Site reasonably free from all unnecessary obstruction and shall store or dispose of any Constructional Plant and surplus materials and clear away and remove from the Site any wreckage, rubbish or Temporary Works no longer required.

Clearance of Site on Completion.

33. On the completion of the Works the Contractor shall clear away and remove from the Site all Constructional Plant, surplus materials, rubbish and Temporary Works of every kind, and leave the whole of the Site and Works clean and in a workmanlike condition to the satisfaction of the Engineer.

LABOUR

34. (1) The Contractor shall make his own arrangements for the engagement of all labour, local or otherwise, and, save insofar as the Contract otherwise provides, for the transport, housing, feeding and payment thereof. **Engagement of Labour.**

(2) The Contractor shall, so far as is reasonably practicable, having regard to local conditions, provide on the Site, to the satisfaction of the Engineer's Representative, an adequate supply of drinking and other water for the use of the Contractor's staff and work people. **Supply of Water.**

(3) The Contractor shall not, otherwise than in accordance with the Statutes, Ordinances and Government Regulations or Orders for the time being in force, import, sell, give, barter or otherwise dispose of any alcoholic liquor, or drugs, or permit or suffer any such importation, sale, gift, barter or disposal by his sub-contractors, agents or employees. **Alcoholic Liquor or Drugs.**

(4) The Contractor shall not give, barter or otherwise dispose of to any person or persons, any arms or ammunition of any kind or permit or suffer the same as aforesaid. **Arms and Ammunition.**

(5) The Contractor shall in all dealings with labour in his employment have due regard to all recognised festivals, days of rest and religious or other customs. **Festivals and Religious Customs**

(6) In the event of any outbreak of illness of an epidemic nature, the Contractor shall comply with and carry out such regulations, orders and requirements as may be made by the Government, or the local medical or sanitary authorities for the purpose of dealing with and overcoming the same. **Epidemics.**

(7) The Contractor shall at all times take all reasonable precautions to prevent any unlawful, riotous or disorderly conduct by or amongst his employees and for the preservation of peace and protection of persons and property in the neighbourhood of the Works against the same. **Disorderly Conduct, etc.**

(8) The Contractor shall be responsible for observance by his sub-contractors of the foregoing provisions. **Observance by Sub-Contractors.**

(9) *Any other conditions affecting labour and wages shall be as set out in Part II in the clause numbered 34 as may be necessary.*

35. The Contractor shall, if required by the Engineer, deliver to the Engineer's Representative, or at his office, a return in detail in such form and at such intervals as the Engineer may prescribe showing the supervisory staff and the numbers of the several classes of labour from time to time employed by the Contractor on the Site and such information respecting Constructional Plant as the Engineer's Representative may require. **Returns of Labour, etc.**

MATERIALS AND WORKMANSHIP

36. (1) All materials and workmanship shall be of the respective kinds described in the Contract and in accordance with the Engineer's instructions and shall be subjected from time to time to such tests as the Engineer may direct at the place of manufacture or fabrication, or on the Site or at such other place or places as may be specified in the Contract, or at all or any of such places. The Contractor shall provide such assistance, instruments, machines, labour and materials as are normally required for examining, measuring and testing any work and the quality, weight or quantity of any material used and shall supply samples of materials before incorporation in the Works for testing as may be slected and required by the Engineer. **Quality of Materials and Workmanship and Tests.**

(2) All samples shall be supplied by the Contractor at his own cost if the supply thereof is clearly intended by or provided for in the Contract, but if not, then at the cost of the Employer. Cost of Samples.

(3) The cost of making any test shall be borne by the Contractor if such test is clearly intended by or provided for in the Contract and, in the cases only of a test under load or of a test to ascertain whether the design of any finished or partially finished work is appropriate for the purposes which it was intended to fulfil, is particularised in the Contract in sufficient detail to enable the Contractor to price or allow for the same in his Tender. **Cost of Tests.**

(4) If any test is ordered by the Engineer which is either **Cost of Tests not Provided for, etc.**

(a) not so intended by or provided for, or

(b) (in the cases above mentioned) is not so particularised, or

(c) though so intended or provided for is ordered by the Engineer to be carried out by an independent person at any place other than the Site or the place of manufacture or fabrication of the materials tested,

then the cost of such test shall be borne by the Contractor, if the test shows the workmanship or materials not to be in accordance with the provisions of the Contract or the Engineer's instructions, but otherwise by the Employer.

37. The Engineer and any person authorised by him shall at all times have access to the Works and to all workshops and places where work is being prepared or from where materials, manufactured articles or machinery are being obtained for the Works and the Contractor shall afford every facility for and every assistance in or in obtaining the right to such access. **Inspection of Operations.**

Examination of Work before Covering up.

38. (1) No work shall be covered up or put out of view without the approval of the Engineer or the Engineer's Representative and the Contractor shall afford full opportunity for the Engineer or the Engineer's Representative to examine and measure any work which is about to be covered up or put out of view and to examine foundations before permanent work is placed thereon. The Contractor shall give due notice to the Engineer's Representative whenever any such work or foundations is or are ready or about to be ready for examination and the Engineer's Representative shall, without unreasonable delay, unless he considers it unnecessary and advises the Contractor accordingly, attend for the purpose of examining and measuring such work or of examining such foundations.

Uncovering and Making Openings.

(2) The Contractor shall uncover any part or parts of the Works or make openings in or through the same as the Engineer may from time to time direct and shall reinstate and make good such part or parts to the satisfaction of the Engineer. If any such part or parts have been covered up or put out of view after compliance with the requirement of sub-clause (1) of this Clause and are found to be executed in accordance with the Contract, the expenses of uncovering, making openings in or through, reinstating and making good the same shall be borne by the Employer, but in any other case all costs shall be borne by the Contractor.

Removal of Improper Work and Materials.

39. (1) The Engineer shall during the progress of the Works have power to order in writing from time to time

(a) the removal from the Site, within such time or times as may be specified in the order, of any materials which, in the opinion of the Engineer, are not in accordance with the Contract

(b) the substitution of proper and suitable materials and

(c) the removal and proper re-execution, notwithstanding any previous test thereof or interim payment therefor, of any work which in respect of materials or workmanship is not, in the opinion of the Engineer, in accordance with the Contract.

Default of Contractor in Compliance.

(2) In case of default on the part of the Contractor in carrying out such order, the Employer shall be entitled to employ and pay other persons to carry out the same and all expenses consequent thereon or incidental thereto shall be recoverable from the Contractor by the Employer, or may be deducted by the Employer from any monies due or which may become due to the Contractor.

Suspension of Work.

40. (1) The Contractor shall, on the written order of the Engineer, suspend the progress of the Works or any part thereof for such time or times and in such manner as the Engineer may consider necessary and shall during such suspension properly protect and secure the work, so far as is necessary in the opinion of the Engineer. The extra cost incurred by the Contractor in giving effect to the Engineer's instructions under this Clause shall be borne and paid by the Employer unless such suspension is

(a) otherwise provided for in the Contract, or

(b) necessary by reason of some default on the part of the Contractor, or

(c) necessary by reason of climatic conditions on the Site, or

(d) necessary for the proper execution of the Works or for the safety of the Works or any part thereof insofar as such necessity does not arise from any act or default by the Engineer or the Employer or from any of the excepted risks defined in Clause 20 hereof.

Provided that the Contractor shall not be entitled to recover any such extra cost unless he gives written notice of his intention to claim to the Engineer within twenty-eight days of the Engineer's order. The Engineer shall settle and determine such extra payment and/or extension of time under Clause 44 hereof to be made to the Contractor in respect of such claim as shall, in the opinion of the Engineer, be fair and reasonable.

Suspension Lasting more than 90 days.

(2) If the progress of the Works or any part thereof is suspended on the written order of the Engineer and if permission to resume work is not given by the Engineer within a period of ninety days from the date of suspension then, unless such suspension is within paragraph (a), (b), (c) or (d) of sub-clause (1) of this Clause, the Contractor may serve a written notice on the Engineer requiring permission within twenty-eight days from the receipt thereof to proceed with the Works, or that part thereof in regard to which progress is suspended and, if such permission is not granted within that time, the Contractor by a further written notice so served may, but is not bound to, elect or treat the suspension where it affects part only of the Works as an omission of such part under Clause 51 hereof, or, where it affects the whole Works, as an abandonment of the Contract by the Employer.

COMMENCEMENT TIME AND DELAYS

Commencement of Works.

41. The Contractor shall commence the Works on Site within the period named in the Appendix to the Tender after the receipt by him of a written order to this effect from the Engineer and shall proceed with the same with due expedition and without delay, except as may be expressly sanctioned or ordered by the Engineer or be wholly beyond the Contractor's control.

42. (1) Save insofar as the Contract may prescribe, the extent of portions of the Site of which the Contractor is to be given possession from time to time and the order in which such portions shall be made available to him and, subject to any requirement in the Contract as to the order in which the Works shall be executed, the Employer will, with the Engineer's written order to commence the Works, give to the Contractor possession of so much of the Site as may be required to enable the Contractor to commence and proceed with the execution of the Works in accordance with the programme referred to in Clause 14 hereof, if any, and otherwise in accordance with such reasonable proposals of the Contractor as he shall, by written notice to the Engineer, make and will, from time to time as the Works proceed, give to the Contractor possession of such further portions of the Site as may be required to enable the Contractor to proceed with the execution of the Works with due despatch in accordance with the said programme or proposals, as the case may be. If the Contractor suffers delay or incurs cost from failure on the part of the Employer to give possession in accordance with the terms of this Clause, the Engineer shall grant an extension of time for the completion of the Works and certify such sum as, in his opinion, shall be fair to cover the cost incurred, which sum shall be paid by the Employer. **Possession of Site.**

(2) The Contractor shall bear all costs and charges for special or temporary wayleaves required by him in connection with access to the Site. The Contractor shall also provide at his own cost any additional accommodation outside the Site required by him for the purposes of the Works. **Wayleaves, etc**

43. Subject to any requirement in the Contract as to completion of any section of the Works before completion of the whole, the whole of the Works shall be completed, in accordance with the provisions of Clause 48 hereof, within the time stated in the Contract calculated from the last day of the period named in the Appendix to the Tender as that within which the Works are to be commenced, or such extended time as may be allowed under Clause 44 hereof. **Time for Completion.**

44. Should the amount of extra or additional work of any kind or any cause of delay referred to in these Conditions, or exceptional adverse climatic conditions, or other special circumstances of any kind whatsoever which may occur, other than through a default of the Contractor, be such as fairly to entitle the Contractor to an extension of time for the completion of the Works, the Engineer shall determine the amount of such extension and shall notify the Employer and the Contractor accordingly. Provided that the Engineer is not bound to take into account any extra or additional work or other special circumstances unless the Contractor has within twenty-eight days after such work has been commenced, or such circumstances have arisen, or as soon thereafter as is practicable, submitted to the Engineer's Representative full and detailed particulars of any extension of time to which he may consider himself entitled in order that such submission may be investigated at the time. **Extension of Time for Completion.**

45. Subject to any provision to the contrary contained in the Contract, none of the Permanent Works shall, save as hereinafter provided, be carried on during the night or on Sundays, if locally recognised as days of rest, or their locally recognised equivalent without the permission in writing of the Engineer's Representative, except when the work is unavoidable or absolutely necessary for the saving of life or property or for the safety of the Works, in which case the Contractor shall immediately advise the Engineer's Representative. Provided always that the provisions of this Clause shall not be applicable in the case of any work which it is customary to carry out by rotary or double shifts. **No Night or Sunday Work.**

46. If for any reason, which does not entitle the Contractor to an extension of time, the rate of progress of the Works or any section is at any time, in the opinion of the Engineer, too slow to ensure completion by the prescribed time or extended time for completion, the Engineer shall so notify the Contractor in writing and the Contractor shall thereupon take such steps as are necessary and the Engineer may approve to expedite progress so as to complete the Works or such section by the prescribed time or extended time. The Contractor shall not be entitled to any additional payment for taking such steps. If, as a result of any notice given by the Engineer under this Clause, the Contractor shall seek the Engineer's permission to do any work at night or on Sundays, if locally recognised as days of rest, or their locally recognised equivalent, such permission shall not be unreasonably refused. **Rate of Progress.**

47. (1) If the Contractor shall fail to achieve completion of the Works within the time prescribed by Clause 43 hereof, then the Contractor shall pay to the Employer the sum stated in the Contract as liquidated damages for such default and not as a penalty for every day or part of a day which shall elapse between the time prescribed by Clause 43 hereof and the date of certified completion of the Works. The Employer may, without prejudice to any other method of recovery, deduct the amount of such damages from any monies in his hands, due or which may become due to the Contractor. The payment or deduction of such damages shall not relieve the Contractor from his obligation to complete the Works, or from any other of his obligations and liabilities under the Contract. **Liquidated Damages for Delay.**

Reduction of Liquidated Damages.

(2) If, before the completion of the whole of the Works any part or section of the Works has been certified by the Engineer as completed, pursuant to Clause 48 hereof, and occupied or used by the Employer, the liquidated damages for delay shall, for any period of delay after such certificate and in the absence of alternative provisions in the Contract be reduced in the proportion which the value of the part or section so certified bears to the value of the whole of the Works.

Bonus for Completion.

(3) *If it is desired to provide in the Contract for the payment of a bonus in relation to completion of the Works or of any part or section thereof this shall be set out in Part II in the clause numbered 47.*

Certification of Completion of Works.

48. (1) When the whole of the Works have been substantially completed and have satisfactorily passed any final test that may be prescribed by the Contract, the Contractor may give a notice to that effect to the Engineer or to the Engineer's Representative accompanied by an undertaking to finish any outstanding work during the Period of Maintenance. Such notice and undertaking shall be in writing and shall be deemed to be a request by the Contractor for the Engineer to issue a Certificate of Completion in respect of the Works. The Engineer shall, within twenty-one days of the date of delivery of such notice either issue to the Contractor, with a copy to the Employer, a Certificate of Completion stating the date on which, in his opinion, the Works were substantially completed in accordance with the Contract or give instructions in writing to the Contractor specifying all the work which, in the Engineer's opinion, requires to be done by the Contractor before the issue of such Certificate. The Engineer shall also notify the Contractor of any defects in the Works affecting substantial completion that may appear after such instructions and before completion of the works specified therein. The Contractor shall be entitled to receive such Certificate of Completion within twenty-one days of completion to the satisfaction of the Engineer of the works so specified and making good any defects so notified.

Certification of Completion by Stages.

(2) Similarly, in accordance with the procedure set out in sub-clause (1) of this Clause, the Contractor may request and the Engineer shall issue a Certificate of Completion in respect of:—

(a) any section of the Permanent Works in respect of which a separate time for completion is provided in the Contract and

(b) any substantial part of the Permanent Works which has been both completed to the satisfaction of the Engineer and occupied or used by the Employer.

(3) If any part of the Permanent Works shall have been substantially completed and shall have satisfactorily passed any final test that may be prescribed by the Contract, the Engineer may issue a Certificate of Completion in respect of that part of the Permanent Works before completion of the whole of the Works and, upon the issue of such Certificate, the Contractor shall be deemed to have undertaken to complete any outstanding work in that part of the Works during the Period of Maintenance.

(4) Provided always that a Certificate of Completion given in respect of any section or part of the Permanent Works before completion of the whole shall not be deemed to certify completion of any ground or surfaces requiring reinstatement, unless such Certificate shall expressly so state.

MAINTENANCE AND DEFECTS

Definition of 'Period of Maintenance'.

49. (1) In these Conditions the expression "Period of Maintenance" shall mean the period of maintenance named in the Appendix to the Tender, calculated from the date of completion of the Works, certified by the Engineer in accordance with Clause 48 hereof, or, in the event of more than one certificate having been issued by the Engineer under the said Clause, from the respective dates so certified and in relation to the Period of Maintenance the expression "the Works" shall be construed accordingly.

Execution of Work of Repair, etc.

(2) To the intent that the Works shall at or as soon as practicable after the expiration of the Period of Maintenance be delivered to the Employer in the condition required by the Contract, fair wear and tear excepted, to the satisfaction of the Engineer, the Contractor shall finish the work, if any, outstanding at the date of completion, as certified under Clause 48 hereof, as soon as practicable after such date and shall execute all such work of repair, amendment, reconstruction, rectification and making good defects, imperfections, shrinkages or other faults as may be required of the Contractor in writing by the Engineer during the Period of Maintenance, or within fourteen days after its expiration, as a result of an inspection made by or on behalf of the Engineer prior to its expiration.

Cost of Execution of Work of Repair, etc.

(3) All such work shall be carried out by the Contractor at his own expense if the necessity thereof shall, in the opinion of the Engineer, be due to the use of materials or workmanship not in accordance with the Contract, or to neglect or failure on the part of the Contractor to comply with any obligation, expressed or implied, on the Contractor's part under the Contract. If, in the opinion of the Engineer, such necessity shall be due to any other cause, the value of such work shall be ascertained and paid for as if it were additional work.

Remedy on Contractor's Failure to carry out Work Required.

(4) If the Contractor shall fail to do any such work as aforesaid required by the Engineer, the Employer shall be entitled to employ and pay other persons to carry out the same and if such work is work which, in the opinion of the Engineer, the Contractor was liable to do at his own expense under the Contract, then all expenses consequent thereon or incidental thereto shall be recoverable from the Contractor by the Employer, or may be deducted by the Employer from any monies due or which may become due to the Contractor.

50. The Contractor shall, if required by the Engineer in writing, search under the directions of the Engineer for the cause of any defect, imperfection or fault appearing during the progress of the Works or in the Period of Maintenance. Unless such defect, imperfection or fault shall be one for which the Contractor is liable under the Contract, the cost of the work carried out by the Contractor in searching as aforesaid shall be borne by the Employer. If such defect, imperfection or fault shall be one for which the Contractor is liable as aforesaid, the cost of the work carried out in searching as aforesaid shall be borne by the Contractor and he shall in such case repair, rectify and make good such defect, imperfection or fault at his own expense in accordance with the provisions of Clause 49 hereof. **Contractor to Search.**

ALTERATIONS, ADDITIONS AND OMISSIONS

51. (1) The Engineer shall make any variation of the form, quality or quantity of the Works or any part thereof that may, in his opinion, be necessary and for that purpose, or if for any other reason it shall, in his opinion be desirable, he shall have power to order the Contractor to do and the Contractor shall do any of the following:— **Variations.**

(a) increase or decrease the quantity of any work included in the Contract,

(b) omit any such work,

(c) change the character or quality or kind of any such work,

(d) change the levels, lines, position and dimensions of any part of the Works, and

(e) execute additional work of any kind necessary for the completion of the Works

and no such variation shall in any way vitiate or invalidate the Contract, but the value, if any, of all such variations shall be taken into account in ascertaining the amount of the Contract Price.

(2) No such variations shall be made by the Contractor without an order in writing of the Engineer. Provided that no order in writing shall be required for increase or decrease in the quantity of any work where such increase or decrease is not the result of an order given under this Clause, but is the result of the quantities exceeding or being less than those stated in the Bill of Quantities. Provided also that if for any reason the Engineer shall consider it desirable to give any such order verbally, the Contractor shall comply with such order and any confirmation in writing of such verbal order given by the Engineer, whether before or after the carrying out of the order, shall be deemed to be an order in writing within the meaning of this Clause. Provided further that if the Contractor shall within seven days confirm in writing to the Engineer and such confirmation shall not be contradicted in writing within fourteen days by the Engineer, it shall be deemed to be an order in writing by the Engineer. Orders for Variations to be in Writing.

52. (1) All extra or additional work done or work omitted by order of the Engineer shall be valued at the rates and prices set out in the Contract if, in the opinion of the Engineer, the same shall be applicable. If the Contract does not contain any rates or prices applicable to the extra or additional work, then suitable rates or prices shall be agreed upon between the Engineer and the Contractor. In the event of disagreement the Engineer shall fix such rates or prices as shall, in his opinion, be reasonable and proper. **Valuation of Variations.**

(2) Provided that if the nature or amount of any omission or addition relative to the nature or amount of the whole of the Works or to any part thereof shall be such that, in the opinion of the Engineer, the rate or price contained in the Contract for any item of the Works is, by reason of such omission or addition, rendered unreasonable or inapplicable, then a suitable rate or price shall be agreed upon between the Engineer and the Contractor. In the event of disagreement the Engineer shall fix such other rate or price as shall, in his opinion, be reasonable and proper having regard to the circumstances. **Power of Engineer to Fix Rates.**

Provided also that no increase or decrease under sub-clause (1) of this Clause or variation of rate or price under sub-clause (2) of this Clause shall be made unless, as soon after the date of the order as is practicable and, in the case of extra or additional work, before the commencement of the work or as soon thereafter as is practicable, notice shall have been given in writing:—

(a) by the Contractor to the Engineer of his intention to claim extra payment or a varied rate or price, or

(b) by the Engineer to the Contractor of his intention to vary a rate or price.

(3) If, on certified completion of the whole of the Works it shall be found that a reduction or increase greater than ten per cent of the sum named in the Letter of Acceptance, excluding all fixed sums, provisional sums and allowance for dayworks, if any, results from:— **Variations Exceeding 10 per cent.**

(a) the aggregate effect of all Variation Orders, and

(b) all adjustments upon measurement of the estimated quantities set out in the Bill of Quantities, excluding all provisional sums, dayworks and adjustments of price made under Clause 70 (1) hereof,

but not from any other cause, the amount of the Contract Price shall be adjusted by such sum as may be agreed between the Contractor and the Engineer or, failing agreement, fixed by the Engineer having regard to all material and relevant factors, including the Contractor's Site and general over-head costs of the Contract.

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(4) The Engineer may, if, in his opinion it is necessary or desirable, order in writing that any additional or substituted work shall be executed on a daywork basis. The Contractor shall then be paid for such work under the conditions set out in the Daywork Schedule included in the Contract and at the rates and prices affixed thereto by him in his Tender.

The Contractor shall furnish to the Engineer such receipts or other vouchers as may be necessary to prove the amounts paid and, before ordering materials, shall submit to the Engineer quotations for the same for his approval.

In respect of all work executed on a daywork basis, the Contractor shall, during the continuance of such work, deliver each day to the Engineer's Representative an exact list in duplicate of the names, occupation and time of all workmen employed on such work and a statement, also in duplicate, showing the description and quantity of all materials and plant used thereon or therefor (other than plant which is included in the percentage addition in accordance with the Schedule hereinbefore referred to). One copy of each list and statement will, if correct, or when agreed, be signed by the Engineer's Representative and returned to the Contractor.

At the end of each month the Contractor shall deliver to the Engineer's Representative a priced statement of the labour, material and plant, except as aforesaid, used and the Contractor shall not be entitled to any payment unless such lists and statements have been fully and punctually rendered. Provided always that if the Engineer shall consider that for any reason the sending of such lists or statements by the Contractor, in accordance with the foregoing provision, was impracticable he shall nevertheless be entitled to authorise payment for such work, either as daywork, on being satisfied as to the time employed and plant and materials used on such work, or at such value therefor as shall, in his opinion, be fair and reasonable.

Claims.

(5) The Contractor shall send to the Engineer's Representative once in every month an account giving particulars, as full and detailed as possible, of all claims for any additional payment to which the Contractor may consider himself entitled and of all extra or additional work ordered by the Engineer which he has executed during the preceding month.

No final or interim claim for payment for any such work or expense will be considered which has not been included in such particulars. Provided always that the Engineer shall be entitled to authorise payment to be made for any such work or expense, notwithstanding the Contractor's failure to comply with this condition, if the Contractor has, at the earliest practicable opportunity, notified the Engineer in writing that he intends to make a claim for such work.

PLANT, TEMPORARY WORKS AND MATERIALS

Plant, etc., Exclusive Use for the Works.

53. (1) All Constructional Plant, Temporary Works and materials provided by the Contractor shall, when brought on to the Site, be deemed to be exclusively intended for the execution of the Works and the Contractor shall not remove the same or any part thereof, except for the purpose of moving it from one part of the Site to another, without the consent, in writing, of the Engineer, which shall not be unreasonably withheld.

Removal of Plant, etc.

(2) Upon completion of the Works the Contractor shall remove from the Site all the said Constructional Plant and Temporary Works remaining thereon and any unused materials provided by the Contractor.

Employer not Liable for Damage to Plant, etc.

(3) The Employer shall not at any time be liable for the loss of or damage to any of the said Constructional Plant, Temporary Works or materials save as mentioned in Clauses 20 and 65 hereof.

Re-export of Plant.

(4) In respect of any Constructional Plant which the Contractor shall have imported for the purposes of the Works, the Employer will assist the Contractor, where required, in procuring any necessary Government consent to the re-export of such Constructional Plant by the Contractor upon the removal thereof as aforesaid.

Customs Clearance.

(5) The Employer will assist the Contractor, where required, in obtaining clearance through the Customs of Constructional Plant, materials and other things required for the Works.

(6) *Any other conditions affecting Constructional Plant, Temporary Works and materials, shall be set out in Part II in the Clause numbered* 53 *as may be necessary.*

Approval of Materials, etc., not implied.

54. The operation of Clause 53 hereof shall not be deemed to imply any approval by the Engineer of the materials or other matters referred to therein nor shall it prevent the rejection of any such materials at any time by the Engineer.

MEASUREMENT

Quantities.

55. The quantities set out in the Bill of Quantities are the estimated quantities of the work, but they are not to be taken as the actual and correct quantities of the Works to be executed by the Contractor in fulfilment of his obligations under the Contract.

56. The Engineer shall, except as otherwise stated, ascertain and determine by measurement the value in terms of the Contract of work done in accordance with the Contract. He shall, when he requires any part or parts of the Works to be measured, give notice to the Contractor's authorised agent or representative, who shall forthwith attend or send a qualified agent to assist the Engineer or the Engineer's Representative in making such measurement, and shall furnish all particulars required by either of them. Should the Contractor not attend, or neglect or omit to send such agent, then the measurement made by the Engineer or approved by him shall be taken to be the correct measurement of the work. For the purpose of measuring such permanent work as is to be measured by records and drawings, the Engineer's Representative shall prepare records and drawings month by month of such work and the Contractor, as and when called upon to do so in writing, shall, within fourteen days, attend to examine and agree such records and drawings with the Engineer's Representative and shall sign the same when so agreed. If the Contractor does not so attend to examine and agree such records and drawings, they shall be taken to be correct. If, after examination of such records and drawings, the Contractor does not agree the same or does not sign the same as agreed, they shall nevertheless be taken to be correct, unless the Contractor shall, within fourteen days of such examination, lodge with the Engineer's Representative, for decision by the Engineer, notice in writing of the respects in which such records and drawings are claimed by him to be incorrect. **Works to be Measured.**

57. The Works shall be measured net, notwithstanding any general or local custom, except where otherwise specifically described or prescribed in the Contract. **Method of Measurement.**

PROVISIONAL SUMS

58. (1) "Provisional Sum" means a sum included in the Contract and so designated in the Bill of Quantities for the execution of work or the supply of goods, materials, or services, or for contingencies, which sum may be used, in whole or in part, or not at all, at the direction and discretion of the Engineer. The Contract Price shall include only such amounts in respect of the work, supply or services to which such Provisional Sums relate as the Engineer shall approve or determine in accordance with this Clause. **Definition of "Provisional Sums."**

(2) In respect of every Provisional Sum the Engineer shall have power to order:— **Use of Provisional Sums.**

(a) Work to be executed, including goods, materials or services to be supplied by the Contractor. The Contract Price shall include the value of such work executed or such goods, materials or services supplied determined in accordance with Clause 52 hereof

(b) Work to be executed or goods, materials or services to be supplied by a nominated Sub-Contractor as hereinafter defined. The sum to be paid to the Contractor therefor shall be determined and paid in accordance with Clause 59 (4) hereof.

(c) Goods and materials to be purchased by the Contractor. The sum to be paid to the Contractor therefor shall be determined and paid in accordance with Clause 59 (4) hereof.

(3) The Contractor shall, when required by the Engineer, produce all quotations, invoices, vouchers and accounts or receipts in connection with expenditure in respect of Provisional Sums. **Production of Vouchers, etc.**

NOMINATED SUB-CONTRACTORS

59. (1) All specialists, merchants, tradesmen and others executing any work or supplying any goods, materials or services for which Provisional Sums are included in the Contract, who may have been or be nominated or selected or approved by the Employer or the Engineer, and all persons to whom by virtue of the provisions of the Contract the Contractor is required to sub-let any work shall, in the execution of such work or the supply of such goods, materials or services, be deemed to be sub-contractors employed by the Contractor and are referred to in this Contract as "nominated Sub-Contractors". **Definition of "Nominated Sub-Contractors."**

(2) The Contractor shall not be required by the Employer or the Engineer or be deemed to be under any obligation to employ any nominated Sub-Contractor against whom the Contractor may raise reasonable objection, or who shall decline to enter into a sub-contract with the Contractor containing provisions:— **Nominated Sub-Contractors; Objection to Nomination.**

(a) that in respect of the work, goods, materials or services the subject of the sub-contract, the nominated Sub-Contractor will undertake towards the Contractor the like obligations and liabilities as are imposed on the Contractor towards the Employer by the terms of the Contract and will save harmless and indemnify the Contractor from and against the same and from all claims, proceedings, damages, costs, charges and expenses whatsoever arising out of or in connection therewith, or arising out of or in connection with any failure to perform such obligations or to fulfil such liabilities, and

(b) that the nominated Sub-Contractor will save harmless and indemnify the Contractor from and against any negligence by the nominated Sub-Contractor, his agents, workmen and servants and from and against any misuse by him or them of any Constructional Plant or Temporary Works provided by the Contractor for the purposes of the Contract and from all claims as aforesaid.

Design Requirements to be Expressly Stated.

(3) If in connection with any Provisional Sum the services to be provided include any matter of design or specification of any part of the Permanent Works or of any equipment or plant to be incorporated therein, such requirement shall be expressly stated in the Contract and shall be included in any nominated Sub-Contract. The nominated Sub-Contract shall specify that the nominated Sub-Contractor providing such services will save harmless and indemnify the Contractor from and against the same and from all claims, proceedings, damages, costs, charges and expenses whatsoever arising out of or in connection with any failure to perform such obligations or to fulfil such liabilities.

Payments to Nominated Sub-Contractors.

(4) For all work executed or goods, materials, or services supplied by any nominated Sub-Contractor, there shall be included in the Contract Price:—

(a) the actual price paid or due to be paid by the Contractor, on the direction of the Engineer, and in accordance with the Sub-Contract;

(b) the sum, if any, entered in the Bill of Quantities for labour supplied by the Contractor in connection therewith, or if ordered by the Engineer pursuant to Clause 58 (2) (b) hereof, as may be determined in accordance with Clause 52 hereof;

(c) in respect of all other charges and profit, a sum being a percentage rate of the actual price paid or due to be paid calculated, where provision has been made in the Bill of Quantities for a rate to be set against the relevant Provisional Sum, at the rate inserted by the Contractor against that item or, where no such provision has been made, at the rate inserted by the Contractor in the Appendix to the Tender and repeated where provision for such is made in a special item provided in the Bill of Quantities for such purpose.

Certification of Payments to Nominated Sub-Contractors.

(5) Before issuing, under Clause 60 hereof, any certificate, which includes any payment in respect of work done or goods, materials or services supplied by any nominated Sub-Contractor, the Engineer shall be entitled to demand from the Contractor reasonable proof that all payments, less retentions, included in previous certificates in respect of the work or goods, materials or services of such nominated Sub-Contractor have been paid or discharged by the Contractor, in default whereof unless the Contractor shall

(a) inform the Engineer in writing that he has reasonable cause for withholding or refusing to make such payments and

(b) produce to the Engineer reasonable proof that he has so informed such nominated Sub-Contractor in writing,

the Employer shall be entitled to pay to such nominated Sub-Contractor direct, upon the certificate of the Engineer, all payments, less retentions, provided for in the Sub-Contract, which the Contractor has failed to make to such nominated Sub-Contractor and to deduct by way of set-off the amount so paid by the Employer from any sums due or which may become due from the Employer to the Contractor.

Provided always that, where the Engineer has certified and the Employer has paid direct as aforesaid, the Engineer shall in issuing any further certificate in favour of the Contractor deduct from the amount thereof the amount so paid, direct as aforesaid, but shall not withhold or delay the issue of the certificate itself when due to be issued under the terms of the Contract.

Assignment of Nominated Sub-Contractors' Obligations.

(6) In the event of a nominated Sub-Contractor, as hereinbefore defined, having undertaken towards the Contractor in respect of the work executed, or the goods, materials or services supplied by such nominated Sub-Contractor, any continuing obligation extending for a period exceeding that of the Period of Maintenance under the Contract, the Contractor shall at any time, after the expiration of the Period of Maintenance, assign to the Employer, at the Employer's request and cost, the benefit of such obligation for the unexpired duration thereof.

CERTIFICATES AND PAYMENT

Certificates and Payment.

60. (1) Unless otherwise provided, payments shall be made at monthly intervals in accordance with the conditions set out in Part II in the Clause numbered 60.

Advances on Constructional Plant and Materials

(2) Where advances are to be made by the Employer to the Contractor in respect of Constructional Plant and materials, the conditions of payment and repayment shall be as set out in Part II in the Clause numbered 60.

Payment in Foreign Currencies.

(3) If the execution of the Works shall necessitate the importation of materials, plant or equipment from a country other than that in which the Works are being executed, or if the Works or any part thereof are to be executed by labour imported from any other such country, or if any other circumstances shall render it necessary or desirable, a proportion of the payments to be made under the Contract shall be made in the appropriate foreign currencies and in accordance with the provisions of Clause 72 hereof. The conditions under which such payments are to be made shall be as set out in Part II in the Clause numbered 60.

Approval only by Maintenance Certificate.

61. No certificate other than the Maintenance Certificate referred to in Clause 62 hereof shall be deemed to constitute approval of the Works.

Maintenance Certificate.

62. (1) The Contract shall not be considered as completed until a Maintenance Certificate shall have been signed by the Engineer and delivered to the Employer stating that the Works have been completed and maintained to his satisfaction. The Maintenance Certificate shall be given by the

Engineer within twenty-eight days after the expiration of the Period of Maintenance, or, if different periods of maintenance shall become applicable to different sections or parts of the Works, the expiration of the latest such period, or as soon thereafter as any works ordered during such period, pursuant to Clauses 49 and 50 hereof, shall have been completed to the satisfaction of the Engineer and full effect shall be given to this Clause, notwithstanding any previous entry on the Works or the taking possession, working or using thereof or any part thereof by the Employer. Provided always that the issue of the Maintenance Certificate shall not be a condition precedent to payment to the Contractor of the second portion of the retention money in accordance with the conditions set out in Part II in the Clause numbered 60.

Cessation of Employer's Liability.

(2) The Employer shall not be liable to the Contractor for any matter or thing arising out of or in connection with the Contract or the execution of the Works, unless the Contractor shall have made a claim in writing in respect thereof before the giving of the Maintenance Certificate under this Clause.

Unfulfilled Obligations.

(3) Notwithstanding the issue of the Maintenance Certificate the Contractor and, subject to sub-clause (2) of this Clause, the Employer shall remain liable for the fulfilment of any obligation incurred under the provisions of the Contract prior to the issue of the Maintenance Certificate which remains unperformed at the time such Certificate is issued and, for the purposes of determining the nature and extent of any such obligation, the Contract shall be deemed to remain in force between the parties hereto.

REMEDIES AND POWERS

Default of Contractor.

63. (1) If the Contractor shall become bankrupt, or have a receiving order made against him, or shall present his petition in bankruptcy, or shall make an arrangement with or assignment in favour of his creditors, or shall agree to carry out the Contract under a committee of inspection of his creditors or, being a corporation, shall go into liquidation (other than a voluntary liquidation for the purposes of amalgamation or reconstruction), or if the Contractor shall assign the Contract, without the consent in writing of the Employer first obtained, or shall have an execution levied on his goods, or if the Engineer shall certify in writing to the Employer that in his opinion the Contractor:—

(a) has abandoned the Contract, or

(b) without reasonable excuse has failed to commence the Works or has suspended the progress of the Works for twenty-eight days after receiving from the Engineer written notice to proceed, or

(c) has failed to remove materials from the Site or to pull down and replace work for twenty-eight days after receiving from the Engineer written notice that the said materials or work had been condemned and rejected by the Engineer under these conditions, or

(d) despite previous warnings by the Engineer, in writing, is not executing the Works in accordance with the Contract, or is persistently or flagrantly neglecting to carry out his obligations under the Contract, or

(e) has, to the detriment of good workmanship, or in defiance of the Engineer's instructions to the contrary, sub-let any part of the Contract

then the Employer may, after giving fourteen days' notice in writing to the Contractor, enter upon the Site and the Works and expel the Contractor therefrom without thereby voiding the Contract, or releasing the Contractor from any of his obligations or liabilities under the Contract, or affecting the rights and powers conferred on the Employer or the Engineer by the Contract, and may himself complete the Works or may employ any other contractor to complete the Works. The Employer or such other contractor may use for such completion so much of the Constructional Plant, Temporary Works and materials, which have been deemed to be reserved exclusively for the execution of the Works, under the provisions of the Contract, as he or they may think proper, and the Employer may, at any time, sell any of the said Constructional Plant, Temporary Works and unused materials and apply the proceeds of sale in or towards the satisfaction of any sums due or which may become due to him from the Contractor under the Contract.

Valuation at Date of Forfeiture.

(2) The Engineer shall, as soon as may be practicable after any such entry and expulsion by the Employer, fix and determine *ex parte*, or by or after reference to the parties, or after such investigation or enquiries as he may think fit to make or institute, and shall certify what amount, if any, had at the time of such entry and expulsion been reasonably earned by or would reasonably accrue to the Contractor in respect of work then actually done by him under the Contract and the value of any of the said unused or partially used materials, any Constructional Plant and any Temporary Works.

Payment after Forfeiture.

(3) If the Employer shall enter and expel the Contractor under this Clause, he shall not be liable to pay to the Contractor any money on account of the Contract until the expiration of the Period of Maintenance and thereafter until the costs of execution and maintenance, damages for delay in completion, if any, and all other expenses incurred by the Employer have been ascertained and the amount thereof certified by the Engineer. The Contractor shall then be entitled to receive only such sum or sums, if any, as the Engineer may certify would have been payable to him upon due

completion by him after deducting the said amount. If such amount shall exceed the sum which would have been payable to the Contractor on due completion by him, then the Contractor shall, upon demand, pay to the Employer the amount of such excess and it shall be deemed a debt due by the Contractor to the Employer and shall be recoverable accordingly.

Urgent Repairs.

64. If, by reason of any accident, or failure, or other event occurring to in or in connection with the Works, or any part thereof, either during the execution of the Works, or during the Period of Maintenance, any remedial or other work or repair shall, in the opinion of the Engineer or the Engineer's Representative, be urgently necessary for the safety of the Works and the Contractor is unable or unwilling at once to do such work or repair, the Employer may employ and pay other persons to carry out such work or repair as the Engineer or the Engineer's Representative may consider necessary. If the work or repair so done by the Employer is work which, in the opinion of the Engineer, the Contractor was liable to do at his own expense under the Contract, all expenses properly incurred by the Employer in so doing shall be recoverable from the Contractor by the Employer, or may be deducted by the Employer from any monies due or which may become due to the Contractor. Provided always that the Engineer or the Engineer's Representative, as the case may be, shall, as soon after the occurrence of any such emergency as may be reasonably practicable, notify the Contractor thereof in writing.

SPECIAL RISKS

65. Notwithstanding anything in the Contract contained:—

No Liability for War, etc., Risks.

(1) The Contractor shall be under no liability whatsoever whether by way of indemnity or otherwise for or in respect of destruction of or damage to the Works, save to work condemned under the provisions of Clause 39 hereof prior to the occurrence of any special risk hereinafter mentioned, or to property whether of the Employer or third parties, or for or in respect of injury or loss of life which is the consequence of any special risk as hereinafter defined. The Employer shall indemnify and save harmless the Contractor against and from the same and against and from all claims, proceedings, damages, costs, charges and expenses whatsoever arising thereout or in connection therewith.

Damage to Works, etc., by Special Risks.

(2) If the Works or any materials on or near or in transit to the Site, or any other property of the Contractor used or intended to be used for the purposes of the Works, shall sustain destruction or damage by reason of any of the said special risks the Contractor shall be entitled to payment for:—

(a) any permanent work and for any materials so destroyed or damaged,

and, so far as may be required by the Engineer, or as may be necessary for the completion of the Works, on the basis of cost plus such profit as the Engineer may certify to be reasonable;

(b) replacing or making good any such destruction or damage to the Works;

(c) replacing or making good such materials or other property of the Contractor used or intended to be used for the purposes of the Works.

Projectile, Missile, etc.

(3) Destruction, damage, injury or loss of life caused by the explosion or impact whenever and wherever occurring of any mine, bomb, shell, grenade, or other projectile, missile, munition, or explosive of war, shall be deemed to be a consequence of the said special risks.

Increased Costs arising from Special Risks.

(4) The Employer shall repay to the Contractor any increased cost of or incidental to the execution of the Works, other than such as may be attributable to the cost of reconstructing work condemned under the provisions of Clause 39 hereof, prior to the occurrence of any special risk, which is howsoever attributable to or consequent on or the result of or in any way whatsoever connected with the said special risks, subject however to the provisions in this Clause hereinafter contained in regard to outbreak of war, but the Contractor shall as soon as any such increase of cost shall come to his knowledge forthwith notify the Engineer thereof in writing.

Special Risks.

(5) The special risks are war, hostilities (whether war be declared or not), invasion, act of foreign enemies, the nuclear and pressurewaves risk described in Clause 20 (2) hereof, or insofar as it relates to the country in which the Works are being or are to be executed or maintained, rebellion, revolution, insurrection, military or usurped power, civil war, or, unless solely restricted to the employees of the Contractor or of his Sub-Contractors and arising from the conduct of the Works, riot, commotion or disorder.

Outbreak of War.

(6) If, during the currency of the Contract, there shall be an outbreak of war, whether war is declared or not, in any part of the world which, whether financially or otherwise, materially affects the execution of the Works, the Contractor shall, unless and until the Contract is terminated under the provisions of this Clause, continue to use his best endeavours to complete the execution of the Works. Provided always that the Employer shall be entitled at any time after such outbreak of war to terminate the Contract by giving written notice to the Contractor and, upon such notice being given, this Contract shall, except as to the rights of the parties under this Clause and to the operation of Clause 67 hereof, terminate, but without prejudice to the rights of either party in respect of any antecedent breach thereof.

(7) If the Contract shall be terminated under the provisions of the last preceding sub-clause, the Contractor shall, with all reasonable despatch, remove from the Site all Constructional Plant and shall give similar facilities to his Sub-Contractors to do so.

Removal of Plant on Termination.

(8) If the Contract shall be terminated as aforesaid, the Contractor shall be paid by the Employer, insofar as such amounts or items shall not have already been covered by payments on account made to the Contractor, for all work executed prior to the date of termination at the rates and prices provided in the Contract and in addition:—

Payment if Contract Terminated.

(a) The amounts payable in respect of any preliminary items, so far as the work or service comprised therein has been carried out or performed, and a proper proportion as certified by the Engineer of any such items, the work or service comprised in which has been partially carried out or performed.

(b) The cost of materials or goods reasonably ordered for the Works which shall have been delivered to the Contractor or of which the Contractor is legally liable to accept delivery, such materials or goods becoming the property of the Employer upon such payments being made by him.

(c) A sum to be certified by the Engineer, being the amount of any expenditure reasonably incurred by the Contractor in the expectation of completing the whole of the Works insofar as such expenditure shall not have been covered by the payments in this sub-clause before mentioned.

(d) Any additional sum payable under the provisions of sub-clauses (1), (2) and (4) of this Clause.

(e) The reasonable cost of removal of Constructional Plant under sub-clause (7) of this Clause and, if required by the Contractor, return thereof to the Contractor's main plant yard in his country of registration or to other destination, at no greater cost.

(f) The reasonable cost of repatriation of all the Contractor's staff and workmen employed on or in connection with the Works at the time of such termination.

Provided always that against any payments due from the Employer under this sub-clause, the Employer shall be entitled to be credited with any outstanding balances due from the Contractor for advances in respect of Constructional Plant and materials and any other sums which at the date of termination were recoverable by the Employer from the Contractor under the terms of the Contract.

FRUSTRATION

66. If a war, or other circumstances outside the control of both parties, arises after the Contract is made so that either party is prevented from fulfilling his contractual obligations, or under the law governing the Contract, the parties are released from further performance, then the sum payable by the Employer to the Contractor in respect of the work executed shall be the same as that which would have been payable under Clause 65 hereof if the Contract had been terminated under the provisions of Clause 65 hereof.

Payment in Event of Frustration.

SETTLEMENT OF DISPUTES

67. If any dispute or difference of any kind whatsoever shall arise between the Employer and the Contractor or the Engineer and the Contractor in connection with, or arising out of the Contract, or the execution of the Works, whether during the progress of the Works or after their completion and whether before or after the termination, abandonment or breach of the Contract, it shall, in the first place, be referred to and settled by the Engineer who shall, within a period of ninety days after being requested by either party to do so, give written notice of his decision to the Employer and the Contractor. Subject to arbitration, as hereinafter provided, such decision in respect of every matter so referred shall be final and binding upon the Employer and the Contractor and shall forthwith be given effect to by the Employer and by the Contractor, who shall proceed with the execution of the Works with all due diligence whether he or the Employer requires arbitration, as hereinafter provided, or not. If the Engineer has given written notice of his decision to the Employer and the Contractor and no claim to arbitration has been communicated to him by either the Employer or the Contractor within a period of ninety days from receipt of such notice, the said decision shall remain final and binding upon the Employer and the Contractor. If the Engineer shall fail to give notice of his decision, as aforesaid, within a period of ninety days after being requested as aforesaid, or if either the Employer or the Contractor be dissatisfied with any such decision, then and in any such case either the Employer or the Contractor may within ninety days after receiving notice of such decision, or within ninety days after the expiration of the first-named period of ninety days, as the case may be, require that the matter or matters in dispute be referred to arbitration as hereinafter provided. All disputes or differences in respect of which the decision, if any, of the Engineer has not become final and binding as aforesaid shall be finally settled under the Rules of Conciliation and Arbitration of the International Chamber of Commerce by one or more arbitrators appointed under such Rules. The said arbitrator/s shall have full power to open up, revise and review any decision, opinion, direction, certificate or valuation of the Engineer. Neither party shall be limited in the proceedings

Settlement of Disputes—Arbitration.

before such arbitrator/s to the evidence or arguments put before the Engineer for the purpose of obtaining his said decision. No decision given by the Engineer in accordance with the foregoing provisions shall disqualify him from being called as a witness and giving evidence before the arbitrator/s on any matter whatsoever relevant to the dispute or difference referred to the arbitrator/s as aforesaid. The reference to arbitration may proceed notwithstanding that the Works shall not then be or be alleged to be complete, provided always that the obligations of the Employer, the Engineer and the Contractor shall not be altered by reason of the arbitration being conducted during the progress of the Works.

NOTICES

Service of Notices on Contractor.

68. (1) All certificates, notices or written orders to be given by the Employer or by the Engineer to the Contractor under the terms of the Contract shall be served by sending by post to or delivering the same to the Contractor's principal place of business, or such other address as the Contractor shall nominate for this purpose.

Service of Notices on Employer or Engineer.

(2) All notices to be given to the Employer or to the Engineer under the terms of the Contract shall be served by sending by post or delivering the same to the respective addresses nominated for that purpose in Part II of these Conditions.

Change of Address.

(3) Either party may change a nominated address to another address in the country where the Works are being executed by prior written notice to the other party and the Engineer may do so by prior written notice to both parties.

DEFAULT OF EMPLOYER

Default of Employer.

69. (1) In the event of the Employer:—

(a) failing to pay to the Contractor the amount due under any certificate of the Engineer within thirty days after the same shall have become due under the terms of the Contract, subject to any deduction that the Employer is entitled to make under the Contract, or

(b) interfering with or obstructing or refusing any required approval to the issue of any such certificate, or

(c) becoming bankrupt or, being a company, going into liquidation, other than for the purpose of a scheme of reconstruction or amalgamation, or

(d) giving formal notice to the Contractor that for unforeseen reasons, due to economic dislocation, it is impossible for him to continue to meet his contractual obligations

the Contractor shall be entitled to terminate his employment under the Contract after giving fourteen days' prior written notice to the Employer, with a copy to the Engineer.

(2) Upon the expiry of the fourteen days' notice referred to in sub-clause (1) of this Clause, the Contractor shall, notwithstanding the provisions of Clause 53 (1) hereof, with all reasonable despatch, remove from the Site all Constructional Plant brought by him thereon.

(3) In the event of such termination the Employer shall be under the same obligations to the Contractor in regard to payment as if the Contract had been terminated under the provisions of Clause 65 hereof, but, in addition to the payments specified in Clause 65 (8) hereof, the Employer shall pay to the Contractor the amount of any loss or damage to the Contractor arising out of or in connection with or by consequence of such termination.

CHANGES IN COSTS AND LEGISLATION

Increase or Decrease of Costs.

70. (1) Adjustments to the Contract Price shall be made in respect of rise or fall in the costs of labour and/or materials or any other matters affecting the cost of the execution of the Works, as set out in Part II in the Clause numbered 70.

Subsequent Legislation.

(2) If, after the date thirty days prior to the latest date for submission of tenders for the Works there occur in the country in which the Works are being or are to be executed changes to any National or State Statute, Ordinance, Decree or other Law or any regulation or bye-law of any local or other duly constituted authority, or the introduction of any such State Statute, Ordinance, Decree, Law, regulation or bye-law which causes additional or reduced cost to the Contractor, other than under sub-clause (1) of this Clause, in the execution of the Works, such additional or reduced cost shall be certified by the Engineer and shall be paid by or credited to the Employer and the Contract Price adjusted accordingly.

CURRENCY AND RATES OF EXCHANGE

Currency Restrictions.

71. If, after the date thirty days prior to the latest date for submission of tenders for the Works the Government or authorised agency of the Government of the country in which the Works are being or are to be executed imposes currency restrictions and/or transfer of currency restrictions in relation to the currency or currencies in which the Contract Price is to be paid, the Employer shall reimburse any loss or damage to the Contractor arising therefrom, without prejudice to the right of the Contractor to exercise any other rights or remedies to which he is entitled in such event.

72. (1) Where the Contract provides for payment in whole or in part to be made to the Contractor in foreign currency or currencies, such payment shall not be subject to variations in the rate or rates of exchange between such specified foreign currency or currencies and the currency of the country in which the Works are to be executed. **Rates of Exchange.**

(2) Where the Employer shall have required the Tender to be expressed in a single currency but with payment to be made in more than one currency and the Contractor has stated the proportions or amounts of other currency or currencies in which he requires payment to be made, the rate or rates of exchange applicable for calculating the payment of such proportions or amounts shall be those prevailing, as determined by the Central Bank of the country in which the Works are to be executed, on the date thirty days prior to the latest date for the submission of tenders for the Works, as shall have been notified to the Contractor by the Employer prior to the submission of tenders or as provided for in the tender documents.

(3) Where the Contract provides for payment in more than one currency, the proportions or amounts to be paid in foreign currencies in respect of Provisional Sum items shall be determined in accordance with the principles set forth in sub-clauses (1) and (2) of this Clause as and when these sums are utilised in whole or in part in accordance with the provisions of Clauses 58 and 59 hereof.

NOTE

FOR CONDITIONS OF PARTICULAR APPLICATION—SEE PART II

FOR CONDITIONS OF PARTICULAR APPLICATION TO DREDGING AND RECLAMATION WORK —SEE PART III

Conditions of Contract

PART II—CONDITIONS OF PARTICULAR APPLICATION

The following notes are intended as an aide-memoire in the preparation of clauses (some of which are dealt with but not exhaustively in Part I) which will vary as necessary to take account of the circumstances and locality of the Works. These variable clauses which must be specially prepared to suit each particular contract should cover such of the under-mentioned matters and any others as are applicable.

Clause 1—Definitions

Employer: The Employer is ....

Engineer: The Engineer is ....

Further definitions as necessary.

Clause 2—Powers and Duties of Engineer.

Define Clauses under which specific approval of the Employer is required.

Clause 5—Language/s and Law

The language is/are ....

The Ruling Language is..

The Law to which the Contract is to be subject is ....

Clause 8—Contractor's General Responsibilities

Employment of local personnel and purchase of local supplies.

Clause 10—Performance Bond

Form and percentage of Performance Bond (if required). Time limit for submission.

Clause 14—Programme

Time limit for submission of programme.

Clause 15—Contractor's Superintendence

Languages to be spoken by Contractor's Agent; registration of expatriate personnel.

Clause 16 —Contractor's Employees

Languages to be spoken by other members of Contractor's staff; employment of locally recruited staff; currency of payments to Contractor's Site staff.

Clause 21—Insurance of Works

Availability of insurance cover note before work commences. Use of local insurance companies; notification by Contractor of changes in the nature or extent of the Works. Additional insurance of Works as required in special circumstances.

Clause 24—Accident or Injury to Workmen

Payments (if any) to be made as dues to a State organisation in respect of Employer's liability, in relation to Contractor's responsibilities under Clause 24 (2).

Clause 34—Labour

Permits and registration of expatriate employees; repatriation to place of recruitment; provision of temporary housing for employees; requirements in respect of accommodation for staff of Employer and Engineer; standards of accommodation to be provided; provision of access roads, hospital, school, power, water, drainage, fire services, refuse collection, communal buildings, shops, telephones; hours and conditions of working; rates of pay; compliance with labour legislation; maintenance of records of safety and health.

Note: Full details to be included in the Specification.

Clause 36—Quality of Materials

Utilisation of local materials.

Clause 43—Time for Completion

Reference to completion by stages, if required.

Clause 45—Night or Sunday

Reference to any special requirements to working by night or on locally recognised holidays.

Clause 47—Bonus and Liquidated Damages

Bonus (if any) for achievement of target date; if none, insert "Nil" in Appendix to the Tender; details of both liquidated damages and bonus (if any) to be included in the Specification including relation to interim dates; in the case of liquidated damages, calculation of amount, method of deducting, upper limit, currency, reduction as work is substantially completed; in the case of bonus, currency of payments.

Clause 49—Maintenance and Defects

In appropriate cases, where the permanent reinstatement is not being carried out by the Contractor, an additional sub-clause should be added to Clause 49 to cover making good all subsidence, etc. in the temporary reinstatement of any highway broken into for the purposes of the execution of the Works and the liability for damage and injury resulting therefrom up to the end of the Period of Maintenance or until possession of the Site has been taken for the purpose of carrying out permanent reinstatement (whichever is the earlier).

Clause 53—Plant

Hire of plant, sale or disposal of plant, payment of or relief from Customs or other import duties, harbour and port dues, wharfage, landing, pilotage and any other charges or dues, any other conditions affecting plant. Define, if used, "Hired Plant", "Essential Hired Plant", "Hire Purchase", "Agreement to Hire", "Ownership". Exclude from the provisions of Clause 53, any vehicles engaged in the transport of labour, plant, equipment or materials to and from the Site.

Clause 59—Nominated Sub-Contractors

Provisions for design by Nominated Sub-Contractor (if any).

Clause 60—Certificates and Payments

Advances on plant and materials where made, conditions covering such advances and their repayment; monthly claims for work executed and certificates of Engineer as to amount due to Contractor for permanent work executed in the month and for temporary works included in the Bill of Quantities and also, if there are no advances for materials and plant amounts, as certified by the Engineer for any materials for permanent work on the Site.

Arrangements for deduction and subsequent release of Retention Money, Percentage and limit of Retention as in Appendix to the Tender.

Correction and withholding of certificates; place of payment; frequency of payment (if not monthly). Minimum amount of Interim Certificates and time within which payments to be made after the issue of the Certificate, as in Appendix to the Tender.

Currency or currencies, proportions of various currencies, rates of exchange and conditions applicable thereto, in and under which payments and/or deductions are to be made, to be included in Clause 60 or, if not to be predetermined, to be as inserted by the Contractor in the Tender, for approval by the Employer and inclusion in the Contract as an Appendix to the Bill of Quantities.

As it is desirable to have all financial matters settled as soon as practicable after completion of a contract, it is suggested that the following or equivalent paragraph be included in Clause 60:—

> "Not later than . . . months after the issue of the Maintenance Certificate the Contractor shall submit to the Engineer a statement of final account with supporting documents showing in detail the value of the work done in accordance with the Contract together with all further sums which the Contractor considers to be due to him under the Contract. Within . . . months after receipt of this final account and of all information reasonably required for its verification the Engineer shall issue a final certificate stating
>
> (a) the amount which in his opinion is finally due under the Contract and (after giving credit to the Employer for all amounts previously paid by the Employer and for all sums to which the Employer is entitled under the Contract),
>
> (b) the balance, if any, due from the Employer to the Contractor or from the Contractor to the Employer as the case may be. Such balance shall, subject to Clause 47 hereof, be paid to or by the Contractor as the case may require within twenty-eight days of the Certificate."

Clause 68—Notices

Employer's address ....

Engineer's address ....

Clause 70—Changes in Costs and Legislation

This Clause should cover such matters as:—

Adjustment of Contract Price, in both local and foreign currency expenditure, by reason of alteration in rates of wages and allowances payable to labour and local staff, changes in cost of materials for permanent or temporary works, or in consumable stores, fuel and power, variation in freight and insurance rates, Customs or other import duties, the operation of any law, statute, etc.; price adjustment formulae to be used, if any.

Clause 73—Taxation

Taxation—payment of or exemption from local income or other taxes both as regards the Contractor and his staff.

Clause 74 etc.—Miscellaneous (To be inserted if required)

Regulations governing importation and use of explosives for blasting; bribery and corruption; photographs of the Works and advertising; undertakings regarding non-disclosure of secret information; submissions of shipping and other documents, etc.

Conditions of Contract

PART III—CONDITIONS OF PARTICULAR APPLICATION TO DREDGING AND RECLAMATION WORK

Introduction

In Dredging and Reclamation Work the Contractor is not normally held responsible for the maintenance of the Works after takeover; the Works are usually taken over in sections as they are completed; the Contractor can only work economically if he is allowed to work continuously by day and by night; the incidence of Plant Costs (mobilisation, supply and demobilisation) forms a much higher proportion of total cost in the case of a dredging contract than is generally the case with construction contracts; as plant supplied by the Contractor almost invariably includes ships and at times includes ships taken on charter by the Contractor he cannot give to the Employer the unrestricted right to sell such plant. The Employer may find cover against the risks of non-completion by an increase of the amount of the performance bond.

Quantities included in the tender documents must necessarily be estimates the accuracy of which is inherently less than normally experienced on construction contracts.

Part III—Conditions of Particular Application to Dredging and Reclamation Work

The Conditions of Contract (International) for Works of Civil Engineering Construction shall be amended by the addition, as Part III, of the following provisions.

Part I and Part II of the Conditions

(a) References to "Constructional Plant" shall be understood to relate to all dredging and reclamation plant and appliances and all ancillary plant required for use in the execution of the Works.

(b) References to "Essential Hired Plant" shall be understood to relate to "Constructional Plant" (as defined in Parts I and III of the Conditions of Contract (International) for Works of Civil Engineering Construction) the withdrawal of which in the event of a forfeiture under Clause 63 might (having regard to the methods of construction, dredging or reclamation employed prior to the forfeiture) endanger the safety or stability of or result in serious disturbance to the execution of any part of the Works and which is held by the Contractor under any agreement for hire thereof.

(c) References to "Maintenance" and "Period of Maintenance" shall have effect only if it is agreed between the parties that the Contractor shall specifically be responsible for Maintenance of the Works or any part thereof.

Clause 5 (2)

For "Parts I and II" there shall be substituted "Parts I, II and III".

Clause 10

For "stated in the Letter of Acceptance" there shall be substituted "indicated in the Tender documents".

Clause 11

The Employer shall have made available to the Contractor with the Tender documents such data on soil specifications and hydraulic conditions as shall have been obtained by or on behalf of the Employer from investigations undertaken relevant to the Works and furthermore depending on the nature and situation of the Works such additional data necessary in connection with the execution of the Works like navigation conditions, environmental conditions, dumping places and such particular data and the Tender shall be deemed to have been based on such data, but the Contractor shall be responsible for his own interpretation thereof. The Contractor shall also be deemed to have inspected and examined the Site and its surroundings and information available in connection therewith and to have satisfied himself, so far as is practicable, before submitting his Tender, as to the form and nature thereof, but he shall not normally be called upon to satisfy himself as to the quantities of materials to be dredged more accurately than he can deduce from the Tender documents and inspection of the Site only.

Clause 12

The words ("other than climatic conditions on the Site") shall be deleted.

Clause 18

Exploratory excavation shall be deemed to include dredging.

Clause 20 (1)

Where arrangements are made for sections of the Works to be taken over as they are completed the Contractor's responsibility for any such section shall cease forthwith upon its acceptance.

Clause 20 (2)

In view of the relatively small but highly specialised labour force employed, the "excepted risks" shall include epidemic disease.

Clause 21

The Contractor's obligation to insure under this Clause shall be limited, unless otherwise specially agreed, to the insurance against normal marine risks of all Plant (including ships) supplied by the Contractor for use on the Works whether owned or taken on charter by the Contractor. Such insurance shall be effected with an insurer and in terms approved by the Employer (which approval shall not be unreasonably withheld).

Clause 40 (1)

(a) In the event of suspension of work by either the Engineer or the Employer, the extra cost to be borne by the Employer shall in case of Plant chartered by the Contractor include the bare boat charter hire of such Plant in lieu of its depreciation.
(b) The stipulation under (c) shall be deleted).

Clause 45

The Contractor shall have the option to work continuously by day and by night and on locally recognised holidays subject only to any specific restrictions stipulated in the Contract.

Clause 51

The alterations, additions and omissions (provided for in Clause 51) shall be imposed upon the Contractor only insofar as they can be executed by means of the Plant used or intended to be used in the execution of the Works as orignally specified by the Contractor in his tender documents.

Where no order has been given by the Engineer under Clause 51 (1) for the variation of any item of the Bill of Quantities and it is found on completion of the Works that the actual quantity of such item differs from the estimated quantity stated in the Bill, a variation shall be deemed to have been made by the Engineer for which no written order is required and to which the scheduled rate for that item shall apply.

For "within seven days" under Clause 51 (2) there shall be substituted "within fourteen days".

Clause 61

For "Maintenance Certificate" there shall be substituted "Final Completion Certificate".

Clause 62

For "Maintenance Certificate" there shall be substituted "Final Completion Certificate".

The Final Completion Certificate shall be issued within 14 days of completion of the Works.

Clause 63 (1)

The last sentence of this Clause commencing "and the Employer may at any time sell" shall be deleted.

Clause 63 (4)

In the case of Essential Hired Plant the Employer shall not be entitled to sell such Plant as is specified in sub-clause 63 (5).

Clause 63 (5)

With a view to securing in the event of a forfeiture under Clause 63 hereof the continued availability for the purpose of executing the Works of any Essential Hired Plant the Contractor shall not bring on to the Site any Essential Hired Plant unless the agreement for hire thereof contains a provision that the owner thereof will on request in writing made by the Employer within 7 days after the date on which any such forfeiture has become effective and on the Employer undertaking to pay all hire charges in respect thereof from such date hire such Essential Plant to the Employer on the same terms in all respects as the same was hired to the Contractor save that the Employer shall be entitled to permit the use thereof by any other contractor employed by him for the purpose of completing the Works under the terms of the said Clause 63.

Clause 63 (6)

The Contractor shall upon written request made by the Engineer (which request shall not be questioned by any arbitrator) at any time in relation to any item of Essential Hired Plant submit to the Engineer a certificate, officially certified by an Authority (e.g. notary public) to the satisfaction of the Engineer stating that the agreement for the hire thereof contains a provision in accordance with the requirements of sub-clause 63 (5).

Clause 63 (7)

In the event of the Employer entering into any agreement for hire of Essential Hired Plant pursuant to the provisions of sub-clause 63 (5) of this Clause all sums properly paid by the Employer under the provisions of any such agreement and all expenses incurred by him (including stamp duties) in entering into such agreement shall be deemed for the purpose of Clause 63 hereof to be part of the cost of completing the Works.

**SHORT DESCRIPTION
OF WORKS**

Form of Tender

(NOTES:—The Appendix forms part of the Tender.
Tenderers are required to fill up all the blank spaces in this Tender Form and Appendix.)

To: ....

GENTLEMEN,

Having examined the Drawings, Conditions of Contract, Specification and Bill of Quantities for the execution of the above-named Works, we, the undersigned, offer to execute complete and maintain the whole of the said Works in conformity with the said Drawings, Conditions of Contract, Specification and Bill of Quantities for the sum of

(£)

or such other sums as may be ascertained in accordance with the said Conditions.

2. We undertake if our Tender is accepted to commence the Works within days of receipt of the Engineer's order to commence, and to complete and deliver the whole of the Works comprised in the Contract within days calculated from the last day of the aforesaid period in which the Works are to be commenced.

3. If our tender is accepted we will, if required, obtain the guarantee of an Insurance Company or Bank or other sureties (to be approved by you) to be jointly and severally bound with us in a sum not exceeding per cent. of the above-named sum for the due performance of the Contract under the terms of a Bond to be approved by you.

4. We agree to abide by this Tender for the period of days from the date fixed for receiving the same and it shall remain binding upon us and may be accepted at any time before the expiration of that period.

5. Unless and until a formal Agreement is prepared and executed this Tender, together with your written acceptance thereof, shall constitute a binding Contract between us.

6. We understand that you are not bound to accept the lowest or any tender you may receive.

Appendix

	CLAUSE	
Amount of Bond or Guarantee (if any)	10 ( )	.... %
Minimum Amount of Third Party Insurance	23 (2)	....
Period for commencement, from Engineer's order to commence	41	.... days
Time for completion	43	.... days
Amount of Liquidated Damages	47 (1)	.... per day
Limit of Liquidated Damages	47 ( )	....
Amount of Bonus (if any)	47 (3)	....
Period of Maintenance	49	.... days
Percentage for Adjustment of Provisional Sums ...	59 (4) (c)	..........per cent.
Percentage of Retention	60 ( )	..........per cent.
Limit of Retention Money	60 ( )	....
Minimum Amount of Interim Certificates	60 ( )	....
Time within which payment to be made after Certificate	60 ( )	..........days

---

Dated this ....day of .... 19.....,

Signature .... in the capacity of ....

duly authorised to sign tenders for and on behalf of ....

....

(IN BLOCK CAPITALS)

Witness .... Address ....

Address ....

....

Occupation ....

Form of Agreement

THIS AGREEMENT made the .... day of

19 .... BETWEEN ....

of ....

.... (hereinafter called "the Employer") of the one part and

.... of ....

.... (hereinafter called "the Contractor") of the other part

WHEREAS the Employer is desirous that certain Works should be executed, viz

.... and has accepted a

Tender by the Contractor for the execution completion and maintenance of such Works NOW THIS AGREEMENT WITNESSETH as follows:—

1. In this Agreement words and expressions shall have the same meanings as are respectively assigned to them in the Conditions of Contract hereinafter referred to.

2. The following documents shall be deemed to form and be read and construed as part of this Agreement, viz.:—

(a) The said Tender.
(b) The Drawings.
(c) The Conditions of Contract (Parts I, II and III*).
(d) The Specification.
(e) The Bill of Quantities.
(f) The Schedule of Rates and Prices (if any).
(g) The Letter of Acceptance.

3. In consideration of the payments to be made by the Employer to the Contractor as hereinafter mentioned the Contractor hereby covenants with the Employer to execute complete and maintain the Works in conformity in all respects with the provisions of the Contract.

4. The Employer hereby covenants to pay the Contractor in consideration of the execution completion and maintenance of the Works the Contract Price at the times and in the manner prescribed by the Contract.

IN WITNESS whereof the parties hereto have caused their respective Common Seals to be hereunto affixed (or have hereunto set their respective hands and seals) the day and year first above written

The Common Seal of ....

.... Limited

was hereunto affixed in the presence of:—

or

SIGNED SEALED AND DELIVERED by the

said ....

....

in the presence of:—

* Delete where inapplicable.

These Conditions have been approved on behalf of the following

Members of FÉDÉRATION INTERNATIONALE
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Associazione Nazionale Costruttori Edili
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Cámara Paraguaya de la Construcción
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5. PROJECT EXECUTION AND SITE MANAGEMENT

The subject of project execution and site management was covered by the lecture entitled "What is required for successful dredging equipment and manpower", presented by Mr. Joep J. Athmer, Aveco. Visits to the dredging works of the Port of Rotterdam, Port of Delfzijl and the Dredging Division of the Public Works Department of Ministry of Transport and Public Works were organized during the Seminar-cum-Study Tour. Extracts of the information circulated and presentations made during the visits are also included in this section.

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5.1 WHAT IS REQUIRED FOR SUCCESSFUL DREDGING - EQUIPMENT AND MANPOWER

By Mr. Joep J. Athmer, Aveco

This question is very difficult to answer, and here an attempt is made to explain some aspects involved before and during the execution of a dredging project.

The nice thing about dredging is the uncertainty about the outcome: it may either be highly successful or a total failure! Dredging is not only a way of thinking, but also a way of living adopted by many generations of people working in the Dutch dredging industry. Experience and research in improvement of dredging methods have brought the dredging industry to its present level, and risks have been reduced.

A large part of the Netherlands has been created by reclamation and dredging during several centuries. In the early days very primitive methods were used for the dredging, but the industrial revolution brought along steam-powered bucket dredgers which made any kind of work possible. New dredgers were built, and the dredged material could now also be transported by means of pumps. In this period companies grew and spread their knowledge worldwide, but it was a small village in Netherlands, Sliedrecht that became the capital of the dredging industry. At that time dredging skills was usually transferred from the father to the sons, and the dredging industry in the Netherlands became soon an occupation with strong family traditions. It was not before the 1950s that the dredging developed into a modern industry and in the 1960s dredging companies started to make scientific research in dredging equipment and operations. Since then dredging equipment and instrumentation has become tremendously more sophisticated, and the cutter suction dredger has made it possible to dredge soils which earlier were not considered dredgeable.

Then, what is dredging? Basically, it is transport of a quantity of soil from one location to another, so dredging is improved by improving the means of transportation. The scientific research done has covered subjects like the production process, friction losses, density flows, efficiency and cutter research. Large-scale dredging works in the Middle East involving dredging of very hard soils have helped in carrying the dredging industry to its present advanced level.

However, even with the most sophisticated dredging equipment, a dredging project cannot be carried out successfully without a proper team of people who have the skill, experience and flexibility to do the job:

DREDGING REQUIRES TEAMWORK

This teamwork involves many different people, and it cannot be carried out, unless the dredging operation is controlled by an efficiently working organization, which may be a government department, a government enterprise, a port authority or a private contracting company.

DREDGING REQUIRES EFFICIENT ORGANIZATION

A private contracting (dredging) company can be taken as an example. It will generally have a number of departments under supervision of a director or a board of directors. These departments are:

- Administration and finance department;
- Personnel department responsible for the employees;
- Marketing department;
- Contracts department;
- Technical department responsible for the dredging fleet;
- Project execution department;
- Research department engaged in improvement of dredging efficiency and dredging methods;
- Survey department;

After tender documents have been obtained and additional soil investigations carried out, a tender will be submitted. After a while the employer will choose the contractor to do the job, and the selected contracting company will then have to start the preparation of the project. The preparation of the project is started by the appointment of a project manager, usually from the project execution department. He will be responsible for planning of the project and mobilization of equipment and personnel for execution of the project. At the same time the site foreman is working at the site, encountering new surprising local conditions, establishing site office, site workshop, housing and survey points. Engineers at the head office are making the planning, and the site staff is briefed on the dredging job. THE DREDGING TEAM IS AT WORK!

After days or weeks of sailing the dredgers arrive at the site. At that time all site facilities should be ready and all preparatory work done, so that the dredging execution can start shortly after without delay causing, costly idle time of the dredgers. When the dredging is initiated, the site organization starts to deal with day-to-day activities like movements of dredgers, crew changes and surveying.

The people working on the dredging site are the following:

- The Project Manager who is responsible for the progress of the project and all communications with the client and the head office.

- The Dredging Superintendent who supervises the operation of the dredgers.

- The Technical Inspector who is responsible for repairs, workshop facilities and purchase of spare parts.

- The Accountant.

- The Surveyor.

- Dredger crew members and other staff including local staff.

These are the people working on the site. However, some people in the head office are also very engaged in the progress of the dredging at a site which may be located thousand of miles away. In the head office the job progress is followed constantly, financial statements are discussed, direct support to the site staff is taken care of, and advice is given on special problems. Such advice may also include visits to the site by dredging experts. People might wonder if it is possible to give all this support from behind the desk. However, it is the policy of some contracting companies that people should not become "desk people", before they have experienced the work on site themselves. This will ensure that all the "desk people" can recognize situations from experience leading to a much more efficient support to the site staff. During the project execution dredging experts from the head office visit sites all over the world on a regular basis in order to direct the production process and to look into any delay affecting the dredger production.

THE STAFF ON SITE AND IN HEAD OFFICE MAKES ONE COMPLETE TEAM WHICH IS NECESSARY TO CARRY OUT THE DREDGING PROJECT SUCCESSFULLY

As already mentioned the dredging industry has developed a lot during the last decades and reached its present advanced level. Dredgers have in general become much larger, production capacities advanced. The present-day dredgers are very expensive to purchase and thus also costly to operate. Emphasis has to be put on the total efficiency during the project execution. The dredgers have to be operated efficiently from the very first day on site. A few days of idle time may be the matter which determines if the contract is a success or a failure. The right people should be chosen for operation of the right equipment. It is important first to consider the requirements set in the contract, then to choose the most appropriate equipment. Always use the right dredger for the right job.

THE COMBINATION OF PERSONNEL AND EQUIPMENT DETERMINES SUCCESS

It is not possible to carry out a dredging project with one man, and often it is neither possible to carry out a dredging project efficiently with only one type of dredger. Governmental departments with limited manpower and/or equipment resources may have to make use of external resources for execution of their dredging projects. A number of options may be viable in this case.

(a) One possibility is to hire equipment and operate it with own staff which in many cases may be advisable, but only if the department has a well-trained team of dredging experts.

(b) To obtain expert assistance for operation or maintenance of the department's dredging fleet.

(c) To make an equipment and experience pool in co-operation with other governmental departments or port authorities, possibly including departments in foreign countries. This may greatly improve the capabilities of participating pool members.

(d) To purchase a new dredger and at the same time obtain expert assistance for operation and maintenance of it and for training of own staff. When making the decision to purchase a new dredger, it should be fully ensured that it will be possible to keep the dredger working full-time with soils suitable for the dredger. Otherwise the dredger may have to be idle now and then or to be used for jobs unsuitable for it! Even if the number of suitable jobs is sufficient, the dredger may still work at a low efficiency because of lack of spare parts, lack of competition, untrained key and middle management personnel or insufficient reporting.

It can finally be advised that anyone responsible for planning of any dredging operation considers one thing first: WHAT IS REQUIRED FOR SUCCESSFUL DREDGING?

5.2 VISIT TO ROTTERDAM PORT (EUROPOORT)

The Municipal Port Authority Rotterdam was visited during the Seminar-cum-Study Tour. Presentation on "History of Rotterdam Port" and "Capital dredging works in Port of Rotterdam" were made by Mr. J. Diefenbach and Mr. van der Weyde of the Municipal Port Authority respectively. The following is a summary of their presentations and also incorporates information from the "Rotterdam Harbour Silt", issued by the Public Works Department Rotterdam in September 1983.

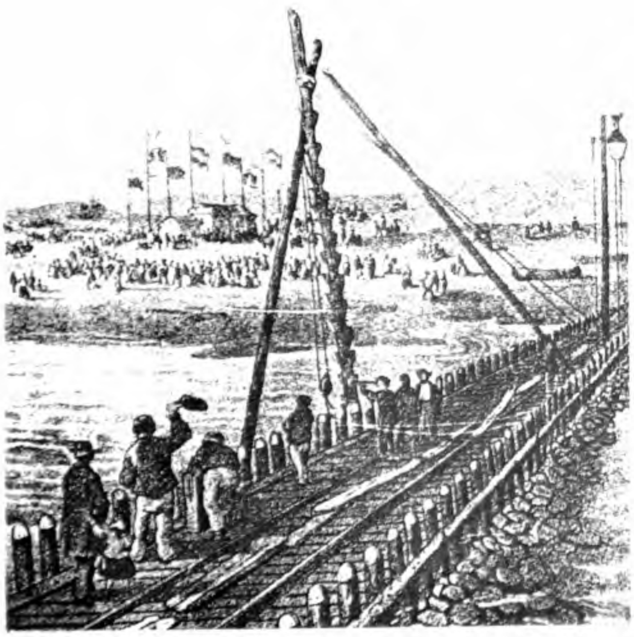
Rotterdam Port is located at the combined mouth of the rivers Rhine and Maas. The town of Rotterdam was established in 1562, but it is not before this century and in particular after the Second World War that the Rotterdam Port has developed dramatically. Today it is the world's largest port serving a large part of the European mainland. In 1983 the total amount of loaded and unloaded goods was 229.6 million metric tonnes.

The whole port from Rotterdam to the Maasvlakte, is governed by the Municipal Port Authority Rotterdam, Rotterdam Municipality. The infrastructure, i.e. roads, quaywalls, waterways etc., is a public belonging. However, all harbour facilities, equipment, warehouses etc. are private property. For the port authority the main sources of income are harbour fees and leasing of land.

The total water area amounts to 2,148 ha (or 21.5 km^2). The port has consecutively been made deeper and deeper in the post war years. The water depth is increasing towards the sea, and today the max. allowable draft is 22 m (72 ft). It is planned to increase this to 23 m (75 ft).

The present yearly dredging requirement is about 20,000,000 cu.m. The harbour basins are maintained by the Municipal Port Authority Rotterdam (about 7,000,000 cu.m./year). The riverine part, the harbour entrance and the navigation channel are maintained by the Public Works Department (Rijkswaterstaat) of the Ministry of Transport and Public Works (about 13,000,000 cu.m./year). The Municipal Port Authority Rotterdam as well as Rijkswaterstaat hire private contractors to carry out the necessary dredging.

The Port of Rotterdam owes its very existence to dredging. From a geographical point of view, Rotterdam occupies a unique position on the North Sea estuary of the Rhine and Meuse. The drawback to this, however, is that the estuary has a strong tendency of silting up. If it had been left to nature, Rotterdam would have remained an insignificant little harbour, on account of this silt problem, and would certainly never have become the world's number one port. After centuries of being at the mercy of the whims of nature, the Dutch joined battle with the silt and sand in the last century. They gave the Rhine a new estuary: the New Waterway, and maintained this canal, the river and the harbour basins at the requisite depth by constant dredging.



The New WaterWay gave Rotterdam an open link with the North Sea

Section of the Rotterdam harbour area

The land on which Rotterdam is built exists thanks to the natural process of silting, also known as depositing or sedimentation. The western region of the Netherlands was formed by silting from two sides: from the sea (maritime deposits) and via the great rivers from the hinterland (fluvial deposits). While the rivers supplied a constant stream of silt, the influençe of the sea was considerably more uncertain. The formation of the coastline and the islands of South-Holland and Zeeland took place, therefore, in a somewhat more capricious fashion.

Together with the forces of nature, man also played his part in the formation of land by applying various methods of water management. An ingenious system of weirs, locks, dams, canals, dykes and cutoffs in rivers ensures that river-water is uniformly carried off. A number of these operations was also put into effect to prevent flooding from the sea. Apart from ensuring proper water management, this also tended to stabilize and localize the process of land formation by silting.

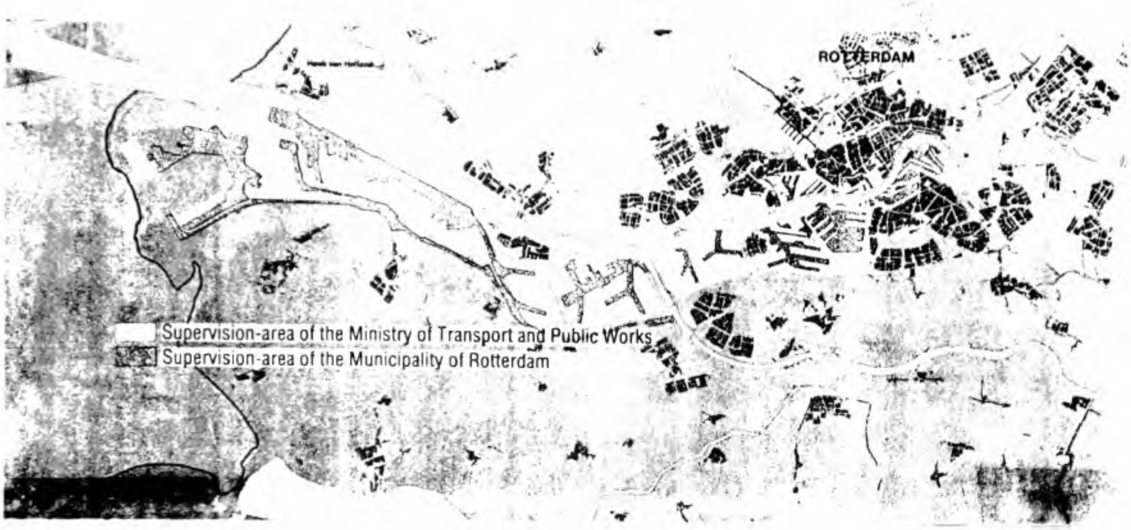
Prevention of silting is impossible. Since the speed of river-currents decreases on opening into the sea, the material carried along is transported no further. It sinks in the mouth of the river. The land therefore extends in a seaward direction. The delta formation took place in this way in the west of the Netherlands over a long period of time. Changes in climate and a rise in the sea-level caused the propulsive force of the sea to increase. It became stronger near Rotterdam due to the fact that between 1863 and 1872 a wide, deep channel was excavated, linking Rotterdam directly with the sea: the New Waterway. This replaced the Voorne Canal, excavated earlier, but which no longer fulfilled the requirements of the rapidly changing shipping.

On account of these radical changes, the depositing of the material carried along by the river tended to occur particularly along the final stretch of the river itself. In addition, the seawater at high tide can flow into the New Waterway. Following the turn of the tide, a layer of silt is left along a considerable length of the river bed.

Silting from the sea and from the rivers does not only occur in the rivers and estuaries. Rotterdam has a large number of harbour basins situated on the river.

As from 1950, the existing harbours could no longer provide the necessary accommodation on account of the enormous expansion of industrial sites and the rapid modernization of shipping. Harbour complexes were constructed with ships of greater draught in mind: Botlek, Europoort and Maasvlakte. At the same time the entrance channel from the sea was deepened.

A broader, deeper river bed tends to decrease the speed of the river current while the flow of sea water increased. The large number of harbour basins also plays a part in slowing down the movement of the water. River bed material, collected by the rivers during their long journey, tends to sink most especially in the harbour area.



Harbour area of Rotterdam

9 million tons dry material

The rivers Nieuwe Maas and Oude Maas, which are branches of the Rhine and the Meuse, respectively carry 800 m^3 and 700 m^3 water per second through Rotterdam. Two million tons of suspended silt is transported annually by that water.

A quantity of sand and silt is carried from the sea by the movement of the incoming tide in the form of material suspended in the water. Due to the powerful current along the bed of the river caused by the penetration of a stream of salt water, a considerable amount of bed-load is also transported. Each year this amounts to seven million tons.

Silt which is carried along by the river principally attacks the eastern harbour area and the bed of that section of the river. The sea-silt mainly sinks in the western harbours and that section of the New Waterway. The action of the tide, however, causes a mixture of both types of silt to be spread over the entire harbour area. A transition area exists for both types of silt.

Over a period of time, the quantity of silt which is transported is influenced by the following factors.

- Melted snow water from the mountains.
  Higher atmospheric temperature causes more water and also therefore more suspended material to be transported by the rivers.

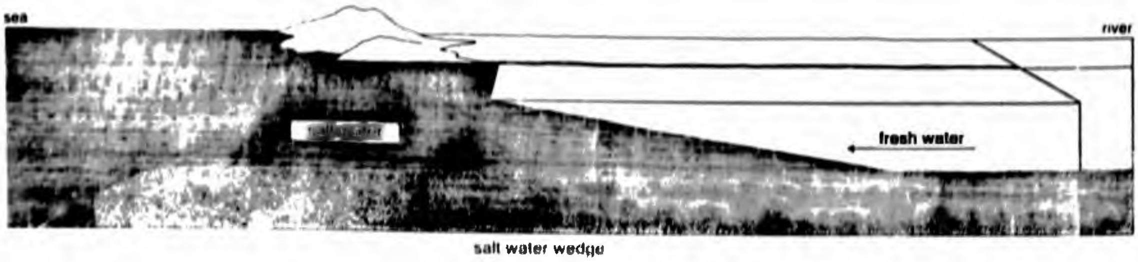
- Rainfall inland.
  Heavy rainfall in Switzerland, France, Germany and Belgium causes more water and therefore more silt to be carried by the Rhine and the Meuse.

- Storms from a westerly direction.
  A storm coming in from the sea causes the level of the water to be whipped up and therefore more water and silt to be carried from the sea.

- Distribution of water from Rhine and Meuse.
  The water discharge systems are subject to change due to the variable action of weirs and discharging sluices. And so the amount of water and silt carried by the rivers also changes.

- Work carried out on the river.
  Work carried out on the river can cause the presence of more or less suspended material in the water.

- Work carried out at sea.
  Apart from the execution of work, the dumping of dredged material can also lead to a rise in suspended silt. This suspended silt can return again to the harbours and the river. Discharge via the Haringvliet sluices will have an influence on the suspended material content of the sea-water.



The two million tons which are transported by the rivers and the seven million tons from the sea together produce nine million tons of dry material which is deposited in the harbours and river areas.

The quantity of dry material means an amount of dredged material of 20 million cubic metres.

We are hereby taking it for granted that this vast quantity of 20 million m^3 of silt is in fact dredged up each year. There is no other alternative. Allowing the harbours and rivers to silt up would mean the end of Rotterdam as a sea-port city and cause problems with regards to the discharge of water from the major rivers.

Composition

The term silt or sediment is used to describe all material which sinks to the bottom. It can be defined on the basis of grain-size. The usual classification of sediment is: coarse sand, fine sand and silt. This classification is based on the results of research. It has been demonstrated that the properties and the behaviour of the particles are closely related to the size of the particles.

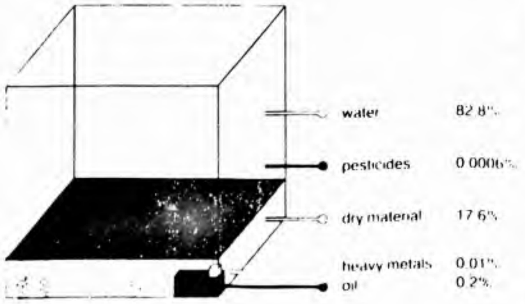
Through micro-photography and analysis of silt samples, it has been possible to establish accurately the origin of different particles. In theory they were traced back to the bed-structure of the course of the river right up to the rocky mountains where the Rhine begins its long journey.

Analyses indicate that the sediment principally consists of clay minerals, quartz, organic matter and carbonates.

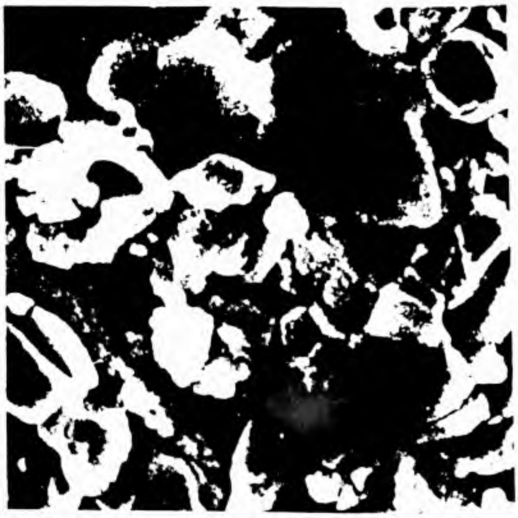
In addition to a study of the composition, research has also been carried out into the behaviour and properties of the sediment.

This has shown that powers of attraction and/or rejection can be present in the silt particles. These powers can lead to all kinds of reactions in the silt material. Certain structures are formed in the silt and these determine the behaviour during the rest of the sedimentation process.

Water movement and composition are therefore important factors in this respect. Through study and research, it is hoped to acquire more insight into the sedimentation process. With this insight, it may be possible to influence the sedimentation process in a way that would have a favourable effect on maintenance of the harbours. In addition, a thorough knowledge of the composition, the behaviour and the properties of the silt is important with regard to the choice of dredging techniques used and the method of disposal to be followed.



Composition of one m³ silt



Microphoto of silt particles

5.3 VISIT TO PORT OF DELFZIJL AUTHORITY

Delfzijl Port is located in the north-eastern part of the Netherlands. It is a port for import and export of industrial products. The Port of Delfzijl Authority was visited during the seminar-cum-study tour. A lecture on the dredging situation of the Port of Delfzijl was presented by Mr. G.P. Nijburg. The lecture paper is reproduced in the following with slight modification.

The Port of Delfzijl Authority is an organization founded by the government, county and municipal authorities for the furtherance of industrialization in the Eemsmond area and exploitation of two seaport industrial areas, i.e. Delfzijl and Eemshaven.

The Delfzijl harbour consists of 3 outer harbour basins with an area of 135 ha and 1 inner harbour basin of 24 ha.

The first outer harbour has an appr. 600 m long quay. The harbour is accessible for ships with a draught of 9 m and a dwt of 20,000 The harbour-entrance has been moved approx. 5 km to the east in order to be able to receive the planned type of ships. This was necessary because the old entrance was too narrow and was wrongly situated with respect to the continuous siltation in the outer channels. Besides, in that way the industrial area obtained a 5 km long shore front. The industrial grounds have an area of 1,600 ha.

The Eemshaven has been built in order to be able to receive larger ships. It is located about 20 km to the west of Delfzijl. For the time being the harbour is suited for receiving ships up to 40,000 grt. with a draught of 11.00 m. but it can be adjusted to receive ships up to 70,000 grt. The Eemshaven Port has three harbour basins and a wing. The Julianahaven has an 1,100 m long quay. The industrial grounds have an area of 650 ha.

The Port Authority consists of three principal sections, i.e. the port department, the management and the civil department.

This civil department is in charge of management and maintenance of all real property of the Port Authority such as grounds, roads, railways, dikes and jetties, quay-walls, sheds as well as the harbour basins and navigation channels.

Furthermore, the civil department is responsible for new projects of the Port Authority, the new industrial clients and it co-ordinates in these projects.

Especially, the maintenance of the bottom of both harbour areas is of interest.

In the outer harbours of Delfzijl , approx. 1,500,000 m^3 of harbour silt coming from the Waddenzee settle each year. Throughout the year this silt is dredged continuously, about 100 hours a week, and then transported to dumping grounds in the mouth of the Dollard; a distance of 8 km. The cost amounts to approx. Dfl. 2,500,000 a year for the time being, and this work is carried out by a Contractor.

In the Eemshaven approx. 500,000 to 700,000 m^3 silt settle each year. This silt is dredged continuously by a 6,000 m^3 suction hopper dredger and taken to a German dumping ground at the North Sea. This dumping ground is to the west of the isle of Borkum at a distance of 35 km. from the harbour entrance. The cost amounts to Dfl. 3,000,000 a year.

The industrial inner harbours of Delfzijl needs dredging of 100,000 m^3 silt a year. The silt of the inner harbours is pumped on agricultural grounds and the cost amounts to approx. Dfl. 200,000 a year.

The Port of Delfzijl Authority thus pays to the contractors for the combined dredging operations almost Dfl. 6,000,000 a year. The cost of management and assistance with the needed equipment of the above-mentioned dredging amounts to Dfl. 600,000 a year.

In Delfzijl, the harbour layout and the dredging situation have changed during the past couple of years. Had these changes not been made, the cost of dredging would have risen to Dfl. 7,000,000.

Some facts from the past. For years - probably as far back as 1893 - the harbour was maintained by an ordinary bucket ladder dredger with two barges and a tug. The dredging took place only during the day.

In 1893 about 175,000 m^3 silt was dredged. In 1958 the amount had increased to approx. 375,000 m^3 The silt was dumped to the west of the harbour mouth into the Eems.

Due to the industrialization of the area around Delfzijl and the extension of the harbour the amount of silt to dredge increased rapidly The area of the harbour was 25 ha. and is now approx. 136 ha. The 375,000 m^3 of silt in 1958 grew up to 900,000 m^3 in 1970.

The one dredger in the meantime had become two, each supplied with three to four barges. This was also necessary, because the dumping ground had been moved about 15 km from the harbour entrance.

As the size as well as the amount of the ships increased due to new industries, it was decided to build a new and much larger harbour entrance on the east side of the industrial area.

This new entrance was situated just opposite the sandbar-crossing from the German fairway.

During the construction of the new entrance it was decided based on simple studies to keep an opening at the old entrance. The reason for not closing the old entrance was the expectation that the filling up and emptying of the harbour mainly through the new entrance would cause unfavourable current speed for the navigation. Furthermore, it was expected that the flow through the harbour by two entrances would have a reducing effect on the siltation; however, this proved to be an almost fatal expectation.

The yearly quantity of silt increased enormously, though this was not noticed right away.

The two entrances made the harbour function as a deep channel for the filling up and emptying of a part of the Dollard. In a short period of time the channel outside the harbour - the Bocht van Watum - silted several metres.

As said before, in the beginning the increased siltation was not noticed, because the sand needed for the construction of the entrance was won from the bottom of the harbour up to a depth of 20 m.

At these water depths enormous amounts of silt settled, but because of the large depths this did not cause any hindrance to navigation and it was thus not recognized. Another reason for not immemdiately noticing this fact was that at that time the sounding-apparatus was not at the disposal of the Port Authority.

The increased flow of silt from the Waddenzee was not recognized until after two years. In 1976 2,000,000 m^3 harbour silt had to be dredged which required two big dredgers working day and night. Despite this dredging the allowed draught for navigation was reduced by 1 m. It rained complaints from the industry and quay-users. Another result was that the budget became unbalanced.

Eventually the pattern of siltation was studied again. It showed that by having two entrances some 30% more water was flowing through the harbour per tide, and as a result 30% more silt entered the harbour

At the request of the Port Authority a study was made inspired by experiments in Rotterdam as to the effects of a silt trap at the new harbour-entrance. The result of the study of the silt trap proved utterly positive - 90% of the silt would concentrate in or near the silt trap. Based upon these studies it was decided to set this silt trap and to close the old entrance entirely. The silt trap with an area of 10 ha and a depth of 5 m below the harbour bottom obtained a capacity of 500,000 m^3

Up till now the closure of the old entrance and the silt trap at the new entrance have proved to be a great success. The siltation decreased with 600,000 m^3 and 90% of the silt settled in the silt trap.

The dredging in the silt trap proved to be very cheap as the dredge production was high due to the concentrated siltation.

Now the time had come to replace the conventional bucket-ladder dredger by more modern equipment - the suction hopper dredger.

The layout of the Delfzijl harbour with a long narrow harbour basin and a silt trap at the entrance made it extremely suitable for the suction hopper dredger. The suction hopper dredger had proved highly effective already in the Eemshaven.

Here the ordinary dredger with its barges could not be used right from the start, because of the inadequate depths and because the silt had to be taken to the North Sea.

Ancillary equipment needed for the operation of the suction hopper dredger had already been bought for the dredging in the Eemshaven. This included a system for position-finding for the dredger and a sounding vessel supplied with recording and processing equipment.

The company occupied with the dredging for years decided to build a modern suction hopper split dredger, named "The Kinhem". "The Kinhem" has a hopper capacity of 800 m^3 and a maximum draught of 3.80 m, which is very low indeed. Besides, this dredger was supplied with an advanced system for position-finding.

Due to this development the price of dredging one m^3 silt was reduced by 50%.

This development together with the above-mentioned reduced amount of siltation (some 600,000 m^3 less) has caused a great financial relief for the Port Authority.

The operation of the hopper suction dredger requires considerably more careful planning and ancillary equipment than the operation of the bucket ladder dredger formerly used.

A bucket ladder dredger, big or small works in a way like an iron, moving from one side to the other side of the harbour.

The dredger had 4 side-wires, a bow-wire and a rear-wire, and if the winches are used in the right way, the position of the bucket-ladder is well adjusted, nothing can go wrong with the job on the harbour bottom.

The bucket ladder dredger always did guarantee an equable flat bottom. Sounding was in fact not so difficult at all. An overlooker on the dredger lowering the sounding line from time to time from the poop-deck was sufficient. The rest of the sounding, if necessary could be done by sounding-rod along a wire or with an optical instrument for position-finding.

Then came the radiolog i.e. an echo-sounder employed in lines set up by flags on the shore and a radio-distance measurement to a fix point on the shore.

The suction hopper dredger demands more care. It sucks up the silt with a minimum of water and has to leave the operational area to empty itself at the dumping-place; it returns to the operational area and has to continue the maintenance of the bottom without missing shallower parts even when it is foggy and during the night.

The controlling sounding-vessel must be able to trace any shallow part at any given moment, it has to find its accurate position and subsequently plot it on paper.

The suction hopper dredger given the information in its turn must be able to locate these places without trouble and has to clear away the shallow parts.

To achieve this equipment for accurate position-finding coupled to the depth measurements has been installed on the suction hopper dredger as well as on the sounding vessel. The Port Authority makes use of the Motorola Mini Ranger coupled to the radiolog Deso 20 of Atlas Krupps and HP computers.

As an aid to the equipment the Port Authority has installed six permanent reference stations on the shores of the Eems on the Dutch as well as on the German side.

On board the suction dredger the position is transmitted on a programmed screen and here the vessel movements can be monitored in detail.

On board the sounding vessel position of the vessel is processed through the computer and together with the measured depths and the water levels accurately stored. At the office the information is translated by the computer onto hydrographic survey maps drawn by a plotter.

The equipment is the same as used in Rotterdam harbour so that exchange of suction hopper dredgers and sounding vessels is possible.

The question of measurement of the hopper production is now remaining. It is important not only how you dredge but also what you dredge and at what price. The estimate of the production can be achieved either by measuring the hopper or on the gauge of the vessel or by sounding the depths. Harbour silt is something special however. Silt mixed with much or little water, and all what is in between these two has been experienced. That is why nobody knows what exactly is one m^3 of silt

The silt at the bottom of the harbour definitely has a different density than the silt brought up by a bucket ladder dredger or the silt in the hopper of a suction hopper dredger, which is mixed with water. In short the one m^3 silt can be quite different from the other.

Therefore no measuring system can be totally correct. One might for this reason wonder about the importance of this.

In fact the important thing is whether the contractor working on the maintenance has sufficient insight into the measuring system and that he knows the amount of money to be paid to him per week for his equipment and his personnel.

Frequent measurements of the available water depths may seem quite good, but is in fact useless if clouds of silt move daily over the bottom of the harbour. Gales, resulting in sudden increased supplies of silt also cause disturbances in measuring in situation.

The centrifuge measuring system is used with the suction hopper dredger. This system tries by centrifuging the hopper silt to estimate the equivalent amount of bottom sediment.

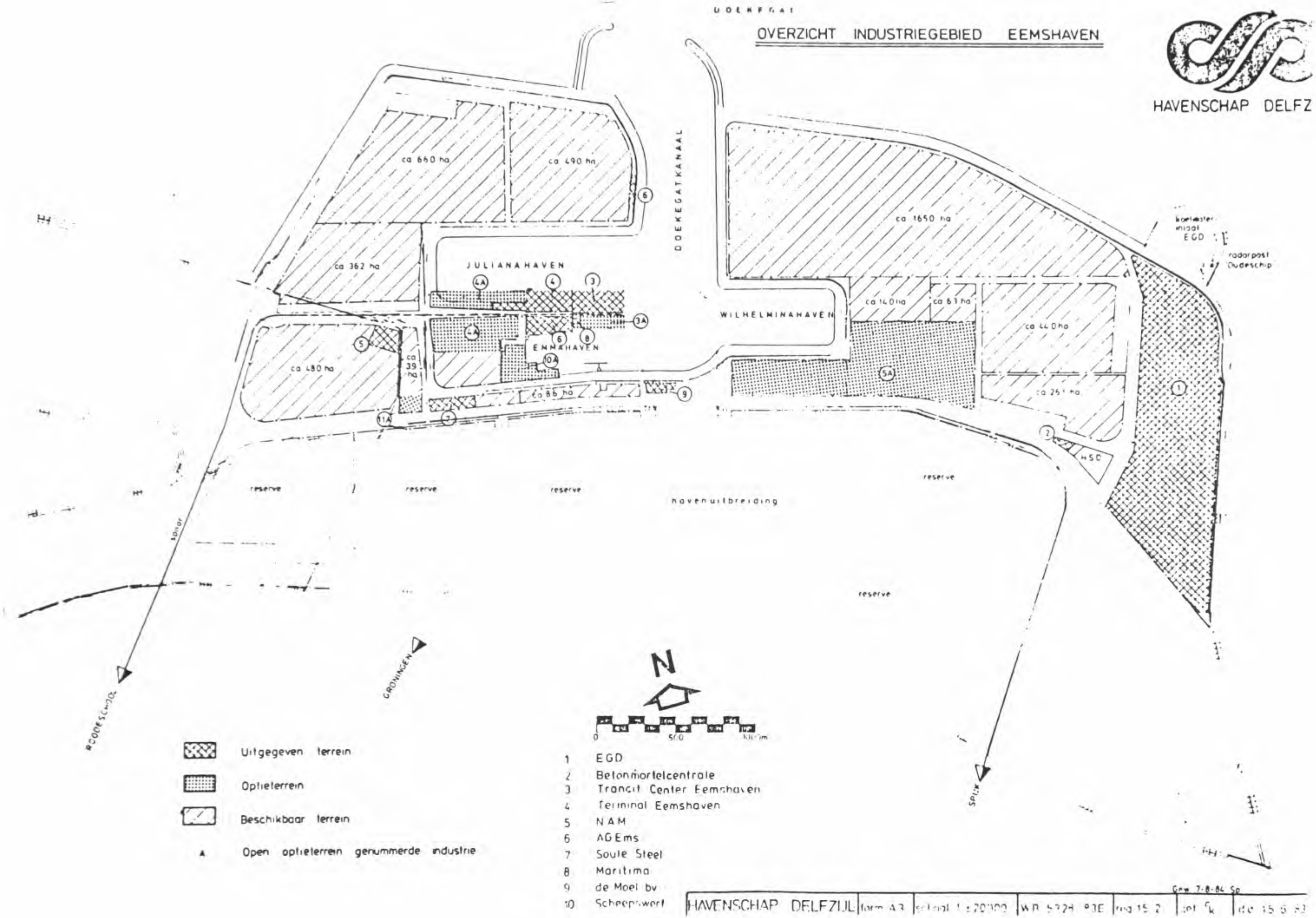
This is the way it works:

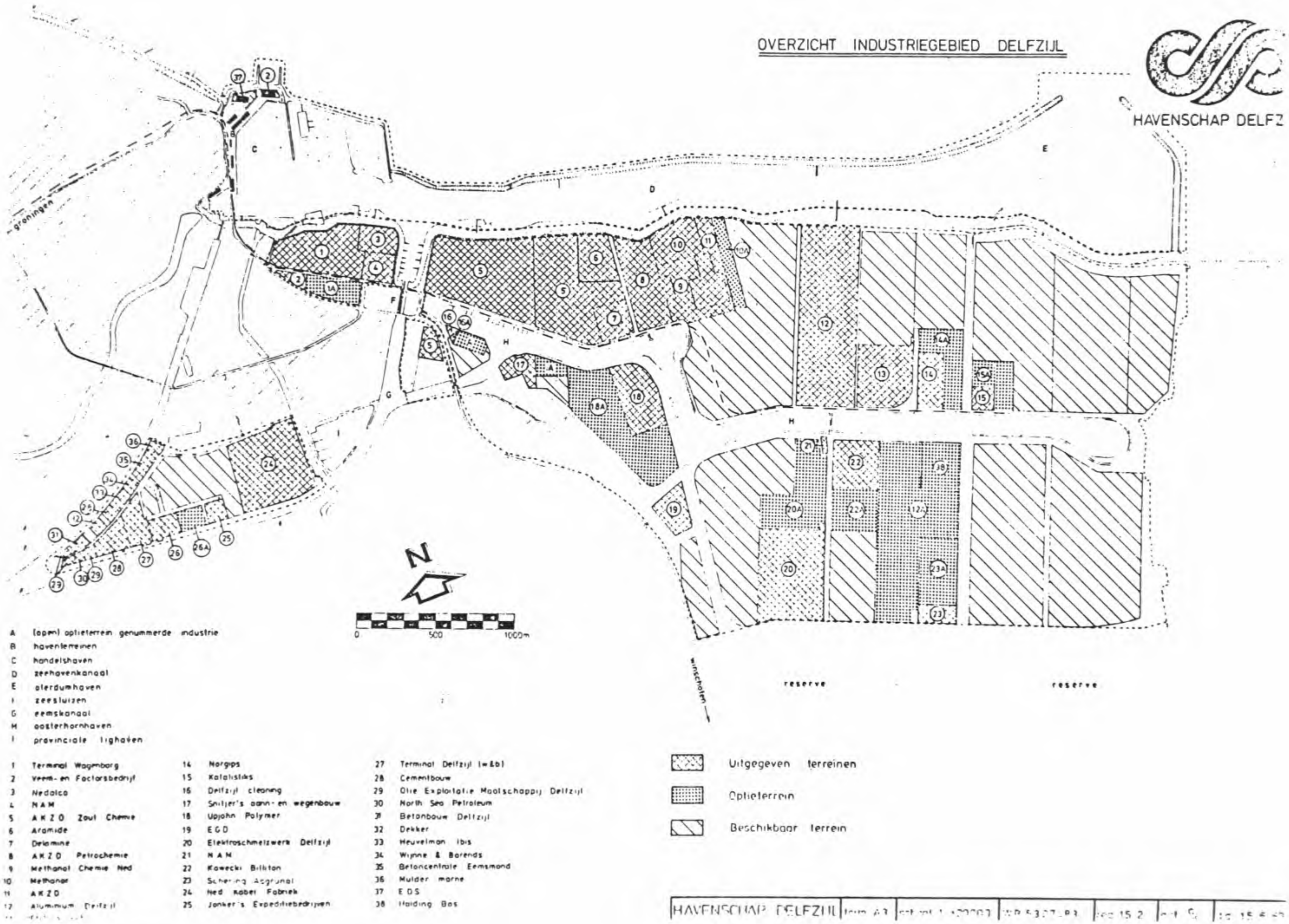
The quantity of solid settled silt is measured in the hopper of the dredger at several spots with special equipment, whereas from the liquid watery mixture on top of the settled silt, samples are drawn at half the height of this liquid mixture.

These samples are centrifuged in a silt-centrifuge for 10 minutes at 1,500 rotations per minute.

The amount of solid silt from the sample thus obtained is converted to the hopper-capacity and added to the measured quantity of solid, settled silt. Needed for these measurements are of course the certificates of registry of the hopper. It can be recommended to ask for the original certificates of registry and not content yourself with photo-copies. Care has to be taken that the certificates are of recent date, otherwise the ship must be remeasured.

From the description of the dredging activities in the Port of Delfzijl, it will be understood that the whole development in dredging has been of great financial importance for the Port Authority. During the last decade, the conventional system with the use of the bucket-ladder dredger has been changed to a modern system using the suction hopper dredger.


OVERZICHT INDUSTRIEGEBIED EEMSHAVEN
HAVENSCHAP DELFZ
DOEKEGATKANAAL
JULIANAHAVEN
EMMAHAVEN
WILHELMINAHAVEN
ca 660 ha
ca 490 ha
ca 362 ha
ca 480 ha
ca 86 ha
ca 1650 ha
ca 140 ha
ca 44 0 ha
ca 25 ha
HSD
reserve
havenuitbreiding
GRONINGEN
N
Uitgegeven terrein
Opttieterrein
Beschikbaar terrein
Open optieterrein genummerde industrie
1 EGD
2 Betonmortelcentrale
3 Transit Center Eemshaven
4 Terminal Eemshaven
5 NAM
6 AGEms
7 Soule Steel
8 Maritima
9 de Moel bv
10 Scheepswerf
HAVENSCHAP DELFZIJL


OVERZICHT INDUSTRIEGEBIED DELFZIJL
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B haventerreinen
C handelshaven
D zeehavenkanaal
E oterdumhaven
F zeesluizen
G eemskanaal
H oosterhornhaven
I provinciale lighaven
1 Terminal Wagenborg
2 Veem- en Factorsbedrijf
3 Nedalco
4 N A M
5 A K Z O Zout Chemie
6 Aramide
7 Delamine
8 A K Z O Petrochemie
9 Methanol Chemie Ned
10 Methanor
11 A K Z O
12 Aluminium Delfzijl
14 Norgips
15 Katalistiks
16 Delfzijl cleaning
17 Snijder's aann- en wegenbouw
18 Upjohn Polymer
19 E G D
20 Elektroschmelzwerk Delfzijl
21 N A M
22 Kawecki Billiton
23 Schering Aagrunol
24 Ned Kabel Fabriek
25 Jonker's Expeditiebedrijven
27 Terminal Delfzijl (w&b)
28 Cementbouw
29 Olie Exploitatie Maatschappij Delfzijl
30 North Sea Petroleum
31 Betonbouw Delfzijl
32 Dekker
33 Heuvelman Ibis
34 Wijnne & Barends
35 Betoncentrale Eemsmond
36 Mulder marine
37 E D S
38 Holding Bos
Uitgegeven terreinen
Optieterrein
Beschikbaar terrein
HAVENSCHAP DELFZIJL

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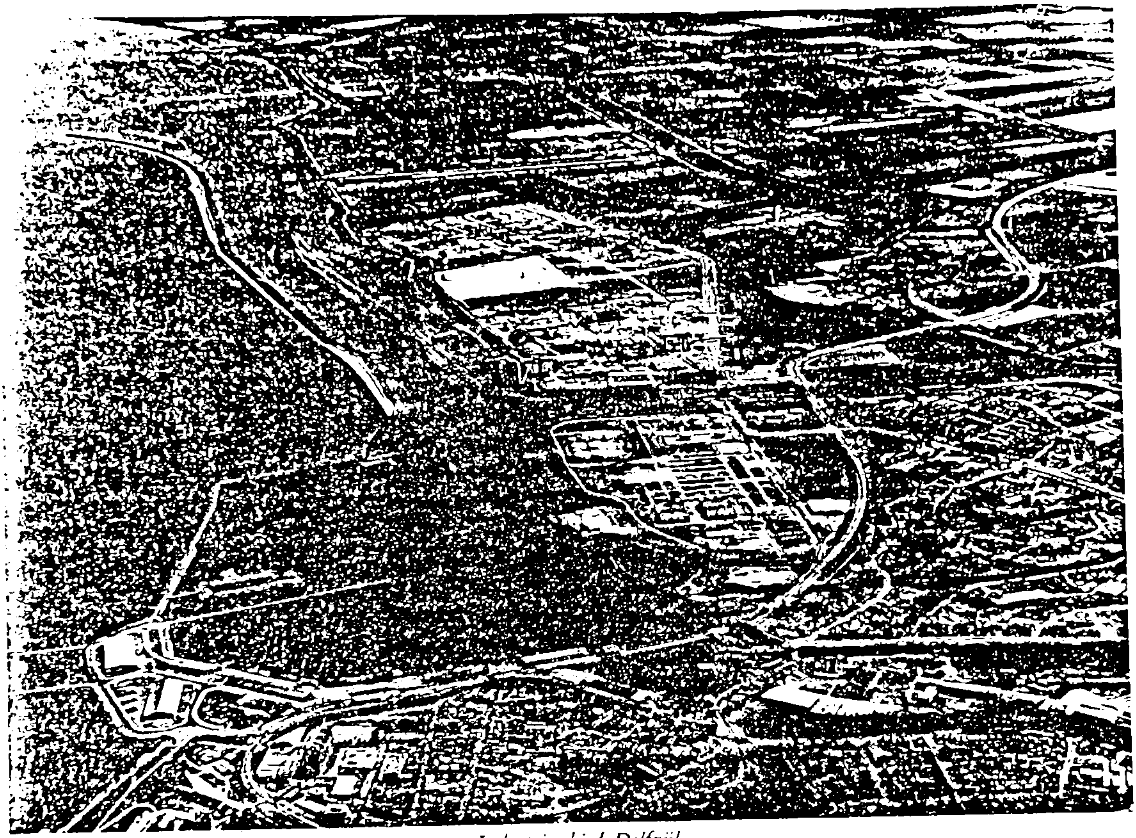
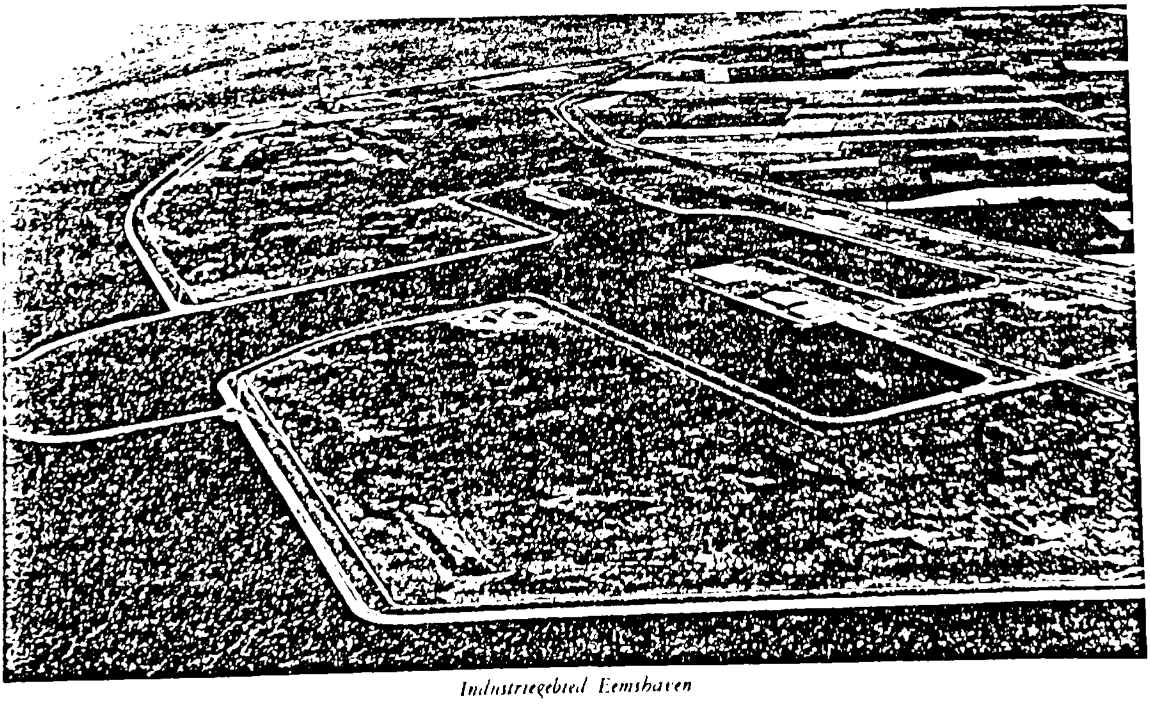
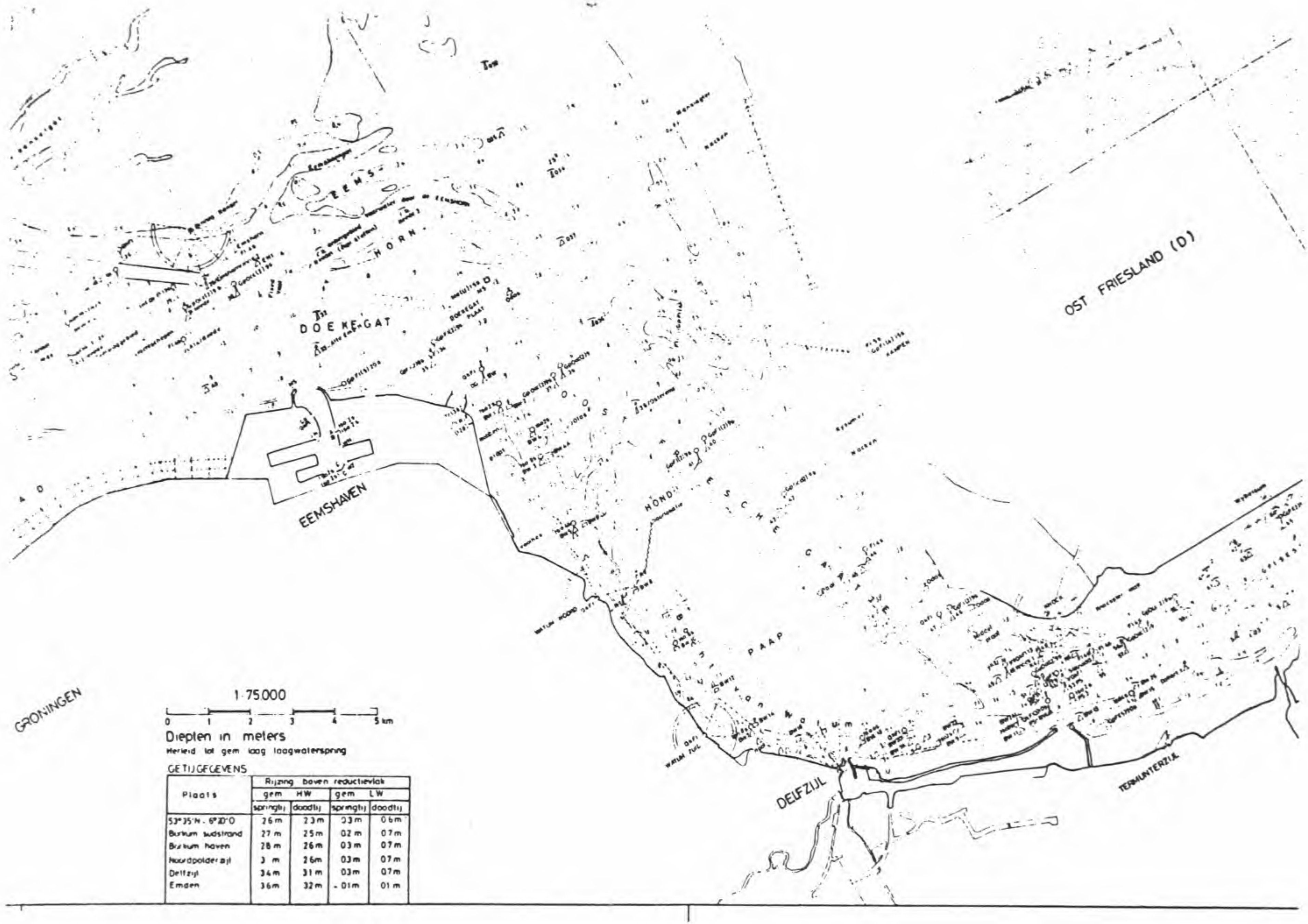


Industriegebied Delfzijl

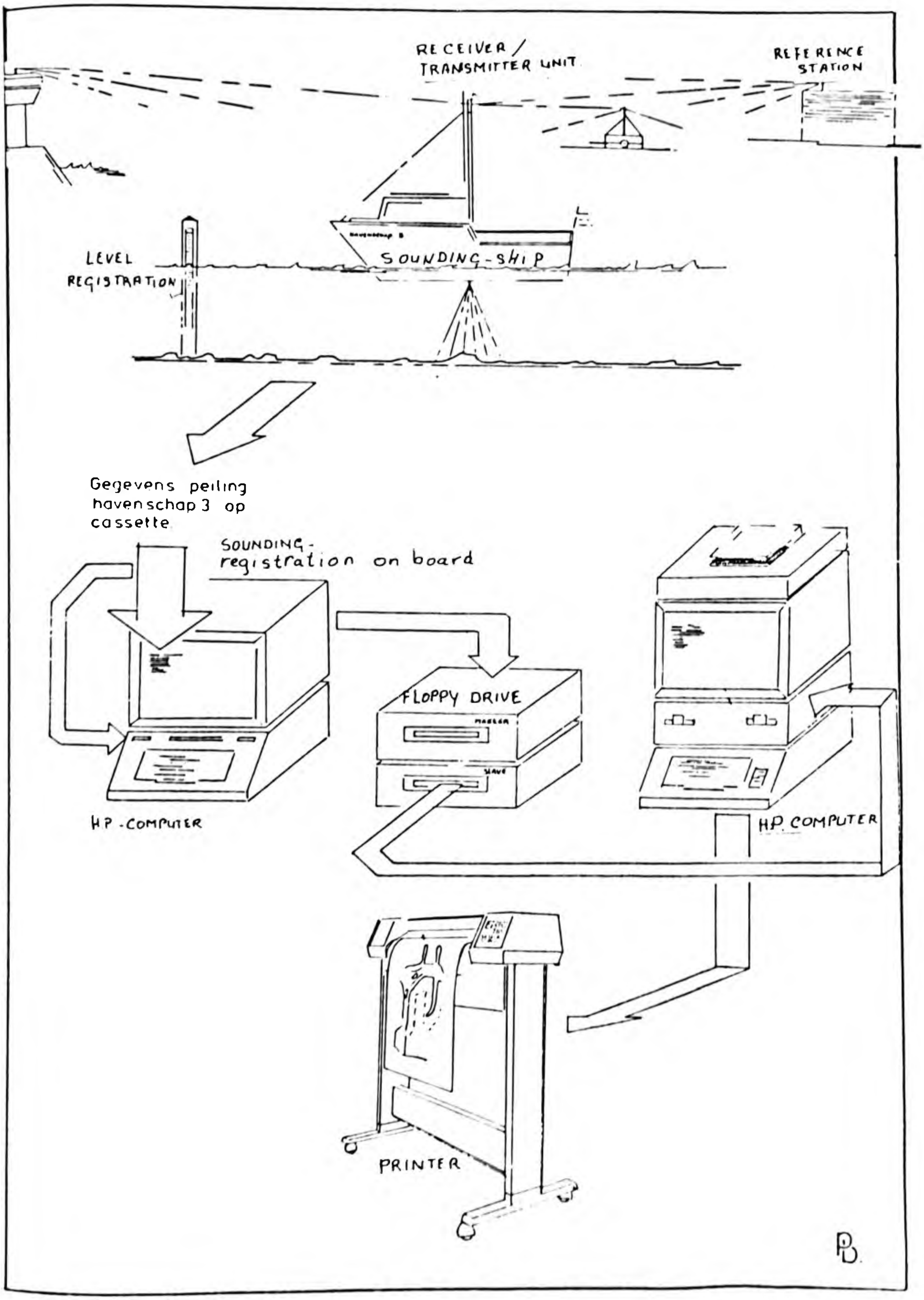


Industriegebied Eemshaven

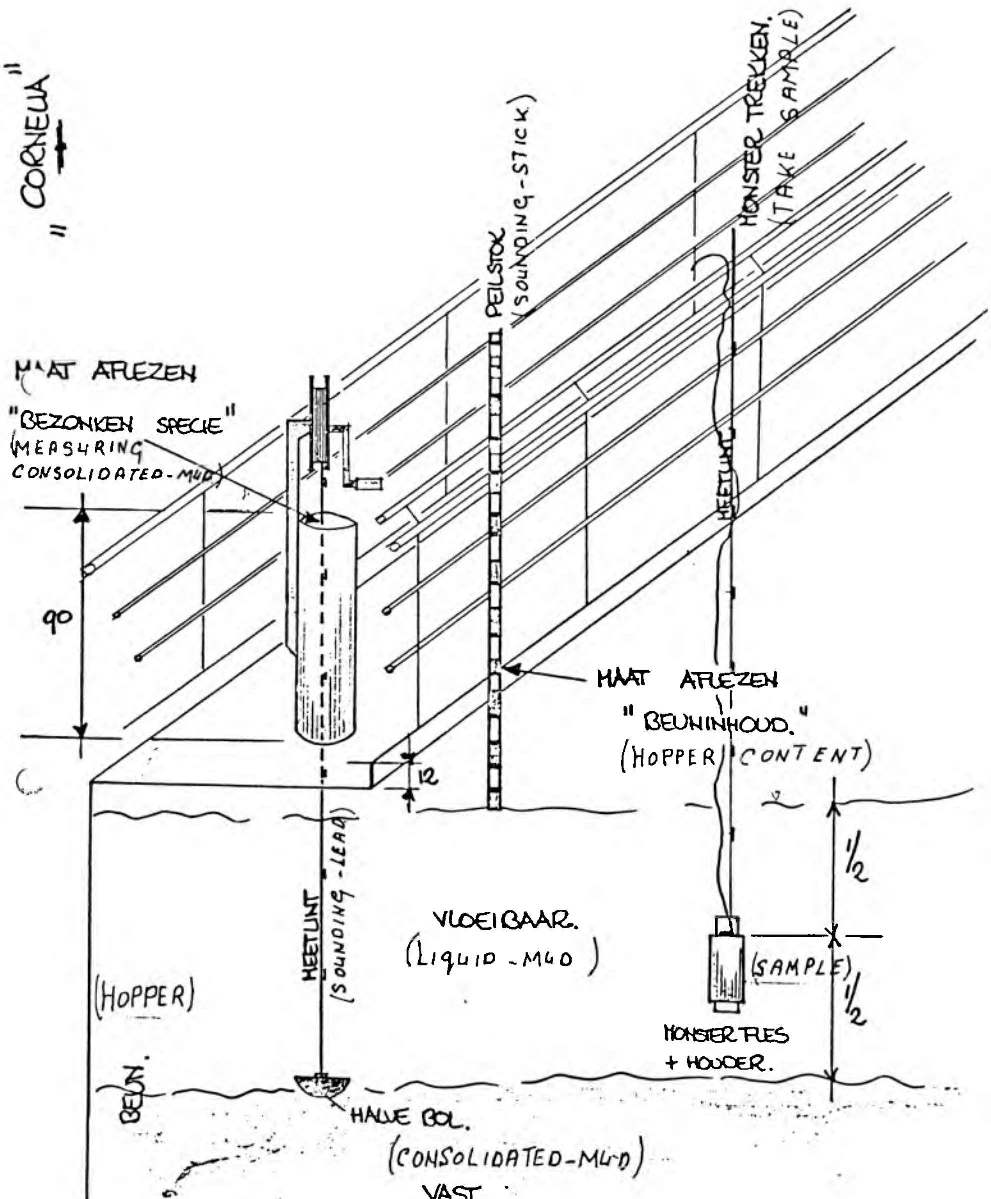


GETIJGEGEVENS

Plaats	Rijzing boven reductievlak			
	gem HW		gem LW	
	springtij	doodtij	springtij	doodtij
53°35'N - 6°20'O	26 m	23 m	03 m	06 m
Burkum sudstrand	27 m	25 m	02 m	07 m
Burkum haven	28 m	26 m	03 m	07 m
Noordpolderzijl	3 m	26 m	03 m	07 m
Delfzijl	34 m	31 m	03 m	07 m
Emden	36 m	32 m	- 01 m	01 m


RECEIVER / TRANSMITTER UNIT
REFERENCE STATION
LEVEL REGISTRATION
SOUNDING-SHIP
Gegevens peiling havenschap 3 op cassette
SOUNDING-registration on board
FLOPPY DRIVE
H.P.-COMPUTER
H.P. COMPUTER
PRINTER

HOE TE PEILEN. (MEASERING HOPPER CONTENT)



Z.O.Z.

5.4 VISIT TO DREDGING DIVISION OF PUBLIC WORKS DEPARTMENT OF MINISTRY OF TRANSPORT AND PUBLIC WORKS, HOOK OF HOLLAND

The Dredging Division of Public Works Department of Ministry of Transport and Public Works is located in Hook of Holland. It is responsible for the maintenance of the riverine part of Rotterdam Port, the harbour entrance and the navigation channel. The Dredging Division was visited during the Seminar-cum-Study Tour. Lectures were presented and information material was distributed to the participants. In addition, a visit was made to the dredger "Cosmos" which is operated for the Dredging Division by a contractor.

Roughly speaking, the yearly maintenance dredging requirement in the riverine part of the port is 2.5 M cu.m., in the harbour entrance 8 M cu.m., and in the navigation channel another 2.5 M cu.m. This makes the total yearly maintenance dredging requirement of the Dredging Division to about 13 M cu.m.

5.4.1 Study on minimization of dredging costs

A presentation on "Reduction of dredging costs in relation to research and development" was made by Mr. Robert van Vechgel, Rijkswaterstaat, Hook of Holland. The following is the presentation supplemented with extracts from "Rotterdam Harbour Silt", a publication issued by the Public Works Department, Rotterdam in September 1983

The dredging works require such enormous amount of money that the Ministry of Transport and Public Works 'Rijkswaterstaat' and the Municipality of Rotterdam decided in 1976 to launch a joint research project on how to keep those costs within reasonable limits. This led to the development of the project on study of the Maintenance Dredging Cost Minimization (MKO) which was officially instituted in 1978. The aim of the project was to 'investigate the possibilities of reducing the costs of maintaining shipping channels and harbours in the Rhine Delta'

The study can roughly be divided into four categories:

A. A basic investigation into the origin, composition, specific properties and behaviour of silt has been carried out by a number of working groups.

B. A study has been made on the problem of how silting can be controlled by the use of mechanical means.

C. Other groups are working on monitoring the dredging process to make it easier to control.

D. Finally, an investigation has been made in a number of projects into the possible methods of disposal and re-use of dredged material.

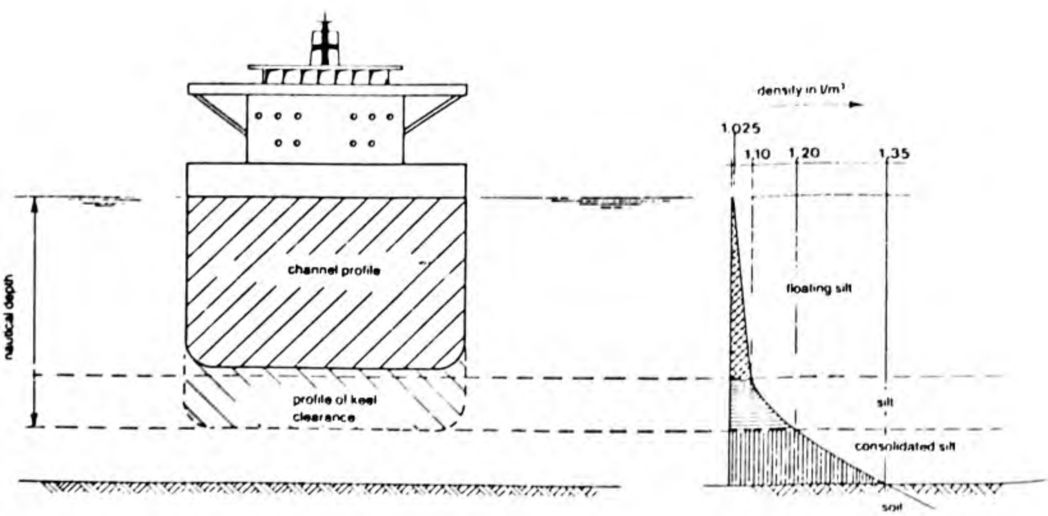
In addition to these four categories of study, a marketing group has been formed and is looking into the conditions and regulations governing the dredging work. The following points are being dealth with: form of contract, duration of contract, policy governing tenders, procedure to be followed, etc.

The studies which have been carried out up till now have provided important information. For example it was possible to establish a new definition of the 'nautical depth' for channels and harbours. During the study, an investigation was made up to what extent it is necessary to remove the top bed-layer of the navigation channel. This layer principally consists of water with a diminished concentration of suspended silt particles; when dredged, it produces a limited amount of silt.

The study was concerned with the extent to which this layer influences the navigation resistance and manoeuvrability of ships. According to the study when the keel of a ship passes through this upper layer, the resistance tends to increase. The manoeuvrability remained the same and was even improved in certain cases. The new concept of 'nautical bed', which was determined by the study for channels and harbours, will be included in the charts.

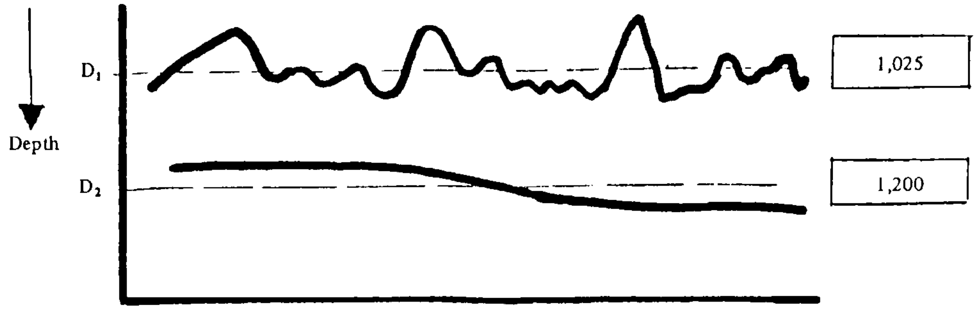
The nautical bed is the depth above which a ship together with its keel clearance (10% of its draught) can safely manoeuvre, see defintion figure below. In Rotterdam, the level where the density is 1,200 kg/cu.m. is defined as the nautical bed.

This introduction of the nautical bed signifies, moreover, the development of new recording techniques to determine the exact depth of this nautical bed. In order to measure the density of the silt layers, use is now made of a radio-active density probe which can measure the level of density in the bed-layer at different depths.



Definition of nautical depth

The signal from normal echo-sounders is high-frequent (about 210 khz) and is reflected when even minor changes in the density occur. These signals may be reflected at the top of silt clouds moving near the bed leaving an impression of a hard bed. At such beds with large silt concentration above the bed, the use of a normal echo-sounder may give an impression of a rather rough bed. On the contrary, identification of the layer with a density of 1,200 kg/cu.m. may show that the nautical bed, in fact, is a rather smooth bed, see the figure below.

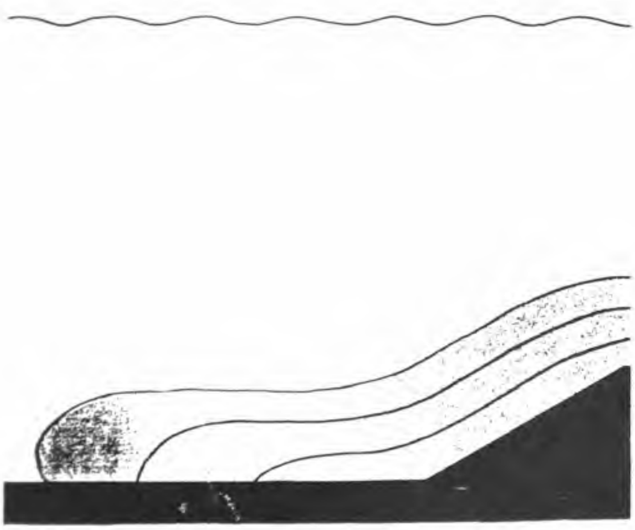


Measured depth variation

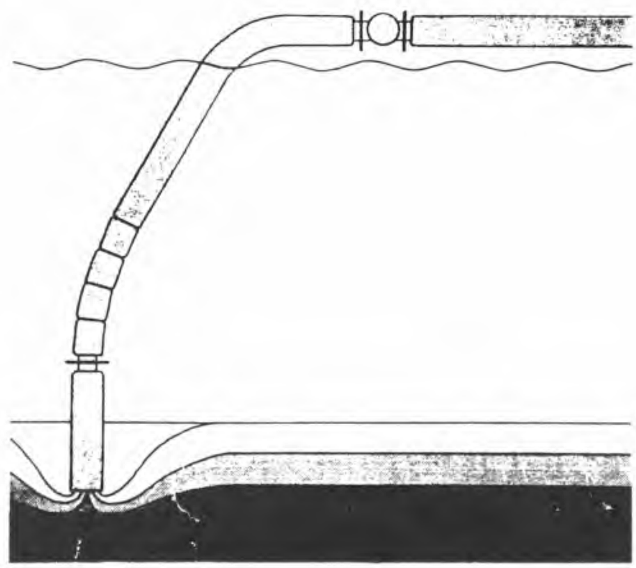
In certain harbours, just behind the mouth of the harbour, more harbour bed was dredged away than was necessary to retain the respective harbour at the right depth. In this way a pit was formed in which the silting process was concentrated. This meant a reduction in dredging work in the section of the harbour lying behind it, while at the same time the silt in the pit could be more efficiently dredged (with higher concentrations)

Once it had been demonstrated that the necessary silt was indeed being collected in suitably located silt catchment pits, a study was made into possible ways of sucking up the harbour silt in one continuous process from one point in the pit using a stationary dredger, and then pumping it via a permanent pipeline to a disposal point. The behaviour of the silt in the pits appeared to be connected with both the silt-sand relationship and also with the degree of consolidation. A density of approximately 1.2 tons/m^3 appeared to be optimal in this respect for a stationary suction system. It also appeared that the power needed for a suction system such as this to suck up the silt is relatively little.

Such studies into the origin, the composition, the behaviour and the re-use of dredged material will, just as the search for methods of reducing and controlling the silting process, also have to be continued in the future.



Collecting silt in pits



Stationary sucking of high density silt

5.4.2 Automation as a principal's tool - Maintenance dredging of the Rotterdam Fairway

This paper was prepared and presented by Mr. Gerard Ottevanger, Dredging Division of Rijkswaterstaat, Hook of Holland.

Introduction

The responsibility for a guaranteed nautical depth in the fairways to and from Rotterdam and Rotterdam-Europoort is in the hands of the Dredging Division of Rijkswaterstaat.

The bulk of the maintenance dredging work to be carried out for that purpose is taking place in the entrance to the Europort-area; a smaller quantity is dredged on the Rotterdam Waterway and adjacent rivers.
Total expenditure per year amounts to some Dfl. 35 - 45 million.
A trailing hopper dredger is used to carry out the necessary work.

In this paper the role of the Principal as it has developed over the years, will be dealt with.

Former situation

Until the end of the seventies Rijkswaterstaat issued regularly open tenders on the market to cover the maintenance dredging needs as assessed for the running period of the proposed contract, mostly in one or two year periods.
The Contractor quoted his prices per cubic meter dredged material, measured in means of conveyance for dredging, transporting and dumping from and to various nominated dredging- and dumping sites.
Responsibility for quantitive output was borne by the Contractor.
The involvement of the Principal was in hydrographic surveying for conservancy and dredge-operational purposes and in taking care of position finding means for the dredge-equipment.
Supervision was merely directed to dredging depth and -location and to establishing dredge quantities.

Present situation

At the end of the seventies the Principal was confronted with a tightening budget situation and therefore alternative forms of contract, leading to a lower price level, were considered.
Thus since 1980 the philosophy has been adopted to cover the basic maintenance dredge requirements on long term basis, starting with a 5-year period.
While the price for such a contract should be fixed and based on cost plus fair profit, instead of being liable to market fluctuations, it became necessary in order to achieve the intended low-price level to minimize the Contractor's risk.
So the contract was deemed to be on charter-mode, although an incentive for productivity increasement was found in a premium in case the production figures should rise above an established norm.

In the charter-mode contract the Contractor hires out fully operational and manned equipment. In this case the interest of the Principal in the equipment's output is quite obvious.
Thus the working method of the Contractor and the constantly changing dredge parameters in their mutual relation become more and more under the Principals judgement.
In order to be able to perform this task the Dredging Division of Rijkswaterstaat has developed the Dredge-o-Graph as a means for auto-

mated dredge data presentation and collection.
The Dredge-o-Graph enables insight in the overall process, incorporating the following parameters in time consumption:

- Status of the ship:
  . sailing;
  . dredging;
  . dumping.
- Position of the ship:
  . chart position;
  . course.
- Hopper-load status.

In so far, as the status of the ship and position of the ship are concerned, the Dredge-o-Graph functions satisfactorily, though the hopper load status, i.e. the hopper load increase, cannot be established with the accuracy demanded.
The existing options for automated collections are:

- the load recorder, working on displacement;
- the production meter, working on flow velocity and concentration of the mixture in the dredge-pipeline.

Both are used indicative and unsuitable for accurate monitoring.
The Dredging Division gives high priority to the development of a sophisticated system to establish load records.

At present the Dredge-o-Graph is used on board as an aid to the work-supervisor and the above mentioned data may be presented on a display screen when called for.
The data are stored on floppy disc to be processed on a shore-based computer for reporting and evaluation.
Finally a frequent use of the system is made for measuring programmes in research and development.

Future situation

Presently it is felt as a disadvantage, that the involvement of the Contractor in the productivity of his equipment has been reduced by engaging charter-mode contracts.
This must be regarded as being in contradiction with the Contractor's discipline.
Certainly it cannot be the Principals aim to degenerate the Contractor to a "Rent a Hopper" firm.
Therefore as soon as relevant parameters can be monitored unambiguously, the Principal's intention is to incorporate in the Contract a manner of Contractor's remuneration related to the data as recorded by the Dredge-o-Graph.
Such a form of Contract can only be implemented if a continuous reliable picture of these relevant data can be presented to the personnel concerned on board.
From this picture an on-line observation should be obtainable as to what extend results are in conformity with the standard norm.

The Dredge-o-Graph in operation

Display presentation on board

A proper presentation on board requires a continuous possibility of making visible:
- where? (three dimensional x, y and z)
- what? (process-status)
- quantity? (time, distance, dredge-quantity)

Where?

During the complete time of operation a presentation is given of the location of the dredge in x and y and in which direction the dredge is progressing (course).

In the dredging phase these data are complemented by chart-datum and depth(s) of the suction head(s) (z).

The horizontal data are derived from the electronic positioning system(s) in use.
In the case of dredging near the Hook of Holland three systems may be read simultaneously:
- Motorola Mini Ranger
- Hi Fix 6
- Trident.

From an automated selection the most probable reading is presented on the screen.

The course is established by automated giro-compass reading.

The actual dredging-depth is determined by measuring hydrostatic pressure with a sensor on the dredge-head.
In an integrated programme the applicable tidal correction is derived from on-line radiographic tide gauge readings, corrected by means of a mathematical model for each specific location.

For the purpose of orientation, the data are presented in the geographical situation, such as shore-line composition, channel alignment, leading-light lines, buoys etc.

Dredge-data, as derived from hydrographic soundings are simultaneously presented on the basic chart.
A special programme has been developed to make it possible to incorporate raw data from automated soundings without further processing.
The dredge data are presented by hatches in the dredge-area, the density of shading marking the priority-areas.
In the present use, the system is a definite improvement on the former trackplotter system, as it shows the dredge-area, the dredge-position and course.
Renewing dredge data from hydrographic soundings can also be done more accurately and quickly, so a better guidance of the dredge in operation and thereby a greater efficiency, is achieved (fig. 1).

Another option leading to greater efficiency is that the instrument can produce on-line hard copies of the track sailed and the matching dredging-depths, which it measures.
The difference between the programmed and actual track during operation is continuously visible and therefore more effectively corrections can be made.
This has proved to be useful, especially in spot-dredging (fig. 2).

The Dredge-o-Graph registers the time-position relation.
Taking into account the specific properties of the equipment in manoeuvring under given conditions, a tolerance may be established for the deviation of the actual track from the dredging boundaries.
Thus it becomes feasible to restrict payment to dredging within the dredge-area and tolerance.
The same may be done for the time-dredging depth relation.

<u>What and how much</u>
During the complete time of operation of the hopper-dredge the status of the equipment in relation to the dredging-process must be continuously visible.
The dredging-process is completely defined by the phases:
- sailing empty
- dredging
- sailing loaded
- dumping
- idle time.

If the status of the equipment in the above mentioned phases can be established unambiguously, presentation of the actual progress within these components will also be possible.
A standard performance is used as a measure for continuous judgement of the dredging-process.

The standard performance for each piece of equipment must be established, considering the dredge's specific properties (i.e. propulsion, pumping power etc.) and given dredging-conditions (i.e. soil classification, dredging-depths, current and tidal conditions etc.). This standard performance may be updated to correspond with experienced results as the job proceeds.

For determination of and progress in the phases, a further specification of the dredging-process becomes necessary, therefore the following questions should be answered by the Dredge-o-Graph:

<u>Sailing unloaded</u> (fig. 3)

- sailing	: yes/no
- stagnation	: yes/no on standard
- flushing	: yes/no
- bottom-valves	: open/closed - number open
- emptying by suction	: yes/no
- empty	: yes/no
- level of mixture	: in m^3 mixture
- rest-load	: yes/no, in m^3 or in tons

<u>Dredging</u> (fig. 4 and fig. 5)

- level of overflow	: in m^3 hopper-content
- bottom-valves	: open/closed - number open
- dredging s.b.	: yes/no
- dredging-depth s.b.	: in meters off chart-datum correct/wrong
- valve s.b.	: inboard/outboard correct/wrong
- dredging p.s.	: yes/no
- dredging-depth p.s.	: in meters off chart-datum correct/wrong
- valve p.s.	: inboard/outboard correct/wrong
- stagnation	: yes/no on volume-standard
- stagnation	: yes/no on tonnage-standard
- overflow	: yes/no
- loading on	: yes/no

Sailing loaded (fig. 6)

- sailing : yes/no
- stagnation : yes/no on standard
- level of overflow : in m^3 hoppercontent
- level of mixture : in m^3 mixture
- bottom-valves : open/closed - number open

Pumping ashore (fig. 7)

- emptying : yes/no
- stagnation : yes/no on standard
- pump : on/off
- shore-pipeline-valve: open/closed
- flushing : yes/no

Dumping

- dumping : yes/no
- bottom valves : open/closed - number open
- flushing : yes/no

The appearance of a negative deviation from the standard invites the question "why?" and consequently "can the deviation be terminated or reduced by intervening in the process?".

As already noticed the Dredge-o-Graph is awaiting a reliable parameter to indicate production-figures.
If such a parameter is made available then the actual dredging-process can be monitored versus the standard, applicable for the equipment under given conditions, and effective time consumption may be translated into remuneration.

The Dredge-o-Graph in research and development

Once a Dredge-o-Graph is installed, the Principal has a powerful and flexible automatic "surveyor" on board. Hardly any phenomenon can escape observation and keep its secret if the adequate sensors are installed and connected to the Dredge-o-Graph.
For instance, the yearly fluctuations in production of a hopperdredge in maintenance work have been studied. From experience it was found that in winter, production is higher than in summer, at least in the Europort-area.
From hydrographic surveys it was concluded that in winter most of the siltation takes place and it seemed quite obvious that this phenomenon was the main cause for the difference in production.
Nevertheless, during a hot summer season detailed observations were made of the performance of the pumps, using the Dredge-o-Graph.
Every two seconds the pumphead, the velocity and the density of the mixture were measured and recorded on a floppy-disc.
Beforehand the relation between pumphead and velocity was recorded whilst pumping water (fig. 8). From these measuring points it was possible to calculate the relation by regression analysis.
For a good production in dredging the pump should maintain this characteristic; this means the lower the velocity the higher the pumphead.
During that hot summer season however the relation between pumphead and velocity turned out to be as shown in figure 9, fluctuating between a velocity of appr. 7 and appr. 1 on the X-scale, instead of gradually lowering to, for instance 4. The pumphead lowered to 6 on the Y-scale in stead of increasing to 8, as might be expected.

Apparently, part of the impeller of the pump was not filled with mixture, otherwise the pumphead should follow the relation for water or even be higher.
The suction side of the pump showed a pressure far from the cavitation point and therefore the sole conclusion could be: "part of the impeller is filled with gas".
So with the Dredge-o-Graph it has been proved that in summer gas is generated in the silt, lowering the production considerably.
By degassing the silt, or properly speaking, by extracting the gas from the impeller, the relation between pumphead and velocity can be restored and brought nearer to the water characteristic, as shown in figure 10. Occasionally the pumphead still falls, but the velocity remains at a higher value.
In the figures 11 and 12 the relation between density and velocity is given for the same measuring points, i.e. without and with gas-extraction.
Remarkable is the upper-limit of the density (5 on the Y-scale), with only some exceptions in figure 11.
The result for the production, i.e. the pumpproduction, is shown in the figures 13 and 14, again for the two cases. The maximum density is again visible (all production points are below a line under 45^{o}).
The big difference however is clearly seen: the average production raises from 2,25 (Y-scale) to about 4,5, so a doubling of the pump-production and that is what counts in maintenance dredging.

Conclusion

Automation as a Principal's Tool:

The installation of the "Dredge-o-Graph, makes the dredging process transparent and thus permits an objective judgement of results.
It thereby contributes to mutual understanding and benefits both contractor and principal.

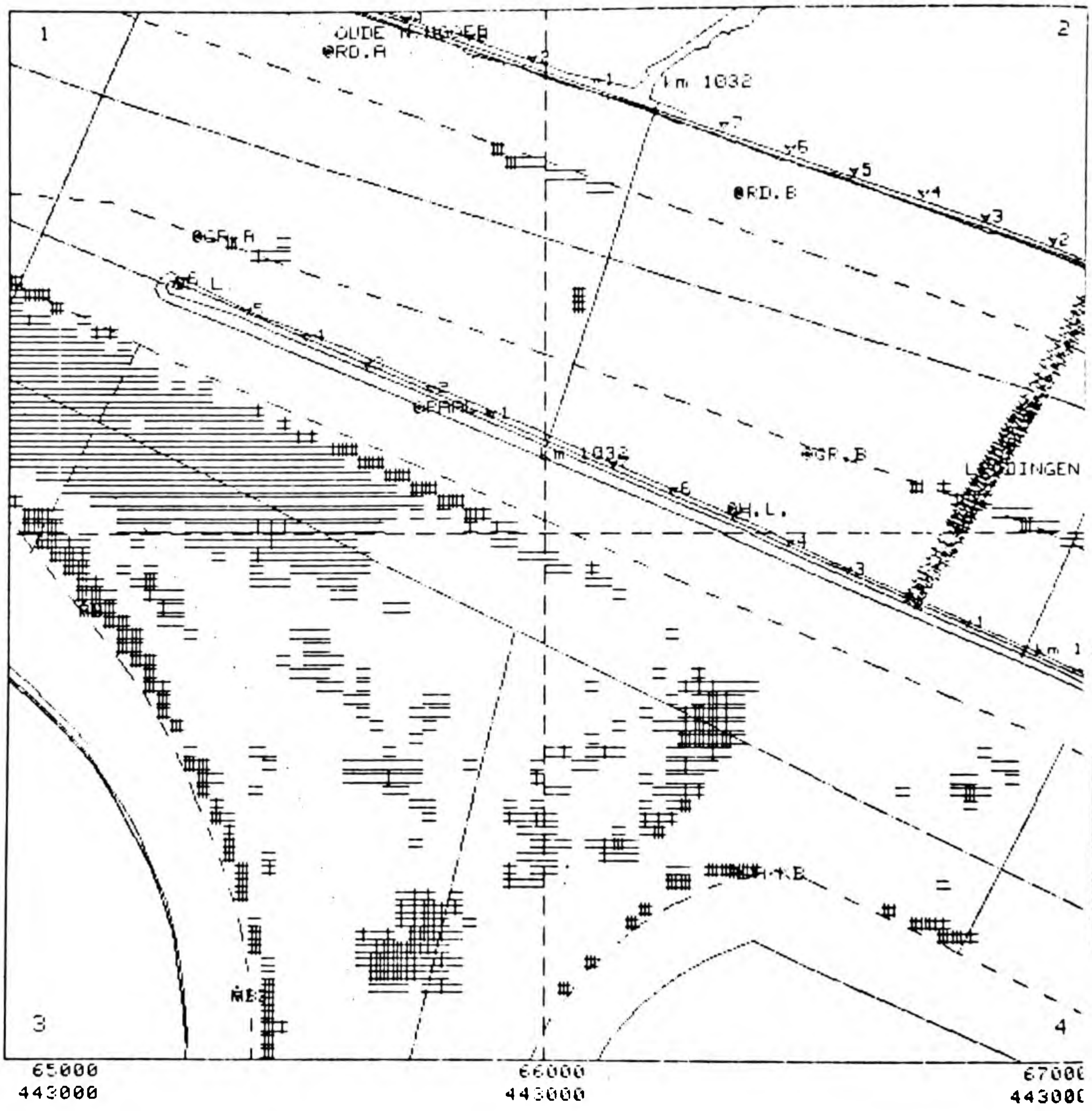

OUDE MAAS
@RD.A
km 1032
@RD.B
@GR.A
@H.L.
@GR.B
@H.L.
km 1032
1
2
3
4
65000
443000
66000
443000
67000
443000

fig. 1

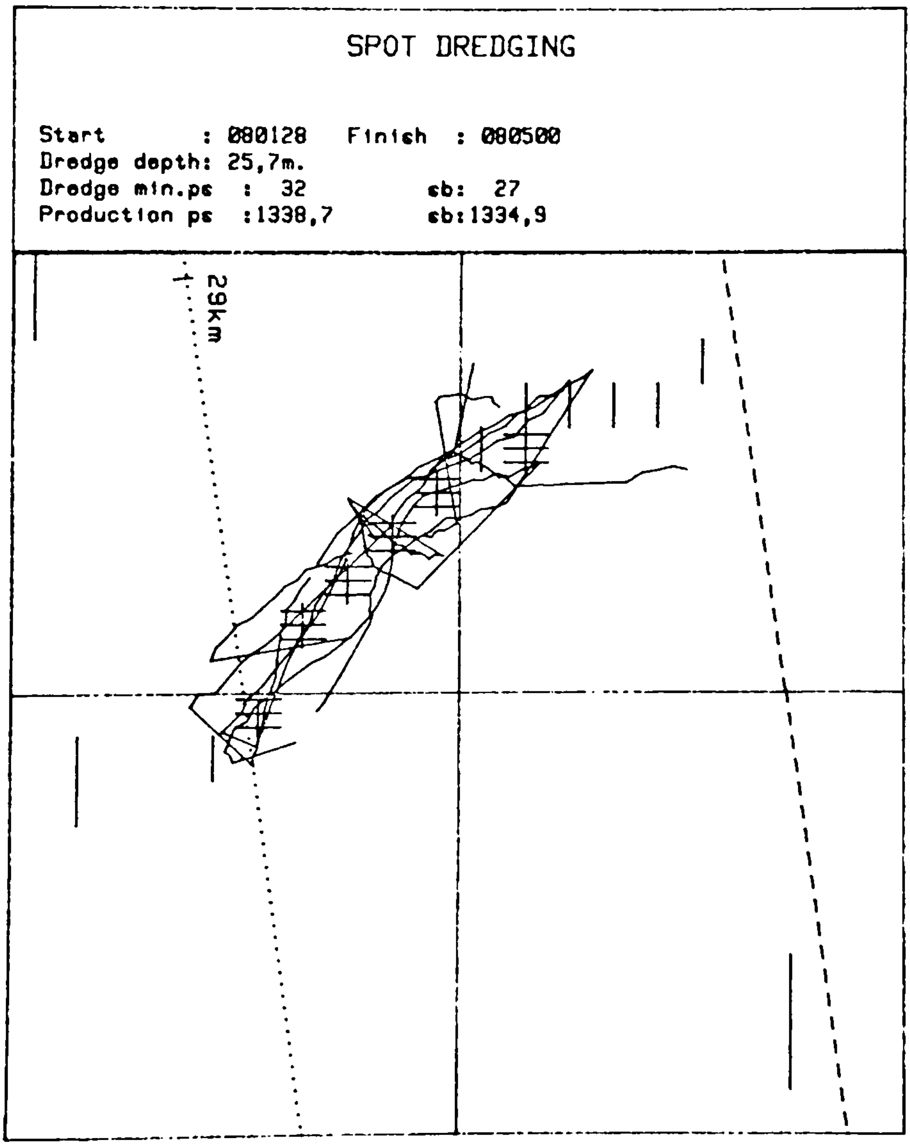
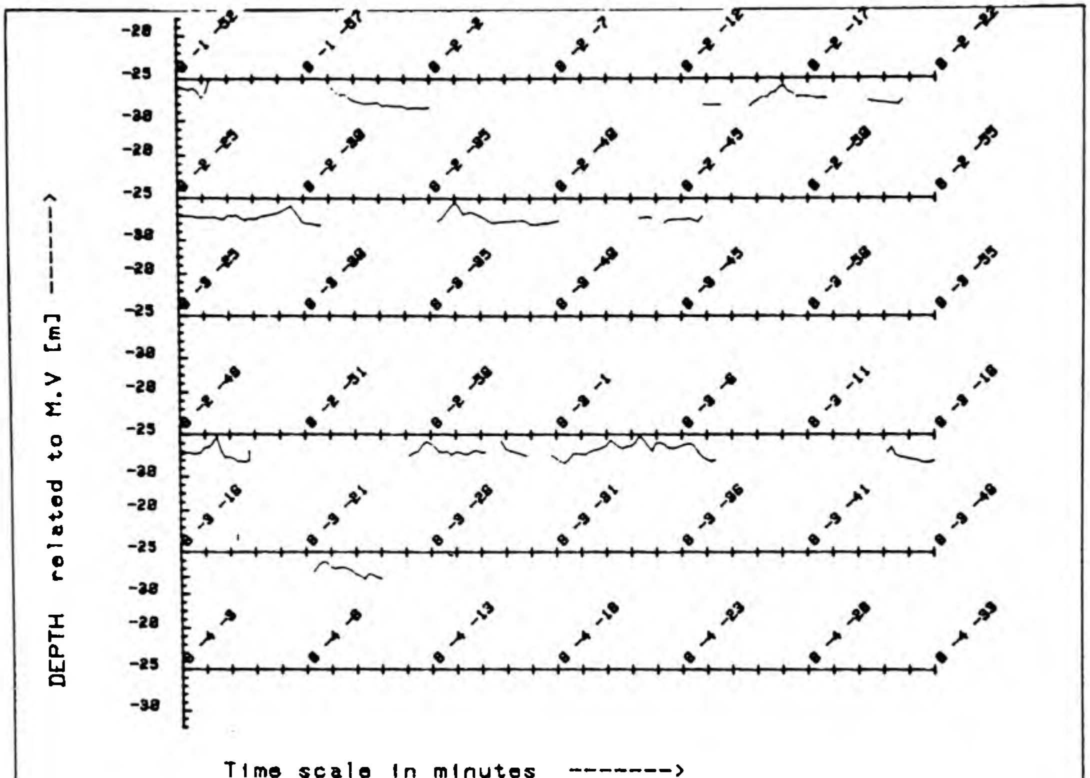

SPOT DREDGING
Start : 080128 Finish : 080500
Dredge depth: 25,7m.
Dredge min.ps : 32 sb: 27
Production ps :1338,7 sb:1334,9
29km

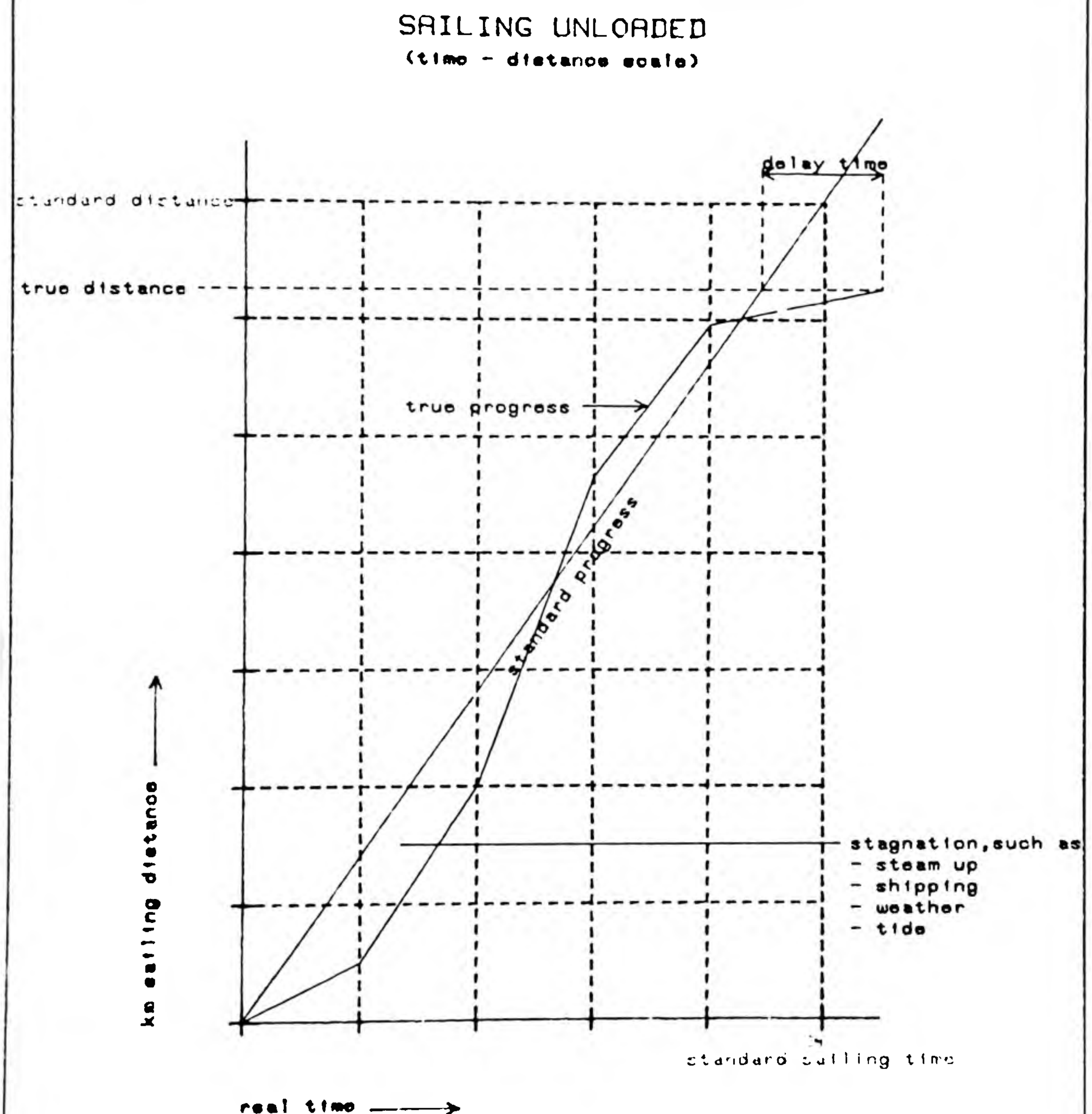
fig. 2



DEPTH SB DREDGE HEAD

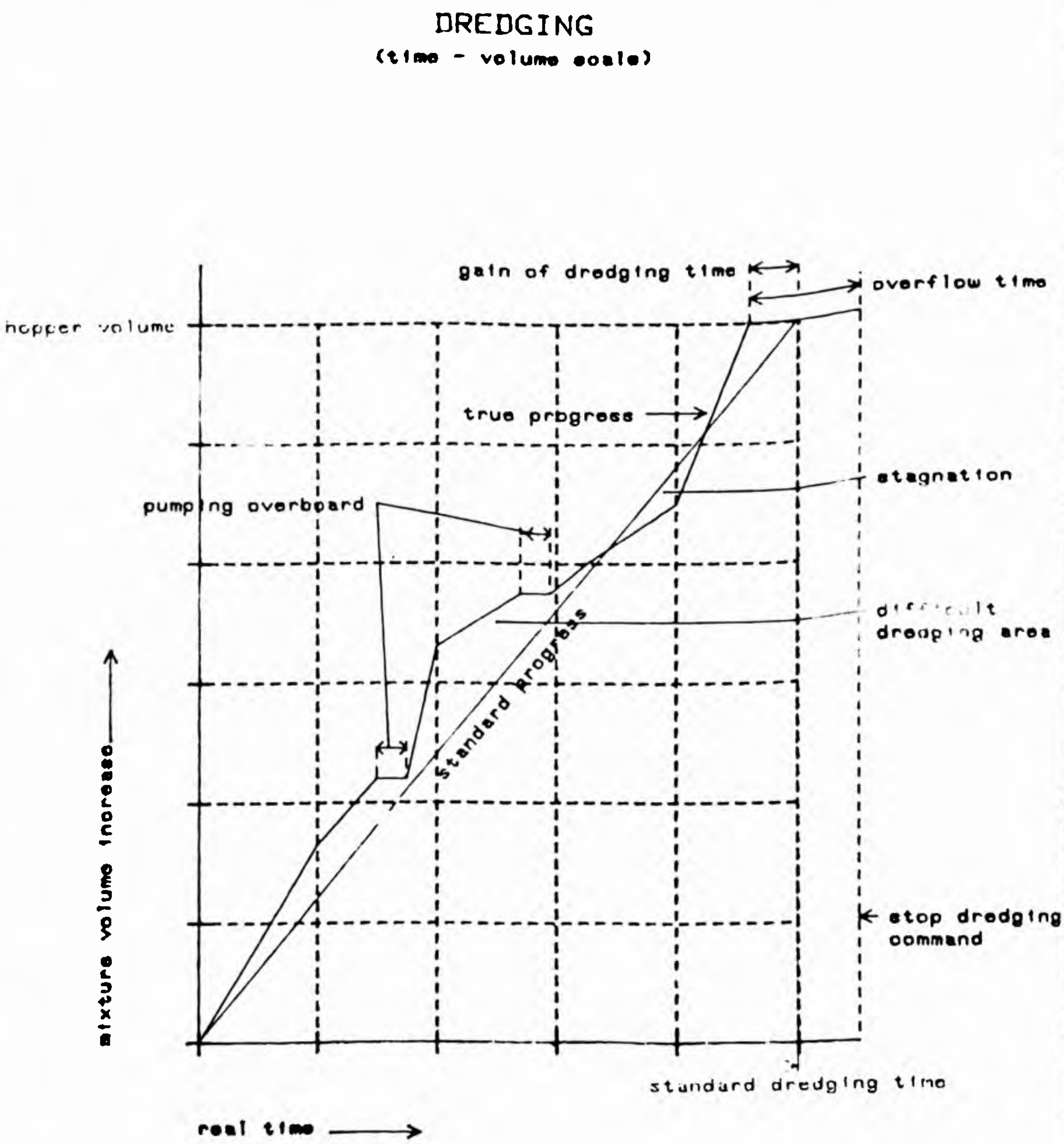
fig. 3

fig. 4



CONCLUSION : smaller distance covered in relatively more time translatable in delay time

fig. 5

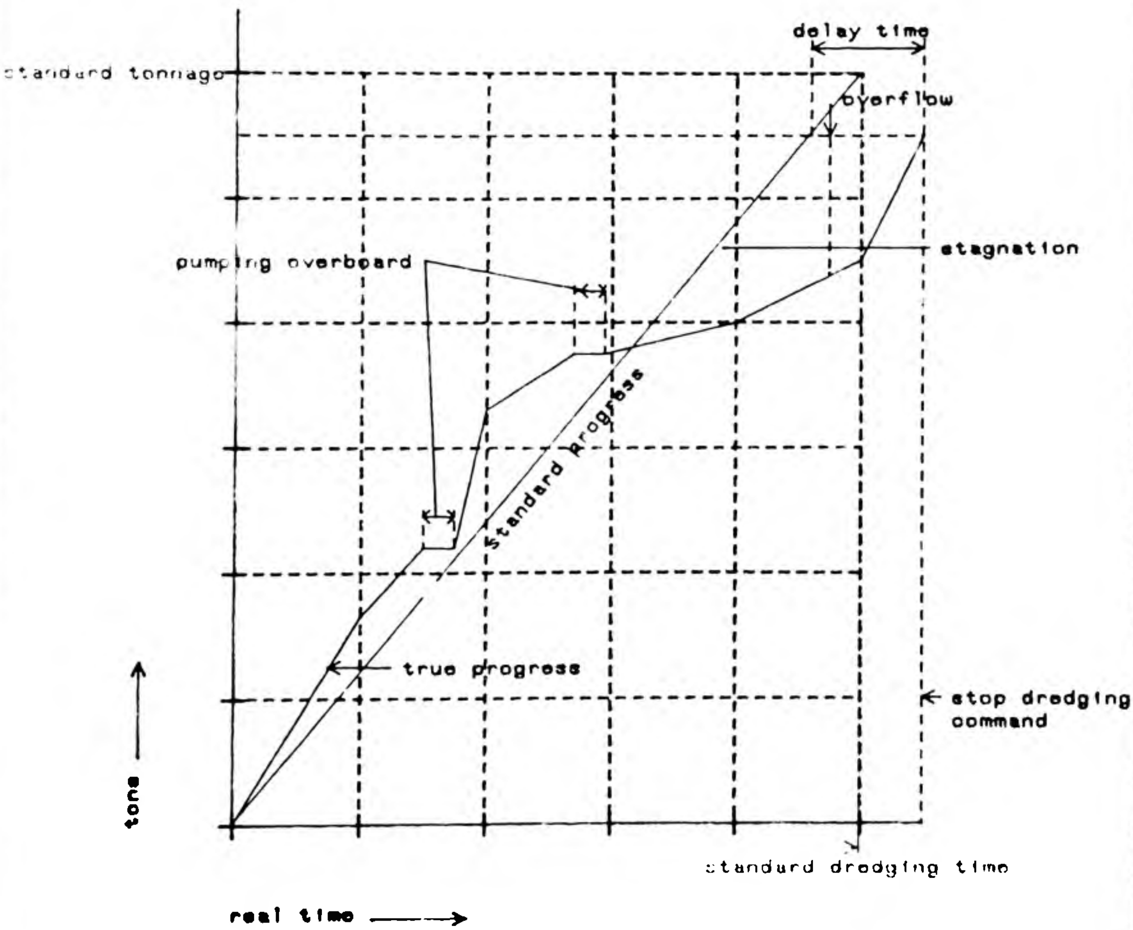


CONCLUSION : hopper volume in less than standard dredging time
overflow time as a result of time tonnage scale

fig. 6

DREDGING

(time - tonnage scale)



CONCLUSION : poor tonnage, exceeded dredging time :
related to standard tonnage progress
stagnation is exactly translatable in delay time

fig. 7

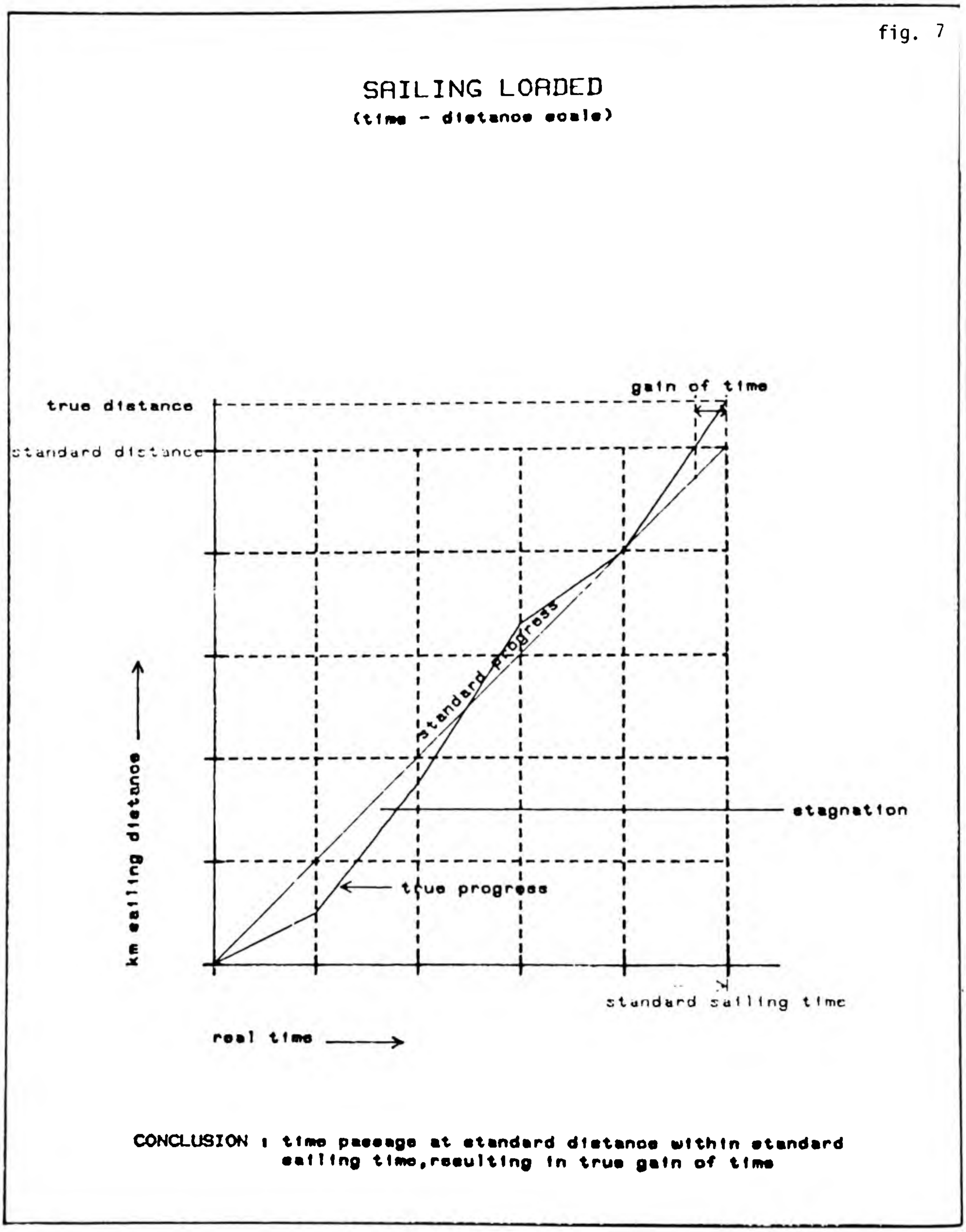
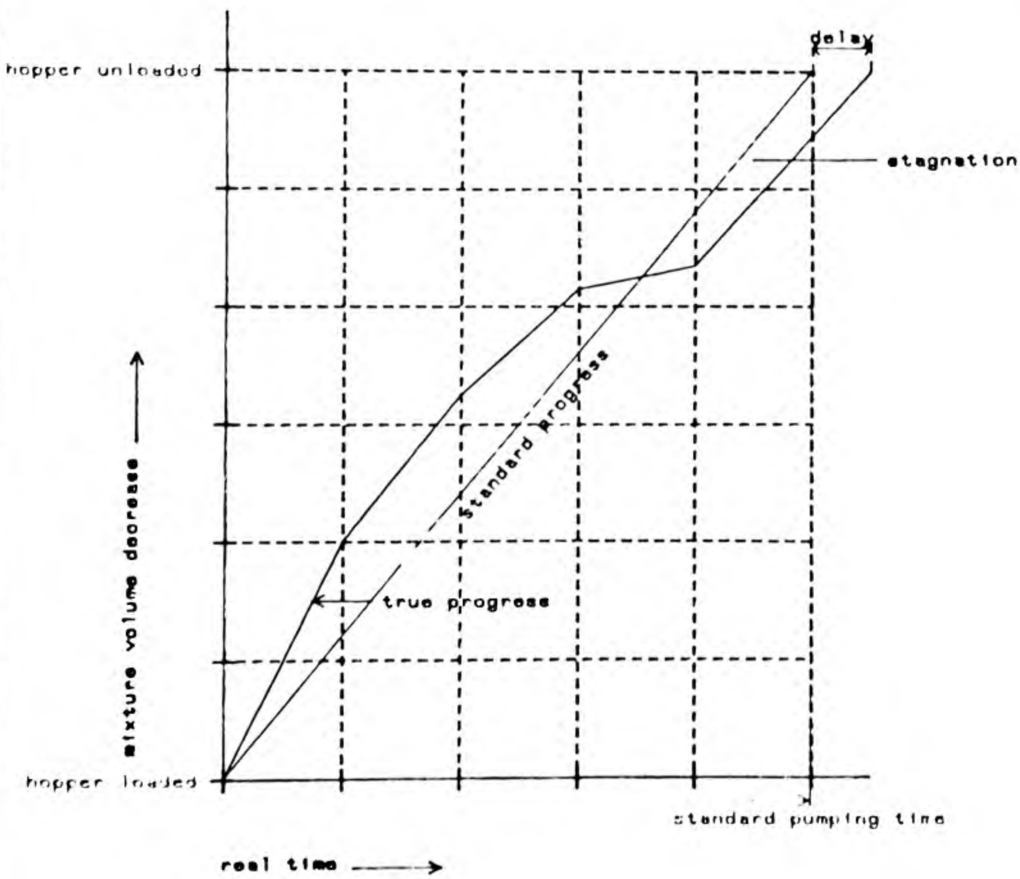

SAILING LOADED
(time - distance scale)
true distance
standard distance
gain of time
standard progress
stagnation
true progress
km sailing distance
standard sailing time
real time
CONCLUSION : time passage at standard distance within standard sailing time, resulting in true gain of time

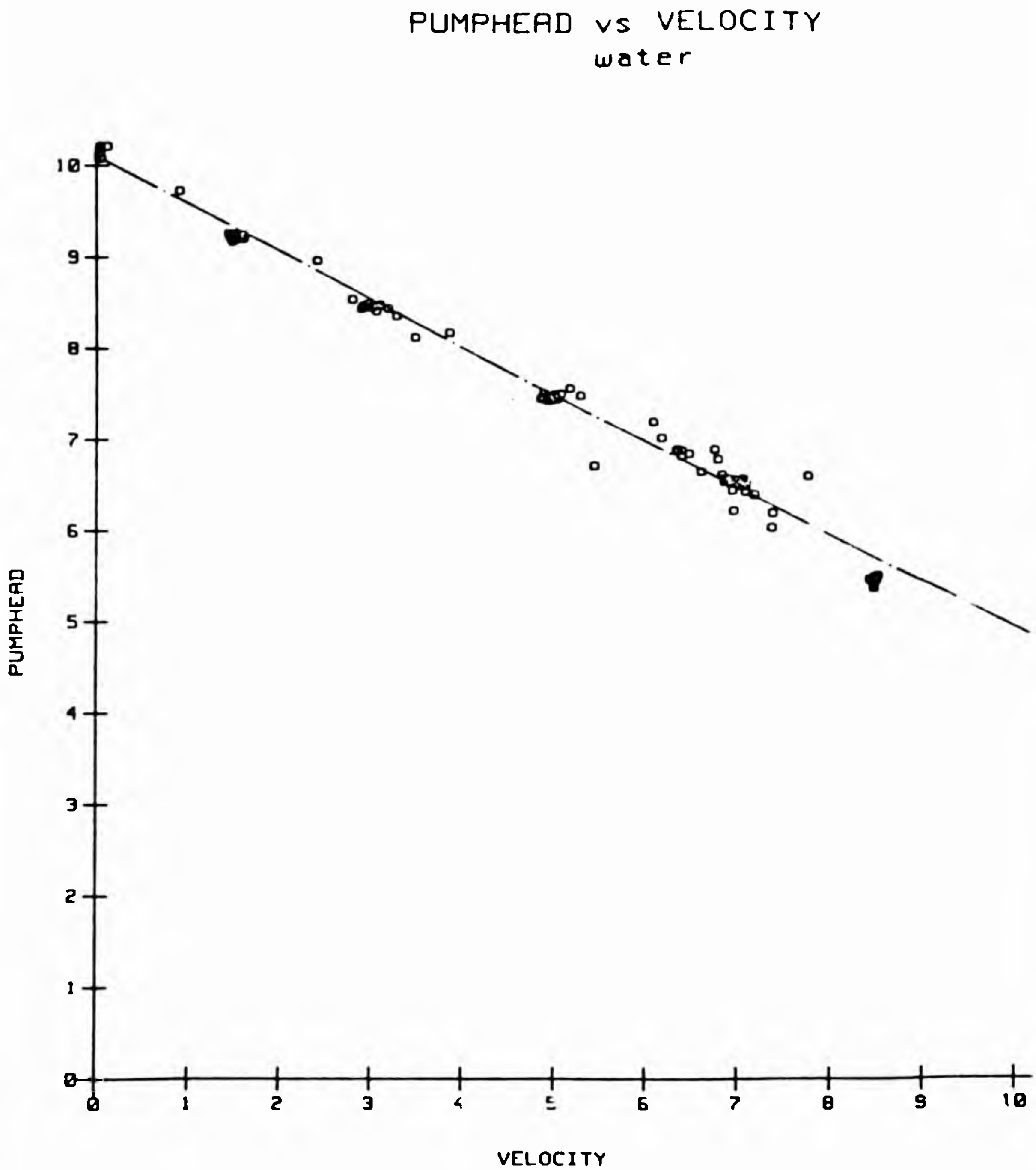
fig. 8

PUMPING ASHORE
(time - volume scale)



CONCLUSION : hopper not yet empty at standard pumping time
time consumption beyond this point is delay

fig. 9

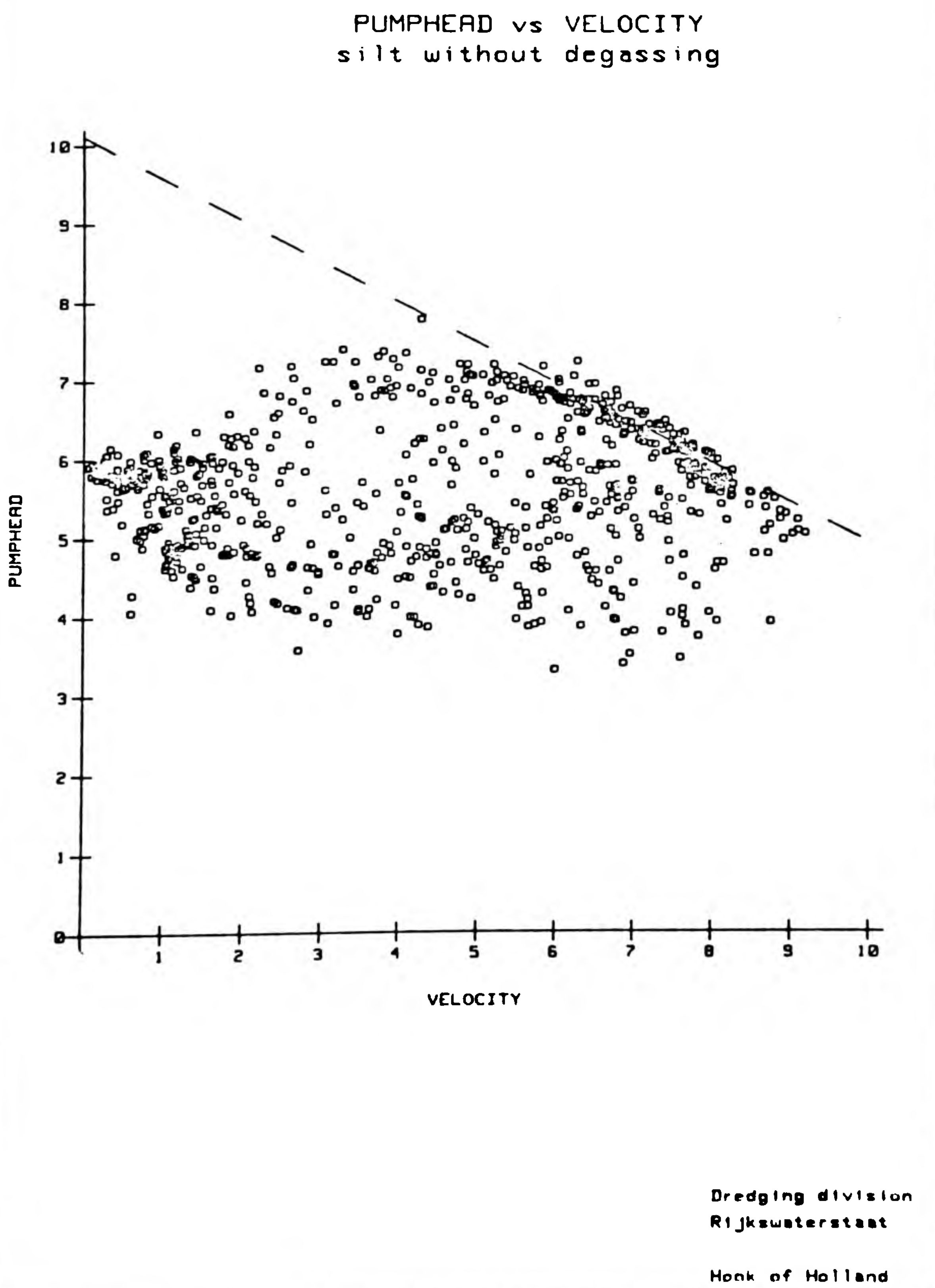


POLYNOMIAL MODEL: Y=A(M)*X^M+A(M-1)*X^(M-1)+...+A(1)*X+A(0)
Coefficients:
A(0)=10.10427193
A(1)=-.522714732
A(2)=.00069163809

Dredging division
Rijkswaterstaat

Hook of Holland

fig.10


PUMPHEAD vs VELOCITY
silt without degassing
PUMPHEAD
VELOCITY
0
1
2
3
4
5
6
7
8
9
10
Dredging division
Rijkswaterstaat
Hook of Holland

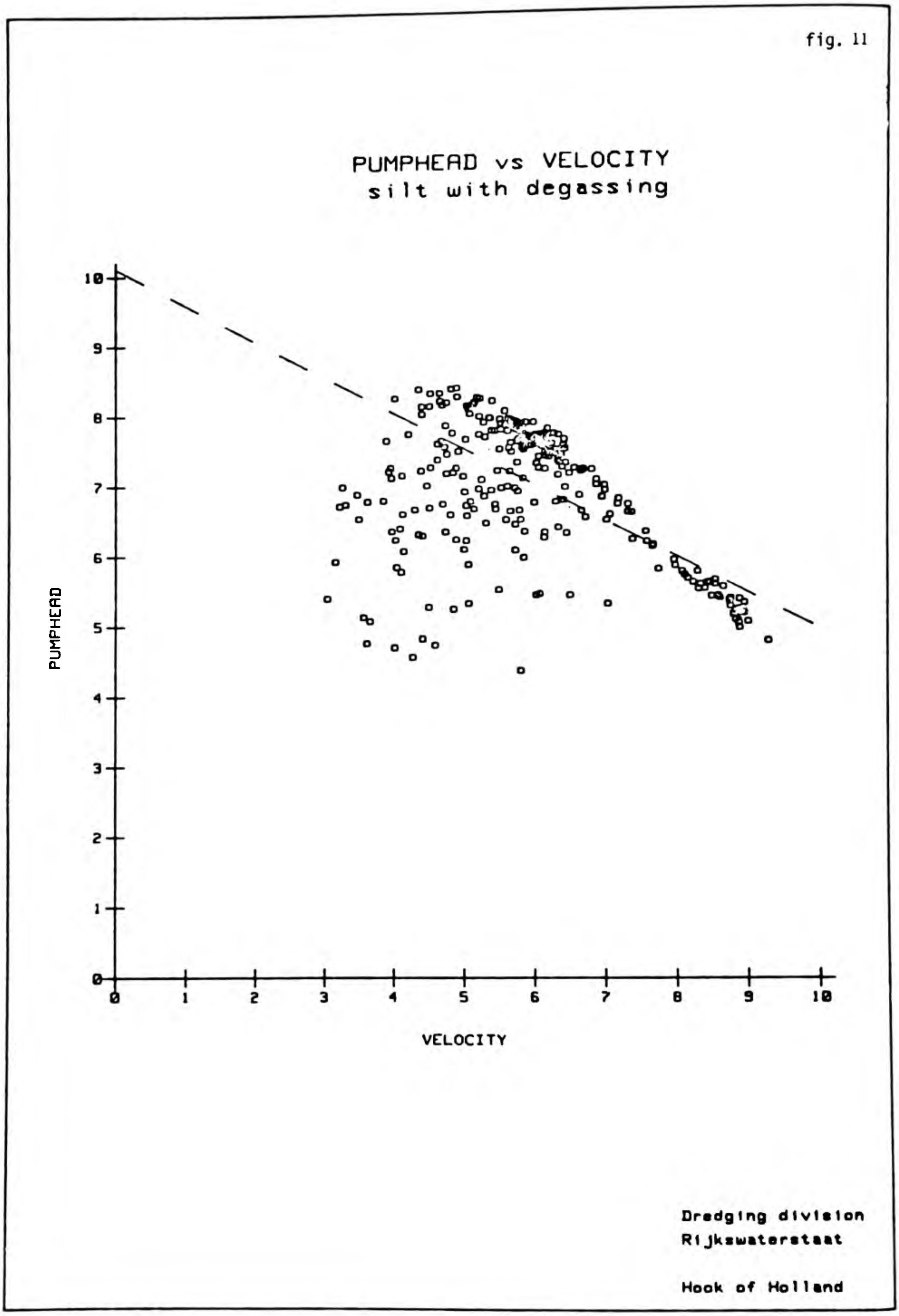
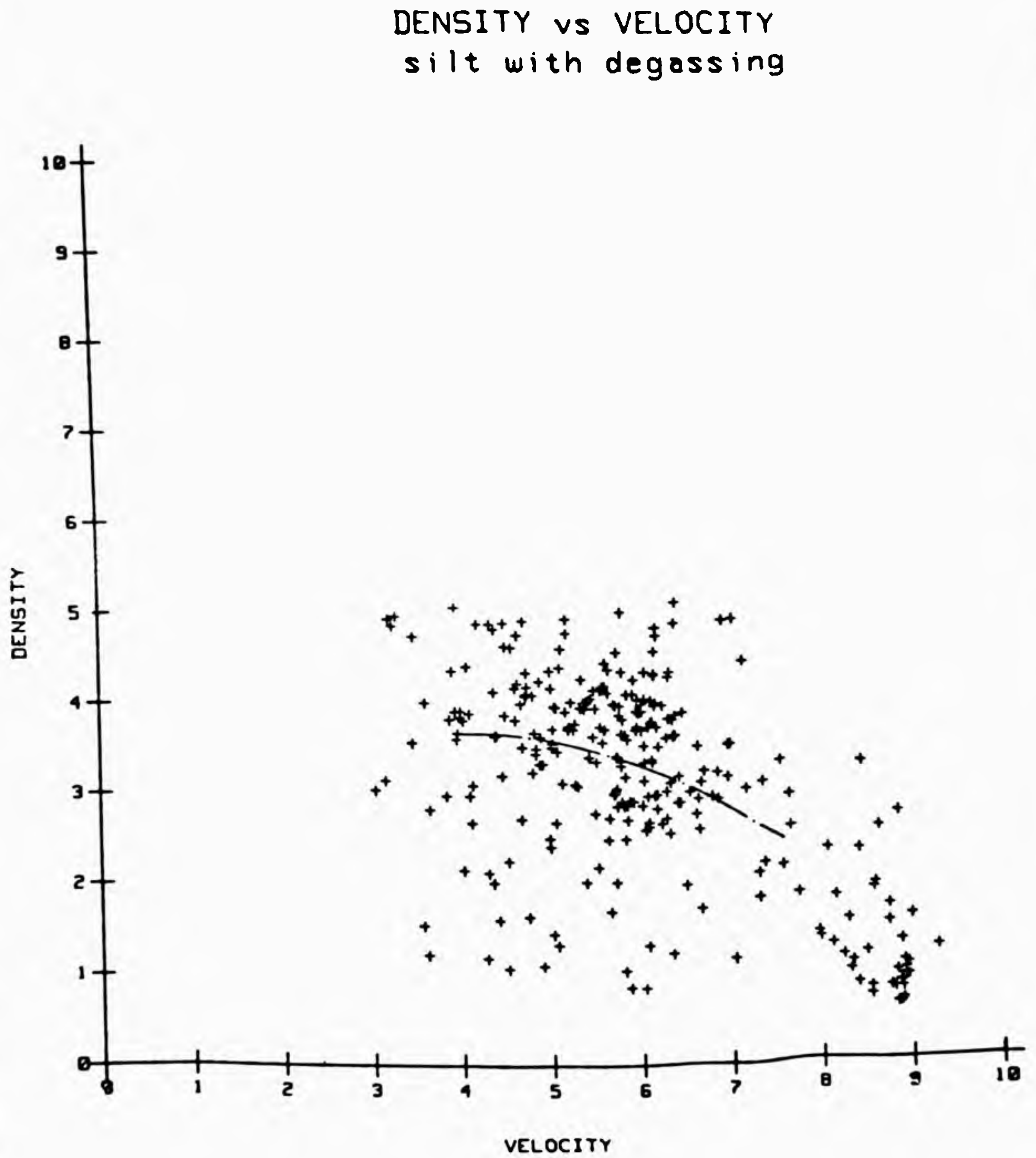


fig. 11
PUMPHEAD vs VELOCITY
silt with degassing
PUMPHEAD
VELOCITY
0
1
2
3
4
5
6
7
8
9
10
Dredging division
Rijkswaterstaat
Hook of Holland

fig. 12

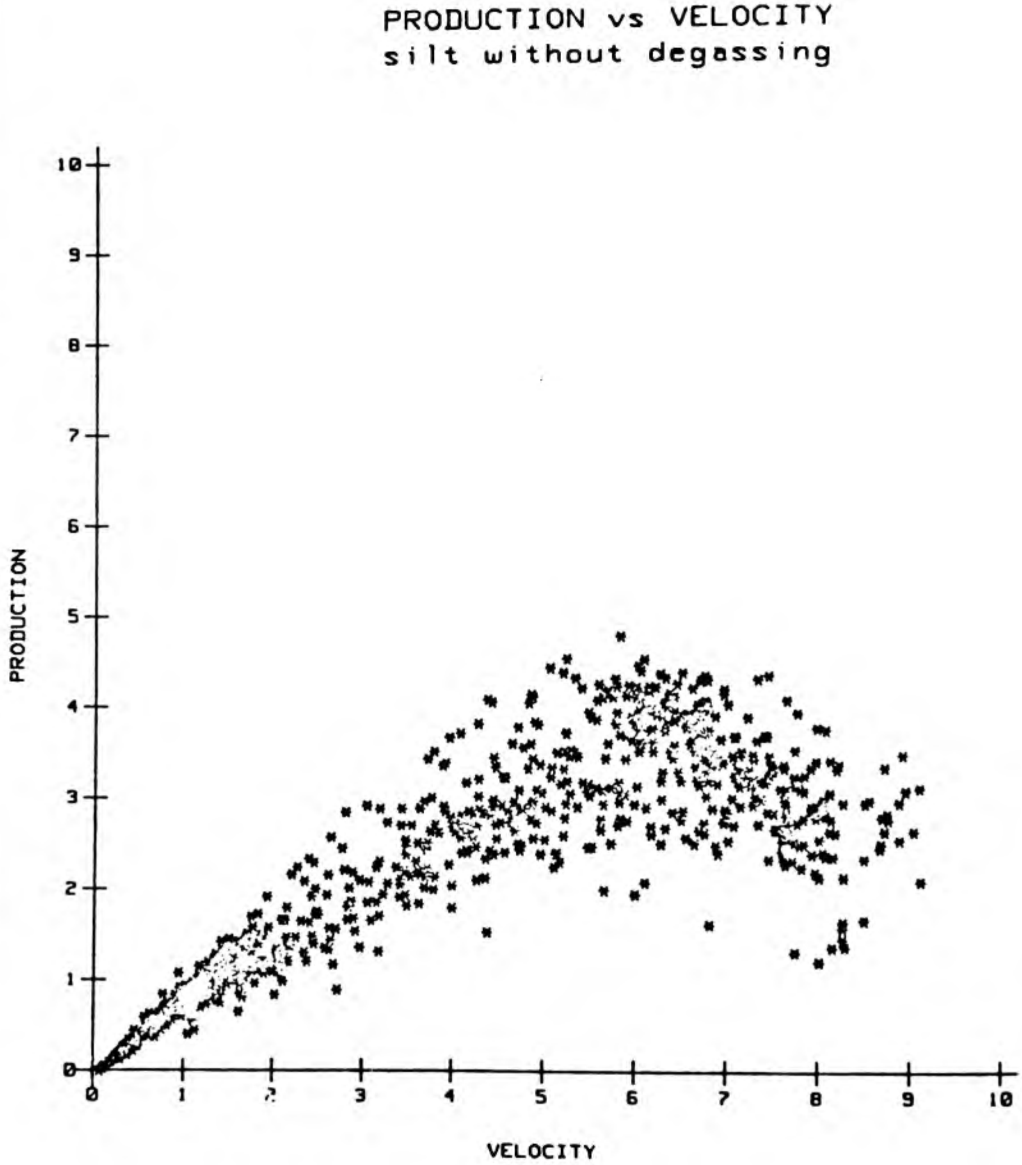


POLYNOMIAL MODEL: Y=A(M)*X^M+A(M-1)*X^(M-1)+...+A(1)*X+A(0)
Coefficients:
A(0)=2.00473963
A(1)=.82654102
A(2)=-.10048798l

Dredging division
Rijkswaterstaat

Hook of Holland

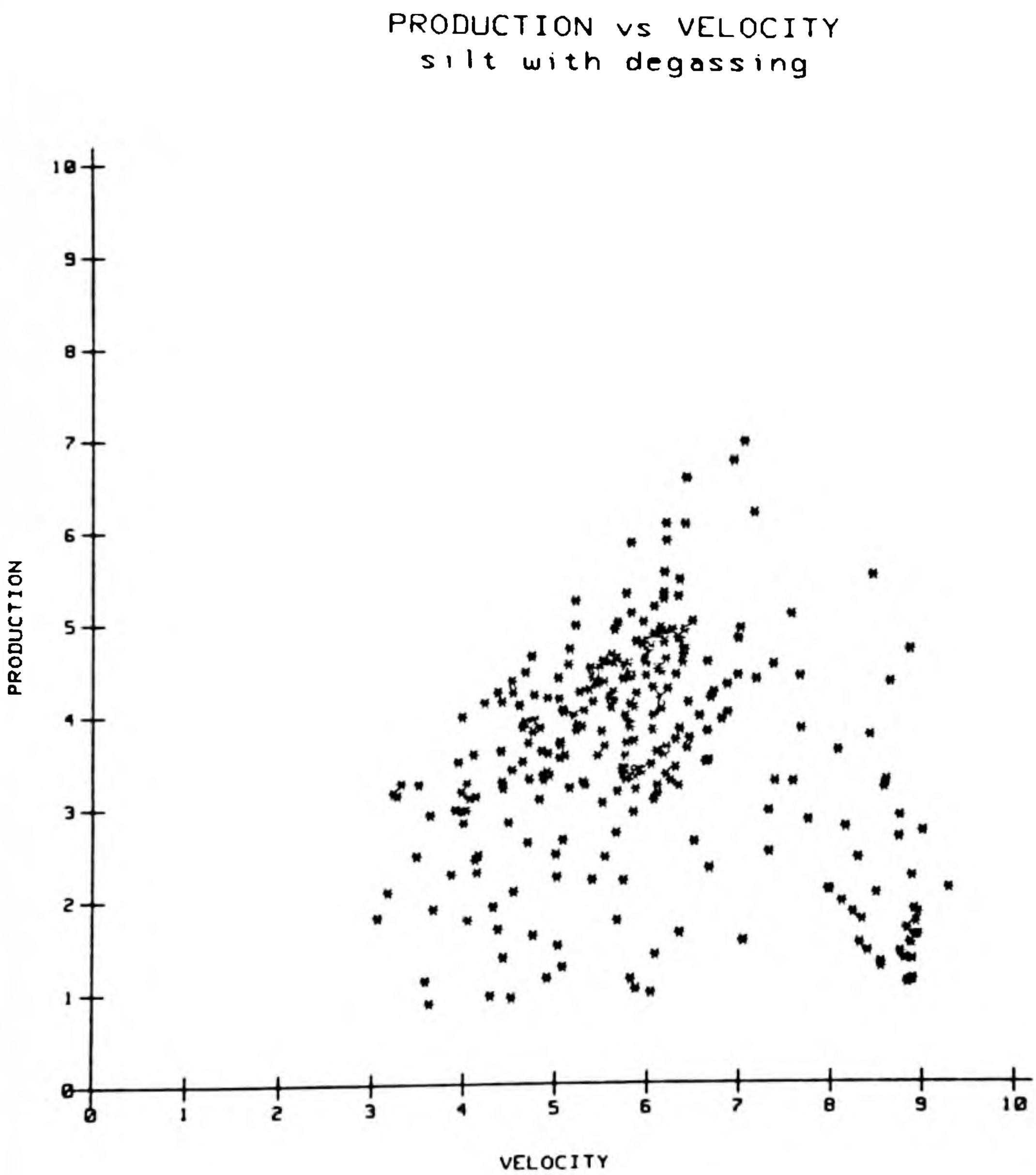
fig. 13



Dredging division
Rijkswaterstaat

Hook of Holland

fig. 14



Dredging division
Rijkswaterstaat

Hook of Holland

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5.4.3 Measurement of hopper production and production-incentives

The following is a summary of the lectures presented at the Dredging Division and the subsequent discussions.

In Hook of Holland, the Principal and the Contractor have agreed on a standard method of production measurement. The payment to the Contractor is based on the production hereby measured.

In a fully loaded hopper, the silt near the bottom is heavier with a density of 1,200 kg/cu.m. or more. Near the hopper surface, the silt is lighter and may be considered as a mixture of dense silt and water. Ideally, the payment should be based on the amount of solid matter in the hopper. However, there is no such simple method by which this amount can be measured with reasonable accuracy.

The agreed procedure is:

a. At 10-20 positions in the loaded hopper, a float with a density of 1,200 kg/cu.m. is lowered down into the hopper. Hereby, the depth down to the level where the silt density is 1,200 kg/cu.m. is measured. The average value is calculated.

b. It is assumed that all the silt below this average depth is of the same density as the bed in the dredged area, and the price will be based on the full volume below this depth.

c. The silt above the established level is assumed to be a mixture of silt and water. For each hopper load, one sample of this loose silt is taken in the central part of the hopper. This sample is taken in half the depth down to the "interface", and with respect to silt content the sample is assumed to be representative for typical conditions in the layer of loose silt.

d. The sample of the loose silt is put into a high revolution centrifuge where the silt in the course of 10-15 minutes will settle (formerly, the silt in the sample was allowed to settle naturally, but this took about 5 hours). After the settling, the percentage of dense silt in the sample can easily be measured, in average it will be about 60%.

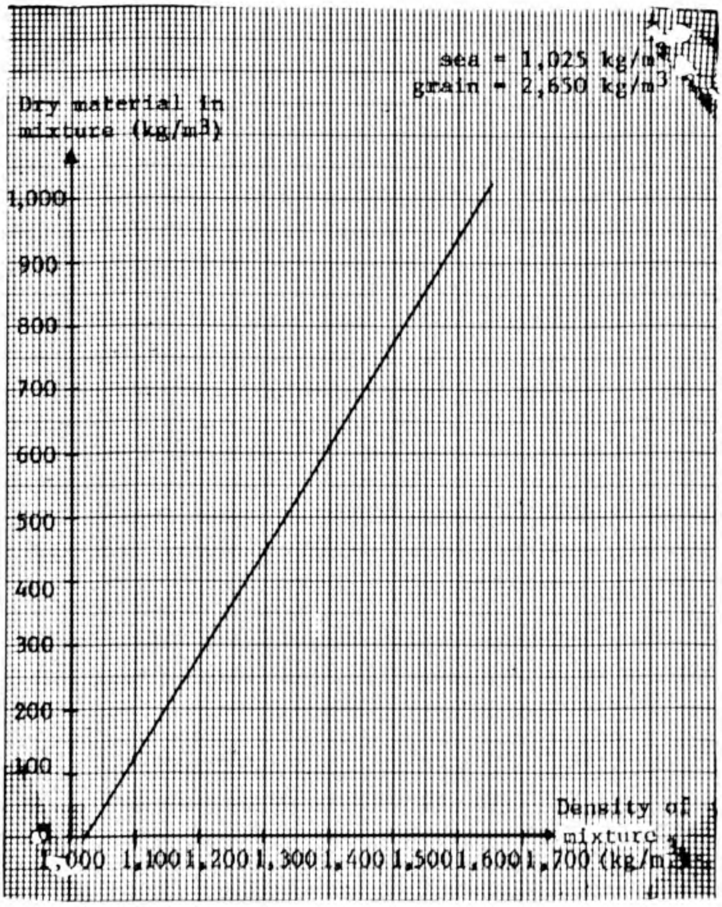
e. The total volume of bed sediment in the hopper is then calculated as the total quantity of sediment below the "interface" plus the amount of dense silt above the "interface". The payment to the contractor is then based on the total volume hereby calculated.

By using the described method of calculating the total volume of bed sediment in the hopper load, it is not at all pretended that the volume found hereby is a physically accurate estimate of the bed sediment actually dredged. However, the great advantage of the method is that the principal as well as the contractor have agreed to it. The method is well-defined leaving insignificant possibilities for disputes between the principal and the contractor.

As already mentioned, high priority is given to the development of s sophisticated system to establish accurate load records to be included in the Dredge-O-Graph. Such a system will be based on measurement of the ship displacement, the surface level of the mixture in the hopper and possibly also of the vertical density profile in the hopper.

Electronic pressure devices outside the ship, electronic pressure devices at the bottom of the hopper, acoustic equipment, electrical step gauges and the nuclear density probe may be used to provide the necessary information for the Dredge-O-Graph.

In the long-term, it is the aim of the Dredging Division to pay the contractor in terms of the mass of dry material dredged instead of the present agreement with payment calculated on basis of the volume of bed material dredged. The relation, the density of the sediment/water mixture vs. the quantity of dry material in the mixture (measured in kg/cu.m.) is plotted in the graph below. It appears that the quantity of dry material in the hopper is heavily dependant on the density of the mixture in the hopper. An accurate estimate of the mixture density is therefore required for a sound payment to the contractor.



The standard price paid to the Contractor is based on the "standard performance" of the dredger. However, the control of the actual progress on the Dredge-O-Graph and the agreed procedure for estimate of dredged bed material during each cycle have made it possible to introduce some production incentives to the Contractor. The actual price paid to the Contractor will depend on the actual performance of the dredger during the cycle, and this price may either be higher or lower than the standard price, i.e. the actual price will be higher for a production higher than the standard and lower for a production lower than the standard.

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6. DREDGING AND DISPOSAL OF POLLUTED MATERIAL

The areas along the River Rhine and the Rhine Delta region are densely populated and heavily industrialized. Waste water from households and industries has become heavily contaminated, and as part of this waste water is carried towards the sea by the River Rhine, large quantities of contaminants are being deposited in the Rotterdam Port area every year. Considerable research in dredging of polluted sediments has been done by the Port of Rotterdam Authority which was visited during the seminar-cum-study tour. During the visit, a presentation on "Environmental aspects and their effects on dredging in the Rotterdam Harbour" was made by Mr. C. de Waard, and areas for disposal of dredged, polluted sediments were visited.

The following material relating to the subject of the lecture was distributed to the participants:

- "A policy plan for the disposal of dredged material from the Port of Rotterdam" by Messrs. P. van Leeuwen, W.C.H. Kleinbloesem and H.J.Groenewegen, Public Works Department, Rotterdam, Part I of the paper presented at the World Dredging Congress held in Singapore, 19-22 April 1983.

- "A special way of dredging and disposing of heavily polluted silt in Rotterdam" by Mr. W.C.H. Kleinbloesem, Public Works Department Rotterdam and Mr. R.W. van der Weijde, Rotterdam Port Authority, Part II of the paper presented at the World Dredging Congress held in Singapore 19-22 April 1983.

- "Rotterdam Harbour Silt", published by Public Works Department Rotterdam, September 1983.

Here, extracts from "Rotterdam Harbour Silt" are presented and a short description of the disposal sites visited is given.

More information on Rotterdam Port is given in Section 5.

6.1 Extracts from "Rotterdam Harbour Silt"

Pollution

Formerly dredging and disposing of the silt represented hardly any problem at all. Dredged silt is in itself an excellent material for a number of purposes. But it gradually became evident that the silt dredged from the harbour area was polluted to varying degrees.

Revolutionary developments in industry and the increase in the population brought with them an appalling increase in the stream of waste products. New products from chemical and petro-chemical industries appeared on the market. Housewives were using washing and cleaning products with an increasingly radical effect. This whole development runs parallel with the process of pollution of land, sea and air. The Rotterdam Harbour area in particular could not be safeguarded from the harmful effects of the pollution.

Industrial and household waste products polluted the water in the Rotterdam rivers and harbours. This was not the only kind of pollution. A considerable amount was also discharged higher upstream along the Rhine and the Meuse and along canals and rivers which lead into them. An extensive chain of industrial sites can particularly be found along the Rhine which starts its course somewhere in Switzerland near the Bodensee and ends on the west coast of the Netherlands.

The stream of waste products which these industries jointly produce partially ends up in the sea. But a large quantity of polluted matter sinks to the bed of the rivers, canals and harbours. Most polluted matter adheres to the small, suspended silt particles. During its journey, natural sediment becomes polluted silt to varying degrees. Local waste water hereby serves to increase the pollution.

For many years, research has been carried out into the nature and origin of the waste products found here in the silt. All analyses of innumerable samples made at home and abroad furnish accurate data concerning the nature of the polluted matter and provide indications

Sampling to determine the quality

Stream of waste products

as to its origin. Together, these analyses give an overall picture of the quality of the water and silt, a quality which had changed little over the years in certain areas of the river or port. Great differences in quality have been found, however, between one harbour and another.

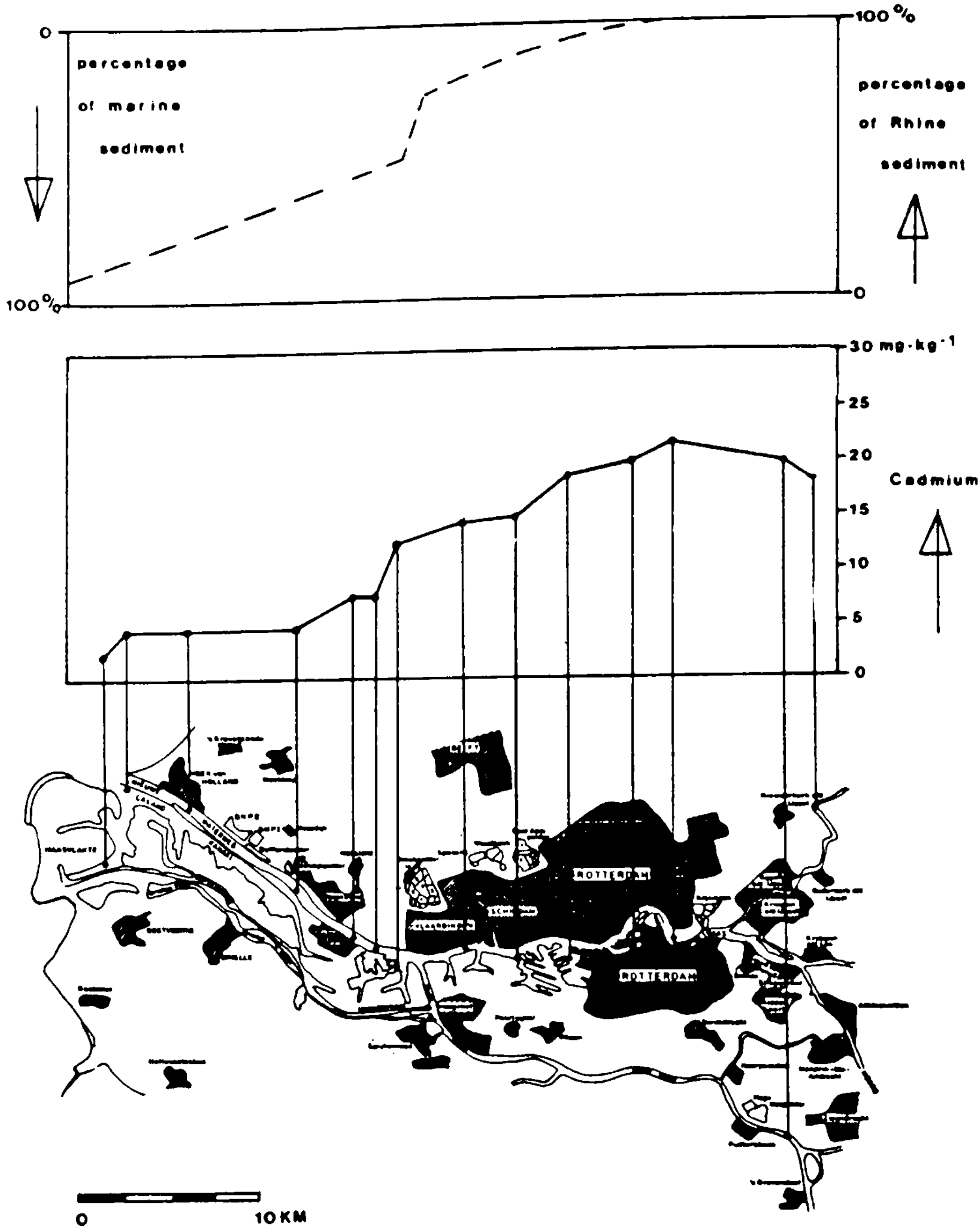
The quality of the silt from the Rotterdam Harbour area is also regularly checked by means of analyses of silt samples. On the basis of the results, the silt was classified into four categories.

Category 1 - Lightly polluted silt; coming from the western harbour area and particularly consisting of sediment transported by the sea.

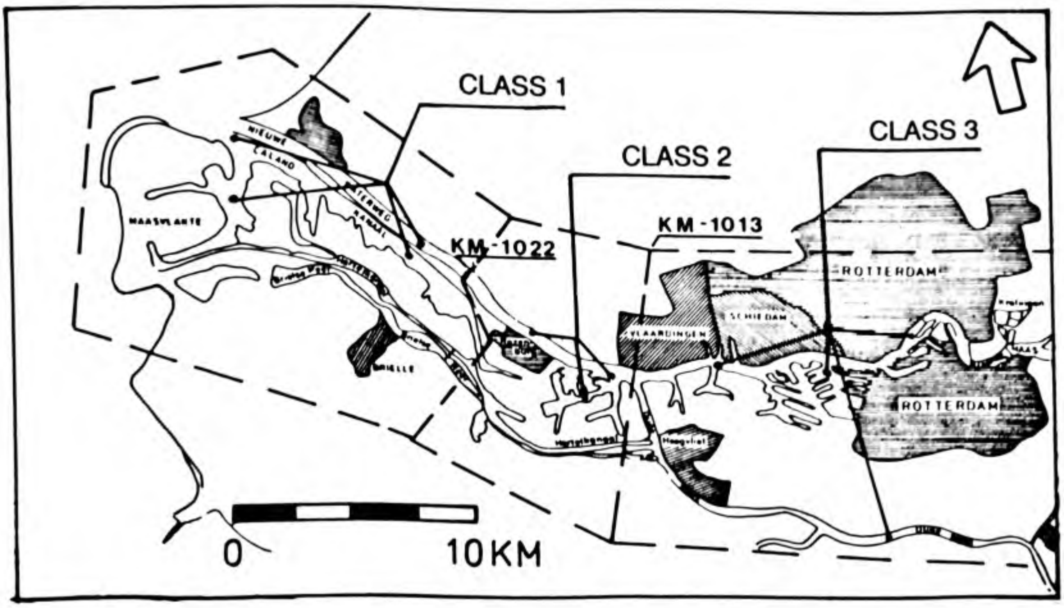
Category 2 - Medium polluted silt; coming from the central harbour area.

Category 3 - Polluted silt; coming from the eastern harbour area and particularly consisting of silt carried by the river.

Category 4 - Heavily polluted silt; present in certain locations in several harbours as the result of local discharge of waste products into the water.



Estimated percentages of river and marine sediment and related cadmium contamination in the Port of Rotterdam



Classification of sediments in the Rotterdam area

The difference in the quality of the silt is caused by the fact that polluted silt is carried from the east via the Rhine while relatively **clean** silt comes from the sea in the west. These two types are mixed in the central area.

On the basis of nature, properties and behaviour, the different types of pollution present in water and silt can be divided into groups. The substances are therefore grouped on the basis of their lesser (A) or greater (B) damaging influence on man and the environment. These two lists are declared by the European community in 1974.

A.
- heavy metals with compounds;
- eutrophic substances (excess of substances which are essential for plant growth in water such as phosphates, sulphates and nitrogen compounds);
- flavouring substances and perfumes;
- mineral oils;
- a number of salts, acids and bases, such as chloride, fluoride and cyanide.

B
- cancer-causing substances (i.e. PCA'S);
- organo-chlorine compounds;
- aldrin, dieldrin, endrin, isodrin, HCB, DDT, PCBs, HCH;
- certain pesticides;
- arsenic and arsenic compounds;
- mercury and mercury compounds;
- cadmium and cadmium compounds;
- organic phosphor and tin compounds.

A number of these substances are naturally present in silt and water. They become a threat to the environment if the concentration of particular substance becomes unnaturally high.

Apart from substances which occur naturally, water and silt are also polluted by substances which are alien to the environment. These often consist of residue from the process of manufacturing innumerable modern products such as insulating material, batteries, dyes, plastics, etc. and semi-finished materials for these products. Every form of pollution interferes with the environment. The nature and properties of all these substances considerably differ. The same applies to the consequences they have on the various forms of life. Pollution can cause the loss of indispensable links in a food chain. Substances which are not biodegradable accumulate in certain organs of a form of life and represent an increasing threat to the next link in the food chain.

In spite of the presence of more or less harmful substances, the sediment which has settled in harbours and rivers must be dredged and subsequently disposed of.

With regard to the lightly polluted silt, (category 1), which is transported by sea, the problems are not so great: it is taken back to the place it came from: the sea.

The sediment in which more polluted substances have adhered to the particles (categories 2 and 3) can best be disposed of on land or in lakes where both it and its effect on the environment can be controlled. With regard to the severely polluted silt from category 4, special measures have to be taken. It needs to be stored under special conditions whereby no further damage can be caused to the environment.

Disposal policy

The municipality of Rotterdam does everything possible under the given circumstances to recover and dispose the harbour silt as responsibly as possible. But they are not alone in this. It is a problem which is not limited to Rotterdam.

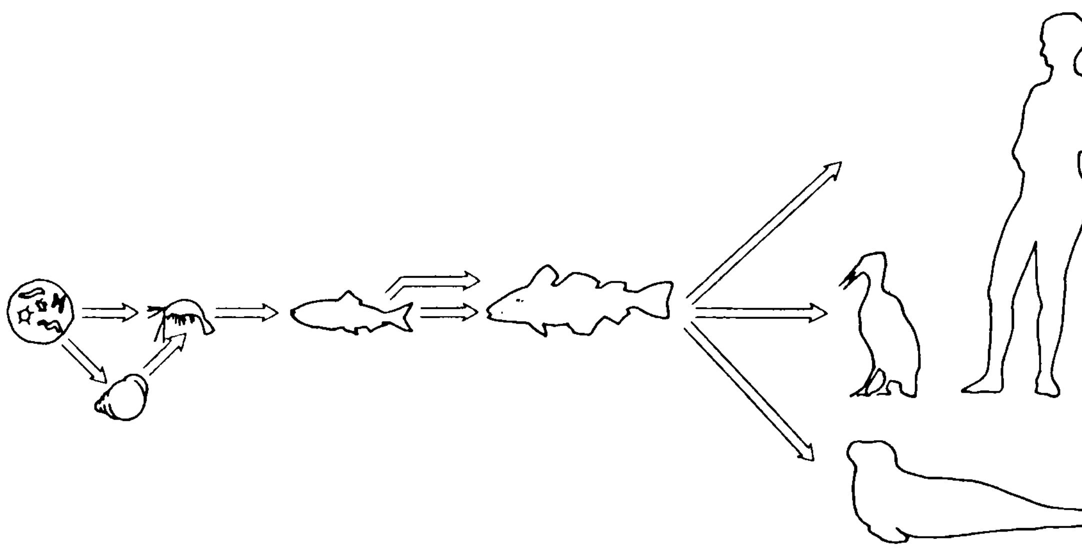
In 1975, a steering committee and a co-ordination commission were set up to find solutions to the problems surrounding the disposal of dredged material in the short and long term. In addition it was necessary to study the effects on the environment of the locations selected. The social and economical aspects of the disposal policy have to be taken in account too. Representatives at these consultations were: the provinces of South-Holland and Gelderland, the Public Authority Rijnmond, the Municipality of Rotterdam, the Ministry of Transport and Public Works and the Ministries of Agriculture and Fisheries, of Public Health and Environmental Hygiene and of Culture and Social Work.

Prior to the determination of any disposal policy, a report was made on the effects on the environment (Disposal of Dredged Material). Included in this report were the effects on the environment of disposing of dredged material in the sea, on land and in lakes.

From the results of the study, it appeared that the disposal of polluted dredged material on land or in lakes was preferable to dumping it in the sea.

It is impossible to control the spread of pollution in the sea. The polluted matter which enters the sea with the silt is carried along by the current. Along the coastline, it may be carried to the Wadden area, the North Sea birth place of many species of fish and shellfish and where they are taken up into the food-chain process.

Lakes which are considered eligible for the disposal of sludge are often lakes which have been formed by the excavation of clay, sand or gravel. Polluted material which enters lakes along with silt can spread outside the lake via sub-soil water or surface water, depending on the water management in that area. Where spreading occurs, a process is being dealt with which takes place very slowly.



Pollutions penetrate in higher species.

Other processes are concerned when dealing with disposal on land. The degree in which the pollution spreads depends, on land, on the local soil composition and the movement of sub-soil water. In low-lying polders it is often difficult for the polluted matter to penetrate the soil due to the upwards pressure of the sub-soil water. But spreading can take place, nevertheless, via the surface water.

If the disposal location lies somewhat higher, water can seep away into the sub-soil water, carrying some of the polluted matter with it.

If agricultural products are grown on harbour silt, the vegetation can absorb the pollution to a certain degree. This process depends on the type of vegetation and the type of pollution. Consumption of this vegetation can therefore have harmful consequences.

Although the steering committee and the co-ordination commission (Disposal of Dredged Material) may have concluded that the disposal of polluted dredged material on land or in lakes may be the least objectionable solution, this does not signify that the locations indicated by them can in fact be filled with dredged material.

The Rotterdam harbours are not exclusively and solely for Rotterdam. Other municipalities in the Netherlands and - since Rotterdam is a world port - other countries to a certain extent have just as much interest in the maintenance of the harbours of Rotterdam at the required depth.

A world port provides employment and prosperity to more people than simply its own residents. Sharing in and enjoying prosperity goes almost without saying in the society. This prosperity unfortunately also has less pleasant side effects. One such side-effect is the polluted silt which has to be dredged from the harbours and then disposed of. This is the point where sharing in the disadvantages of prosperity is not taken so much for granted.

The government, provinces, municipal authorities are responsible for policy related to space and the environment. The disposal of dredged material generally comes up against considerable resistance. It is essential that this policy should be carried out through negotiation in such a way as to find a responsible solution to the problem of dredged material. Negotiations must also lead to restraint in the discharge and dumping of waste products. These negotiations must also take place with other countries.

A start has been made. "The Rhine Countries Commission" represents just such negotiations at an international level. Its aim is to improve the quality of the water of the Rhine by means of international guide-lines and rules.

Finding a solution to the environment problem is hindered by the fact that along with environment interests economic and social interests play a major role too. You cannot simply close down a factory without compensation for workers and employers.

Industries are not solely responsible for the pollution of land, water and air. They may be the immediate cause of the stream of waste material, but they are doing it because people are all so keen to buy the articles which they produce.

People are all jointly involved in the cause of pollution. So it is necessary to find a joint solution to the problem of the pollution of the environment.

Through negotiations and through a co-ordinated effort, it will perhaps be possible in the future to reduce pollution, with respect to the discharge of waste material, to an acceptable level. Where the rivers are concerned, this will signify in the long-term that the silt which they transport and which then sinks in the Rotterdam estuary and harbour basins will once again be clean. It will then be able to dispose the 20 million cubic metres of dredged material without any problem.

Industrial area, source of pollution

Dredging

Consideration is not only paid to coarse refuse but also to chemical pollution of the silt. Contamination occurs in several places in the harbour area. It is mainly caused by discharging slop or chemicals directly into the water or by repeated spillage during loading or discharging oil. If the harbour bed is severely contaminated and dredging is necessary, like for instance the 1st Petroleum harbour, special precautions have to be taken.

When dredging the contaminated material, it is essential to avoid spreading to adjacent areas or silt being carried away to sea by the river current. A specially designed suction-head can be used to dredge the contaminated material.

The dredging process has to be carefully controlled and if necessary a de-gassing installation can be used.

When dumping dredged material into a specially made deep pit in the harbour itself, special techniques also have to be employed to avoid any spreading.

For this reason the dredged material is discharged, in the pit via a discharge pipeline which can be lowered under water to the very bottom of the pit. At the bottom end of the discharge pipeline a specially designed discharge opening is fitted to regulate the speed while discharging.

In this way the flow of the material can be controlled during the discharging process. None of these measures, however, can do anything to avoid the silt from being polluted. This is the main problem which also has to be dealt with when disposing of the dredged material.

Searching for locations

The disposal of dredged material never caused any problem. On the contrary, it was a popular product and much in demand. Low-lying areas were filled with it to raise the level of the land and improve the bearing capacity of the soil. These land-filled areas were used for building homes and establishing industry. Since ripened silt is very fertile, it was also a very desirable form of soil for agriculture, forestry and horticulture.

These possible uses of harbour silt suddenly blocked when, in the early seventies chemical analyses of the harbour silt showed that the Rotterdam silt was polluted.

From that time onwards, it became increasingly difficult to find locations where the silt could be deposited. Very often neighbouring municipalities did not want the silt within their boundaries. The possibilities of disposing of the silt within Rotterdam's own boundaries decreased rapidly. The disposal of dredged material does not only represent a problem of Rotterdam; it is a problem for the Ministry of Transport and Public Works as well. There are in addition - in the area south of the rivers - smaller harbours belonging to other municipalities and to private companies, such as shipping wharves.

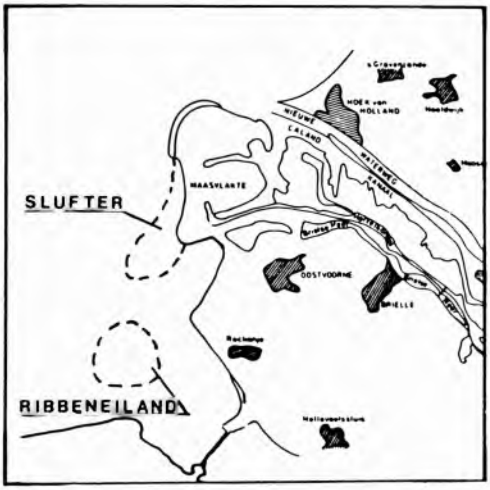
In the Environmental Effects Report issued in 1979 by the Steering Committee on Disposal of Dredged Material, it was concluded that disposal of dredged material on land or in lakes could be better controlled and was preferable to dumping in the sea.

The study, carried out by the Co-ordination Commission on Disposal of Dredged Material together with the Ministry of Public Health and Environmental Care did not take into consideration the lightly contaminated silt from the western harbours (Europoort and Maasvlakte). This silt can be dumped in the sea since its chemical composition corresponds with that of the sea-bed. The Environmental Effects Report also recommended that areas raised by silt should not be used for either agricultural or horticultural purposes because certain plants can absorb some pollution. Consequently, the pollution can then be taken up into the food-chain-process.

The Provisional Policy Plan on Disposal of Dredged Material which appeared in December 1980 named approximately forty land-disposal sites. Following a round of consultations in 1981, the final Policy Plan was edited in March 1982. This plan included long, medium-long and short-term recommendations.

- The long-term activities shall be aimed at cleaning up industrial waste and other waste water discharged into the rivers and harbours so that eventually only unpolluted silt will be found in harbours and rivers. In view of the fact that this matter is also being handled at an international level, this aim of attaining clean silt is only likely to be achieved in the long-term (20-30 years).

- Medium-long term: since approximately 10 million m^3 of silt have to be disposed of annually, the policy plan has sought to provide a solution in a large-scale location. The pro's and con's of the following two possibilities are being considered: the 'slufter' plan off the coast of the Maasvlakte and Voorne and an island in front of the Haringvliet estuary (sea side).



Designs for a long scale disposal area; solution for the medium-long term

- The Short-term: since the above-mentioned large-scale location will not be available before 1987, the plan has indicated a number of locations on land and in lakes for the period between 1983 and 1987. These locations were chosen following careful consideration in which the development plan for the area, the environment and the capacity and cost all played a role.

Permits

Before a start can be made on disposing of dredged material at any particular location, the legislative permits have to be applied for. Before applying the Public Works Department makes a study on the following aspects:

- the situation of the site.
- origin and composition of the silt.
- the geo-technical and geo-hydrologic situation.
- pollution to be expected in the ground, subsoil water and surface water in and around the land fill.

If these studies show that the expected effects on the environment are acceptable, a report is drawn up to be used as a basis of applications for a permit.

Precisely which permit is necessary depends on the location. It is usually a question of permits granted by the province of South-Holland and the 'Rijnmond Public Authority. Sometimes a construction permit is necessary from the municipality concerned and a permit from the Ministry of Transport and Public Works by virtue of the law governing the pollution of surface water. Applications can be open for inspection and consultation is possible. The result of this will be incorporated and the permit may or may not be issued.

Interested parties can appeal to the Council of State against a granted permit on the basis of the A.R.O.B. (General Jurisdiction Government Decrees).

Permission to dump silt in the sea is granted by the Ministry of Transport and Public Works, North Sea Management.

Disposing of dredged material

If all permits have been granted and an agreement has also been reached with the owner of the land to use the site, preparations can be made for actual disposal of the dredged material.

First of all, a small dyke is constructed around the entire disposal area This is made with earth from inside the disposal area and serves to retain the dredged material. If the disposal area is large, it can be divided into several smaller sections by dykes.

A seepage ditch is constructed all around the disposal area to collect the water which percolates through the dikes. By maintaining the ditch level below the level of the surrounding (polder) wastes, direct sideways seepage can be collected and transported to open water.

In the river or channel lying close to the disposal area, a pontoon is installed to connect the barge unloading dredger or a self-expelling trailing suction hopper dredger to the pipeline in order to transport the silt from this location to the disposal area. If the length of this pipeline is more than three kilometres, a booster station is added to ensure the appropriate pressure in the pipeline.

After settling, the silt remains behind in the disposal area while the excess water is pumped back to the open water. For this purpose a drainage box is constructed. The excess water and the water from the seepage ditch flow through this to a sedimentation basin where any silt particles still present in the excess water can deposit. The water is subsequently returned to the channel via a return pipeline.

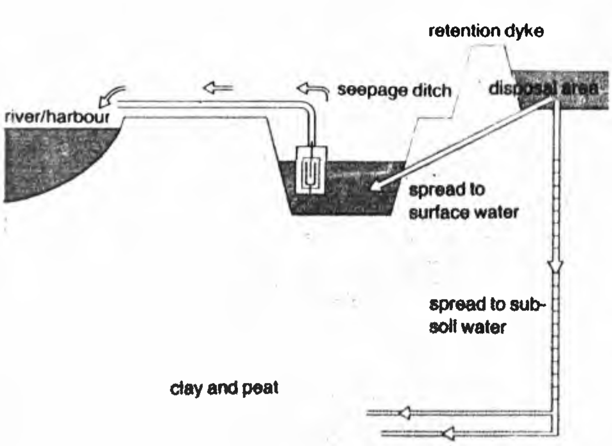
The dredged material is taken to the unloading pontoon by barges or by means of a trailing suction hopper dredger and transported to the disposal area via the pipeline. At the disposal area the pipeline bifurcates in order to spread the silt particularly over the sections. The sections are filled up in layers of approx. 1 to 1.5 metres. The silt layer pumped into the disposal area consists of 80 to 90% water.

In time a large proportion of the excess water gradually disappears and the disposal area changes from a mud-pool into an accessible site. But even then some pore-water remains between the silt particles. This water can be drained in various ways.

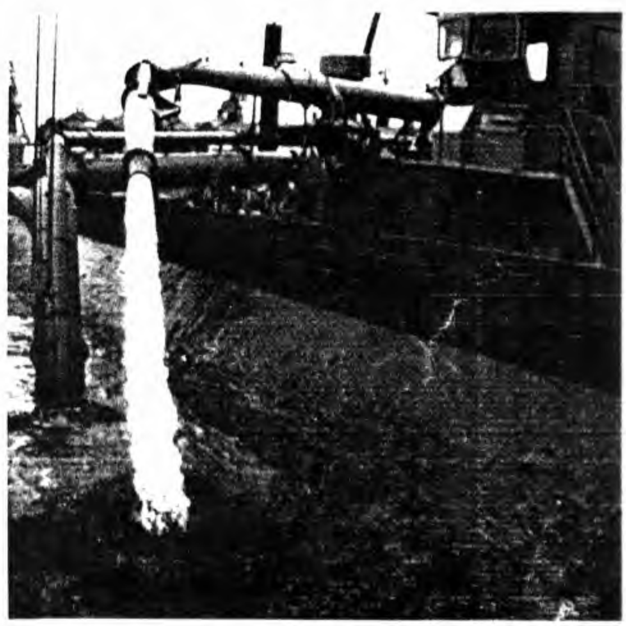
- It can emerge on the upper surface of the silt layer and either run off into the drainage box or evaporate.

- It can penetrate the retention dykes and percolate into the seepage ditch.

It can reach the seepage ditch via the subsoil or mingle with the sub-soil water.



Surplus of water from the disposal area is transported via seepage ditch



Sucking for transport by high-pressure pipeline

During and following the discharge of silt into the disposal area, the pollution remains absorbed by the silt particles. They are therefore left behind in the ground. The contaminants in the pore-water can spread via the disposal area surface water, the sub-soil water or, at a later stage when the area is in use, through absorption by plants. The contaminated pore-water which enters the surface water of the raised area itself is returned to the river via the return pipeline. The seepage ditch which has been constructed ensures that the water in the disposal area and the water in the neighbouring area are kept separate. Pore-water containing contaminants which penetrates the sub-soil water percolates with this sub-soil water to deeper levels. This is not likely to occur in the first decades. After this period, some sub-soil water from the disposal grounds might crop up the surrounding polders. However the rate of pollution of the seepage water is rather small. Furthermore the total quantity of seepage water is limited as well (approx. some percent of the precipitatin surplus). Therefore only a small effect on the environment of the neighbouring polders has to be expected.

The withdrawal of the water from the silt in the disposal area is called the ripening (or consolidation) process. This process can be accelerated. As soon as the disposal area is accessible, it is furrowed with an amphiroller. This is a machine on two helical (screw-shaped) rollers. With these rollers, which are placed lengthwise on the machine, it furrows through the dredged material. After some time these furrows are deepened by large disc wheels. Through its disc shape, the wheel sinks into the furrow which in that way becomes deeper. On account of these furrows, the pore-water can emerge faster and consequently the compaction process will be accelerated as well. Rainwater drains away quickly through the furrows and tends to penetrate the silt matter less.

After about 1 1/2 years, the silt has changed into young clay with a 40%-60% water content. When this stage is reached, the surrounding dykes can be raised with earth from inside the disposal area. A following layer of silt can then be added.

When a disposal area has reached its ultimate height and the silt has been sufficiently consolidated (stiffened), the area can then be used for various purposes. If it is intended for building houses, it is advisable to apply a layer of clean earth at least in the private gardens. This will prevent plants grown in a vegetable garden from absorbing pollution from the ground. It is also possible to cover the entire disposal area with a layer of clean sand.

A disposal site is also ideal for use as an industrial site or recreation area. On the basis of present knowledge, there are no special measures necessary. Account should, however, be taken of the fact that, whatever the ground is used for, it will continue to settle for quite some time since the consolidating process, two years after the final layer, is not yet wholly completed.

More ways with silt

More can be done with dredged harbour silt than merely dumping it in the sea or depositing it in lakes or disposal area on land. In order to dispose of the vast quantity of silt amounting to 20 million m^3 which is recovered annually from the Rotterdam harbours and rivers, in a way that is safe, more needs to be done. This is why authorities which are concerned such as the Ministry of Transport and Public Works, the Public Works Department and the Port Management of the Municipality of Rotterdam are seeking possible ways of using this silt for other purposes. They are also studying ways of controlling the ripening process as far as possible and of carrying out the dredging work itself as cheaply as possible.

Dumping dredged material in the sea or in lakes has one purpose only: to dispose of the silt. The concept of using dredged material for other purposes is based on a useful application of the material. In this instance, useful means something other than dumping it in a safe way simply in order to dispose of it. Raising a piece of land with silt is an example of useful application. If that piece of land were not raised with harbour silt, some other material would have been chosen. In its ripened form, dredged material can be used for many purposes. One principal application is as a replacement material for clay. These purposes are now being studied from technical and environmental-hygiene aspects.

The possible uses of dredging material can be divided into use as earth and as raw material.

1. Use of dredged silt as earth

   a. Use as raising material for housing, industry, recreation and forestry.

b. Use for hydraulic engineering projects such as improvement of river dykes, construction of dykes and quays and use as a protective coating.

c. Construction of embankments as a visual or anti-noise shield.

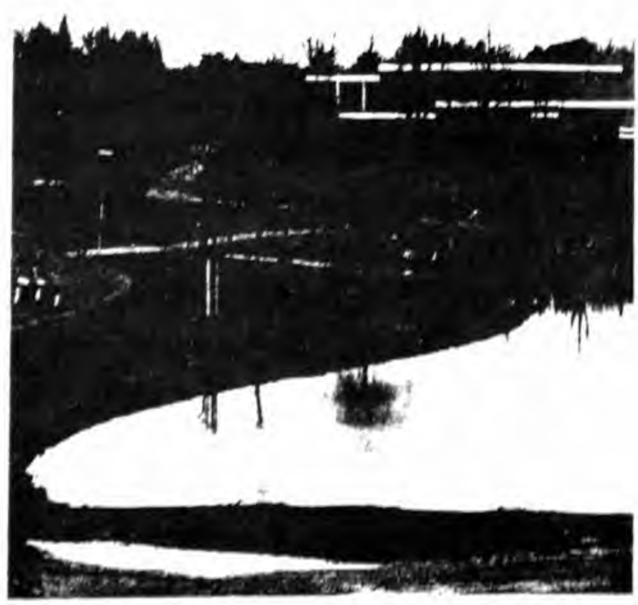
d. Use for land reclamation, such as an island in the sea or land reclamation near the coast.

2. <u>Use of dredged silt as a raw material</u>

a. Use for coarse ceramic industry e.g. bricks, roof-tiles, cobble stones etc.

b. Use for fine ceramic industry e.g. earthware, tiles etc.

c. Other applications such as artificial gravel, light additives and other building materials.



Recreation area raised with silt

The use of ripened dredged material instead of clay could be of major importance particularly in the coming years. Each year the coarse ceramic industry uses 4 million m^3 and the fine ceramic industry 0.2 million m^3 of clay. Clay is also used for the construction of anti-noise and partitioning embankments and new hydraulic engineering projects. Up to 1995, 19 million m^3 of clay will be needed for the improvement and strengthening of sea and river dykes alone. The Dutch sub-soil still contains sufficient clay for the coming years. But it lies in places preferably not to touch on account of their natural and landscape values. This is the reason why even clay has been imported from abroad for some years now. The quantity of silt which is dredged annually from the Rotterdam harbours and rivers is more than sufficient to meet the demands for clay.

With regard to the coarse ceramic industry tests have shown that when mixea with river lay, ripened dredged material can serve a useful purpose. Any further development is at present inhibited due to the collapse of the building market. The future prospects seem very favourable with regard to its use in dyke construction. The Public Works Department of Rotterdam had already had some experience in designing dykes near disposal areas. Ripene˙ dredged material from the disposal area was used for this purpose.

The Laboratory for Soil Mechanics in Delft, which carried out research into soil mechanical aspects such as compaction, contraction, crack-formation, permeability, erosion etc. reached the conclusion in its final report that ripened drdged material is suitable for use in the core of dykes. The approval of specifications drawn up in the study must of course be fulfilled. These of specificaitons are particularly directed towards the grain composition and a sufficiently low clay moisture content. Similar specifications also apply to natural river clay. A further investigation is being carried out in a trial section into the use of ripened dredged material as a coating layer on dykes.

'In addition to soil mechanics, a study was also made of the environmental aspects. This was carried out by a work-group consisting of several different authorities and under the chairmanship of the South-Holland Provincial Authority for Transport and Public Works. In its final report, this work-group reached the conclusion that use of ripened silt dredged from the Rotterdam harbour area could safely be used for the improvement of dykes from an environmental point of view. It must not be expected, however, that the potential forms of re-use just mentioned will provide a sufficiently large-scale solution for the problem of disposing of the dredged material. A partial solution of the problem, although valuable in itself, is the most that can be expected.

6.2 Visit to sites with disposal of polluted silt

Two sites with disposal of polluted silt were visited during the seminar-cum-study tour. The first site visited was the temporary disposal site at Maasvlakte. Afterwards a previous disposal site in Vlaardingen was visited.

The "Slufter" large scale disposal site (Class 2 and 3 sediments) is being developed and is expected to become operational in 1987, see figure on p. 311. Until its completion a temporary disposal site is used at Maasvlakte, and the sediments deposited here will later on be redredged and transported to the "Slufter"

The temporary disposal area covers an area of 300 ha and is protected by dykes 8 m high. It will be filled to a level 1-1.5 m below the crest level. Its capacity is thus about 20,000,000 cu.m The present annual quantity of dredged class 2 and 3 sediments is about 7,000,000 cu.m.

After the redredging and transport to the "Slufter" the total cost of dredging the contaminated sediments will amount to 10 Dfl/cu.m. This should be compared to a cost of 3 Dfl/cu.m. for class 1 sediments dumped offshore.

Environmental groups are opposed to the construction of the "Slufter", because the dykes 20 m high and surrounding the area will cause a reduced quantity of salt spray on the present coastline. This will affect rare natural vegetation in the dunes.

The disposal site in Vlaardingen was used in the late 50's and in the 60's. Disposal of sediments was stopped in 1968. The total quantity of disposed contaminated sediments was then about 25,000,000 cu.m. In 1970-71 the area was planted with trees, and today it is a recreational area.

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7. DREDGER BUILDING

The dredging plants of IHC Holland in Kinderdijk and Sliedrecht were visited during the Seminar cum Study Tour. Some of the recent developments in dredger building were presented.

A brief description of the IHC Beaver wheel dredger is made on the basis of IHC information material provided and a paper on the multi-purpose dredger is reproduced in this section.

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7.1 IHC beaver wheel dredgers

The invention of the dredger wheel is a great contribution to the development of the dredging industry in the latest years. The dredger wheel is particularly applicable to dredging of very hard soils like boulder clay.

The dredger wheel consists of about 15 bottomless buckets which during operation cut the soil and transport it to the suction inlet. Compared with a cutter suction dredger the wheel dredger is working rather efficiently, and production increase of up to 50 per cent may be obtained. This increase is achieved by a number of advantages which may be enumerated as follows:

- the dredger wheel has high cutting efficiency;

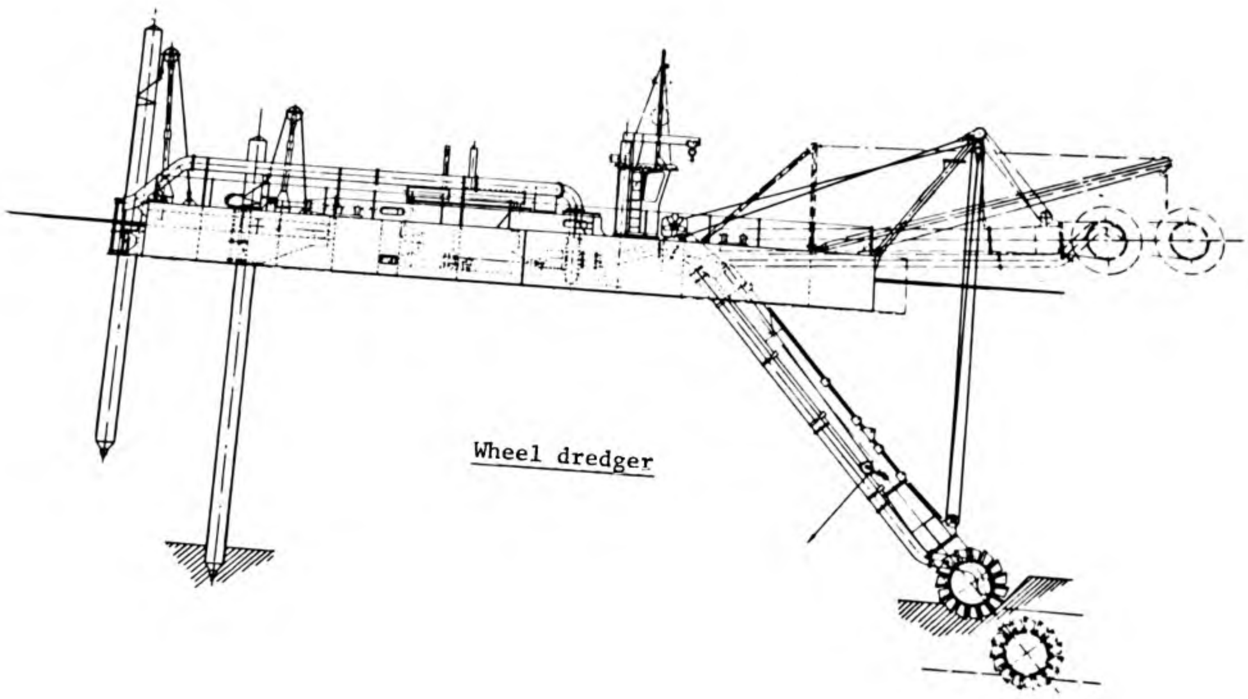
- the aperture between two successive cutting edges is smaller than the narrowest passage in the soil transport system; this eliminates blockage. Debris such as tree trunks or large stones cannot enter the dredging wheel and cause blockage;

- the dredging wheel has bottomless buckets to which sticky soils do not adhere;

- the soil dislodged by the cutting edges immediately reaches the suction mouth resulting in no spillage;

- the cutting force of the dredging wheel is directed upwards and is equally effective in both directions of swing.

The dredger wheel is heavier than a cutter, and this has consequences for the overall design of the wheel dredger. The wheel dredger design appears in the figure below, its similarity with the cutter suction dredger is evident.



Wheel dredger

7.2 Philosophy behind a new multi-purpose dredger for operation in small ports and waterways

By Messrs. R.H. Loevendie and R.J.A. Pander Maat, IHC Holland N.V.

SUMMARY

Maintenance dredging in small ports and waterways is often a problem. The large, specialized high tech dredgers of the worldwide operating dredging companies cannot enter these ports because of their length and draught.
In addition these vessels are often specialized in one kind of job. As a consequence dredging jobs in such a small port may require application of several types of dredgers. And this in turn will be uneconomic, especially if the port is rather far away from the dredgers homeport.
Local authorities in small ports are best served with an appropriate small dredger, which combines several dredging facilities.
In many circumstances even the small dredger will not be fully occupied throughout the whole year. Therefore the vessel should also be able to be of help with other port authority jobs, like buoylaying, pile driving, inter harbor transport, etc.
The vessel, designed for these situations is called Multi Purpose Dredger, and its design will be highlighted in this paper.
Length, hopper capacity, dredging equipment, propulsion and accommodation can be chosen within a modular system, which enables the owner to operate his "tailormade" multi purpose dredger within a short period.
Operating and maintenance are kept very easy to enable operation with local skills and experience. Besides that, the design is very well suited for construction in a local yard because it is built up with commonly available materials.

1. INTRODUCTION

Every nation, regardless of its social, political or economic structure, is faced with increasing expenditure on behalf of its development.
One of the main concerns is the infrastructure.
To meet the growing needs of the country, access to channels and port basins has to be maintained. Depending on influences such as tides, currents and weather conditions, differing volumes of silt have to be removed by maintenance dredging.
In this paper we shall consider dredging problems in small ports and waterways.
In many small ports in remote areas, hardly any dredging is done nowadays. There are several reasons for this.
The size of most dredgers in internationally operating dredging fleets makes

them unsuitable for operation in small waterways.
Moreover, such dredging jobs are in most cases small in relation to the mobilization distance, which the dredger has to cover to reach the port or waterway concerned. As a consequence contract dredging is fairly costly.
In most cases, the purchase of an own dredger is not the optimum solution, because the vessel will be unused for the greater part of the time. Furthermore, the cost is too high.
The next problem is that the dredger offered by builders of dredging equipment are often technically complicated tools, which are difficult to operate and to maintain in local circumstances. Also its price will be too high.

It was against this background that we set out to develop a philosophy to deal with the difficulties in maintaining small ports and waterways.

2. ECONOMIC CONSIDERATIONS

To start with we tried to find an economic solution to the problem of maintenance dredging.
There are two principal approaches:
The first is to use locally owned and operated dredgers; the second to employ usually foreign dredging contractors on a contract basis.

Basically dredging costs are the sum of the capital costs, maintenance costs, personal costs and fuel costs. In addition the cost of getting the vessel to the site can play a major part.
With the aid of computer programs we have made some comparative calculations, which now will be highlighted.

In fig. 1a, in which the cost per cubic metre of dredged material is related to the volume to be dredged annually, a comparison is made between the cost of contract dredging with a 750 m^3 suction hopper dredger and that of dredging with a government-owned dredger of 160 m^3.
Mainly because of the capital costs, the latter will be rather expensive unless the vessel is occupied throughout the year; this is clear from the left-hand part of the figure. In such cases, contract dredging is cheaper. However, if the volume of spoil to be removed annually is large, and a government-owned vessel can be provided with work continuously, this is the more economic solution, as is shown in the right-hand part of fig. 1a.
Unfortunately, volumes in the type of ports which we have in mind are not very large.
A similar comparison is made in fig. 1b, but here the total cost is compared with the annual volume.

Another approach is to compare the capital outflow involved in contract dredging and dredging with a locally-owned vessel. In our calculations we assumed that crew and maintenance costs paid in the local currency would account for at least one-third of the overall cost of operations carried out by governmental agencies. The proportion could, of course, be even higher if the vessel were to be built and financed locally and if local fuel is available.
The expenditure in foreign currency for both types of operation is compared in figs. 2a and 2b. For the smallest annual volumes, contract dredging again offers the most economical solution.
If the capital costs could be reduced, it might be possible to arrive at a satisfactory locally-owned dredger suitable for small annual volumes. Merely to design for maximum economy is not sufficient, however. We believe that we have

found a solution in a vessel which could be used for other purposes when not required for dredging.
In small ports there are, in addition to maintenance dredging, many operations which have to be performed, such as piledriving, buoy-laying, quay-building and transport. A dredger which could undertake such tasks as well would not be idle in between maintenance dredging operations; and as the capital cost could be spread, the dredging costs would be reduced. The ideal is that if only 8 weeks a year of dredging is necessary the other 44 weeks are occupied with other jobs, but this is unlikely to happen. In our trial calculations, we assumed that a multi-purpose vessel would spend 50% of its time on operations other than dredging.
If for instance the dredger needs 8 weeks for the annual production we estimated that 8 more weeks will be occupied with other jobs.
The results are shown in figs. 3a and 3b. The availability of such a vessel for other work will, of course, depend on the annual volume of spoil. Therefore the two curves will coincide at larger annual production, where the dredger is fully occupied in just dredging.

If we incorporate these effects in figs. 4a and 4b, we see that a locally-owned, multi-purpose dredger can be attractive for all annual outputs, instead of merely for large outputs as a normal dredger would be.
Our examples are, of course, somewhat simplified. The actual values are open to discussion; however, the trends are unmistakable.

A locally operated dredger offers other advantages too.
It offers local employment both in operation and in maintenance activities.
A training on the job and own dredging experiences will improve local skills.
Besides the dredger will be immediately available if maintenance dredging is required.

3. DESIGN PHILOSOPHY

We are concerned with dredging problems in small ports and waterways, and therefore length, breadth and draught are governed by the operating conditions. For example, the dredger should not be larger than the largest ship which will use the port. The criteria will differ from one port to another.
To provide the most flexible design possible, a modular system was chosen. With this, a custom-built hull can be built up from standard modules at minimum cost. Once the hull is built up (and even when the vessel is already in service), it must be possible to add various tools or items of dredging equipment as required.

As already stated, capital costs are the prime element in dredging costs. Using the modular concept, we can reduce drawing, building and assembly costs without detracting from the merits of a custom-built vessel.
To meet local political situations, local construction and assembly should be possible. The design, therefore, must take account of national standards and allow the use of commonly available materials. Modular design also facilitates local construction.
Maintenance costs also play an important part in dredging costs. We take the view that the multi-purpose dredger design should be optimized in terms of local maintenance facilities. This means avoiding vulnerable hi-tech elements and concentrating on reliable, straightforward constructions with components which are readily available in the country concerned.
To facilitate service and ensure continuity of supply, the owner can use equipment manufactured locally or supplied by companies which are represented

locally.
The dredger must be capable of being operated by a small crew, and should not be as sophisticated as the majority of modern vessels.
In this respect, too, straightforward construction is of importance. A brief period of training should suffice to enable the owner's employees to operate the vessel.

4. THE ACTUAL DESIGN

The above mentioned considerations led to the development of a series of standard components from which various types of dredger can be built. Up to now, only vessels of 7.20 metres beam and with a loaded draught of 2 metres have actually been designed. Larger types will be available in due course.
All the types are based on the same fore and aft ship, with in between closed and hopper sections of various lengths. To permit unloading with a grab crane and other operations, the hopper bottom is flat and has no keelson.
Depending upon the requirements, single or twin rudder propellers, a simple wheelhouse or a wheelhouse plus accommodation can be provided.
Using these modules, several types of barge or transport vessel can be built up. If dredging operations are envisaged, the vessel can be equipped with a dredgepump and trailing suction pipe, or a grab crane/backhoe, or both. The grab crane or backhoe can be equipped with tracks or tyres to permit operation on land when not required on board. If required, bottom doors can be incorporated in the hull, and spud and pneumatic piledriving installations added as a module. Depending on the local conditions, the winches can be hand-operated, diesel-driven or hydraulically-powered, with or without remote control facilities.

The principal particulars of the 7.20 m version are:

Lenght overall	16 m	36 m
Beam	7.20 m	7.20 m
Maximum hopper capacity	80 m^3	200 m^3
Load capacity	140 tons	300 tons
Laden draught	2.00 m	2.00 m
Suction pipe diameter (where fitted)	-	250 m
Max. dredging depth		8 m

The construction of these ships is according to the rules of Bureau Veritas.
According to requirements of the Netherlands Shipping Inspectorate dumping on open sea within a limited distance from the coast is allowed.
An artist impression of an MPD "Multi Purpose Dredger" is shown in figure 6.

6. CONCLUSIONS

1) Up to now, maintenance dredging in the world's smallest ports and narrow waterways has been a problem.
2) Suction hopper dredgers generally are unable to enter the smallest ports because of their size.
3) Multi Purpose Dredgers of limited dimensions can provide the cheapest way of dredging in even the smallest ports.

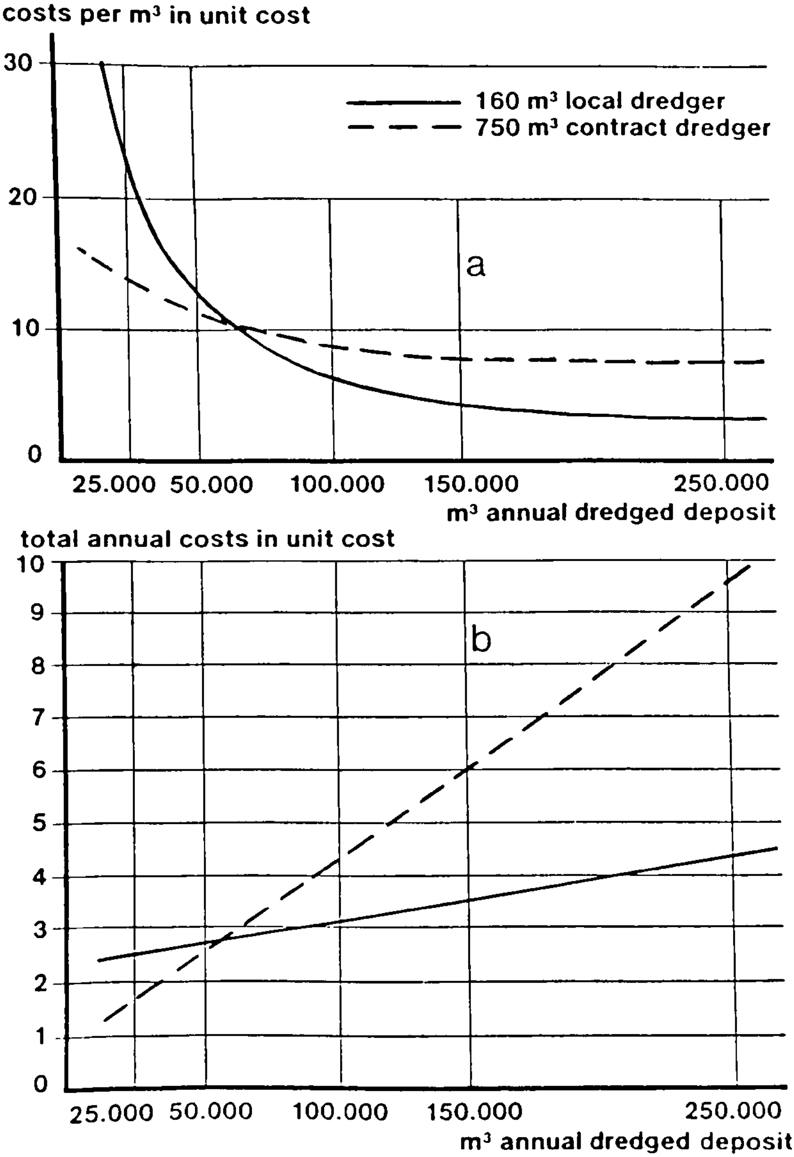


Figure 1 Comparison between contract dredging and local owned and operated dredging

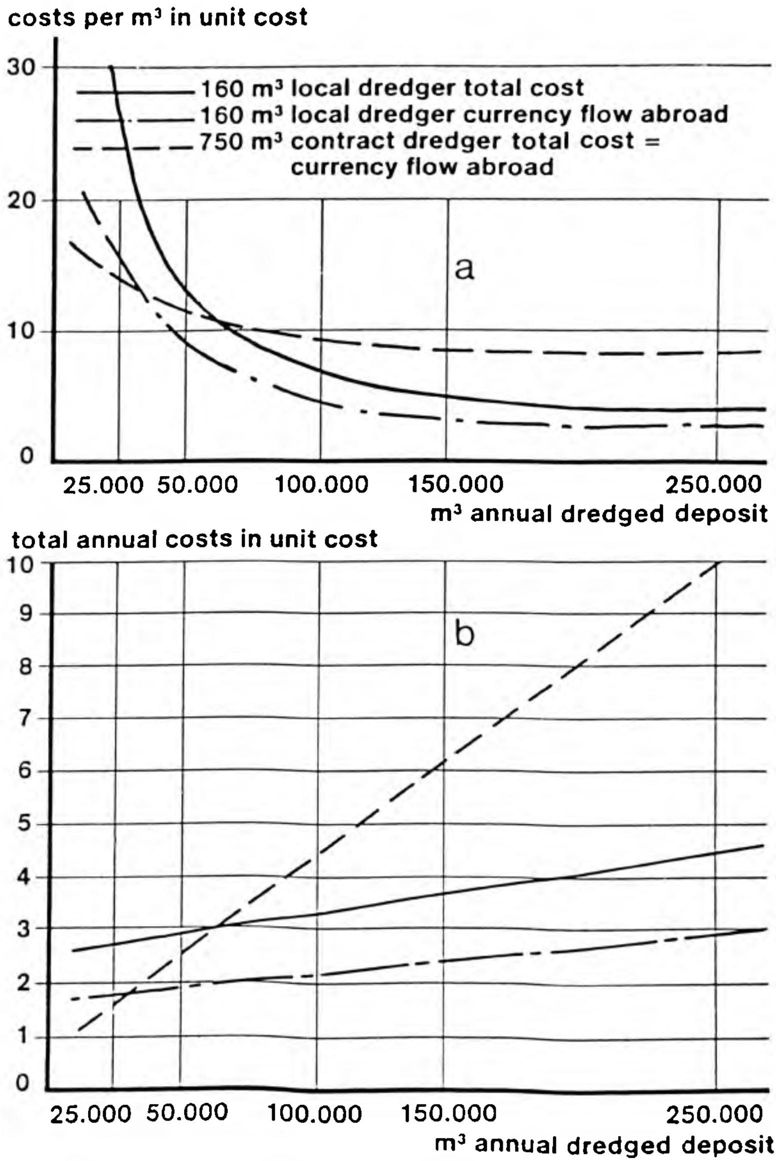


Figure 2 Indication of expenditure in foreign currency

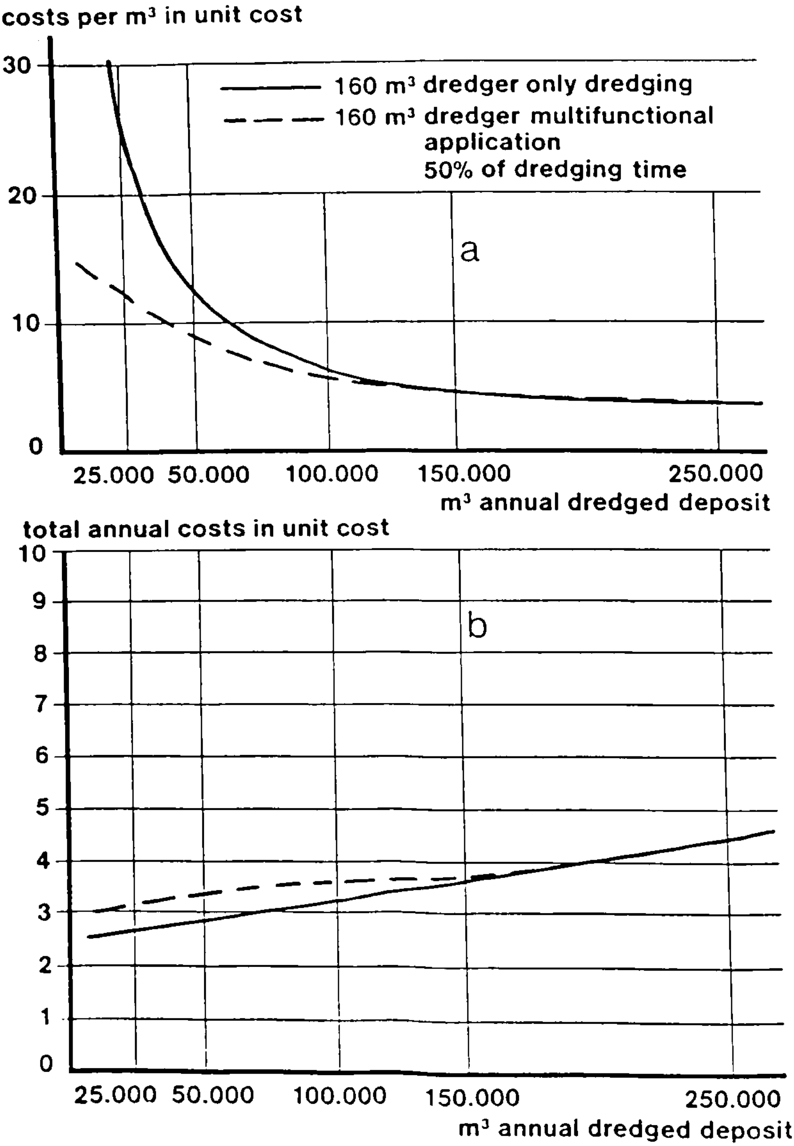


Figure 3 Effect on expenditure of multifunctional application of the vessel

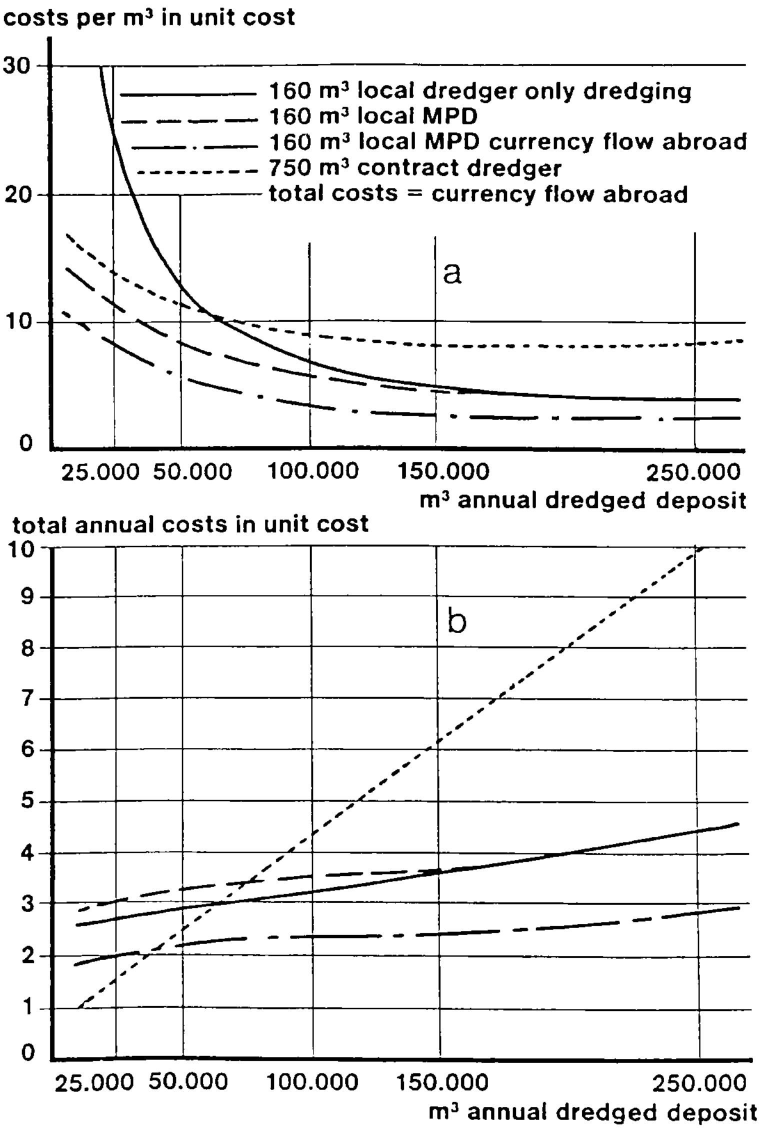


Figure 4 Comparison MPD and 750 m³ contract dredger

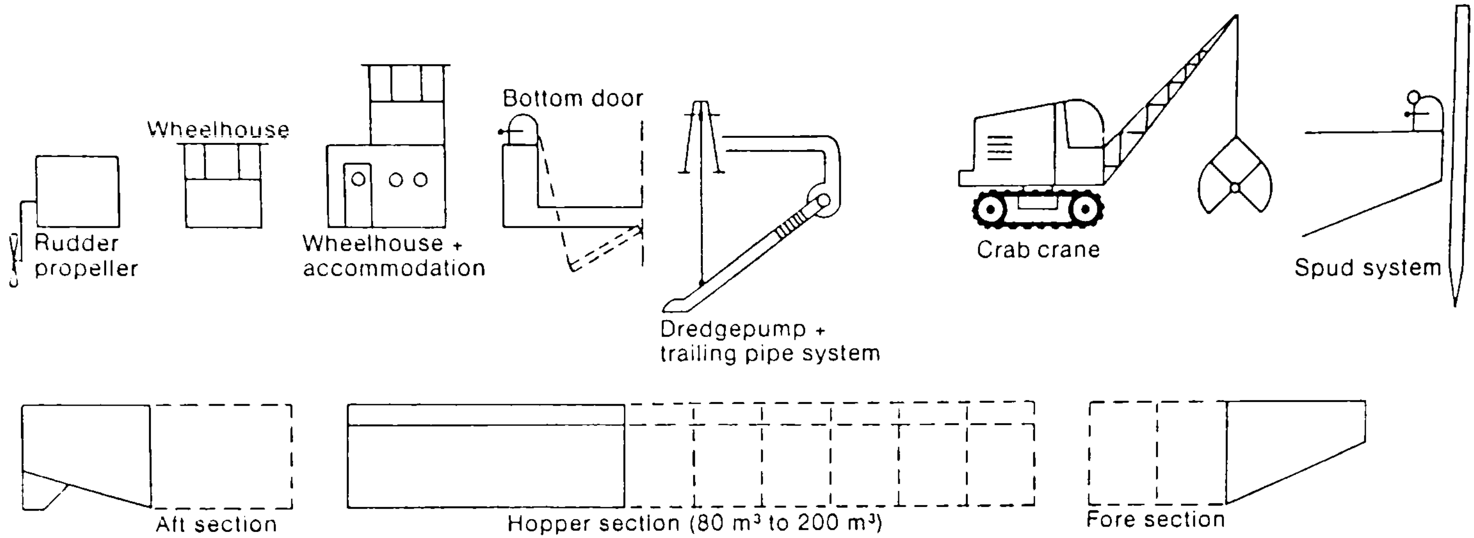


Figure 5 Construction box principle

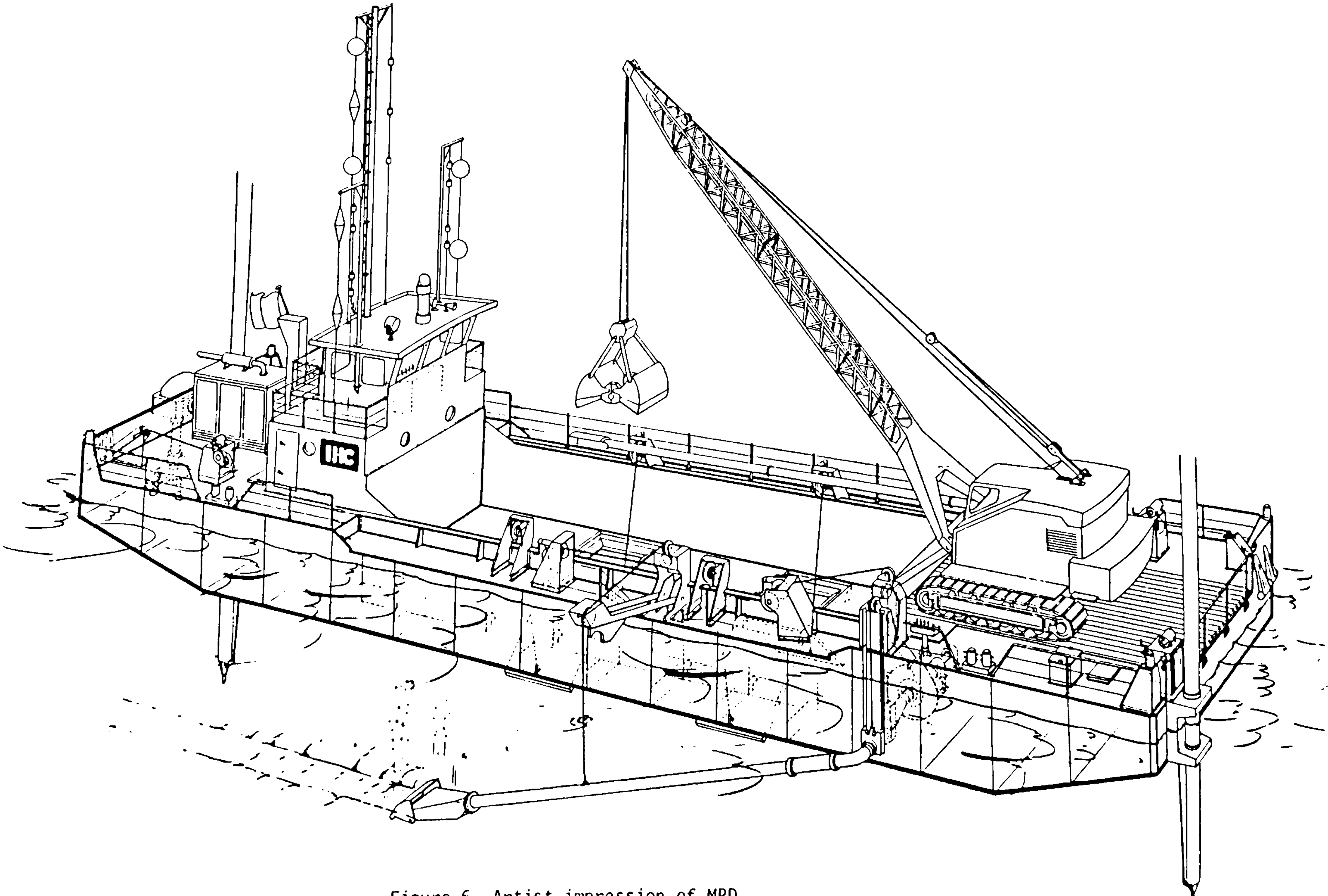
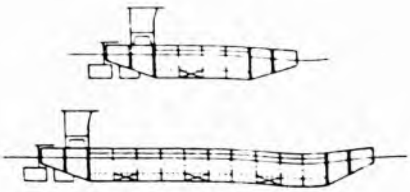


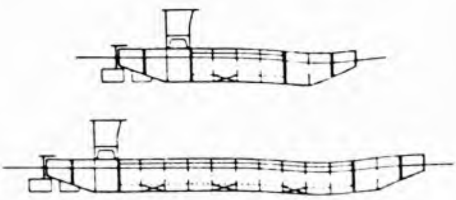
Figure 6 Artist impression of MPD

Hopper barge



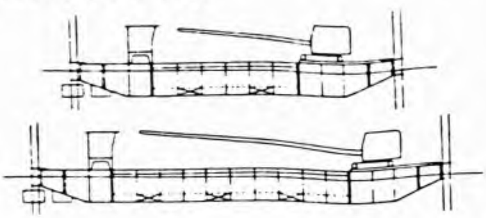
81 – 203 m³ sg 1.76 – 1.4

Hopper barge



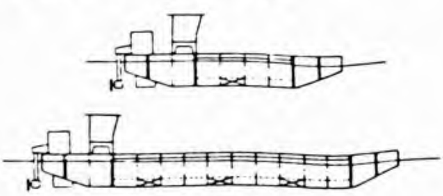
93 – 205 m³ sg 2.09 – 1.63

Grab hopper dredger



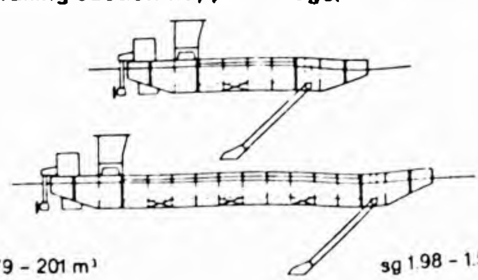
117 – 196 m³ sg 1.92 – 1.63

Self-propelled hopper barge



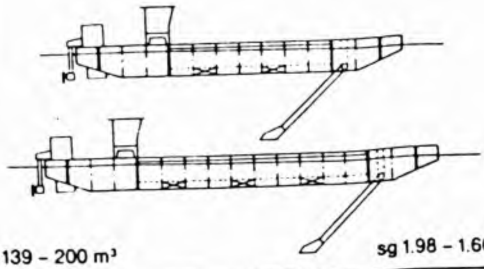
79 – 197 m³ sg 2.01 – 1.53

Trailing suction hopper dredger



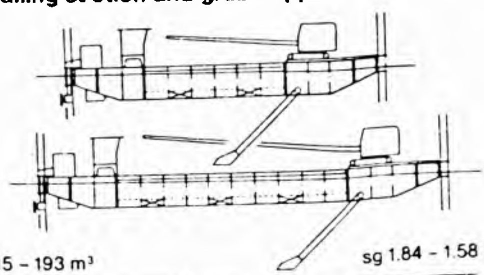
79 – 201 m³ sg 1.98 – 1.59

Trailing suction hopper dredger



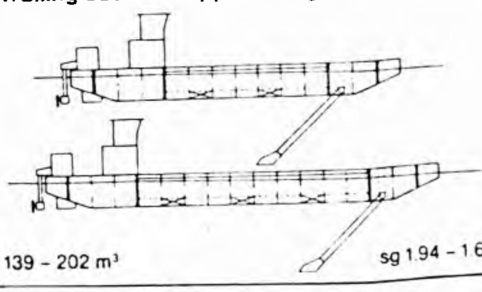
139 – 200 m³ sg 1.98 – 1.66

Trailing suction and grab hopper dredger



115 – 193 m³ sg 1.84 – 1.58

Trailing suction hopper dredger



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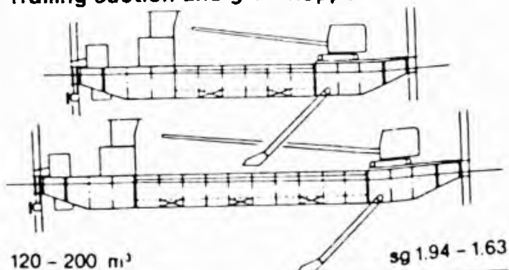
Trailing suction and grab hopper dredger



120 – 200 m³ sg 1.94 – 1.63

SERIES MULTI-PURPOSE
DREDGERS **MPD-7**

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8. EQUIPMENT AND INSTRUMENTATION

During the visit to IHC Holland, two lectures were delivered on dredging equipment and instrumentation.

The first lecture, entitled "Dredging instrumentation and automation", was delivered by Mr. T. van Zupthen, IHC Holland.

The second lecture, delivered by Mr. J.A. Piet, Bureau voor Scheepsbovw, was entitled "Spare parts position"

The text of these two lectures is reproduced here.

The Delf Hydraulics Laboratory is also involved in research in dredging technology. The test facility was also seen during the visit to the laboratory. A short description of the research activities in the field of dredging technology is presented. It is an extract from Hydro Delft, No. 70, a special issue on dredging published by the Delft Hydraulics Laboratory in February 1985.

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8.1 Dredging instrumentation and automation

By T. van Zupthen, IHC Holland

The history of dredging can be traced to the Middle Ages; it came about as a result of the demands of shipping and the need to control the movements of water. Then, with the aid of simple tools and a good deal of physical labour, channels were dug, dykes constructed, rivers deepened and harbours created.

As the speed of vessels increased, and labour became more costly, more sophisticated tools were called for, and this led to the establishment of companies dedicated to the construction of equipment matched to the latest state of the art. But the manufacturers went further: they undertook research and development, as a result of which the efficiency of dredging systems was improved, not, however, merely to meet customers' requirements, but also for reasons of competitive advantage.

Today, as the costs of equipment and labour steadily increase, greater and greater efficiency is demanded. On the equipment side, this is achieved by improving the reliability and performance of dredgers; on the labour side, the answer lies in training personnel to operate the equipment in the best possible manner.

The efficiency of dredging operations, however, can be further improved by the selective use of instruments and automatic controllers. These not only assist the operator, but also afford a more accurate analysis of the dredging process.

Various types of measuring equipment were tested, but those which were derived from onshore technologies proved unsuitable for use in dredging. The phenomena associated with the hydraulic transport of solids, and the vibration which accompanies the use of high-powered centrifugal pumps in a marine environment, necessitated the development of special instruments.

A number of measuring systems were developed especially for the dredging industry, but in the majority of these accuracy was sacrificed in the interests of reliability. When adequate reliability was achieved, a predictable demand for greater accuracy set off a fresh train of development. In particular, those manufacturers who were connected with the building of dredgers had to make immense efforts to produce the most reliable and accurate systems.

In the initial phase of instrumentation, the objective was to provide the dredgemaster with information concerning the principal parameters of the dredging process, and thus with a more accurate basis on which to determine his course of action.

In the second phase, the aim went beyond the principal data, indeed beyond the purely informative function, and embraced local or central automation.

In the third - and provisionally final - phase, the dredging programme is determined in advance and the operations are fully automated on the most economic basis, the dredgemaster's role being limited to supervision.

The purpose of automation is to obtain maximum efficiency in terms of the vessel and its crew, enabling the operations to be carried out as economically as possible to the mutual benefit of the contractor and the principal.

Basically, the dredging process can be improved by keeping the dredgemaster better informed and relieving him of repetitive, low-intelligence duties. If these are entrusted to an automatic controller, the dredgemaster can devote more time to important operational matters.

Needless to say, the process information must be reliable if erroneous conclusions and the consequent risk of mistakes in the control of the process are to be avoided.

To meet the needs of the dredging industry, a range of instruments and automatic controllers have been developed which, respectively, provide the information necessary for a smooth, efficient dredging process and relieve the dredgemaster of operations which could detract from his primary objective of achieving optimum solids production. The equipment in this range fully meets the stringent requirements in terms of resistance to vibration and protection from humidity which a marine environment imposes.

From the point of view of instrumentation and automation, dredgers are broadly divided into two categories: those which have a hold, or hopper, into which the spoil is loaded, or which discharge it into barges, and those which transport the spoil to a reclamation point with the aid of their own pumps.
Bucket dredgers constitute a separate category.

In vessels of the first type, the efficiency of the dredging process is primarily determined by the suction process. In those of the second type, the delivery process must also be taken into account; moreover, the importance of the suction and delivery processes varies according to the arrangement and the nature of the particular operation.

Both types, but particularly the latter, will be used for different sorts of work and will preferably be equipped to cope with almost any requirement which may arise. As far as the measuring equipment is concerned, this implies that both the suction and delivery processes must be monitored and controlled if maximum efficiency is to be achieved.

For control of the suction process, it is basically necessary to have data concerning the dredgepump vacuum, the mixture concentration and, to a lesser extent, the mixture velocity. For control of the delivery process, the important data are the delivery pressure, the mixture velocity and, to a lesser extent, the solids concentration of the mixture.

Generally speaking, the data required to assess the progress of the operation are the momentary production and the cumulative production.

The various measuring instruments developed to meet these requirements all follow a pattern, having three basic components:

1. The transmitter

2. The signal amplifier

3. The visual instrument.

Together these constitute an "indicator". This term, however, is often applied to the visual instrument alone.

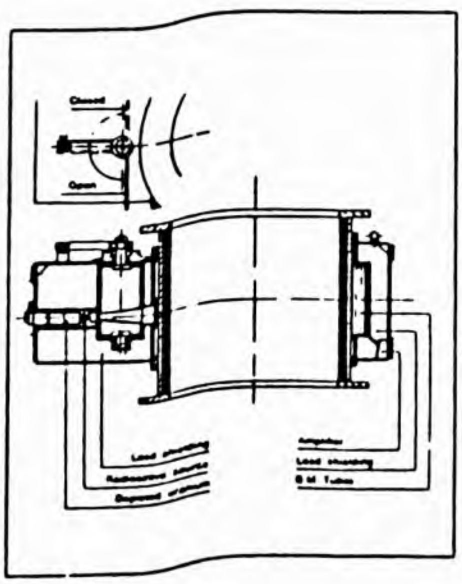
As a rule, the transmitter is the most important component, since the signal amplifier and the visual instrument, provided they are suitable for the purpose, will not be a source of difficulty.
In the dredging industry, transmitters have to be mounted on the pipes carrying the mixture and must therefore be capable of withstanding the abrasive properties of the spoil as well as varying pressure, mechanical vibration and a humid environment.
If adequate reliability and accuracy are to be achieved, and at the same time a reasonable service life under the prevailing circumstances, conflicting requirements must be met.

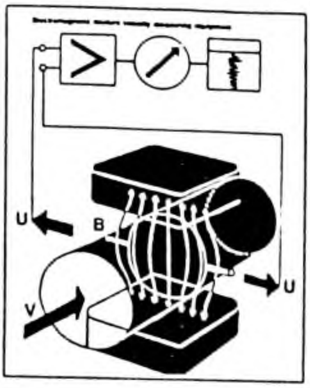
The basic equipment for a suction dredger comprises:

(a) Vacuum Indicator
Typical of the requirements for this is an ability to withstand pressure surges caused by water hammer, which may be as high as 70 bars (more than 1,000 p.s.i.), while the measuring range is only 1 bar (15 p.s.i.).

(b) Pressure Indicator
The requirements are similar to those for the vacuum indicator; however, the ratio between the measuring range and the maximum survival pressure is more favourable.

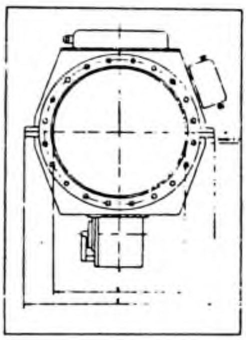
(c) Concentration Indicator
Owing to the abrasive nature of dredged material, only the radioactive type of concentration indicator is used on board dredgers. In this application, Type A, Class I - WHITE - shielding of the radioactive source must be provided.
In contrast to onshore uses, the marine environment requires the use of the Geiger Müller detector system.





(d) Flowrate Indicator

In view of the abrasive properties of the mixture and the differences in the velocities of the particles and the vehicle, the inductive flowrate indicator is the only type used in the dredging industry.

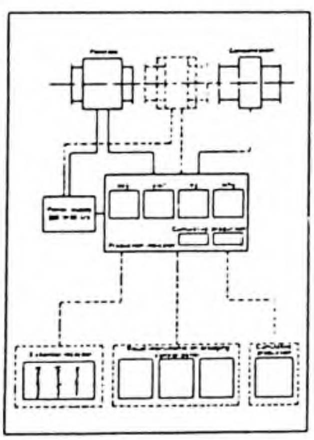


(e) Integrated Concentration and Flowrate Indicator

This is a further development of the separate units, its principal features being smaller length and reduced maintenance requirement.

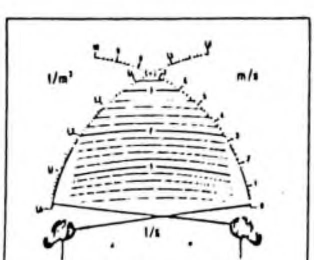
In addition to the standard unit, a model with a replaceable wear-resistant liner is available. The liner can be replaced on board, reducing downtime and repair costs.

The latest refinement is the use of carbon rubber electrodes which completely eliminate the problem of leakage sometimes encountered with other types of electrode.



(f) Production Indicator

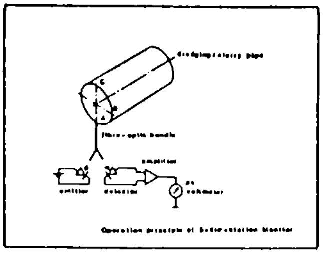
To ascertain the volume of solids passing through the system, the signals emitted by the Concentration Indicator and the Flowrate Indicator are processed, the momentary and cumulative production being computed and shown on visual instruments.

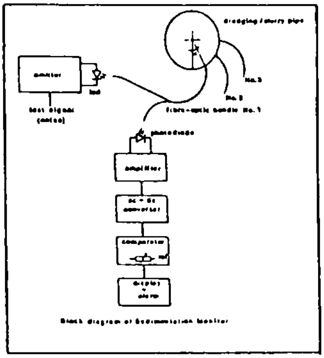


(g) Yield Indicator

The principal function of this indicator, which is in fact a dual-system instrument, is to enable the dredgemaster to see at a glance the influence on production of changes in the process variables.

SEDIMENTATION INDICATOR



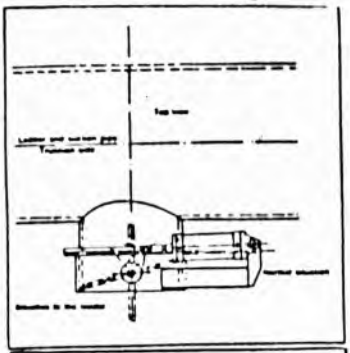


The sedimentation Indicator serves to inform the dredge operator on the eventual sedimentation in the delivery line.

Sedimentation in a horizontal pipeline is the result of settling of the solid particles in the slurry. The moment at which this occurs is governed by the granular composition of this mixture, the solid concentration and the velocity of the mixture in the pipeline.

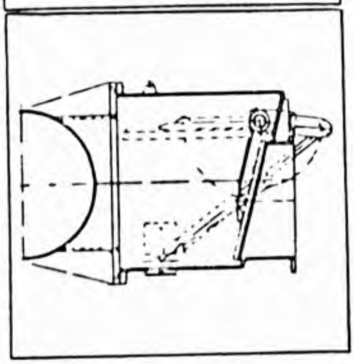
The Sedimentation monitor operated on the principle of light reflection by the particles in the mixture. The light is transmitted through optic fibres. By measuring the reflection at various points around the circumference of a pipe, the degree of settlement can be determined.

Additional items of equipment available to improve the performance of cutter suction dredgers are:



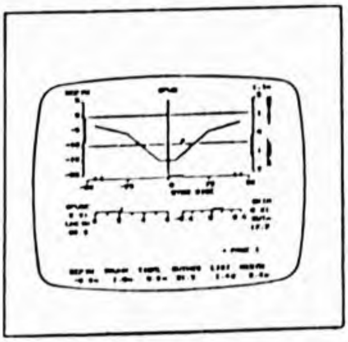
(h) Vacuum Relief Valve

When opened, this valve allows plain water to enter the suction pipe in the event of the vacuum becoming too high.
Manual and automatic versions are available.



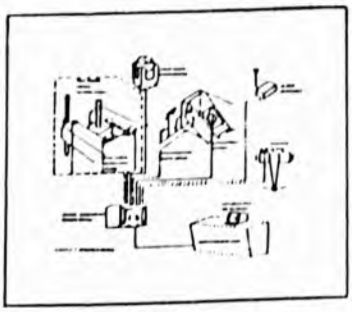
(i) By-pass valve

If the delivery pressure falls below the permitted minimum value, the valve is opened to permit water to enter the pipe linking the suction and delivery pumps.
The by-pass valve is automatically actuated by the intermediate pressure sensor.

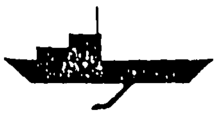


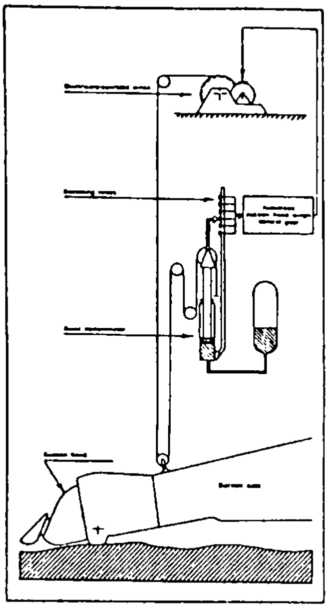
(j) Dredged Profile Monitor

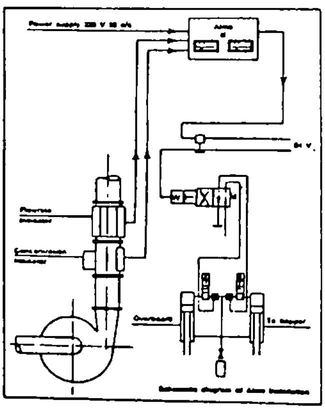
The position of the cutter or dredging wheel in relation to the shape of the channel to be dredged is of utmost importance to the dredgemaster, as to be able to carry out the dredging work in an efficient and accurate way.
The D.P.M. system enables the dredgemaster to check and control the cutter's or wheel's position accurately, avoiding over-or underdredging, and also contains features for automatically adapting to variations of the dredgers draught or to tidal differences.
The D.P.M. system can be suited with automatic profile dredging controls, acting as an autonomous unit as well as an information system for fully automatic dredging control.

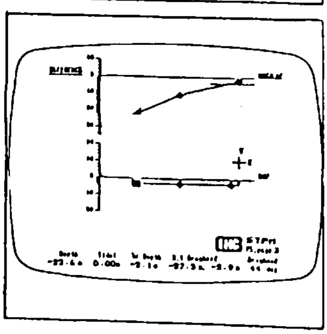


The following are available to improve the performance of trailing-suction hopper dredgers:









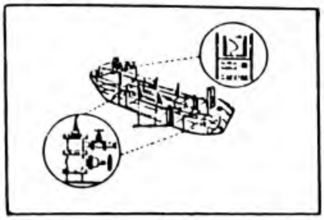
(k) Automatic Draghead Winch Controller
This controller automatically actuates the draghead winch to compensate for variations in the dredging depth, the vessel's draught, and the effects of tide and swell. The swell compensator normally installed is equipped with a positional transmitter, the signals from which are used to actuate the suction head winch, keeping the hydraulic ram of the compensator in the midway position.

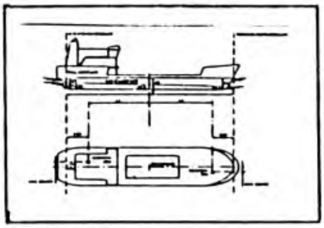
(l) Automatic Light Mixture Overboard (ALMO) Installation

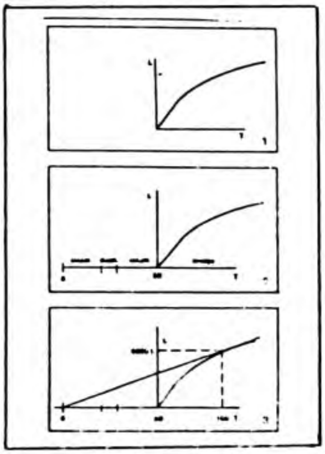
The function of the ALMO installation is to increase the efficiency of the hopper loading process. This it does by ensuring that only mixture with a predetermined specific gravity enters the hopper; lighter mixture is discharged overboard.
The installation is fed with signals from concentration and flowrate indicators, and itself emits impulses which actuate gate valves.

(m) Suction Pipe Position Indicator
If the positions of the draghead and the suction pipe, in relation to the vessel, are known, greater accuracy can be achieved, particularly when dredging a channel in an accidented seabed. By using measured profiles, redundant dredging can virtually be avoided.
Unfortunately it has not so far proved possible to achieve the desired degree of accuracy in controlling the position of the draghead with respect to the vessel.

DRAUGHT AND LOADING MONITOR







The draught and Loading monitor supplies accurate data on the loading of the hopper and the draught of the vessel.
These data enable the dredge master to achieve efficiënt and safe loading of the hopper, taking in account the varying circumstances in sailing distance to the dump site etc.
Besides the data of draught and loading also the draught on perpendiculars and the load-rate signals are made available for improved hopper loading efficiëncy.

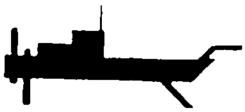
Bucket dredgers, by reason of their nature, demand a different approach in terms of instruments. To date, the following systems have been developed to determine the efficiency of the operation of such vessels:

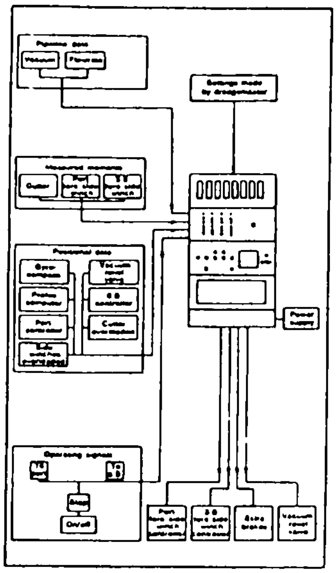
(n) Bucket Rate Indicator
Bucket Number Totalizer
Bucket Chain Drive Load Indicator
Head Pulling Force Indicator
Side Wire Pulling Force Indicator
Dredging Depth Indicator
Paid Out Wire Length Indicator

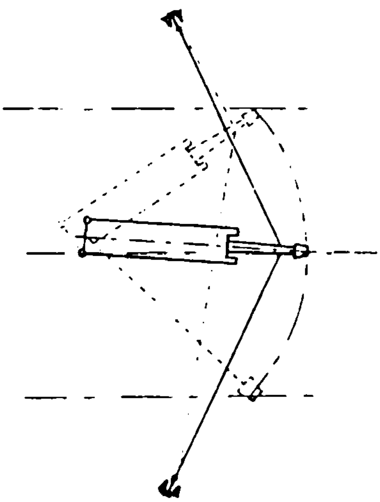
Automation

In the area of dredging, the principal function of automation is to relieve the operator of repetitive, low-intelligence tasks. The first step, therefore, was to analyse the operations and, where possible, assign these to automatic devices, leaving the operator free to concentrate on the primary objective - maximum production.
It is not, however, sufficient for automatic devices to initiate control procedures; they must also continuously monitor the performance of the equipment to which they are connected. In practice, this means that an automatic controller must incorporate monitoring and alarm facilities which reveal any malfunction. In almost all cases, early experiments with controllers which lacked means for continuous monitoring led to serious problems, because minor defects were not recognized in time and incorrect commands were initiated.
The requirements can only be met economically by the use of computerized systems, the components of which can be used in standardized form for different purposes and the programmes written in a structured mode, while permitting minor changes to suit the characteristics of a specific dredger.

The Automatic Cutter Controller was developed for use on cutter suction dredgers. A number of these controllers are now in service.







The heart of the Automatic Cutter Controller is a micro-computer which controls the dredging process and shows the process data on a video display.
Optimum production is obtained by setting the highest possible swing rate at a given horizontal and vertical cut.
In most cases, this swing rate will be achieved when one or more of the following process magnitudes assumes a decisive value:

(a) cutter load

(b) swing winch load

(c) vacuum before the dredgepump

(d) pressure between suction and delivery pumps

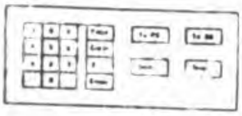
(e) mixture concentration

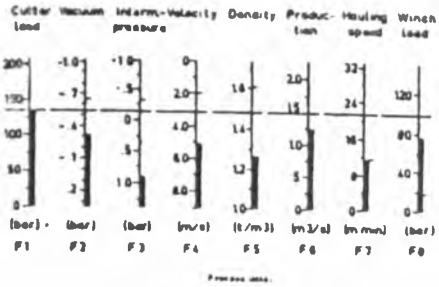
(f) mixture flourate.

These can be influenced by varying the rate of swing.
In a manual control situation, therefore, the dredgemaster must constantly monitor the magnitudes and, on the basis of the decisive values, increase or decrease the rate of swing.
But because he also has other matters to attend to, he will not always be able to achieve optimum production.
Fatigue on the part of the dredgemaster also plays an important role.

It was with these factors in mind that the Automatic Cutter Controller was designed to take over control of the swing winches, vacuum relief valve, ladder winch and spud carriage.

The position of the dredger with respect to the centreline of the channel is also an input and, as an optional extra, a slope programme can be incorporated in the controller.



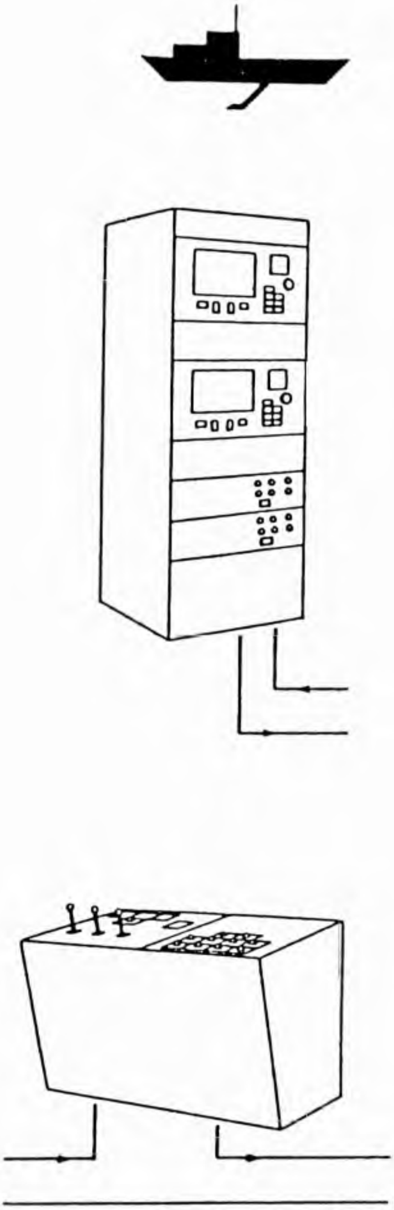


For automatic control of the process, the decisive and maximum permitted values of the magnitudes - e.g. the maximum load on the swing winches, depending upon the anchors and the nature of the bottom - are fed into the controller.

Control is effected by means of a keyboard, in conjunction with a video display, situated in the control cabin. The keyboard is divided into two parts: on the left are the numerical and function inputs, and on the right the command inputs.

The data, together with requests for inputs, appear on the display.

For trailing-suction hopper dredgers, an Automatic Suction Pipe Controller is available.



The controller, the nucleus of which is a micro-computer, actuates the winches in order to swing the pipe outboard or inboard, or to alter its position during dredging.

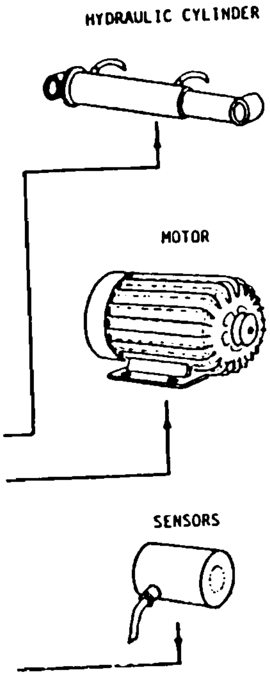
The unit also controls the swell compensator, and incorporates a number of safety systems. When in the automatic mode, it controls and regulates the movements of the suction pipe, preventing dangerous situations.
With the unit in the manual mode, the winches and gantries can be controlled from the console in the normal manner.
When in the manual mode, the controller can be switched off. The changeover from "manual" to "automatic" can only be made if the unit was in the "on" position before the pipe was removed from the cradle.

For the purposes of automatic control, three situations are defined:

A. Inboard
Suction pipe in cradles, trunnion carriage locked and swell compensator fully paid out or blocked.

B. Horizontal
Suction pipe in horizontal position, trunnion in guides and trunnion latch locked.

C. Outboard
Draghead on the bottom and swell compensator operating, or preset maximum dredging depth has been reached.



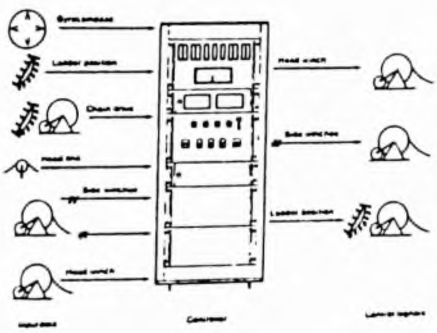
The principle of operation is based on the measurement of the position of the gantries and the length of wire paid out from the winches. Moreover, the movements of the pipe are sub-divided to provide defined points in the programme. The controller commands the three winches and monitors the position of the pipe. If, in the manual mode, a dangerous situation arises, the controller will cause the pipe to be brought into a safe position before the automatic sequence is initiated.
If a command given by the controller is ignored, a warning signal is emitted and the controller reverts to the manual mode.

The controller is operated by four push-buttons, which automatically initiate or stop actions. Only two adjustments to settings have to be made, namely for maximum dredging depth and gimbal correction.

For bucket dredgers, an automatic controller has been developed which monitors and controls the speeds of the four side winches.

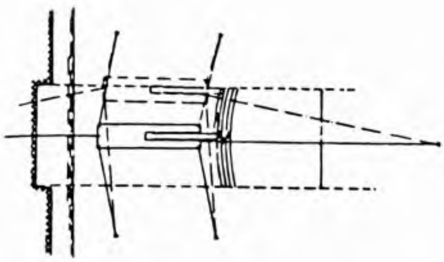
The Automatic Bucket Dredger Controller was designed to improve the output of vessels of this type by ensuring full utilization of the dredging installation. The controller automatically operates the head and side winches, and protects the head winch and bucket chain against overloading, thus enabling the dredgemaster to concentrate on the dredging process, barge handling, etc.

The loads on the head winch and the bucket chain drive are the decisive factors in the control process. The head winch was chosen because the load on it is most directly related to the soil-cutting force.
The side winch speeds are measured by means of tachogenerators, the signals from which are fed to the controller.



The position of the vessel with respect to the centreline of the channel is measured with the aid of a gyrocompass. The angle of swing can be preset between 0 and 30 degrees to port and starboard.

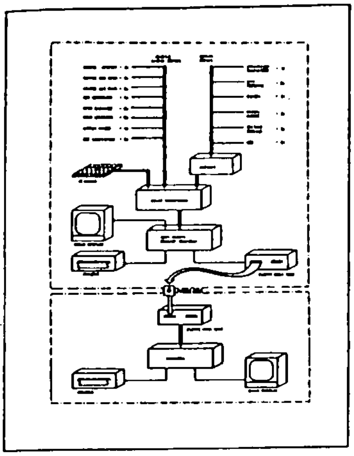
For the purpose of control, the braking torque of the paying-out winch is related to the pulling power of the hauling winch. This means that, even in the event of sudden braking or sharp deceleration, the paid-out wire will not become slack. This applies to both the forwar and after winches.
The after winch which is in the hauling mode is commanded by the dredging angle repeater in order to obtain the correct dredging angle.

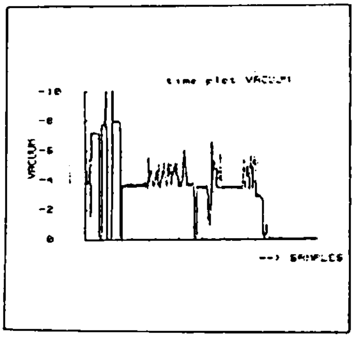


An auxiliary position-indicating system is incorporated which provides signals representing "end of swing" and "pre-warning end of swing." If the latter signal is emitted, the control sequence automatically changes, recommencing with the end of swing procedure.

When the "pre-warning end of swing" signal is received, the controller will cause the dredging angle to change to the preset value for approaching the slope, and reduce the speed of the hauling winches.

The end of swing procedure also incorporates preset advance and ladder lowering steps.





<u>Data acquisition and operation reporting</u>

The need for data based on practical experience as an aid to research for the benefit of future works has led to the development of data recording and logging equipment which is easy to operate.
The data are collected with the aid of a multi-pen recorder, which provides continuous registration. If very large quantities of data are required, a multi-point recorder, affording sequential sensing of up to 12 channels, is used. Where it is desired to record a large number of signals for subsequent processing ashore, a data aquisition system is employed.
The data aquisition system scans the signals in succession, the scanning rate being adjustable and registers the momentary values, while at the same time identifying the signal concerned and the time of registration.

As the volume of data can assume considerable proportions, particularly where registration is for the purpose of investigation, the floppy disc system, borrowed from the world of computer technology, is employed for storage.

A small video display is incorporated to permit the registration process to be followed. Presentation of the data on the display is controlled from a keyboard.

For compilation of operation reports, the system is suited with a printer, by which,on command of the operator, reports in different grades of complexity can be generated.

Data collected on board a number of vessels can, of course, be centrally processed ashore.
This implies that the shipborne equipment can be operated by persons without specific training.

8.2 Spare parts position

By J.A. Piet, Bureau voor Scheepsbovw

Question : "How is a package of spare parts brought together?"
Example : New vessel (dredger) with spare parts included in the contract.

1. In the design stage:

- Depending on owner/working area/type of vessel/capacity: the make of various installations provisionally chosen by designer/builder if not specified by client.

- Final decision about makes depending on wishes of the client, suitability for the job, after sales service and parts stocks.

- Philosophy to limit down time:
  - -- non vital system/installations to be isolated without interfering with other installations
  - -- vital installations with back-ups (stand-by's) = doubling (each other spare) or splitting: keep installation running or on half power/production (failure of spare parts leads to cannibalizing)

2. Type of spare parts basically:

Consumable parts and calamity parts.

- Consumables are predictable such as:
  - -- running consumables
  - -- maintenance consumables
  - -- wear consumables (dredging due to sand/mixture)
- Calamity spares are unpredictable.

a) Running consumables: depend on prescription of manufacturers (power installation, generator sets etc.) items to be replaced after ..... running hours based on preventive maintenance or guarantee terms (costs due to spares and stop time!).

b) Maintenance consumables : items damaged when opening up installation for preventive maintenance or predictive maintenance operations/inspections.

c) Wear consumables in dredging : depend on type of soil. After investigations of type of soil predictable, however often "positive/negative surprises".
Parts are vital for production and mostly voluminous, long(er) delivery times (heavy castings - machining - dredge pumps).
Risk/policy depends on working circumstances, location, duration (varying per job).

d) Calamity spares : unpredictable
Therefore to refer in general to direct safety of vessel (safe coming home condition - classification Society).
In dredging : means to gain material (sand) are exposed outside the vessel, (suction pipe, cutter ladder etc.) and the connection between bottom and "moving vessel".
Damaging can occur if operational limits are crossed.
Cause: nature or wilfully by man to gain production.

3. Quantity and price of spares

Which amount to reserve for spare parts?
Depending on financial sources (now and future).
Policies differ from client to client.
More year package (2-year - 5-year) has the advantage of "quantity discount" or price negociations when ordered together with installations to be built into the vessel.

Danger: interpretation of "more-year package":

- one who is not familiar : no other parts needed for ... years.
- one who has to chose the parts: to think of everything, also in calamities. This leads to useless or never used spare parts.

From some examples derived to cover for a period of 4-5 years without any comment, only indication and all depending on policies:

- for simple (smaller) vessels: abt. 1% of the new building price (main part of the amount for running and maintenance consumables).

- for complicated installations (dredgers/extensive power installations) abt. 4-5% of the new building price (of this amount about 50% was used for wearing parts/dredging).

4. Composition of the package

The moment builder request manufacturers for quotations of installations, also to request for:

- adviced quantity of consumables and calamity spares for certain period
- itemized prices and delivery times.

The moment of ordering: builder + client to settle quantity of spares.
Preferably open quotations + agreed administration/packing/handling fee.

5. Administration of spare parts

In practice the system of the builder (purch. dept.) is also used by the client at least in the first operational period. Thus important: administration complete for practical purposes!

6. Packing and shipment

Type of conservation/packing in agreement with client.

Check suitability of packing for long period stowage on board/at site (tropical conditions, vibrations etc.).

7. Client's organisation

To be ready to receive shipment.

Important elements in organisation:

- organisation on board
- storage of parts on board/ashore/central
- administration central
- feed-back to adm./purchase dept. of:
  consumption or reasons of failure.

A spare part package will never be complete or cover every event.

Therefore: in building stage flexibility (budget) for "last moment adjustments"
: in operation flexibility (budget) for "rush orders".

Most important: to have flexibility = money (budget) on easy accessible account for client, for instance at bank overseas. (When financed by devel. aidfunds: problem to spend money within year of allocation!).
This method can ease to overcome the barriers/blockades for the client, such as:
- obligations to pay in local currency
- restriction to pay in foreign currency
- payment on long term considered as loans and prohibited
- custom procedures
- black list articles and/or obligation to tender on local market - (non) original parts.

Purchasing dept. of client, faced to get lowest price, has different ways for quotations, i.e.:

- from licensed importers
- from local service/sales agent, with or without stocks local or overseas
- directly from manufacturer or builder.

Orders from manufacturer/builder ensures right parts in case of doubt about identification, parts numbers, modification etc.

Also manufacturers/builders can offer special arrangements such as:

- parts-deliveries on prenegotiated fixed price-base for certain periods (preventing time consuming procedures to ask quotations for every occasion).
- For smaller vessels: overall spare parts package deliveries at site for limited time periods. Costs based upon consumption of parts.

8. General

Some aspects which contribute to "restrict" unexpected breakdowns of installations by mechanical interruption or caused by man:

- correct functioning from the beginning = thoroughly testing of installations
- familiarization of (operating) personnel
- support during guarantee period by special personnel from builder/manufacturer
- good instruction books, system drawings etc.

....

8.3 Towards better tools - research at Delft Hydraulics Laboratory

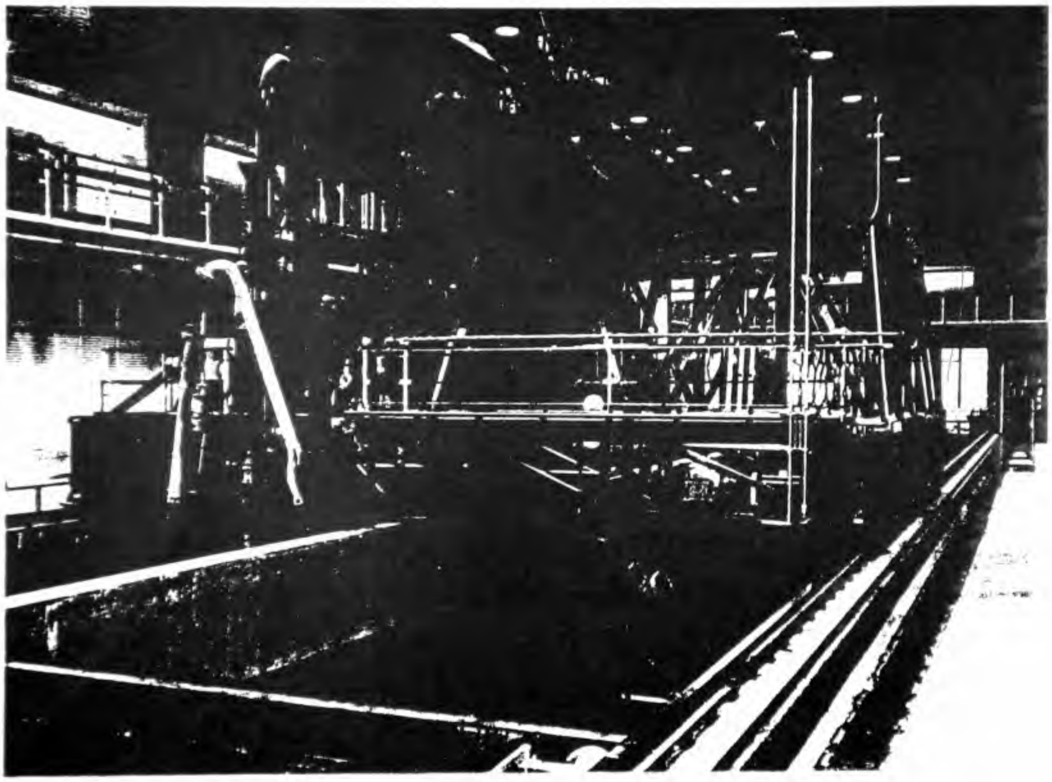
Much of the increase of the scale of dredging projects is due to the development of ever more powerful and efficient equipment for the actual dredging and for the transportation of the material. It is a long way from the ancient spoon-and-barge to the present suction hopper-dredge or the cutterhead dredge. The Delft Hydraulics Laboratory contributes to the technical innovation in this field with fundamental and applied research in its dredging laboratory as well as facilities for the study of pumps and industrial circulations. Moreover, the experience from investigations connected with the behaviour of vessels in waves is successfully applied to dredging equipment. About 1 million US dollars is every year spent on development and research in dredging technology at Delft Hydraulics Laboratory.

A very important part of the dredging process is the loosening of the material from the bottom. Because of the efficiency of hydraulic machinery, attempts are made to cut ever harder rock into pieces fit for hydraulic transport. Consequently, the main attention of the research has gradually shifted from the suction of granular material to the cutting of clay and soft rock. Much of this research has been, and is still being, performed for the Combination Dredging Research in which the Netherlands Public Works Department of the Ministry of Public Works and Transport and five large Dutch contractors have joined hands. However, others also were clients for specific studies and experiments. In this research, the sister institute, the Delft Soil Mechanics Laboratory, contributes with its own expertise. Investigations being made concern specific problems arising from the execution of a job, as well as long-term research aimed at the basic understanding of physical processes and leading to models which can be applied in practice. In the latter category, the cutting process is receiving much attention. The main aspects are:

- the physical processes involved in the cutting of sand, clay and rock (in real dimensions as well as reduced in models);
- the soil mechanical (also rock mechanical) processes;
- the development of measuring techniques for forces, tensions and deformations; and

- the development and testing of cutting devices, including water jets.

Sophisticated facilities for those purposes are a cutting rig, a flume for experiements on cutters and trailing suction devices, and means to prepare soil or rock to the required specifications.

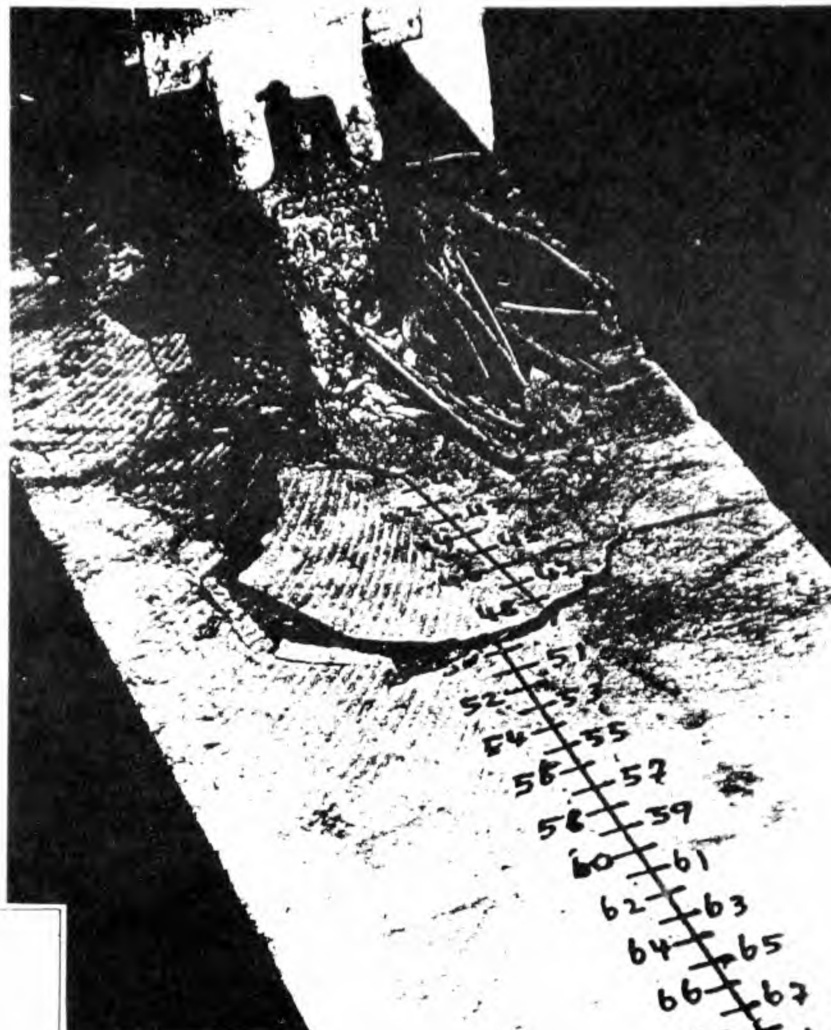


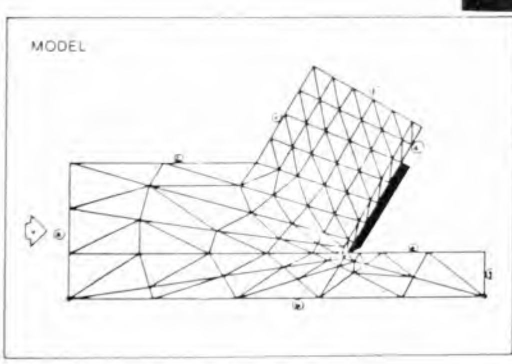
The cutting rig can be used for tests on actual size or to scale as far as the scale rules (which arose from the research) and the measuring techniques allow. It consists of:

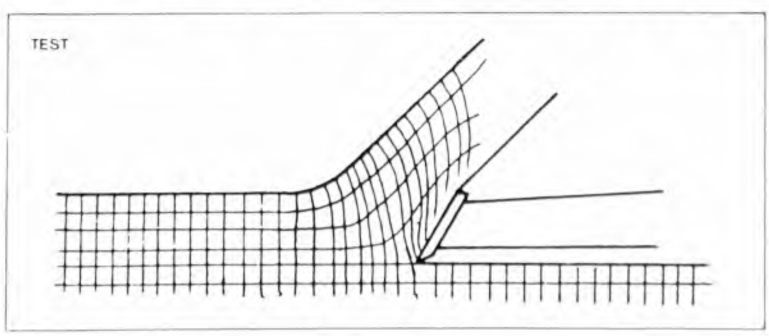
- a cutting tank for soil samples up to 0.7 x 0.9 x 6.0 m^3;
- a plunger-driven (0.01 to 5 m/s, up to 100 kN, 6 m reach) arm to which tools can be attached;
- devices for measuring and recording all forces on the device and in the sample during the cutting process; and
- a pressure tank to simulate water depths up to 30 m.

The dredging flume is 50 m long, 9 m wide and 2.5 m deep. It can be used for model tests on cutting and suction devices but also for other purposes such as a ship's propeller in ice. A carriage on top of the flume moves the device along at speeds of 0.05 to 2.5 m/s, the rotation speed of a cutterhead can be 10-100 rpm. Pumps up to 0.25 m^3/s are installed. Observation and recording of forces (up to 17 kN) in three dimensions as well as torques (up to 5 kNm) is possible.

The prepartion of samples of soil and rock is necessary to obtain homogeneous material to the right specifications. Clay is made from powder and water in a special mixer/extruder, and "Loaves" of clay are fitted together in the other facilities to form the required bed. Depending on the specifications, artificial rock can be prepared using various materials such as sand, water, cement, clay and gypsum. Comparative tests with natural and artificial clay and rock provide the experience for this part of the studies.

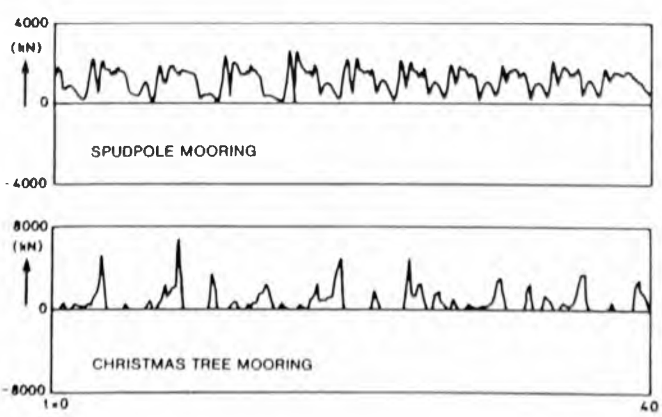






Collapsing of the soil; plastic deformation

Cutterhead forces with two types of mooring



TIME SERIES CUTTERHEAD FORCE ON DREDGE, OPERATING IN IRREGULAR SEAS

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9. NEW DEVELOPMENTS IN DREDGING TECHNIQUES

The lecture entitled "New developments in dredging techniques" was delivered by Prof. Ir de Koning. A summary of this lecture is presented here.

As already mentioned the dredging industry has developed phenomenally during the last two decades. Today, the field of dredging has developed into a science. The design of equipment, the planning, operational and management aspects are now all subject to thorough investigations and analyses at the desk, in the laboratory and on the site

<u>The dredging cycle</u>

The dredging cycle in itself can be divided into a set of processes making up the whole cycle. Each of these may be examined carefully. The processes are:

(i) Disintegration of the soil.
(ii) Digging and mixture forming.
(iii) Reaction forces counteracting the dredging forces (anchorage etc.).
(iv) Vertical transport.
(v) Loading into the means of transport.
(vi) Acceptance by the means of transport.
(vii) Spill of spoil.
(viii) Classifying improvement of the quality of the spoil or the slurry.
(ix) Horizontal transport.
(x) Discharging into the dump area (underwater).
(xi) Discharging in the fill.
(xii) Compacting and shaping.
(xiii) Protection against external forces.

Let us look closely at some of the processes that have been listed above.

Disintegration of the soil Cutting of soil is very very complicated far more complicated for instance than making concrete or building a steel bridge as the soil differs and differs and differs.

It can be done in four ways: (i) chemically by blasting, (ii) cutting by knives, (iii) hydraulic erosion and (iv) underdigging a slope or making a slope unstable. Mechanical cutting is shearing and the force required increases with soil strength. The other method of disintegrating the soil or making it loose is hydraulic erosion. If there is a sandy bank and a stream of water plays on it the grains start to flow with the water. There are empirical formulae to determine this critical velocity but what really happens we do not know. Anyhow,we know from experience that a certain velocity of water flow will erode the sand and mix it and carry it into the pipe. For harder soil the eroding velocity is of the order of 10 metres per second and loss is 5 metres of water head which is enormous because from the air only 8 metres is available and only 3 metres are left to lift the mixture in the suction pipe If the pump in the hopper dredge is below water level, maybe three or four metres can be added so that 6 metres is available to lift the material up to the water surface. To improve the dredge, the first improvement is disintegrating the bed so that a velocity of 3 or 4 metres can erode. The pressure loss of 16 over 20 is of the order of 1 metre of water and we save 4 metres of water column.

The next step is to establish a sand flow in the pit or create active banks. The sand will flow in a very heavy concentration - a soil flow or spoil flow over the bottom with densities of 1,800 kg. per cubic metre. The skill of the dredge master is to dilute this heavy mixture into a lighter mixture that a pump can lift. This is the principle of underdigging. A mistake is made when people think that a bigger dredge in a sand pit will get more production. This is not true. Production is only controlled by the dredging depth, and the dredge has to be adjusted according to the pit production. Thus pit prdduction is autonomous. Sand dredging has been done since 1875 but this principle was published for the first time in 1968, which is only 15 years ago.

Digging and mixture forming. Sand or soil is mixed with water and prepared so that it can be transported mechanically or hydraulically.

To position the dredger and keep it in position, and move it in the way wanted. There is a lot of equipment to accomplish this -

instruments, anchors, spudpoles, winches, wires, etc. Spudpole carriers are an improvement which saves movement time. Christmas tree arrangements help operate dredgers in rough weather conditions.

Vertical transport. The spoil is moved above water. Vertical transport is achieved with a bucket dredger through mechanical vertical transport - the hard way. Hydraulically vertical transport is achieved with the centrifugal pump and the latest development is the submerged pump.

To load the spoil into the means of transportation. The spoil is loaded into a box, a pipeline or a belt conveyor.

To accept the material into the means of transportation and prevent spill of spoil. In the United States of America six international dredging companies went broke in the 1960s because of this problem alone. When the trailers of the American Army Corps of Engineers, who are responsible for the maintenance of harbours, left behind streams of turbidity, photographs of the phenomenon were taken from small planes and subsequently prevented the dredgers from operating. . At that time there were no rules about how dredgers should be built and what were the ecological requirements.

The quality of the spoil or the slurry can be improved hydraulically by settlement in settling tanks with hydro-cyclones or by dewatering systems, and mechanically by using vibrating screens, shaking screens or crushers.

The horizontal transport. It can be done hydraulically, or mechanically - by box, by belt conveyor or by truck. There are many systems of floating pipelines and shore pipelines and a lot of know-how related to this area. The principle of the split barge is another interesting innovation.

The discharge into the underwater dump area is another problem area we know very little about. What happens when the bottom of a hopper dredger is opened? Where will the spoil go? If there are sea currents the spoil could move into areas where it is not wanted.

Putting the spoil into the reclamation. This is another problem which needs a lot pre-study because a fill on unstable sub-soil can create many problems such as slides, or sub-soil boiling up above reclamation.

Compacting and shaping is never possible with hydraulic fill. If wanted it will have to be done with equipment.

Earth construction must be protected against destruction by external forces. A dyke is provided to prevent an earth construction from collapsing through the action of waves. Protection against wind erosion, traffic, and rainwater is also to be provided.

Latest developments

During the last two decades dredging requirements in connection with the execution of larger projects have become very large. It has become necessary to dredge much deeper which also has had the implication that dredging of harder sub-soils or soft rock has become a rather frequent activity. Because of deeper ships, the navigation channels have become very long requiring dredging in more exposed waters. Offshore excavation of very deep pipeline trenches and dredging in Arctic areas have also required development of new dredging techniques. These are the technical reasons for the fast development of dredging technology.

Other reasons are increased competition between international companies and increased fuel prices. Costs of employing specialist crews for dredger operations are extremely high. It has become economically feasible to develop advanced equipment and instrumentation for accurate control of the whole dredging process. Microprocessors and modern information technology have become common onboard modern dredgers. Current research and development take place with the aim of monitoring and controlling the whole dredging process with computers. Hereby, the registration and processing of dredging data also can be used as a management tool. The whole dredging cycle may be carried out automatically, but manual adjustments may be carried out on basis of the continuous recordings of the dredging process.

More specifically, the recent developments of dredging equipment, dredging methods and dredger instrumentation have mainly been directed at:

- improving the disintegration of cohesive soils, the excavation and the mixture forming.

- a more accurate determination of the horizontal and vertical position of the cutter or suction head, and the path of this.

- attaining lower dredging tolerances for modern civil engineering constructions.

- improving efficiency of hopper loading.

- improving dredging methods in exposed waters.

- establishing accurate systems of measuring dredger production - this is one of the most difficult problems in dredging.

When contracting, it should always be considered if the dredging tolerances agreed are reasonable. There should also be a reasonable relation between the vertical and horizontal tolerances. The costs of dredging increase dramatically when tolerances become very narrow.

Dredging by trailing suction heads may be improved considerably by using jets to help agitate the bed sediment. Hereby, dredger production may be increased by 30-40%. Now, efforts are also being made to make rock dredging by trailing suction dredgers feasible. However, this is not only a matter of the design of the trailing suction heads - the whole design of the dredger needs to be changed in order to be able to cope with rocks.

Dredging of clay has been greatly improved by the invention of the dredging wheel, and the future of the dredging wheel seems very bright.

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10. MANPOWER TRAINING

In the Netherlands training or education is organized formally for personnel engaged in any phase or discipline of a dredging project for planners, designers, dredger operators etc. During the Seminar-cum-Study Tour, the Oranje Nassau School for Dredging Education, the Delft University of Technology and the International Institute for Hydraulic and Environmental Engineering were visted. The information gathered during the visit is summarized under this subject. In addition to the education at these educational institutions, companies involved in dredging also offer further training to their staff.

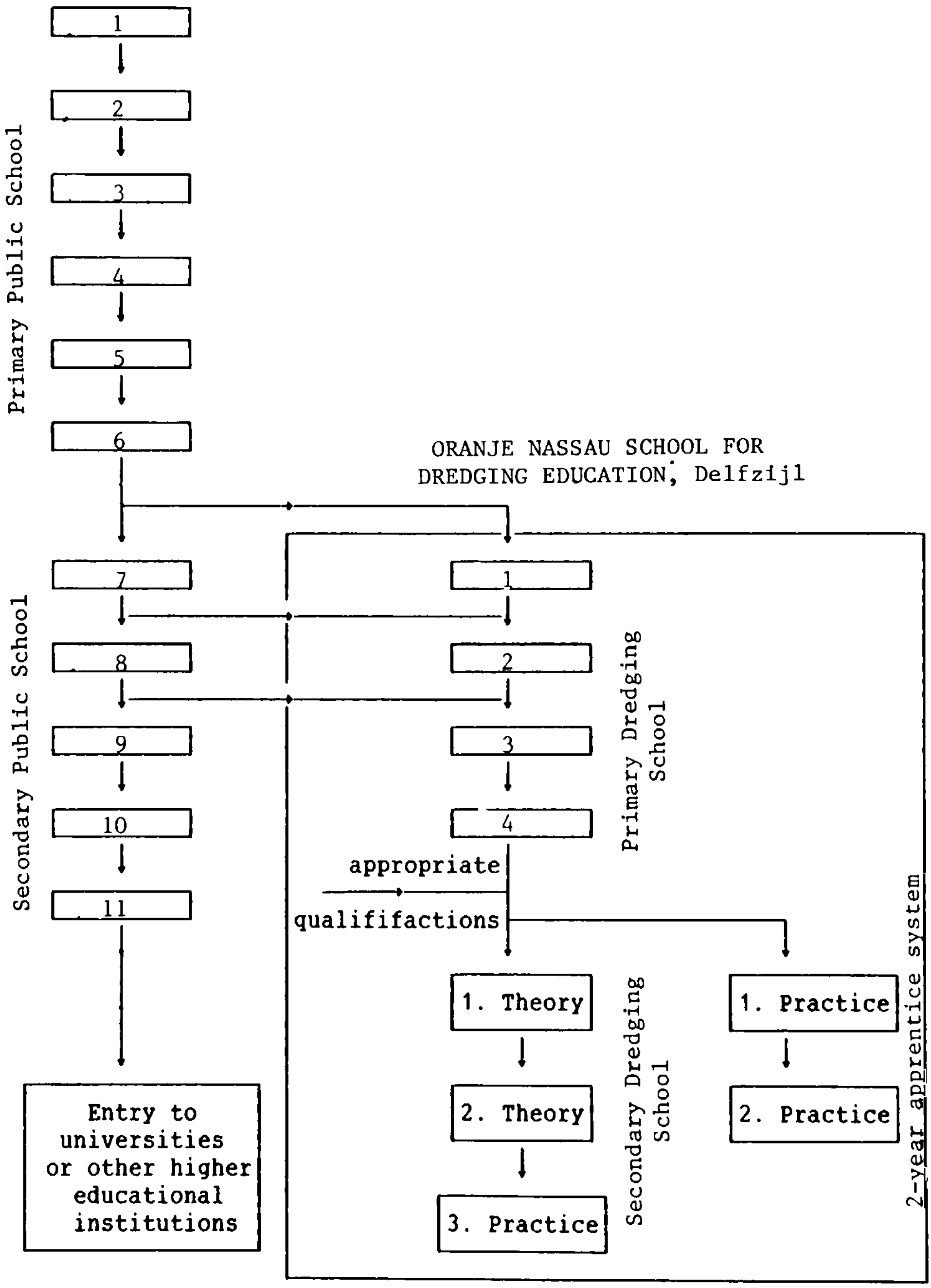
10.1 Training at the Operative Level

The governmental Royal Education Foundation for Shipping and Inland Waterways (Stichting Koninlijk Onderwijsfonds voor de Scheepvaart) has 5 schools. One of these schools The 'Oranje Nassau School for Dredging Education' in Delfzijl in the northeastern part of the Netherlands - is specialized in training of manpower for operation and maintenance of dredgers.

It was opened in 1966. It is a boarding school and divided into the 4-year Primary Dredging School and the 3 year Secondary Dredging School. In addition, a two-year apprentice system as an alternative to the Secondary Dredging School is organized in co-operation with the Dutch dredging industry and Rijkswaterstaat.

The minimum entrance requirement to the Primary Dredging School on the first-year level is completion of the 6 year Primary Public School, and the age of admittance must be below 16 years. A thorough medical test also has to be passed. During the first two years of the Primary Dredging School there is actually no teaching in dredging at all. Those 2 years may be considered as a continuation of the general public school and serve as a period for the students to get accustomed to the boarding school and daily life of the school.

However, the first 2 years are not compulsory, as the Primary Dredging School may be entered at the third year level. A schematical presentation of the education at the dredging school is presented below:


Primary Public School
1
2
3
4
5
6
Secondary Public School
7
8
9
10
11
Entry to universities or other higher educational institutions
ORANJE NASSAU SCHOOL FOR DREDGING EDUCATION, Delfzijl
1
2
3
4
Primary Dredging School
appropriate
qualififactions
1. Theory
2. Theory
3. Practice
Secondary Dredging School
1. Practice
2. Practice
2-year apprentice system

The subjects taught in the Primary Dredging School (3rd and 4th year) are dredgers and dredging, geography, navigation, mapping, instrumentation, legislation and regulations, first aid, engines and tools. The Primary Dredging School is completed by an examination at the end of the fourth year, after this about half the students choose the Secondary Dredging School, the other half the apprentice system. In 1985 about 150 students were enrolled in the Primary Dredging School.

The subjects taught in the Secondary Dredging School (1st and 2nd year) are dredgers and dredging (dredger construction and design, equipment processes and instrumentation, ship operation and pump operation), soil mechanics, hydraulics, planning of dredging operations, project exectuion, Dutch, English, mechanics, physical training and first aid. Practical training is given in soil investigations, hydrographic surveying and operation of dredging equipment. After the second year of the Secondary Dredging School the students must pass an examination, which is followed by one year of practical training onboard an operating dredger. Upon completion of this, the students receive the Diploma from the Secondary Dredging School.

As an alternative to the Secondary Dredging School, the students may choose the two year apprentice system with practical work on an operating dredger in two years. However, in connection with this some theoretical teaching is also given.

All teaching at the school is given in Dutch, and there are no foreign students (except for a few Belgiums who have Flemish as their mother tongue).

The school has close co-operation with the dredging industry, and usually the practical training and jobs will be secured for the students upon enrollment in the school scheme.

The school has a sophisticated cutter suction dredger simulator with instrumentation as on a real cutter suction dredger. The water depth, soil data and dredger data are stored in a computer, and then the "dredging" may be carried out as in nature. The efficiency and progress of the dredging can be evaluated by using the instrumentation, and all forces, position of cutter, etc. can be adjusted. The dredger simulator may be used for any type of soil and any dredger size, and thus the trainees may obtain experience on any dredging job. There are six control rooms for trainees and one central control panel for the instructor. The instructor can thus monitor the progress of the dredging done by the individual trainee. The school uses the simulator for classes about 4 hours/day. Private dredging companies are also using the simulator to pre-train dredger staff for specific jobs.

Staying at a boarding school is considered to be a very important part of the education. Through living with school mates and carrying out daily duties in the school, the students are prepared for the atmosphere on board an operating dredger.

Upon completing their education, the students are usually 20-23 years old. With the Diploma from the Secondary Dredging School or successful completion of the apprentice system (including the theoretical training), they are qualified to become a dredge master. However, it is the general philosophy in the Dutch dredging industry that all dredger crew members must have experienced all kinds of work on board an operating dredger. Thus, everybody will have to work as a deck-hand for some time, before they are promoted to higher posts. Depending on company philosophy, the size of dredgers, etc., people do not usually become dredge masters before they are aged 25-30.

10.2 Project planners, site engineers and dredger designers

Education of project planners and site engineers takes place at the Delft University of Technology.

Admission to the Delft University of Technology takes place after successful completion of secondary public school, after 11 years of schooling.

The course at Delft University of Technology lasts for four years, but a small number of students will be admitted to post-graduate study. Of interest to the dredging industry is the hydraulic engineering course at the Department of Civil Engineering. Further, there is a possibility of specializing in dredger design or operation at the Faculty for Technology of Soil Movement, Mechanical Engineering Department.

Movement, Mechanical Engineering Department.

At the Civil Engineering Department the first two years of the curriculum are devoted to the subjects that are obligatory for all students: mathematics, mechanics, functional and structural design. An overview is given of the role that civil engineering plays in society and students are made aware of the demands this may make on their capabilities for co-operation and communication. In the third year diversity is achieved by means of a selection of instructional modules, each requiring six to seven weeks of study time. The fourth year is devoted to more advanced study in the discipline or application field in which the student wishes to specialize. The requirements include working under guidance on a project (thesis) at professional level.

At the Civil Engineering Department there are five laboratories where practical research in a number of subjects may be carried out by the students and/or as part of the research at the Civil Engineering Department. Amongst these laboratories can be mentioned thé Laboratory of Fluid Mechanics ad the Geotechnical Laboratory. The Civil Engineering Department has presently an on-going study on disposal on the banks of material dredged in rivers or canals.

10.3 Post-graduate programes at the International Institute for Hydraulic and Environmental Engineering

The International Institute for Hydraulic and Environmental Engineering is located in Delft.

The aim of the Institute is to promote the transfer of experience and know-how in the field of science and technology related to water and the environment to professionals, especially from developing countries. The 11-month study programme offers lectures, laboratory work, workshops, project work and field studies in a great variety of subjects. Successful participants will receive a diploma at the end of the course.

The history of the International Institute for Hydraulic and Environmental Engineering began in 1957 when it was set up as a joint venture of the Delf University of Technology and the Netherlands Universities Foundation for International Co-operation (NUFFIC). The establishment of the Institute was a logical consequence of the general policy of the Netherlands Government to contribute actively to the international exchange of knowledge in science and technology.

Since the Dutch language is accessible to few, the Dutch university structure was reinforced by special institutes offering post-graduate instruction in English in subject areas selected on the basis of available expertise in the Netherlands and relevance to ugent problems of development.

The permanent staff of the Institute is relatively small, the major part of the teaching faculty consists of experts working at universities, institutes and government authorities in the Netherlands and abroad. The curricula of the Institute's programmes are entirely independent of those of the Delft University of Technology in order to ensure a high degree of flexibility. The Institute is sponsored by UNESCO and assisted both by the World Health Organization (WHO) and the World Meteorologoical Organization (WMO).

The following study programmes are offered:

1. International Course in Hydraulic Engineering with the following branches of study:

a. Hydraulic engineering in upland areas.
b. Hydraulic engineering in low land areas.
c. Land and water development.
d. Experimental and computational hydraulics.
e. Port engineering.
f. Coastal and offshore engineering.

2. International Course for Hydrologists.

3. European Course in Sanitary Engineering, dealing with the control of waste pollution and the provision of drinking and industrial water in densely populated industrial areas.

4. International Course in Sanitary Engineering, dealing with drinking water supply, sanitation and health administration in agricultural areas and initial phases of development.

5. International Course in Environmental Science and Technology dealing with practical ecological problems in industrialized as well as developing areas.

6. The Institute regularly organizes seminars and other short-term programmes. Additional programmes of study are in a preparatory stage. Courses may be arranged in languages other than English.

7. The Institute is prepared to carry out education components of development projects related to water and the environment, including their social impacts, or to execute projects for the establishment of education and research capabilities in developing countries.

In view of the level of instruction, the principal condition for admission is that participants hold a degree from a university of recognized standing. For the course in hydraulic engineering this should be a degree in civil engineering or a related branch of engineering; for the course for hydrologists a degree in civil engineering or a related branch of science or engineering is required; for the courses in sanitary engineering one should hold a degree in civil engineering, sanitary engineering, chemical engineering or a related branch; and for the course in environmental science and technology a degree in biology, chemistry, chemical engineering or a related branch of science is required.

In principle, candidates should have at least three years of practical or research experience after graduation. However, as no simple international formula can be given for the conditions of admission, all applications will be considered individually. Since instruction, as well as examinations, will be given in English, it is essential that participants have a good command of English. If this proves to be insufficient during the course, participants can be excluded from further participation.

International co-operation.

The Institute is sponsored by UNESCO: the courses in hydraulic engineering and for hydrologists closely co-operate with its Division for Water Sciences. The course in environmental science and technology has adapted its contents to the UNESCO programme on environmental education for engineers. Under the aegis of UNESCO the Institute closely co-operates with other UNESCO-sponsored institutes for post-graduate education in science and technology. WHO gives assistance to the course in sanitary engineering and the course in environmental science and technology. WMO assists the course for

11. COUNTRY PAPERS

One of the highlights of this Seminar cum Study Tour was the presentation of country papers by the participants, followed by discussions. The papers served the purpose of providing an opportunity for the participants to exchange views and experience on the dredging industry. Each country paper outlined planning and execution activities of selected dredging projects in the country. A summary of the country presentations is given in this section.

Burma

The Port of Rangoon is located at the confluence of three rivers, and access to the sea is through the 35 kilometer long Rangoon River estuary. The main navigation channel meanders through the estuary. The depth available for navigation is restricted by two bars, the Inner Bar near the city of Rangoon and the Outer Bar off the mouth of the estuary. At the Outer Bar the depth was about 15 ft below Chart Datum in 1984, whereas the available depth at the Inner Bar ranged from 9 to 13 ft. At spring tide the tidal water level variations average 5.9 m (19 ft). The tidal currents are strong. In the monsoon season, when high fresh water discharges are superimposed on the tidal flows, the ebb currents may reach maximum velocities of 3.5 m/sec in the harbour area.

The Burma Ports Corporation requirement is to be able to accommodate vessels up to 15,000 dwt. For this purpose it is necessary to maintain the navigation channel at a depth of 15 ft below lowest low water (LLW), whereas at the wharves the design depth is 30 ft. The largest vessels may thus only enter the port at high tide.

In 1984 dredging had to be carried out at the Inner Bar and in the harbour area. For the dredging works the Burma Ports Corporation is in possession of the following dredging equipment:

(a) One bucket dredger with two self propelled barges utilized for dredging along the main berths. The dredging requirements here average up to 190,000 cu.m. annually

(b) One trailing suction hopper dredger with a hopper capacity of 850 cu.m. This is used for dredging at the Inner Bar, where the dredged quantity was about 600,000 cu.m. in 1984.

(c) Three grab dredgers with dump hopper barges. These are mostly used for dredging at the foreshore jetties, where the annual dredging requirement is approximately 200,000 cu.m.

During 1984 the target depth of 15 ft at the Inner Bar was not fully achieved. However, generally speaking, it can be said, that the Burma Ports Corporation managed to meet the dredging requirement of the Port of Rangoon in 1984. This was achieved by full utilization of the dredging fleet.

It can be foreseen that the present favourable navigation conditions at the Outer Bar will not continue, and if a dredging requirement here arises again, the dredging requirements at the Port of Rangoon cannot be met by the existing dredging fleet. Because of this the Burma Ports Corporation is planning to expand the dredging fleet.

Of the inland waterways in Burma, the Irrawaddy River is the principal river. It runs from north to south and is 2,010 km long with a catchment area covering more than half of the total Burmese territory. In its lower course the width of the river is 2 km or more. The fresh water discharge ranges from 1,300 cu.m./sec in the dry season to 64,000 cu.m./sec in the rainy season with an average discharge of 13,000 cu.m./sec. The maximum difference in the water level between the dry season and the rainy season is 10 meters. The largest tributary of Irrawaddy, the Chindwin River, is also used for inland water transport.

During the dry season the water level decreases, and at about 10 places in the Irrawaddy River and 8 places in the Chindwin River the river becomes too shallow for navigation. The Waterways Department is responsible for dredging operations at these places. Based on survey maps and the availability of dredging equipment, the department prepares dredging schedules and cost plans for the maintenance works.

The Waterways Department at present has seven working cutter suction dredgers. In addition, they have four old cutter suction dredgers which are not in working condition.

The volume dredged has increased dramatically in recent years, from about 50,000 cu.m. in 1980/1981 to approximately 1,400,000 cu.m. in 1984/1985. The main reason for the increase was the purchase of five new dredgers in 1981.

China

China has a coastline of 18,400 km, providing favourable conditions for developing water-borne transportation.

Since 1973, to meet the dredging requirements of large-scale port construction and maintenance projects aimed at accommodating larger and deeper vessels, most of the old dredgers were replaced by modern ones. China now possesses one of the largest dredging fleets in the world. At present, under the Ministry of Communications alone there are more than 120 dredgers, 80 per cent of which were built in the 1970s, with an annual dredging capacity of 20 million cu.m. They include:

1. **Two 6,500 m^3 trailing suction hopper dredgers with sidecasting booms.**

2. **Twelve 4,500 m^3 trailing suction hopper dredgers.**

3. **Nine 1,500 m^3 trailing suction hopper dredgers.**

4. **Nine cutter suction dredgers.**

5. **Six 750 m^3/h and one 500 m^3/h self-propelled bucket dredgers.**

Apart from the above-mentioned dredgers purchased from the Netherlands and Japan in the mid-1970s, China also operates many dredgers of its own design and built by its own yards to the specifications of the Chinese Classification Society. Among them are:

1. One 13 m^3 grab dredger.
2. Ten 8 m^3 grab dredgers.
3. Many grab dredgers with a grab capacity of 1.2 ~ 1.5 m^3.
4. Five diesel electric bucket dredgers having a capacity of 500 m^3/h.
5. Twenty cutter suction dredgers of 1000 m^3/h pumping capacity.

In recent years, most of the major ports have undergone considerable development. Harbour basins and navigation channels have been deepened to increase and maintain the required water depth. In addition, China has also contracted international dredging projects.

However, the dredging capacity still seems unable to meet the growing demand for dredging works. It is estimated that the annual capital and maintenance dredging requirements will increase to more than 200 million cu.m. in the year 2000.

While continuing efforts will be made to expanding the existing dredging fleet, there is a great need to improve the management of the industry and to upgrade the knowledge and skills of dredging personnel at all levels.

Fiji

Fiji is a country comprising approximately 350 islands of which only about 100 are inhabited.

The primary mode of transporting cargo to and from Fiji is by sea. With the exception of one small purpose-built sugar terminal, all import and export of cargo is through three international ports (Suva, Lautoka and Levuka), which are controlled and operated by the Ports Authority of Fiji, a statutory body established in 1975 by an act of Parliament.

Fortunately, the three international ports are located in natural harbours with adequate water depths along the berths and the approach channels. The average tidal range for the three ports is 1.7 metres. All three ports have natural protection from heavy seas by coral reefs. However, the two bigger ports have siltation problems due to creeks discharging silt nearby and due to obstruction of littoral drifts by artificial headlands created by reclamations.

The Port of Suva is situated on the island of Viti Levu and handles most of the general cargo. This port handles overseas vessels as well as local inter-island vessels. At one wharf the harbour basin has silted up from between 40 centimetres and 1 metre, limiting the draft of vessels to 1.5 metres on the eastern side and 3.5 metres on the western side. At another wharf the siltation is in patches. The annual dredging requirement is 700 - $1000m^3$ thus making it very difficult to attract contractors to bid for the works. Whilst the volume of dredged material is very small, the problem of providing adequate water for berthing of overseas vessels still exists. In effect approximately 50 metres of much required berth space becomes unusable.

The Port of Lautoka is situated on the opposite side of Viti Levu. This port has a sugar berth, mainly used for bulk export of sugar, which is Fiji's primary export commodity, a wharf for overseas cargo vessels and local passenger cruise vessels, and another wharf for local inter-island cargo vessels. Generally, the port is free of siltation. However, one wharf has had significant siltation over the years due to the creation by reclamation of a headland which obstructs the self-balancing littoral drift. This wharf is now limited to very shallow draft vessels at high tide and has very limited use at present. Studies are under way for carrying out dredging operations to remove approximately 100,000 m^3 of silt, or to relocate the facilities since the wharf structure would need considerable capital works for upgrading.

Owing to the geographical distance between the three ports and the small volume of annual maintenance dredging it has become extremely difficult to attract contractors to bid for the dredging works.

Dredging equipment owned by the Marine Department and the Drainage and Irrigation Section are only suitable for dredging in rivers and at very small jetties in shallow waters. Moreover, the fleet owned by these two government departments are fully committed to their own requirements.

Apart from the dredging equipment owned by the two government departments, there are no other full-time dredging contractors in Fiji. All minor dredging works for the private sector is carried out by means of clam shell through cranes on barges or backhoes loaded on barges.

The main problem faced by the Ports Authority of Fiji is to obtain a dredging system which can economically and readily dredge up to 2000 m^3 of silt in each location in a depth of water ranging from 7 to 8 m. The equipment should be easily mobilized and transportable from one location to another.

India

India has a coastline of 5,700 km., the east coast is 3,000 km. long, and the west coast 2,700 km. There are 11 major ports, 16 intermediate ports and 78 minor ports.

Along the west coast the tidal range varies from 1 m at the southern part to 11 m at the northernmost part. The slope of the sea bed is very gentle. Bed materials are mainly fine, such as silt, clay and mud. The littoral drift along the west coast is in the order of 0.1-0.2 million cu.m./year with no general transport direction.

Along the east coast the tidal range varies from 1.2 m. in the south to 5 m at Calcutta. The sea bed is rather steep, and bed materials are mainly medium to fine sand. Heavy littoral drift takes place, during the south-west monsoon from May to September towards the north, during the north-east monsoon from October to April towards the south. The net transport is directed north and amounts to 1-1.5 million cu.m./year. It is largest along the northern part.

Most of the major Indian ports have undergone considerable development in the past two decades, and harbour basins and navigation channels have been deepened up to 19 m, so that they may accommodate bulk oil carriers and VLCC's.

The siltation problems encountered at the ports are caused by the following mechanisms:

a) Littoral drift in the breaker zone.
b) Wave distribution combined with tidal currents.
c) Settling of silt brought by the rivers.
d) A special problem is the flocculation of suspended silt, where the fresh riverine water mixes with the salt sea water.

Capital dreding requirements are mainly being undertaken by the Dredging Corporation of India Ltd., (DCI). DCI is a Government of India undertaking formed in 1976 under the Ministry of Shipping and Transport. DCI took possession of all dredgers and other supporting floating craft from April 1977. Today, the Corporation has 5 trailing suction hopper dredgers of hopper capacities varying from 2,500 to 6,500 m^3, and 3 cutter suction dredgers. One more trailing suction hopper dredger of 4,500 m^3 hopper capacity was expected to be delivered by March 1986.

All the old ports have their own dredgers to meet their maintenance dredging requirements. The ports which have been constructed in recent years have needed the assistance of the Dredging Corporation of India to meet the needs for maintenance dredging (a total quantity of 190 million cu.m). At the 11 major ports alone, the yearly maintenance dredging requirement is about 40 million cu.m.

In India, dredging is also carried out for maintenance of inland waterways, and for desiltation of intake channels, cooling ponds, reservoirs of industrial settlements, recreation lakes and irrigation reservoirs. DCI is also involved in some of these works In addition, DCI also acts as a contractor for international dredging projects.

Indonesia

Indonesia is a large country of islands which covers a vast area. The country is thus heavily dependent on sea communication. Ports are traditionally located in river estuaries offering good opportunities for trade with the hinterland.

Today, the locations of the ports at the river estuaries are not favourable, because the development of ships has led to demands for increased water depths, and the silt transported by the river settles at a higher rate in the deeper basins. Further, the process of siltation in the ports is aggravated by increased soil erosion in the hinterlands, causing larger quantities of sediment to be carried to the river estuaries.

Dredging has been carried out for many decades in Indonesia. Equipment used ranges from simple agitation mud wheels to sophisticated trailing suction hopper dredgers.

Until 1983, a subdirectorate of the General Directorate of Sea Communications was responsible for maintenance dredging in the ports. Dredging works were financed by the Government, which allocated an annual budget with fixed unit rates.

In 1983, the "Perum Pengerukan", a state-owned dredging enterprise, was established. The equipment of the former subdirectorate were transferred to the "Perum Pengerukan" which has an independent status. In addition to carrying out maintenance dredging in the 41 main ports, the "Perum Pengerukan" is also allowed to act as a contractor in demestic as well as in international dredging projects.

The dredging fleet of "Perum Pengerukan" now consists of 13 trailing suction hopper dredgers, 3 cutter suction dredgers, 3 bucket dredgers and 8 clamshell dredgers. Most of the fleet is relatively new dating from 1980 or later.

The yearly dredging capacity of the fleet is about 40 million cu.m., but the annual maintenance dredging requirements at the Indonesian main ports - to which priority is given - is only 12 million cu.m. The surplus capacity may thus be used for projects not included in the national maintenance programme.

Since the "Perum Pengerukan" was established strong efforts have been made to make it an efficiently run company. The main part of the personnel are former government officials, and the management is aware that great attention has to be paid to a change in attitude, from "budget-minded" to "profit-making" The personnel attends dredging courses in order to familiarize themselves with modern dredging techniques. In addition, joint dredging operations are organized with experienced dredging companies for transfer of know-how.

The "Perum Pengerukan" has already participated in projects in Malaysia and Singapore, and it is expected that in the future the enterprise will play an important role with regard to dredging projects in the South east Asian region.

Malaysia

Peninsular Malaysia has quite a large number of ports both on the east and west coasts. Out of these, 4 ports have been nominated as federal ports, namely:

1. Port Keland
2. Penang Port
3. Johore Port
4. Kuantan Port

Each of these ports is managed by separate port authorities. The rest of the ports are referred to as minor ports. In addition to these minor ports, there are a number of estuaries and river mouths which are used as fishing ports, local ports or ports of refuge.

The responsibility of dredging and maintaining the depth in the federal ports lies with the specific port authorities, and the responsibility for dredging in the minor ports rests with the Marine Department. The Drainage and Irrigation Department (under the Ministry of Agriculture) is responsible for the fishing ports.

Capital dredging works in the federal ports have been undertaken through international contracts secured through open tenders. From 1979 to 1983 a total of over 79 million m^3 of capital dredging have been contracted out involving a sum of over $ 266 million (Malaysian ringgit).

For maintenance dredging, in the period 1979-1983 a total of over 9 million m^3 was contracted out, involving a sum of over $ 23 million. Only two of the port authorities, namely Port Kelang and Penang Port own dredgers for maintenance dredging. Their activity limited to dredging along the berth.

The Marine Department and the Drainage and Irrigation Department also have a number of dredgers,mainly for the dredging of their minor ports and fishing ports. The number of dredgers owned by them is too small even to keep up with their own dredging requirements.

Having reviewed and analysed the existing situation and having established that there is and is likely to be continued to demand for capital and maintenance dredging, the next task is to determine the organizational structure for a more efficient application of dredging technology. The objectives to be achieved through this organizational structure are:

a. Dredging at the most economic cost;
b. Stimulation of development of dredging technology;
c. Transfer of technology to increase national participation and save foreign exchange.

It has been suggested that the Government will set up a dredging management unit to be responsible for all dredging projects and also to assist the local contractors in dredging. By doing this the dredging services to be performed can be obtained at reasonable rates. This unit will also store knowledge in a data bank to draw upon for future use, and provide management for project realization.

Pakistan

In Pakistan, there are two major ports, Karachi Port and the new Port Qasim. Karachi Port handles mainly general cargo and oil products, whereas Port Qasim is a bulk, container and industrial port.

Karachi Port has a 4.5 km long navigation channel. The port has a yearly dredging requirement of about 1 million cu.m., and the port authority operates for this purpose a trailing suction hopper dredger. This has a hopper capacity of 2,000 cu.m.

Port Qasim is located 45 km east of Karachi. It accommodates vessels up to 12 m. The port is reached through a 14 km long approach channel in the open sea, a 25 km long natural inner channel and a 4.5 km long reach channel. Before construction the annual maintenance dredging requirement was forecast to average 2.4 million cu.m. Based on detailed economic analyses, the port was recommended to purchase a new 3,500 cu.m. trailing suction hopper dredger to deal with the maintenance dredging requirement. The economic feasibility of acquisition of a second-hand dredger or continuation of contract dredging was investigated as an alternative.

In the westernmost part of Pakistan, the Government has decided to build a fishing port at Gwadar. The port will also handle food, grain, oil products and other cargo. The port is required to accommodate vessels with a draught of up to 3.5 m. The annual maintenance dredging requirement has been estimated at 90,000 cu.m. With the construction of this port, it is the hope of the Government that the living conditions in this rather undeveloped part of Pakistan will be improved.

Freight traffic in Pakistan has been growing for several years. Transported items are agricultural products, cement, steel and iron ore. Today, goods are mainly transported by road and rail and costs are high. However, considerable cost savings may be achieved by the development of an inland water transport system. The Government has thus decided to initiate detailed technical and economical studies of the feasibility of such a system.

Philippines

There are 94 national ports, 528 municipal ports and 216 registered private ports under the Philippine Port Authority. These ports have been classified into big, medium and small ports and most of them require maintenance dredging. Only two ports are classified as big: Manila and Cebu.

The Philippine Ports Authority (PPA) has since 1977 been responsible for all maintenance dredging activities, whereas capital dredging is the functional responsibility of the Ministry of Public Works and Highways. The policy of PPA in implementing dredging projects is to give priority to the major ports, particularly the Port of Manila. Maintenance dredging has been carried out in two stages. Initially, as many ports as possible have been dredged to a safe navigable depth. The second stage of the maintenance dredging is then carried out when navigation requires such action.

The Maintenance and Equipment Department of PPA has an Engineering and Equipment Division which is responsible for planning the dredging programmes. For this purpose it has two sounding boats equipped with a Motorola Mini-Ranger Positioning System, and annual periodic hydrographic surveys and charting are carried out by the survey team. The annual maintenance dredging programme (which is tabulated on a quarterly basis) comprises: dredge volumes, available equipment and financial aspects. A big part of the implementation of all the dredging programmes goes to contract, awarded either to a government-owned corporation or a private company. Formerly, PPA negotiated contracts with, for example, the Philippine Navy and the defunct Bureau of Ports and Waterways, but because of the obsolescence of their dredgers PPA decided to purchase its own new modern dredgers. Foreign loans were used to finance six dredgers: two split-type trailing suction hopper dredgers, two trailing suction hopper dredgers, and two grab hopper dredgers.

PPA has entered into a contract with the Philippine National Construction Corporation (PNCC), a government construction and dredging corporation, to operate and maintain five units of its dredging fleet. One unit, the grab hopper dredger, is being operated by PPA. Under the contract PNCC will dredge all the ports and navigable waters under the jurisdiction of PPA. The contractor has to provide all the manpower, fuel, and all other ancillary equipment, and cover operating expenses. PNCC is then paid by PPA at a specified unit price. PPA is responsible for the planning, programming, monitoring, reporting and supervision of the five contracted dredgers. Pre- and post-dredging surveys are carried out by PPA, and payment is calculated on the basis of the results of these surveys.

The grab hopper dredger operated by PPA is used in the port of Manila only, as this port provides sufficient work for the dredger to work throughout the year. For operation and maintenance the

EED has personnel with mechanical and electrical engineering backgrounds. They are also responsible for the inspection and supervision of the five contracted dredgers.

Singapore

Singapore is a small island nation with a comparatively deep natural harbour, and dredging has traditionally not played an important role. Most of the maintenance dredging works carried out in Singapore have traditionally been in the rivers and river basins. However, since the beginning of the 1970s dredging has also become important in connection with large-scale land reclamation projects and capital and maintenance dredging work with the purpose of admitting larger and deeper vessels to the port.

Land reclamation projects have been carried out under the Port of Singapore Authority (PSA), the Housing and Development Board (HDB) and the Jurong Town Corporation (JTC). PSA has been involved with the reclamation of recreational offshore islands, of areas for the New Changi Airport and of areas for port development. A considerable portion of the soil needed for the reclamation has been obtained by dredging, and trailing suction hopper dredgers and cutter suction dredgers have been used for this purpose. A quantity in the order of 60 million cu.m. of sea bed material for the reclamation has been obtained by dredging.

PSA is responsible amongst other things for maintaining the designated depths required in the rivers, channels, alongside wharves and in the turning basins and navigation channels, to ensure safe navigable access of vessels to the various gateways to the Port of Singapore. The total sea area maintained by the Port of Singapore Authority is approximately 267 hectares and the total length of wharves is 12.6 km.

PSA operates a small fleet of 3 grab dredgers and 8 self-propelled, split hulled hopper barges. These dredgers are employed to dredge the rivers and river basins. They are not suitable for dredging busy port areas where the grab dredgers cause hindrance to ship movements. Such areas are maintained by employing trailing suction dredgers through separate contracts.

Because ofthe limited sea space available in Singapore, it is a problem to find suitable dumping grounds located near dredging locations. Earlier much of the spoil was used for reclamation works. However, most of the shallows have already been filled making it more difficult to find suitable dumping grounds.

Hydrographic surveys and analysis of sea bed samples are carried out regularly to ensure that spoil dumped is not transported back to the dredged areas.

The selection of dumping grounds is made after careful studies are made including hydraulic model studies. PSA has established facilities to conduct detailed studies on physical as well as numerical models. Capabilities to carry out fluorescent/radioactive tracer studies and in-situ silt density measurements using gamma back scatter equipment have also been set up to assist in coastal hydraulics studies.

Sri Lanka

Sri Lanka has four commercial ports: Colombo, Galle, Trincomalee and Kankasanturai. More than 95 per cent of the cargo handling takes place through the Port of Colombo. The Sri Lanka Ports Authority (SLPA) controls and operates the three ports of Colombo, Galle and Trincomalee, whereas the Port of Kankasanturai is privately-owned For capital and maintenance dredging in the commercial ports, SLPA operates a fleet consisting of a 220 cu.m. hopper grab dredger, a bucket dredger, a 650 cu.m. trailing suction hopper dredger, a 14 inch cutter suction dredger and three small grab dredgers. SLPA has the necessary survey, workshop and engineering facilities to operate this fleet.

The Port of Colombo covers an area of 260 hectares, and the total quay length is 3,200 metres. Dredging in the Port of Colombo dates back to 1880. Lately, construction of a modern container terminal, which has been ongoing since 1983, has involved considerable capital dredging works. These works comprise a deepening of the port up to 13 metres and also dredging for reclamation and quay foundations.

The siltation in the Port of Colombo is caused by the littoral drift, the existence of a major river mouth about 1 km north of the port, and the presence of municipal storm water outlets within the port. The annual capacity of the dredgers of SLPA exceeds the annual maintenance dredging requirement of the port,which is about 100,000 cu.m. per year. However, it is expected that the amount of siltation will increase after the completion of the ongoing development works. The tidal range at the port is about 0.6 m.

The ongoing development works include dredging of a total of 3.7 million cu.m. of soil. A foreign contractor has carried out the dredging for quay-wall foundations and reclamation (2 million cu.m.), whereas the deepening of the harbour basins has been carried out by SLPA (1.7 million cu.m.). Most of the material dredged has been silt, sand, silty sand and clay. However, rocks have been encountered at certain places, and it has been necessary to blast about 7,500 cu.m. of rock.

The Port of Galle is located on the south coast of Sri Lanka. In 1984, capital dredging works comprising 850,000 cu.m. soil (of which about 25,000 cu.m. rock) were completed by a foreign contractor. Soundings are now being carried out in order to study the siltation pattern in the port.

The Port of Trincomalee is an excellent natural port on the east coast of Sri Lanka. No dredging is carried out here.

In addition to SLPA, a few other governmental institutions have dredgers for maintenance of irrigation channels, canals, flood outlets and fishing ports.

Thailand

The first inland waterway project of Thailand was completed in July 1985. A 200 km long, non-tidal part of the main river, the Chao Phraya River, has been developed to allow all-year navigation. On this part of the river, there is also a dam with a sluice. The water level of the river varies strongly with the season, and the dam serves to ensure a certain minimum flow downstream during the dry season.

The development works have included dredging, establishment of hydraulic structures like groynes, bottom pannels, dykes and bank protection, and an aids-to-navigation system.

The design dimensions of the navigation channel in the river are a width of 40 metres at the bottom, a horizontal clearance of 80 m between structures on opposite banks, and a depth of 1.70 metres throughout the year.

Maintenance dredging takes place in the period from mid-November to May. The Harbour Department of the Ministry of Communications is responsible for the maintenance of the navigation route in the river. However, shortage of manpower, equipment and financial resources will probably put a constraint on efficient maintenance of this new inland navigation route.

Viet Nam

The system of rivers in Viet Nam has formed a convenient natural water transport network. However, up to now studies to improve them to satisfy the requirements of navigation have not been significantly implemented. A large number of rivers are still in their natural state.

Some jetties have been constructed to remove sediment and deepen the channel, but this is still not sufficient for navigation. Dredging thus has to be done in order to ensure a certain water depth for navigation in the shallow reaches of the river. The annual volume of the dredged sediment is about 3-5 million cu.m.

The rivers are classified into two groups: tidal rivers and rivers without tidal influence.

Observations and measurements of geographic and hydrologic conditions are carried out in order to establish the relationship between water depths and bed levels of sandbars and to obtain knowledge of the movement of migrating dunes. Based on this, a suitable dredging schedule is worked out, and during and after dredging operations hydrographic surveys are carried out.

Near their estuaries the rivers are affected by the tide, which, in the northern part of Viet Nam, is mainly diurnal. Tidal amplitude is about 2-4 m. Advantage is taken of the tide to reduce the maintenance dredging requirements.

In the tidal parts of the rivers, the maintenance dredging requirement is usually larger than in the upstream parts. In the estuaries, maintenance dredging may have to be done 2-4 times per year in order to ensure the navigability of the access channels.

The coast of Viet Nam is 3,200 km long, with about 20 river mouths. Most of them are still not used for navigation because of sedimentation problems. Sandbars with lengths of up to 8 km intersect the navigation channels. The natural water depth on the bars is only 3-4 metres. The annual volume of sediment dredged in the coastal navigation channels is more than 10 million cu.m.

At present there are three ports in Viet Nam open for seagoing vessels: Haiphong, Danang and Ho Chi Minh. The dredging capabilities are limited, and often the objectives are not met.

In future, it is expected that mathematical and physical modelling, together with field measurements and air photographs, will help the planning of dredging operations. It is also foreseen that the dredging fleet will become larger, and there will be a great need for training people at the management as well as the operational level.

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