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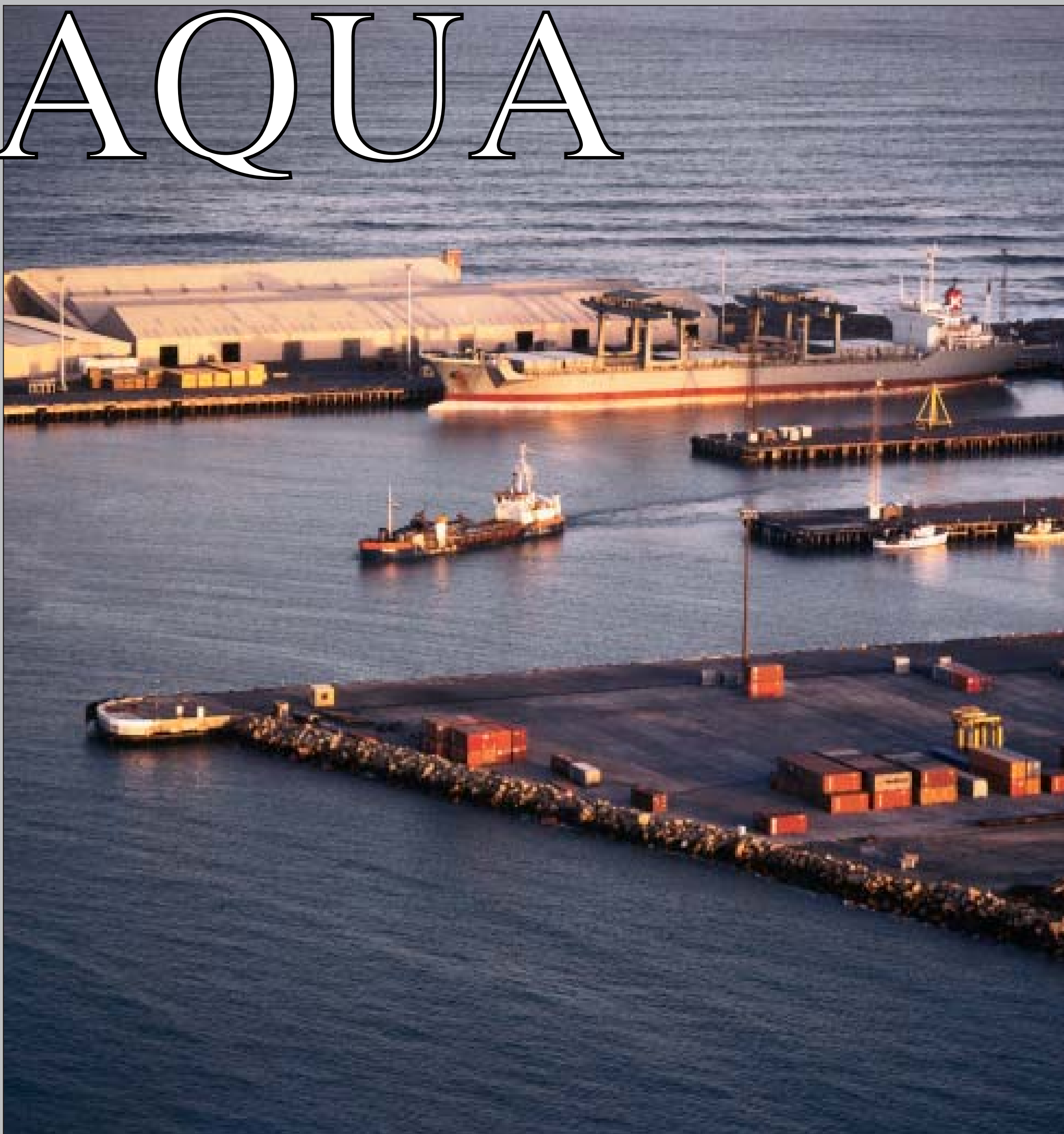

INTERNATIONAL ASSOCIATION OF DREDGING COMPANIES

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Front cover:
Privatisation of dredging in New Zealand has proven cost efficient and profitable. Trailing suction hopper *Pelican* can be seen at work day and night, everyday, summer and winter in one New Zealand port or another. Here she is dredging the approach channel at Tauranga (see page 11).

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International Association of Dredging Companies

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ET AQUA

Editorial

Bridges, roads, harbours, beaches, tunnels, airports -- would these exist if dredgers with their trusty "digging" tools were not busy as beavers damming a river? Dredging started long ago and over hundreds of years has played a significant role in the development of civilisation as we have come to know it. Often, focussed on a particular project, we haven't the time nor inclination to stop and think of what the world would be like if dredgers did not dredge.

The articles in this issue of *Terra* cover a range of subjects, from the technological to the political. Laboratory research provides important technological information to the dredging industry (page 3). This in turn provides an essential service when applied to a specific problem. For instance, by applying dredging technology, dredgers are able to ensure clean water for recreation – for swimming and fishing. Such was the case in Barcelona, Spain (page 18).

As the dredging industry prepares to gather at the WODCON in November in Amsterdam, the theme of the conference, "Dredging Benefits", gives reason to pause and take inventory of just how important the contribution of dredging has been and continues to be to our economic and social well-being. And the question arises: how does the future look?

Governments are being forced to tighten their budgets; cost containment when considering infrastructure projects is becoming an ever greater factor. It is no revelation that IADC is of the opinion that the private dredging industry is better able to meet this challenge through free market competition than are state-run monopolies. "A Tale of Two Dredgers" was written tongue-in-cheek to contrast the differences. "Privatisation of Ports in New Zealand" presents a case study which gives concrete support to this point of view. The choice of course lies with the ports and harbour authorities, but it is certainly worth thinking through.

Marsha R. Cohen
Editor

H.J.R. Deketh

The Wear Sensitive Cutting Principle of a Cutter Suction Dredger

Abstract

The operating principle of a rock cutterhead such as used on cutter suction dredgers is an inefficient excavation process from a wear-point of view, because at each revolution of the cutterhead a pick-point has to enter the rock to make a new cut. Especially in the range of small feed, at the start of each cut, high rates of wear of the cutting tool are expected.

At least, this is shown by specially designed small scale rock cutting laboratory experiments. In these experiments high rates of wear were experienced at small penetration rates (feed) of a chisel cutting into rock. Mechanical properties and composition of the rock to be cut determine the range of feed where the high rates of wear are taking place and they affect the level of wear in the entire cut. The relevant mechanical properties are the unconfined compressive strength (UCS) and the Brazilian tensile strength (BTS). The compositional features affecting wear are the grain size and the volume percentage of the abrasive minerals in the rock; abrasive minerals are those minerals which are harder than the tool material under the conditions (stresses and temperature) of cutting.

Considering that wear occurs mainly at the start of a cut, some recommendations can be made to improve the cutting method or to optimise the cutterhead design or the cutting process, for example, by tuning operational parameters like haulage and rotation velocity of the cutterhead to the type of rock to be cut. Besides, a better understanding of the different wear processes and the effect of properties and composition of the rock on wear provides a better basis to estimate pick-point consumption in advance of a rock dredging project.

This research was sponsored by the Technology Foundation (STW), The Netherlands.

In 1991 Jan Reinout Deketh received his MSc in Mining and Petroleum Engineering from Technical University Delft, The Netherlands, Engineering Geology Department. Since then he has been working as a research officer at the university, studying the wear of cutting tools on rock excavation machines in relation to the rock types being excavated. In March 1995 he obtained a PhD on this subject at TU Delft. At present he is observing the working performance of rock cutting trenchers at various construction sites throughout Europe.

Jan Reinout Deketh

Introduction

This article is based on the book *Wear of Rock Cutting Tools, Laboratory Experiments on the Abrasivity of Rock* (Deketh 1995). The book is the result of research which aimed at getting a better understanding of the wear processes acting in rock cutting operations and to determine which factors control these wear processes. An improved understanding of these processes finally allows for a better basis to predict expected rates of pick-point consumption in rock dredging practice. The insight in the wear processes can be useful to optimise the dredging method or dredger from a wear point-of-view.

In this paper the laboratory test set-up is described and some experimental results are shown. The relevancy and application of these experimental results to a rock cutter suction dredger is discussed and finally some recommendations regarding wear prediction and optimisation of the dredging process are made.

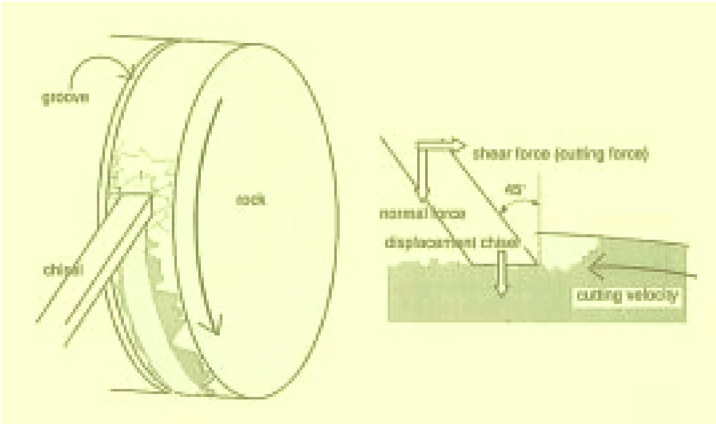


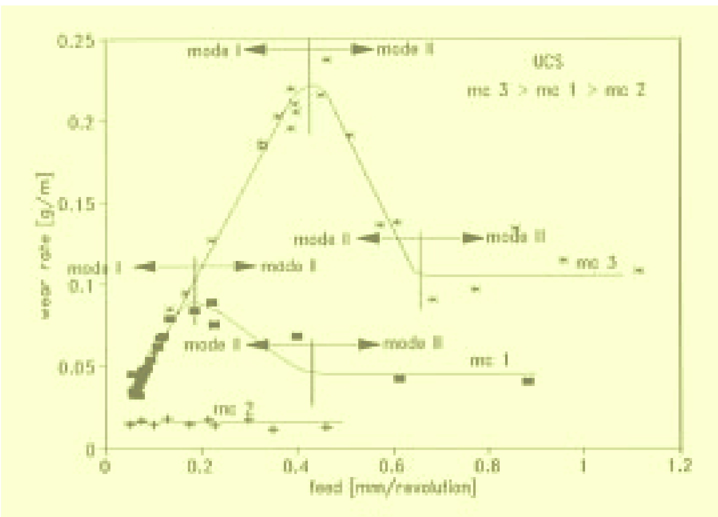
Figure 1. Scraping test.

Laboratory Rock Cutting Wear Experiments

Experiments have been designed to investigate wear processes resulting from sliding of the wear-flat of a test chisel over the surface of different rock types with the variation of the feed of a chisel into the rock, in such a way that the transition from scraping to cutting of rock by the test chisels could be investigated.

In Figure 1 the rock cutting wear test (named the scraping test to stress the feed range at which the experiments are carried out) is illustrated. The test is displacement controlled. A lathe is used to carry the test arrangement. Rotating rock cores are penetrated by steel chisels (steel type Fe60 K, relatively soft steel (Vickers hardness ± 3000 MPa) or steel type SRO 57N, hardened steel from dredger teeth (Vickers hardness ± 6000 MPa)) with a continuous feed. When the chisel moves to the centre of the disc of rock, the angular velocity is automatically increased to keep the cutting velocity constant. Most experiments are executed at a cutting velocity of 0.4 m/s.

Figure 2. The influence of the unconfined compressive strength on the rate and type of wear for mortars mc1, mc2 and mc3 for various feeds.



Cutting forces, feed (displacement of the chisel into the rock per revolution of the rock disc) and cutting velocity are automatically recorded and stored by a data acquisition software package on a personal computer. Loss of mass of the chisel and amount of cut rock material are measured manually and fed into the computer. Finally wear phenomena of the chisel are described and photographed.

About 1000 different tests were carried out. Natural and artificial rocks were used. Artificial rocks (mortar) allowed for a controllable variation of one rock property at a time. The rock strength, the grain size, the volume percentage and the shape of the abrasive minerals (mostly quartz) have been varied. Experiments on natural rocks (sandstones and limestones) showed to which rock types the results of the experiments on artificial rocks could be applied.

Next to the rock properties also the feed, and in some experiments the cutting velocity, of the test chisel into the rock has been varied.

The loss of mass of the chisel in one test run per metre sliding length is taken as a measure for the rate of wear. The loss of mass of a chisel in one test run per cubic metre of cut rock material, the specific wear (SPW) is taken as a measure of the efficiency of the cutting process with respect to wear specific for this test.

Experimental Results

The following factors showed to affect the wear process of the experiments on the mortars and the sandstones:

- the tensile and compressive strength of the rock.
- the grain size and volume percentage of abrasive minerals in the rock.
- the feed of the chisel into the rock.

Above a certain value of feed, which was determined by the properties of the rock to be cut, the type of wear changed and the rate of wear decreased rapidly.

In Figure 2 the effect of the feed on the rate of wear can be seen for three mortars, which differ in unconfined compressive strength (UCS), other properties were approximately the same (the mortars contained ± 60 % of rounded quartz grains with an average grain size of 1.5 mm). The unconfined compressive strength of the mortars mc1, mc2 and mc3 was respectively 30, 18 and 64 MPa. In the graph each dot represents one test run in which all parameters were kept constant.

At low values of feed, the rock production was relatively low (scraping process) and the level of wear high; high temperatures and plastic deformation of the steel at the wear-flat of the chisel occurred, two-body abrasive wear dominated: *wear mode I.*

At higher levels of feed the rock production was relatively high (cutting process) and the level of wear low; lower temperatures and less plastic deformation took place, three body abrasive wear dominated: *wear mode III.* The feed at which a transition from the first type of wear during the scraping process to the latter type of wear during the cutting process takes place, was also dependant on rock strength (UCS and BTS), grain size and volume percentage of abrasive minerals (quartz) in the rock. The transition from wear mode I to wear mode III is called *wear mode II.* In Figures 4 and 5 photographs of chisel wear-flats in wear mode I and in wear mode III are shown.

The chisel worn in wear mode I shows clean parallel continuous grooves on the wear-flat, pointing to two-body abrasive wear. High temperatures at the wear-flat resulted in burs, tempering colours and plastic deformation of the steel, leading to adhesive wear, additional to the two-body abrasive wear. The chisel worn in wear mode III shows irregular, sometimes abruptly ending grooves, which are infilled by crushed rock material, pointing to three-body abrasive wear. The absence of burs, tempering colours and plastic deformation of the steel indicates lower temperatures at the wear-flat and therefore adhesive wear is not likely to occur.

These results hold for mortars as well as for the tested sandstones. Limestones behaved differently, probably due to the fact that the calcite in the limestone was not hard enough to be abrasive to the tested steel types.

In Figure 3 some scraping test results on a sandstone are shown. In the left graph both the influence of the feed and the cutting velocity on the rate of wear is shown. In the right graph the range of feed and cutting velocity at which the disadvantageous wear and cutting mode I is delineated.

Relating the Experimental Results to Dredging Practice

Before a comparison is made, first the relevancy of the laboratory experiments to dredging practice are put into perspective. Pick-point consumption in practice is due to damage, which is either failure (breakage) or wear of the pick-points. Whereas wear is a surface process, failure concerns the whole body of the cutting tool. In this research only wear has been considered.

The experiments in the laboratory are only remotely related to rock dredging in practice; in the experiments the chisel cuts continuously, but in practice only for about 25 % of each revolution of the cutterhead. In the experiments only wear due to sliding contact between tool and rock is studied. In dredging also wear due to impact may play a role. These and other differences between the experiments and wear in practice make a quantitative comparison questionable. Still major trends and wear phenomena observed in the laboratory experiments agree with those experienced in practice of rock cutting (Giezen 1993).

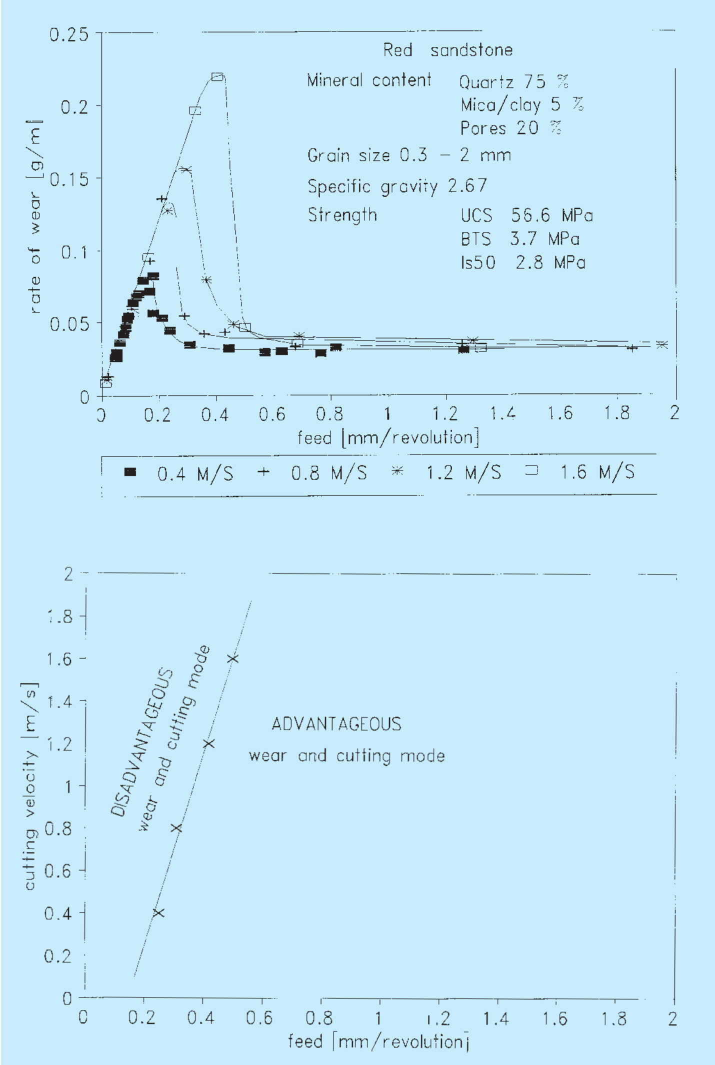


Figure 3. Rates of chisel wear in scraping tests on a sandstone as a function of the feed for different cutting velocities. At a higher cutting velocity a higher feed is needed for an advantageous mode of wear.

The pick-points mounted on the cutterhead of a cutter suction dredger make an arc-shaped cut through the rock at each revolution. The feed of each pick-point during a cut gradually increases from 0 at the start of the cut to a maximum feed at the end of the cut.
The scraping test experiments showed that with an increase of feed the rate and type of wear changes. This can be applied to a pick-point making a cut in the rock.

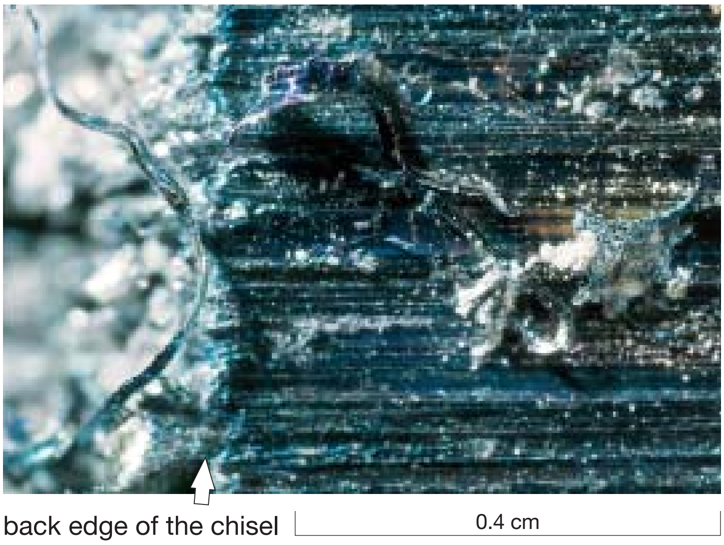


Figure 4. Part of a test chisel wear-flat worn in wear mode I.

Figure 5. Part of a test chisel wear-flat worn in wear mode III.

At the start of a cut a pick-point rather scrapes the rock than that it cuts the rock; there is relatively little production of excavated rock. Moreover, in this range the friction is high (two-body wear) causing high temperatures which in their turn weaken the tool material which then becomes vulnerable to abrasive wear.
At a certain feed, the scraping action of the pick-points changes gradually into cutting with further increase of feed. At the same feed the mode of wear changes from mode I to mode III via mode II; two-body wear changes to three-body wear with lower temperatures at the wear-flat and lower rates of wear.

In Figure 6 a cut made by a pick-point mounted on a cutter head is shown for three different situations:

- Case A shows a pick-point which reaches at the end of the cut a maximum feed which is lower than the feed at which a transition from mode I to mode III occurs (left graph). The rate of wear in this case is high in the entire cut.
- In case B, and more profoundly in case C, the maximum feed is larger than the feed at which a transition from mode I to III takes place (left graph).
  The greater the portion of the cut in mode III the lower the total rate of wear will be as can be seen in the right graph. The maximum feed value, at the end of a cut, depends on the resistance of the rock to cutting, the ability or power and design of the cutting machine (number of blades on the cutterhead) and the conditions of cutting (haulage and rotation velocity of the cutterhead).

Recommendations to Reduce Wear of the Pick-points

In general the amount of wear can be reduced by minimising or avoiding the time the cutting process is taking place in the disadvantageous wear mode, which is at small feed of the pick-points. This can be achieved by choosing a type of dredger with a cutting principle in which the pick-points do not cut at small feed (e.g. a trailing hopper dredger instead of a cutter suction dredger).

If we still are dealing with a cutter suction dredger a solution to decrease wear is to increase the maximum feed reached by a pick-point at the end of each cut by:

1. increasing the power of the dredger. An increase of power on the cutterhead and winches results in an increase of the penetration of the cutterhead (and therefore also of the pick-points) per revolution of the cutterhead.

2. increasing the ratio haulage velocity over rotation velocity of the cutterhead. This results in a higher maximum feed of the pick-points. An additional effect of a lower cutting velocity is that the temperatures at the tool-rock contact will remain lower, which ensures that the wear resistance of the cutting tool does not drop, by softening of the steel.

3. changing the cutterhead design such that the maximum feed of each pick-point increases.
   For example a reduction of the number of blades of a cutterhead would result in a higher maximum feed per blade (and therefore per pick-point).

   A higher feed per pick-point can also be realised by positioning the pick-points in such a pattern on the cutterhead that the cutting paths of pick-points on different blades are not making a cut in the same groove made by a pick-point positioned on the previous blade. This can be achieved by situating the pick-points on the odd and even blades in staggered positions.

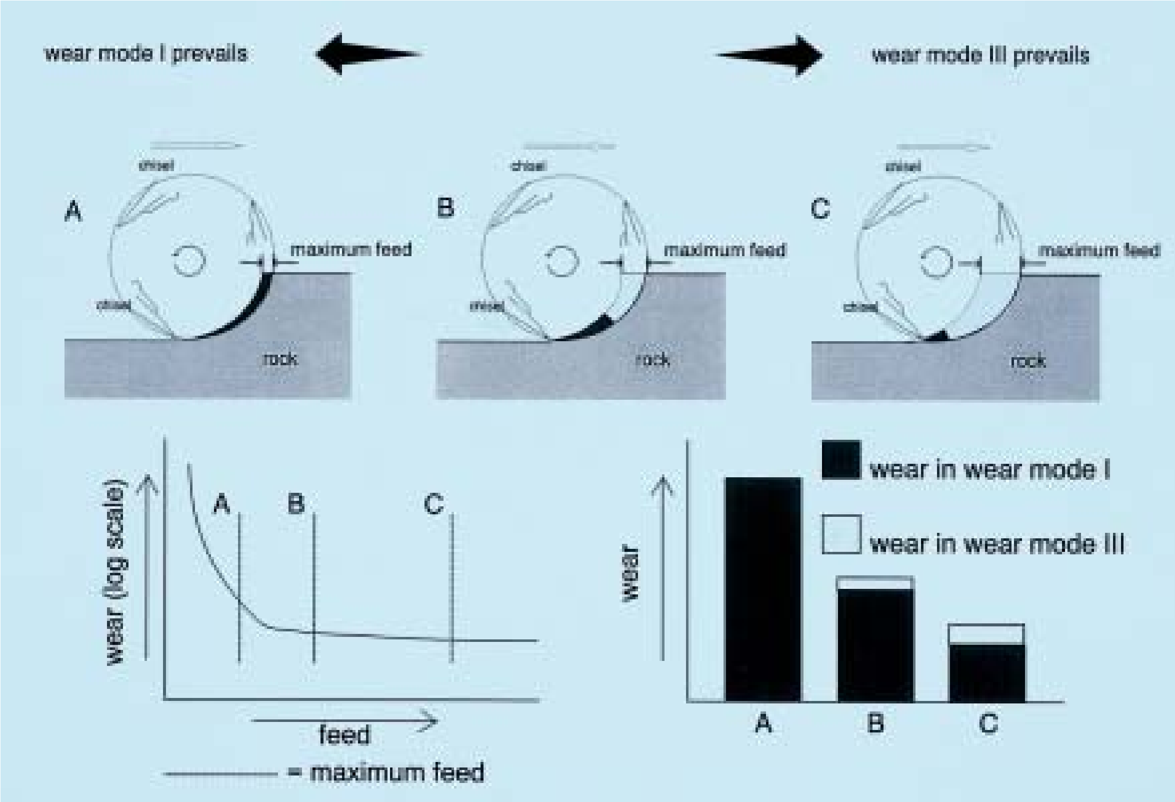


Figure 6. Wear at low feed (start of a cut) is higher than at higher feed (end of a cut). The wear during a cut is determined by the magnitude of the contribution of wear mode I.

Conclusions: Implementation of Research Results in Wear Prediction

The experiments showed that wear is mainly occurring at the start of a cut in wear mode I. To predict the rate or amount of wear for a specific dredger it is therefore very important to determine for what part of the total cut made by a pick-point this disadvantageous wear mode I will take place.

For that we have to calculate:

1. the maximum expected feed per pick-point of the chosen dredger in the rock to be dredged. This is a function of the advance (haulage) rate and rotation velocity of the cutterhead. These dredging parameters depend in their turn on the dredger characteristics like power on the cutterhead and the winches, cutterhead design etc. and the resistance of the rock to cutting.
2. the feed at which a transition (mode II) from wear mode I to III takes place. The transition is a function of the UCS, BTS, the content (vol.%) and the grain size of the abrasive minerals in the rock.

The total expected wear is approximated by:

- the percentage of the cut at which wear mode I takes place multiplied by the magnitude of wear in wear mode I.
- the magnitude of the wear in wear mode I is determined by the same rock properties and by the sensitivity of the tool material to wear.

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Adrian Hunt

A Tale of Two Dredgers

Adrian Hunt

A freelance technical journalist specialising in the construction sector, Adrian Hunt has been writing for and about the dredging industry for almost 20 years. He is involved in the editing and production of several periodicals published by leading contractors in the dredging and construction fileds. He is a past winner of the Woodrow Wyatt Award presented by the British Association of Industrial Editors.

This article was originally part of the IADC presentation at the Dredging '94 Conference in Orlando, Florida, USA in November 1994.

This is a story about two men, two dredgermen. One works in the private sector; the other in the public sector. Eric Van GATT, he's the private sector man; and Barri ER, he's from the public sector.

Eric Van GATT is employed by the "World Dredging Company" which has an international spread of offices and operations covering more than 30 countries. Its fleet is substantial and multi-functional, and it is backed by state-of-the-art R&D, Technical and Logistical Departments.

Figure 1. Introducing Eric Van GATT from the private sector and Barri ER from the public sector.

Barri ER works for the "State Legislature of Waterways" (SLOW for short). It has responsibility for the maintenance of one principal port and several minor ports in a faraway country somewhere. Very little capital dredging is ever carried out, the work is mostly maintenance. The small fleet is dated and frequently in dock.

The Tale

We take up the story one morning quite recently.

"Damn", said Barri ER as he nicked himself shaving in front of his hotel mirror. He was rarely in a good mood these days. Almost two decades with his SLOW employer had taken their toll. There was little to interest him any more. One cubic metre seemed much like the other. The same routine, day in day out. Oh, but there was that one occasion, when was it? six or seven years ago, when he thought he'd found live ammunition in the hopper. As it happened, the bomb turned out to be the end of a suction pipe that SLOW's principal trailer, the *Elderly Statesman,* had lost some years earlier. Was it his fault that the thing had dropped off because of rust? He had been saying for years that a replacement trailer was needed.

SLOW agreed that it was needed and had appointed a committee to look into it. Good progress had been made in the first 18 months. Several sub-committees had been formed and these were due to report back within the year. But then the whole process began to slow down. The committee members couldn't agree on the vessel's specification. Ideally, two or even three different types of dredgers were needed. But, there were only sufficient funds to build one. With all the bickering and disagreement the replacement ship, code-named *New Statesman,* was still not commissioned.

"May I join you?"' said Barri ER fifteen minutes later as he arrived for breakfast in the busy hotel dining room. The question was addressed to a man whose bright, alert expression belied his real age. Eric Van GATT beckoned the newcomer to sit down.

He had been deep in thought, scribbling notes and sketches on his paper napkin. He was intrigued by a technical problem on his current dredging project.

He liked nothing better than a challenge. The time he had spent at head office, working in the various project support offices, and his wide operational experience had equipped him to deal with most problems that face today's busy project managers working for international dredging contractors. There was never time to get bored, moving from one project to another, from one country to another and from one dredger to another. There was real variety to his working life. He was fascinated by the technological advances that were being made.

Take, for example, the vessel he was currently working with, the trailer *Free Trader*. She is a powerful, big capacity ship full of sophisticated electronics and gadgetry. It had taken just 18 months from the time that the Board of Directors decided to invest in a new dredger, to the time that *Free Trader* took to the water. Eric Van GATT was only too aware that to be competitive you need to have modern and efficient equipment.

Eric Van GATT and Barri ER chatted happily over breakfast. After all, they had much in common – dredging. Eric explained that he had just flown in from the Far East where he was working on a new petro-chemical port. He was then scheduled to go to South America for port maintenance work combined with reclamation.

Barri ER listened enviously in the knowledge that he would shortly be returning to the same dredger, to the same port work and to the same old routine. But, for the time being at least, he had a few days in which to broaden his mind and to see what was happening in the "real" world of dredging. Looking at his conference programme, he said to Eric Van GATT: "Which of the papers are you most looking forward to hearing?"

"Why, the IADC presentation of course", came the reply. Outside, the sun shone on the Buena Vista Palace grounds.

Figure 2. Barri ER in despair awaits the commission of a new dredger.

Figure 3. Eric Van GATT, intrigued by his current dredging project.

The Conclusion

Eric Van GATT and his counterpart from the state dredging sector, Barri ER, are of course purely fictitious. The problems faced by the equally fictitious SLOW organisation, whilst being greatly exaggerated, do demonstrate some of the difficulties facing state dredging agencies. The lack of public funds is the principal one. Without a proper investment programme, dredging operations must inevitably suffer which in turn will affect port efficiency and productivity. For it to survive, the private sector must be properly equipped with modern, efficient plant. The range of plant must also be sufficiently wide and versatile to deal with the wide variety of dredging challenges facing today's international contractors. The right dredger for the right job is vital for efficient production. Cash-strapped state agencies cannot hope to equip themselves other than for the day-to-day operational duties.

Competition is the Driving Force

Competition is the driving force in the private sector. Everything is geared toward dredging that cubic metre more efficiently and at less cost than the competition. Overheads and administration are kept to a minimum; research and development are on-going; personnel training is fundamental. The independence to react quickly and positively to market requirements is of paramount importance.

As the benefits of a competitive trading environment become better understood, the world dredging market is steadily becoming more open, more accessible.

Figure 4. Private sector investments in research and equipment vs. a lack of public funds for state dredgers.

Figure 5. Legal obstacles are the protective net that state dredging agencies use to limit competition.

Admittedly there are still notable exceptions, where certain countries still cast a "protective net" around their markets and refuse to permit "foreign" contractors – outsiders – to compete for work openly and fairly. We trust that more and more such countries will soon see the error of their ways.

Figure 6. Despite obstacles, when it comes to least-cost, least-time and most technically sound solutions, the winner is the private sector dredger.

Last year, for instance, we witnessed the sale of the bulk of the Mexican state-owned fleet and the transfer of maintenance dredging to the private sector. This winding-down process is being repeated in Argentina, and Brazil intends to phase out its state fleet too.
As long ago as the mid-1970s a multi-million dollar dredger investment plan in the Federal Republic of Germany was abandoned in the wake of an official investigation which concluded that it would be less expensive to delegate part of the annual dredging programme to the private sector. Not only was the state relieved of the initial investment burden but the operational savings amounted to 10 percent.
The introduction of competition was also responsible for the state-owned dredgers improving performance substantially.

Open Door Policy is the Trend

The trend towards increased competition through privatisation and opening the door on so-called protected markets is worldwide. There are numerous other examples, such as India and New Zealand, that one could draw upon.

Cost-efficiency is of course not the only consideration of those countries evaluating a more laissez-faire approach. There are also social implications which need to be carefully evaluated. Some people in the state sector would also point to other barriers, such as the implications for national security, but practice has proved these to be unfounded worries. Often there is resistance to abandoning state involvement simply for historical reasons, because dredging has always been handled in this way and always with local suppliers.

This attitude cannot continue. As the demands on public funds become ever greater, so the need for greater cost-efficiency increases. Specifiers of dredging services are looking for the least-cost, least-time and most technically sound solution, and that can only be provided if there is a competitive, open market.

Heini Evers and Roy Weaver

Privatisation of Ports in New Zealand

Heini Evers worked for Volker Stevin for more than 30 years and was the Managing Director of both Australian Dredging & General Works and New Zealand Dredging from 1982 until 1992. At that time both companies were part of the Volker Stevin Group of The Netherlands. He is presently an independent consultant with his resident office in Australia.

Heini Evers

Roy Weaver is a member of the Institution of Professional Engineers New Zealand and has a Master's Degree in Business Administration. He joined the Port of Timaru Ltd. in 1985 and is presently its Deputy Chief Executive and Manager of Port Operations.

Roy Weaver

Abstract

The New Zealand economy has undergone significant change in the last ten years. The Ports Industry is one of the many areas affected by changed Government policy since the mid-1980s. This paper sets out how three ports – Tauranga, Taranaki and Timaru – responded to the changing political and economic climate in one aspect of their business operation: port dredging. It describes the shift from port-operated dredgers to contract dredging.

The dredging situation in New Zealand until 1986 is presented, followed by a summary of the investigation conducted by the three ports of all options open to them. Financial and engineering analyses carried out by independent consultants are reported. The conclusion of these analyses was that the most cost-effective option was clearly to pool their dredging workloads and enter into term contracts with an international dredging contractor. This was effectuated in 1988.

The contract operation is discussed from the perspectives of the contractor and the port companies including: dredging programme flexibility; plant utilisation; human resources and industrial relations; long-term planning of operations; utilisation of port company resources; and contract benefits and problems. The paper concludes with an update on the present situation of this cooperative dredging arrangement.

The paper was first presented at the Australasian Port and Harbour Conference in 1990. The authors wish to acknowledge the contributions to the original paper of John Palmer, who was then Engineering Manager of the Port of Tauranga Ltd. and is presently a consultant for port planning and development based in of Tauranga; of Peter Atkinson who continues to be Technical Services Manager of Westgate-Taranaki Port as it is now known; and of Hadyn Pike, who was Contracts Manager of Australian Dredging & General Works Pty. Ltd. at the time the contract was signed.

Introduction

Many ports find the costs of dredging to be one of the major annual operating costs of the port. Such was the case of three New Zealand ports – Tauranga, Taranaki and Timaru (Figure 1). They investigated in detail the options open to them collectively and individually, and finally settled on contract dredging as the most cost-effective solution.

Historical Background

New Zealand ports, where they had significant on-going maintenance or capital development programmes, historically owned their own dredgers. This stems from the geographic isolation of New Zealand with the consequent very high mobilisation costs of bringing dredgers from even the closest neighbour, Australia. Until 1970 dredgers owned by individual harbour boards were designed, manned and set up for work at their home port only, and there was no real sharing of equipment or contracting out of work to other harbour boards.

Figure 1. The North and South Islands which form New Zealand, with the three ports involved in contract dredging indicated – Tauranga, Taranaki and Timaru.

If a port required capital dredging the practice was to invite tenders from overseas-based companies and enter into a contract. Upon arrival of that contract dredger in New Zealand, it succeeded in picking up other work around the coast and there was some sharing of the overall mobilisation costs to New Zealand.

Port-owned Dredgers

In 1976 the Port of Timaru concluded that the era of bucket dredging at its port was finished and decided to convert the bucket dredger *W.H. Orbell* to a trailer suction dredger. The conversion was carried out recognising that ports such as Tauranga, Napier, Otago and others would intermittently require some on-going trailer dredging work.

In 1985 the Port of Otago constructed the 600 m3 hopper trailer dredger *New Era* designed for work particularly in the Port of Otago. During the 1970s and early 1980s the Port of Tauranga had been undertaking a major reclamation using material from capital dredging, primarily from its own cutter suction dredger but also with some pump-ashore from trailer dredging contracts. Using the *New Era* as a model of the type of equipment that could be built, the Port compared the option of building and owning a similar dredger, and contracting with the *W.H. Orbell.* This investigation showed that, given a reasonable on-going annual volume and even allowing for the fact that the Port of Timaru had been successful in achieving some reductions in the crewing of the *W.H. Orbell,* ownership was a more economic option than retaining the services of the *W.H. Orbell.*

Since 1959 the Port of Taranaki had owned the 560 m^3 trailer suction dredger *Ngamotu.* In the early 1980s this vessel was upgraded, first with new dredging equipment, and then with the replacement of the steam engines with diesel.

In 1983 the Government expressed their concern at the high cost of getting goods from farm to marketplace and began what became known as the "Onshore Costs Study". This study focussed particularly on ports and highlighted the need for structural change within the industry to achieve lower costs and greater efficiency.

Port Companies

In 1984 the Government immediately set about eliminating subsidies wherever they were and freeing up the New Zealand economy from many of the controls that it had traditionally been under. All industries were affected in many ways by the changes and the Government took up the Onshore Costs Study and progressed it vigorously. This eventually led to the formation of Port Companies to manage the commercial port operations and probably had the effect, as far as dredging was concerned, of making all ports more aware of their dredging costs and more receptive to looking at alternative or new means of reducing them.

In 1986 the question arose as to whether it was economic to have three dredgers in New Zealand doing work which could be performed by one or perhaps two of the existing dredgers or by contract. As a result, the ports of Tauranga, Taranaki and Timaru held a meeting at which the idea of carrying out a detailed study into the best option for dredging the three ports in combination was explored. Thus in December 1986 the study into the optimal dredging method for the three ports was initiated in a political and economic environment which encouraged a fresh and more stringently economic approach to dredging policies.

Evaluation of Dredging Options

The study canvassed the following options:

1. Contract dredging by international companies;
2. Replacement vessel, size of the *W.H. Orbell* (1200 m3);

3. Replacement vessel, size of the *New Era* (900 m3);
4. *W.H. Orbell* in a joint venture; and
5. *Ngamotu* in a joint venture.

Responsibility for the investigation was awarded to Deloitte Haskins & Sells, Financial Consultants, with Becca Carter Hollings & Ferner acting as Engineering Sub-consultants.

Their proposal was to undertake the study in three parts:

- Data collection, port investigations, discussions, creation of financial models.
- Evaluation of the options, using financial and non-financial criteria.
- Establishment of the joint venture, including the selection of vessel, management, industrial considerations.

Stage 2 was completed in April 1987 at a cost of $65,000. It clearly showed that the operation of a joint venture brought about significant reductions in the total cost of dredging operations at the three ports. Each option was considered by using the "most likely", "maximum", and "minimum" volumes to be dredged as well as three inflation and interest rate scenarios.

The total costs of the joint venture for the period 1988-2000 under each option was established, and after discussions with the engineers from the three participating ports, Option 1 "Contract Dredging" was selected as the most favourable. The total dredging bill for the three ports was slashed by over $1,000,000 per annum as a result of the change to contract dredging.

The Contractor

The contract was awarded to New Zealand Dredging & General Works, which at the time in 1988 was a wholly owned subsidiary of Royal Volker Stevin of The Netherlands. Since 1992 New Zealand Dredging & General Works is owned by WestHam of Sydney, Australia. The contract is for a period of fifteen years with a review every five years.

To execute the work a 1,000 m3 trailer suction split-hopper dredger, *Pelican,* was mobilised from Europe (Figure 2). The *Pelican* is basically stationed in New Zealand but also makes the occasional side trip to Australia. Work for third parties is only undertaken after consultation with the three main client Port Companies.

Figure 2. The Pelican is a split-hopper trailing dredger, equipped with a suction installation allowing the dredged spoil to be discharged ashore. The dredge pump has been mounted halfway along the suction pipe enabling the vessel to dredge highly concentrated mixtures at great depths.

The InterPort Agreement and Dredging Contract

A contract had to be negotiated which would bind the four parties together. The most practical way to achieve this was for the three ports to formulate an agreement to use a common contractor, and under this Heads of Agreement enter into individual contracts with the dredging contractor for the work at each port.

Heads of Agreement

This document set out the intention of the three ports to employ a common contractor for trailer suction dredging work. It also set out such matters as the establishment of separate contracts, cross-liability, the sharing of establishment costs, refunds, contract intelligence and cooperation in dealing with the programming of dredging and urgent dredging.

Dredging Contracts

Each individual contract between the Port Company and the Dredging Contractor is divided into three parts: Part A, Special Conditions of Contract; Part B, Specification; and Part C, Schedule.

Part A, Special Conditions of Contract

In this part the most significant section is clause 7, Payment, which is commerically sensitive and can therefore not be elaborated upon in depth. Clause 7g is the market fluctuations clause and contains two elements that merit further comment.

The first element is the labour adjustment factor. At the negotiating stages of the contract, the manning for the vessel was not known so the contractor was required to make the initial offer subject to eventual outcomes of the labour negotiations.
The three ports were obviously reluctant to enter into a contract which was open ended in regard to a major cost component. Eventually both sides agreed to share a degree of the risk associated with the labour negotiations. For the purposes of the unit rates in the dredging contract, a nominal manning level was agreed and a notional gang rate reflecting the cost of manning the dredger was calculated.

It was then agreed that any variations to the anticipated manning levels be carried by the ports to a limited extent and thereafter by the dredging contractor. It was also agreed that the maximum variation from the expected cost per crew member that the ports would meet by way of the adjustment to the notional gang rate, and hence the unit rate, would be +/- 15 percent. If the final rate negotiated varied more than this amount, the cost or savings would be borne by the contractor.

Thus at the point of contract negotiations, the maximum risk resulting from labour cost variations was prescribed and an incentive to the contractor to hold these costs was provided.

The second element worth noting is that after two and a half years of operation of the market fluctuations formula, a re-assessment of the notional gang rate was made from base data and substituted in the formula replacing the value derived by reference to the movement of the wage rate index. This was done to ensure that actual rates are not overly influenced by statistical data not directly related to the operation of a dredger.

Clause 9, The Term of Contract, sets out the procedure for extending the contract beyond the initial period of five years.

Part B, Specification

In Part B the contract details the work to be carried out at each port and specifies an annual volume of dredging that each port has contracted to provide to the dredging company. The rates for this work are specified along with adjustments ot be made if the contract volume increases or decreases. The contract allows a port to defer or cancel its dredging, but it must pay a minimum sum to the contractor in so doing.

Sections 5 and 6 of Part B deal with the measure of the work and the planning and control of dredging. Tolerances on minimum areas of dredging are presented as guides.

Contract Operation

Dredging Programme Flexibility

Control of the dredging programme essentially lies with the Port Companies and is driven by their needs. The long-term programme of the contractor is reviewed by all parties on a biannual basis where each Port Company's individual forecast of dredging needs is programmed with other work the contractor may have or considers likely together with other requirements such as vessel maintenance.

The Port Companies are able to take advantage of the contractor's ability to be flexible in dredging operations and programming campaigns. This can enable the port to be confidently operated with some tolerance or variation to the port operating parameters, e.g., draught, channel, width, and so on.

There are no physical limits as to the volume dredged each year, therefore each Port Company is able to choose whether to bring forward, defer or combine dredging campaigns to meet their own shipping or cash flow needs. Instead of slavishly following a "clear depth over a clear toeline" concept essential for "one off" contracts, the Port Companies can tailor each dredging campaign and time a campaign for a better

Figure 3. The Pelican at work in the evening, dredging the harbour of Timaru. Dredging takes place 24 hours a day, 6 1/2 days per week.

overall return for the Port. Any urgent or unexpected need for dredging can be accommodated under the contract by a variation to the long-term programme. Co-operative programming between the Ports also enables the cost of mobilisation and demobilisation to be kept to a minimum by minimising the inter-port voyages of the dredger.

Plant Utilisation

By virtue of their co-operation the three Port Companies have:
- eliminated future capital spending on plant for maintenance dredging;
- eliminated a significant part of the operation cost of the dredging.

By employing a contractor with a modern dredger with a capacity matching typical dredging needs the Port Companies do not need to invest in new equipment, keep existing equipment in operation or modify equipment for specific purposes. In the long-term this means that capital potential is able to be utilised for other revenue earning activities.

The benefits to the Port Companies from sharing the contractor's dredger are many:
- The dredging contract is based on working 24 hours per day 6 1/2 days per week.
- Greater plant utilisation by the contractor reflects in lower contract prices.
- Port Companies can do away with maintenance and supervision systems of their own.
- The contractor has broader experience in dealing with different dredging problems.
- "The creation of work" is eliminated.

Human Resources and Industrial Relations

Introduction of a dredging contractor working on a long-term basis on the New Zealand coast necessitated the negotiation of new industrial agreements with the Maritime Union. Existing industrial agreeements generally only covered vessels working in their home port. Negotiation of these agreements was not made any easier by the fact that all facets of port operations in New Zealand were undergoing dramatic change at the direction of the Government.

The emergence of the new industrial agreements and the fact that the contractor has now taken over the roll of the employer with all its responsibilities meant that the Port Companies could either free up their own personnel for other duties or reduce their static workforce and management.

By using the contractor's dredger and crew the following benefits are forthcoming:
- Labour costs are reduced in maintenance dredging, reflected through lower unit contract rates.
- A pool of dredging personnel with a greater diversity of dredging experience is established.

Long-term Planning of Operations

The long-term contract enables the contractor to view the employment of the dredger from a more "stable"

position, particularly when considering:
- long-term maintenance and slippings;
- investment in new technology;
- investment in modifications or improvements;
- investment for diverse operations.

Long-term maintenance can now be carried out in the most preferred manner and location rather trying to fit it in between projects or for the sake of expediency when passing a slipway or drydock. This enables the repair costs to be better controlled and overall cheaper.

Upgrading the technology in the vessel to maintain its competitiveness can be viewed more rationally knowing its occupancy more accurately for the long-term contracts.

Modifications or improvements can be more readily made knowing the expected increased return from the modification and the pay back period for that return.

Should changing materials or disposal methods be required by the client, *the investment in the dredger* to meet those needs can be explored more rationally than for the "one off" situation. All of the above factors contribute to keeping the maintenance costs to a minimum and enable the vessel to be kept in competitive condition.

The benefits of the long-term contract to the contractor ultimately flow to the Port Companies by resulting in lower contract rates and from the decision-making process available through the flexibility in programming dredging campaigns. Conversely the contract term of 5 years is not so long as to remove the incentive of future renewals.

Utilisation of Port Company Resources

Typically dredging contracts require the contractor to be self-sufficient in all facets of the execution of a contract. This ensures that the areas of responsibility are clearly defined. Also, contractors operate with different priorities with regard to time.

Quite often this results in a contractor duplicating resources that already exist within a port's infrastructure. Therefore whilst such duplication may be necessary for a single contract, the contractor proposed that if it were possible for the Port Companies to provide support to the contractor as a condition of the contract there would be multiple effects:

1. Direct reduction of the contract price resulting from reduced capital investment or hire by the contractor.
2. Reduction in the contractor's site staff, again providing a reduction in the contract price.
3. Greater utilisation and hence cost benefit of the Port Companies' own personnel, plant and equipment.
4. Reduced mobilisation and demobilsation costs as the contractor does not have to set up/end dismantle a site infrastructure for each campaign.

Under the long-term contracts the Port Companies are required to provide all hydrographic surveying support necessary for both the administration of the contract and also for the day-to-day operation needs of the contractor. The Port Companies are also required to provide a service vessel to support the dredger for crew changes and day-to-day requirements.

Contract Benefits

The benefits of the long-term contract are for both parties and are summarised below.

Benefits for the Port Companies are:
- free to tailor maintenance dredging needs and programmes to suit shipping requirments;
- instead of ports having to create additional work or obtain work outside of the ports to keep personnel and plant viably occupied the contractor can be used only as required;
- reduced direct expenditure for maintenance dredging;
- fixed term unit rate contract is an incentive for the contractor to remain competitive.

Benefits for the contractor are:
- stabilisation of vessel occupancy in the long term;
- smooth regulation of cash flow in the long term;
- increased efficiency from working in the same environments on a regular basis.

Contract Problems

Some difficulties can be met in the execution of the long-term contracts, and these are summarised below.

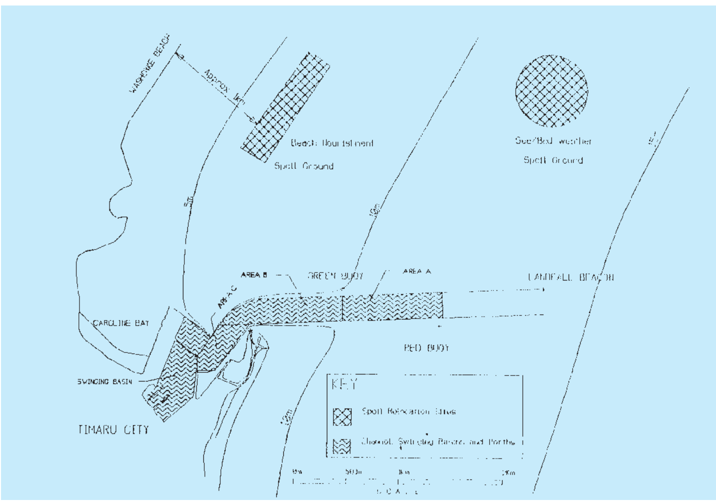

Figure 4. The general layout of the Port of Timaru.

Problems which can arise for the Port Companies are:
- digression from the original concept or intent of the actual dredging to any large extent that does not easily fit in with the exisiting unit rate price structure;
- adopting variations to their own dredging programmes should the contractor obtain other work outside of long-term contracts.

Problems which can arise for the Contractor are:
- logistical problems of short campaigns in personnel and spare parts;
- short-term peaks and troughs can create difficulties in manning the vessel and deploying site staff.

Overview

Since the implementation of this contract in 1988, the Port of Timaru has dredged 160,000 m^3 per annum (Figures 3 and 4), Westgate-Taranaki 120,000 m^3 per annum, and Tauranga (Figure 5) approximately 350,000 m^3. During 1993 Timaru gained ISO 9002 Certification for a key customer interface, its container yard and freight station area. It was the first port in Australia or New Zealand to do so.

Conclusions

The waterfront reform in the mid-1980s in New Zealand resulted in the privatisation of all the ports in New Zealand. Port Companies, with a considerably different focus, were established. The need for structural change in the industry became apparent immediately, and in several ports the new approach resulted in a shift from port-owned and -operated dredgers to contract dredging.

In the ports of Tauranga, Taranaki and Timaru this was the case, and this re-appraisal resulted in a contract for a period of fifteen years, with a review every five years.

The contract is now in its eighth year and is without a doubt of great benefit to the three Port Companies. In less than ten years time since the study into the optimal dredging method was made, New Zealand ports have moved from world-ranked laggards to the top echelon of international ports in terms of profitability and performance. They have become customer focussed and flexible. It seems therefore quite likely that a similar arrangement will continue in the future.

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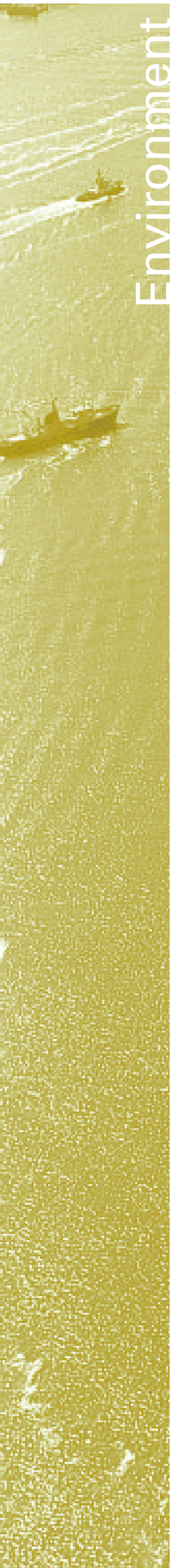
Figure 5. The Pelican dredging the approach channel at Tauranga in 1990. Its modest size and high manoeuvrability make the vessel ideally suited for operations in smaller harbours as well as for dredging pipeline and cable trenches in shallow coastal waters.



Bert Dijkstra and Stuart McIntyre

Besòs Long Sea Outfall, Barcelona

Abstract

Besòs Long Sea Outfall, Barcelona, Spain, is one of Europe's largest long sea outfalls installed by the bottom pull method. The outfall consists of a cement mortar lined 19 mm thick steel liner pipe with a structural reinforced concrete coating and a total length of 2900 m. This paper provides a brief overview of the project and discusses in greater detail the somewhat unusual dredging activities carried out which allowed its successful installation.
Dredging activities included soil improvement by removal of soft clay and its replacement by compacted sand, the dredging of a 7 m deep trench beneath a high pressure gas pipeline located approximately 1 km offshore and the dredging of a 2900 m long trench in water up to 55 m deep.

Introduction

In the light of recent EC legislation, EMSSA (the Barcelona sewerage disposal authority) had been reviewing the performance of the sewerage disposal system to Barcelona. They had identified a need for a substantially improved outfall system to the north of Barcelona that would replace the existing outfall which was leaking badly and not long enough to satisfy EC bathing water quality directives.

An EPIC (Engineer, Procure, Install Commission) contract for the outfall and associated pumping station was then drafted, and ultimately awarded to a joint venture company comprising two Spanish contractors, SATO, and Cubiertas y Mzov, and two Dutch contractors, Smit Tak and Ballast Nedam Dredging. Two British consultants were engaged; Andrew Palmer and Associates were responsible for the detail design of the outfall, and Watson España provided engineering support to the client. A truly pan-European venture.

The contract was awarded in January of 1994 and by January of 1995 the outfall had been designed, built and installed. The final part of the project, Pump Station Commissioning, was completed in May 1995. Figure 1 shows the outfall location.

Figure 1. Location of the outfall at Sant Adrià de Besòs.

Outfall Description

The outfall consists of a cement mortar lined 19 mm thick steel liner pipe with a structural reinforced concrete coating to produce the following overall dimensions:

Bore	2.10 m
Outside Diameter	2.62 m
Structural Concrete	222 mm thick
Total length	2900 m
Diffuser section	
(with 15 diffusers)	840 m
Total dry weight empty	16,800 T
Submerged weight	150 kg/m
Maximum flow rate	12.4 m^3/ s.

The outfall was installed to a maximum water depth of 55 m using the bottom pull method. Installation to this, in the context of outfalls, extreme water depth, with such a large diameter pipe, required state-of-the-art pipeline analysis using finite element analysis.

The large diameter of this pipe is considered close to the practical limits for the bottom pull method of installation because with a submerged weight of only 2 to 3 per cent of its dry weight, factors such as concrete density, water absorption and construction tolerances may determine whether the pipe floats or is too heavy to pull. Recognition of this led to the somewhat unusual step of concrete coating the individual 9 m steel pipes off site. This ensured that the concrete coating was of the highest quality.

The high concrete quality achieved will help ensure that the outfall fulfils its 100-year design life. Further measures used to maximise longevity included coating the concrete reinforcement with fusion bonded epoxy, and the liner pipe with a two pack epoxy paint and connecting the liner to an impressed current CP system.
Although the pipe is enormously heavy when dry (5800 kg/m), because of its large displacement, the pipe has a low submerged weight (150 kg/m) when empty. Traditional two-dimensional stability models indicated that the pipe was only stable in very small waves, and more sophisticated three-dimensional analysis was required to determine the limiting installation weather conditions.

Land-Based Construction

This part of the work was undertaken by SATO and Cubiertas. The outfall is made up of 9 m long steel pipes, fabricated near Barcelona. These pipes were individually concrete coated in a specialist factory, again near Barcelona.
When the pipes were delivered to site they were welded together to form strings 117 m long.

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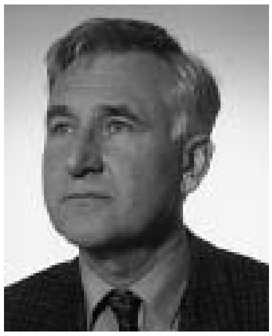
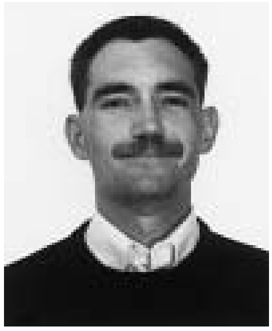


Bert Dijkstra

Stuart McIntyre holds a BSc in Civil Engineering and is a Charter Civil Engineer. He works as a Senior Engineer with Andrew Palmer and Associates, and was posted to Spain by them for the duration of the outfall design and installation as Assistant Project Manager.



Stuart McIntyre

The strings were then moved sideways into stock and the joints between pipes completed with the concrete coating. The temporary works required to allow the handling of such large pipe strings was one of the major investments onshore; its successful operation determines whether welding is completed on time. Figure 2 shows the partially completed string number one about to be moved sideways into stock.
During the welding and fabrication process, the offshore trench was being dredged. The dredging of the trench is the primary focus of this paper.

Dredging Activities

Planning
The dredging works consisted of dredging the 4-m deep, 2900-m long trench and, after installation of the pipe, backfilling of the trench with sand. The overall

Figure 2. The first pipe string being moved from the welding area to the stock area. The structures on top of the pipe are the starters for the diffusers.

Figure 3. Cutter dredger Rozenburg, 160 m from cofferdam and hopper dredger Lelystad, 600 m from cofferdam, launching preparations on shore side.

programme was for construction to begin in February of 1994, with completion in May 1995.

The critical path for the project lay through:
- welding of the pipe strings on site;
- trench dredging;
- pipe pulling;
- testing;
- backfilling; and
- pumping station construction.

Because of the client's extreme concern that dredging activities should not cause turbulence which could arrive on the beaches during the holiday periods, strict controls were enforced. These included limiting the dates during which dredging could take place, and requiring the suction hopper dredger to work without overflow.The above restrictions effectively resulted in two periods of dredging activity: a period in the spring of 1994, prior to the peak summer holiday period, and a period after summer and into the autumn/winter of 1994.

The first season of dredging work comprised the dredging, backfilling and compaction of a soil improvement area designed to support a future breakwater crossing of the outfall. The second season of work comprised the dredging of the main trench. The activities in these two seasons are discussed below.

Four different dredgers were utilised (Figure 3):
- trailing suction hopper dredger *Lelystad* to dredge up to 55 m below seabed;
- trailing suction hopper dredger *Poseidon* to facilitate backfilling of the trench through one of the suction pipes;
- cutter suction dredger *Rozenburg* to make the trench in the nearshore shallow waters; and
- submerged jetpump in combination with FLYGT pump (2 cutter system) operated from the pontoon *Kutxa* to allow for very accurate dredging near the existing pipeline.

Spring 1994

Breakwater Soil Improvement

The future harbour breakwater will be constructed over the outfall, in approximately 20 metres of water. To support this massive construction so that it does not damage the outfall required the removal of 200,000 m^3 of soft clay and mud.

The soft material was removed by the suction dredger *Poseidon,* and on acceptance of the dredged area by the client, was backfilled by the same vessel with sand with a D50 of 400 µm.

The borrowing of sand for this purpose is controversial, as sand is particularly valuable in Spain for the formation and maintenance of beaches.

After backfilling, the area was compacted using twin torpedo vibro-compactors supported from the crane pontoon *Kutxa* (Figure 4), in a pattern that compacted 5 m^2 per point. Design of the soil improvement area to support the breakwater and protect the outfall, even during earthquakes, used specialist three-dimensional consolidation, finite element models developed by Cambridge University, followed by finite element dynamic earthquake analysis using real earthquake recordings, scaled appropriately to the design criteria at Barcelona.

Autumn/Winter 1994

Main Trench Dredging

This season of work comprised dredging of the outfall trench and was divided into four sections:
1. Beach cofferdam to water depth 15 m (chainage CH 40 m to 430 m).
2. Water depth 15 m to gasline crossing (chainage CH 430 m to 1125 m).
3. Gasline crossing (chainage CH 1120 m to 1165 m) at 35 m water depth.
4. Gasline crossing to end of trench (chainage CH 1165 m to 2920 m)

Longitudinal Profile

Because of the very high longitudinal stiffness of the pipe, the trench longitudinal profile had to be very carefully designed and executed, particularly through sag curves and at the end of the ‘launch ramp’. The analysis ensures that if the pipe is very stiff and light, it will not ‘lift off’ in sag bends, particularly underneath the gas line. Similarly, when soils are very soft and the pipe is not able to lift, at the end of the launch ramp for example, it does not plough-in and become embedded.

Figure 4. After backfilling, the area was compacted using twin torpedo vibro-compactors supported from the crane barge Kutxa. Kutxa is seen here dredging under the gas line, with a pull barge behind.

The high stiffness of the pipe determines that changes in the longitudinal profile must occur slowly. This meant that, although the target trench depth was 3.6 m below original seabed, the trench was frequently deeper than this in areas of profile change. A major part of the profile design process was therefore the optimisation of stresses within the pipe to minimise dredge quantities and ensure that the pipe would follow the design profile. The trench profile adopted is shown in Figure 5.

To allow accurate dredging of the trench to a maximum water depth of 55 metres required a large trailing suction hopper dredger, *Lelystad.* This vessel uses extremely sophisticated positioning and control equipment which allows very tight dredge tolerances and ensured that the position of the suction head was exactly known at all times.

Trench Section 3: Gas Line Crossing

The first item of work to be started on the dredging of the main trench was the offshore crossing of a 20 inch outside diameter high pressure gas pipeline. This was located 1 km offshore in approximately 26 m of water. Because of its arterial role in the distribution of gas

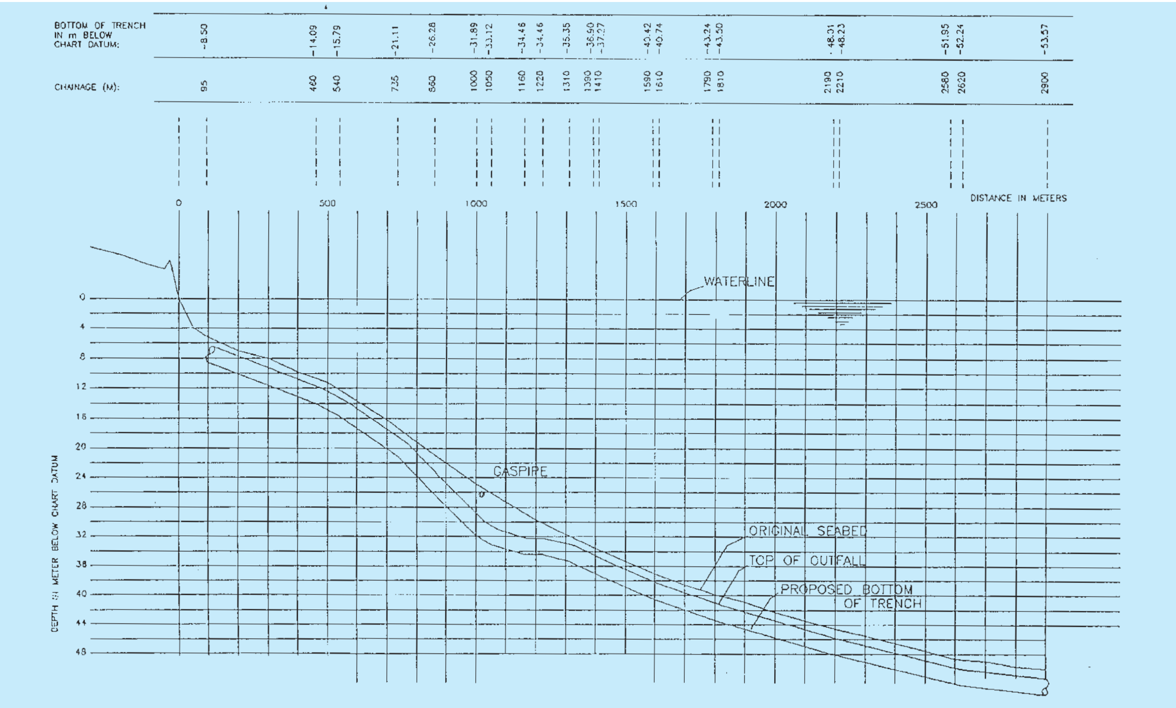


Figure 5. Basic design, longitudinal profile. Minimum radius at gasline crossing: 4500 m.

around Barcelona, the gas line could not be shut down to allow dredging of the trench. It was therefore supported on a lattice 'bridge' with a length of 60 m and a clear central span of 40 m. The bridge was designed in accordance with API RP2A (Figure 6). Although this solution worked well, considerable restrictions were placed on dredging activities.

Before dredging could begin, the owner of the gas pipeline, Gas Natural SA was provided with detailed method statements and work procedures. These procedures considered contingencies and were developed in conjunction with Gas Natural so that risks to the pipeline were minimised. In this way, should an unfortunate event have occurred, the dangers to crew

Figure 6. The gas pipeline bridge is lowered into the harbour in preparation for towing out to site. This support bridge is 60 m overall length.

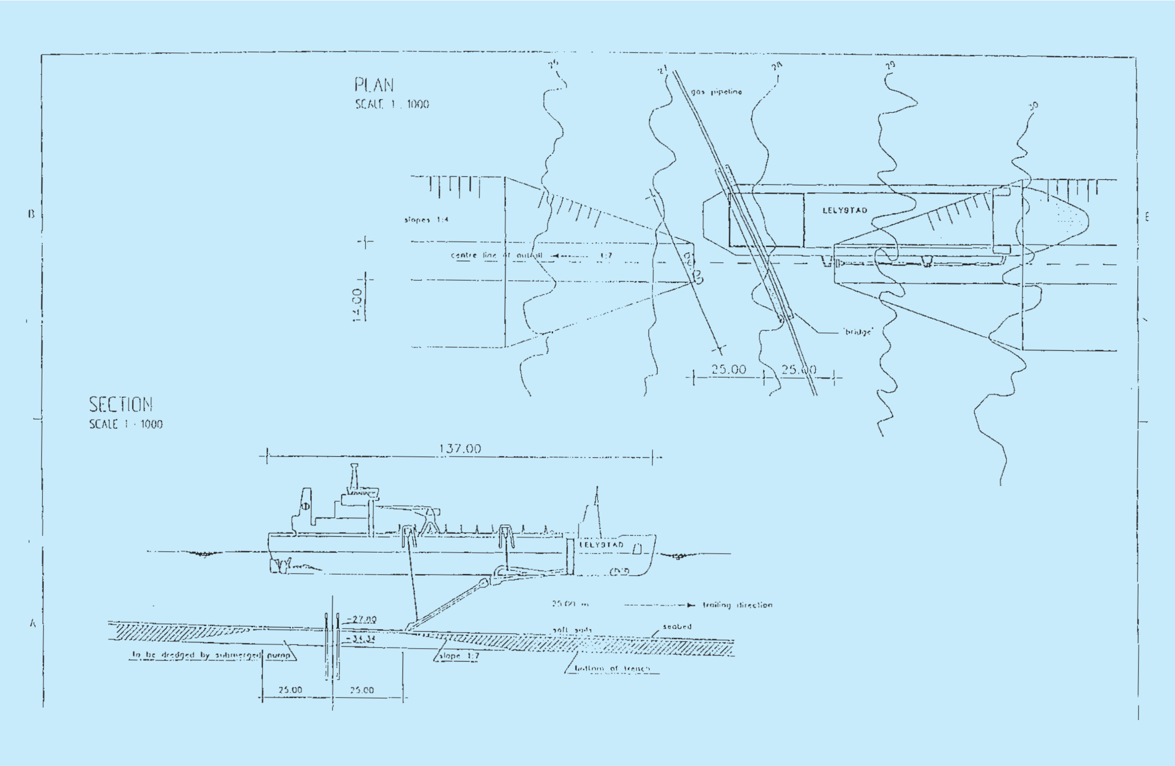


Figure 7. Situation at the pipeline crossing. Window of suction pipe of Lelystad.

were minimised, and the pipeline could have been returned to service as quickly as possible.

The procedures also placed restrictions on the movement of vessels and required that the suction heads of the dredger were always at surface when crossing the gas pipeline (Figure 7). After the pipe bridge had been installed and the procedures agreed, dredging to remove the 30,000 m^3 of material underneath and close to the pipeline could begin.

The dredging of this gas line crossing section had originally been planned for an underwater, remotely controlled vehicle carrying a jet pump. Unfortunately, production targets could not be met and the work method was changed to two cutter FLYGT pumps mounted on a vertical steel tube, supported by a crane aboard the pontoon *Kutxa.* High pressure water jets were also mounted around the pumps to help dislodge material around the pumps. Figure 8 shows the dredging system used at the gas line crossing.

Because of the nature of the sandy clay encountered, excavation slopes were steep (approximately 1:1). This had the advantage of reducing the overall amount of material to dredge, but as the material was not free running towards the pump and cutters, every part of the required trench area had to be thoroughly covered by the cutters. Figure 9 shows the trench cross-section near the gas line. It makes clear just how steep the trench slopes were.

Survey was carried out by survey launch, supported by divers when necessary. The divers were also required to manually remove the small amount of material lying directly underneath the pipe bridge.

Trench Section 1: Cofferdam to 15 m Water Depth

This section of trench was dredged by the cutter dredger *Rozenburg* on a box cut of 40 m width. The bottom width required before pipe pulling was 10 m. As the prevailing wind direction is from the northwest, and because of a slight coastal drift and the close proximity to shore and the surf zone, a small amount of trench maintenance was expected. In the event however, no maintenance dredging was required. Dredged material was dumped via a floating pipeline 450 m to the south of the trench.

Trench Sections 2 and 4: 15 m Water Depth to Gas Crossing, Gas Crossing to End of Trench

These sections were dredged by the hopper dredger *Lelystad.* Bottom width was set at 15 m while the side slopes were expected to be stable with slopes of 1:4. Dredge tolerances were determined by the pipe, with computer analysis on site to verify that the profile was acceptable. Tolerances were typically plus 10 cm to minus 40 cm per cross-section.

Difficulties encountered in the dredging of section 4 of the main trench included the material being very soft, the requirement for very tight tolerances at great depths, and being restricted to dredge without overflow. Overcoming these difficulties required a great deal of skill and attention.

A difficulty encountered in dredging section 2 was the presence of a "hard spot" in the trench at CH 480 (Figure 10). The difficulty with dredging such hard spots is that the suction head follows the path of least resistance, and the danger arises of overdredging one side of the trench and leaving the other side high. This again calls for experience and skill from the crew and the dredging engineer on the bridge.

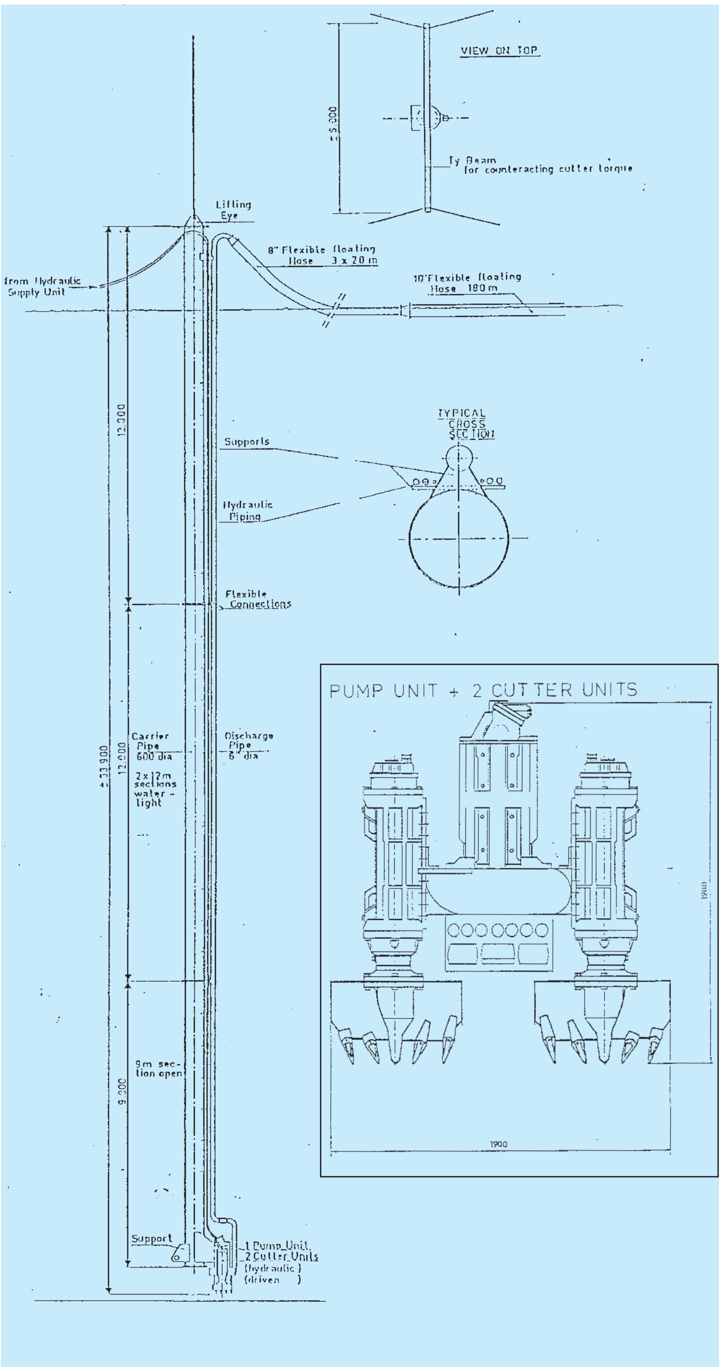


Figure 8. General arrangement of the steel pump; insert: one pump unit and two cutter units, hydraulic driven.

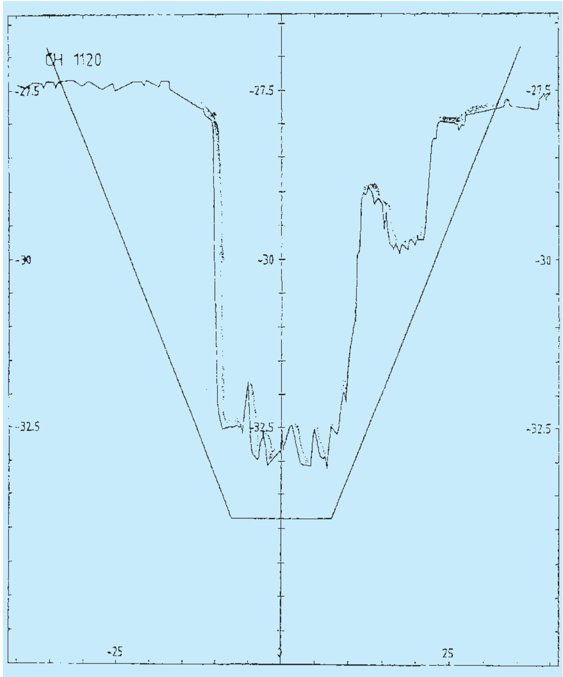


Figure 9. CH 1120 cross-section. Progress bridge 19 November 1994.

Pipe Pull

When dredging of the trench was complete and accepted by the client, the outfall could be pulled out. The pull out went very smoothly, with the outfall being pulled into the trench using the *Taklift 8* pull barge with an installed winch capacity of 600 tonne reacting against four huge anchors placed further offshore (13 Tonne Stevpris type). One 117 metre string was fully welded, wrapped, concrete coated and pulled out every 24 hours (Figure 11).
The pull barge was initially anchored 1.5 km offshore with the pull pennant passing underneath the gas line only 400 m away. Considerable detailed engineering and monitoring was required to ensure that the pull wires did not lift off close to the gas line, threatening contact with it.
During the pull, continuous survey was carried out to determine that the pipe was following the correct profile and monitoring the cable touchdown point. Installation of the diffusers, traditionally a very weather-sensitive and timeconsuming activity also went very smoothly. All 15 diffusers were installed within 30 hours. This is all the more remarkable considering that this was carried out by divers in 50 metre water depth with one metre visibility. The diffusers were installed using the deck crane aboard the pull barge.

Backfilling

After the pipe and diffusers had been installed and approved, backfilling could begin. Unfortunately, the quantity of sand available in the contractual sand bor-

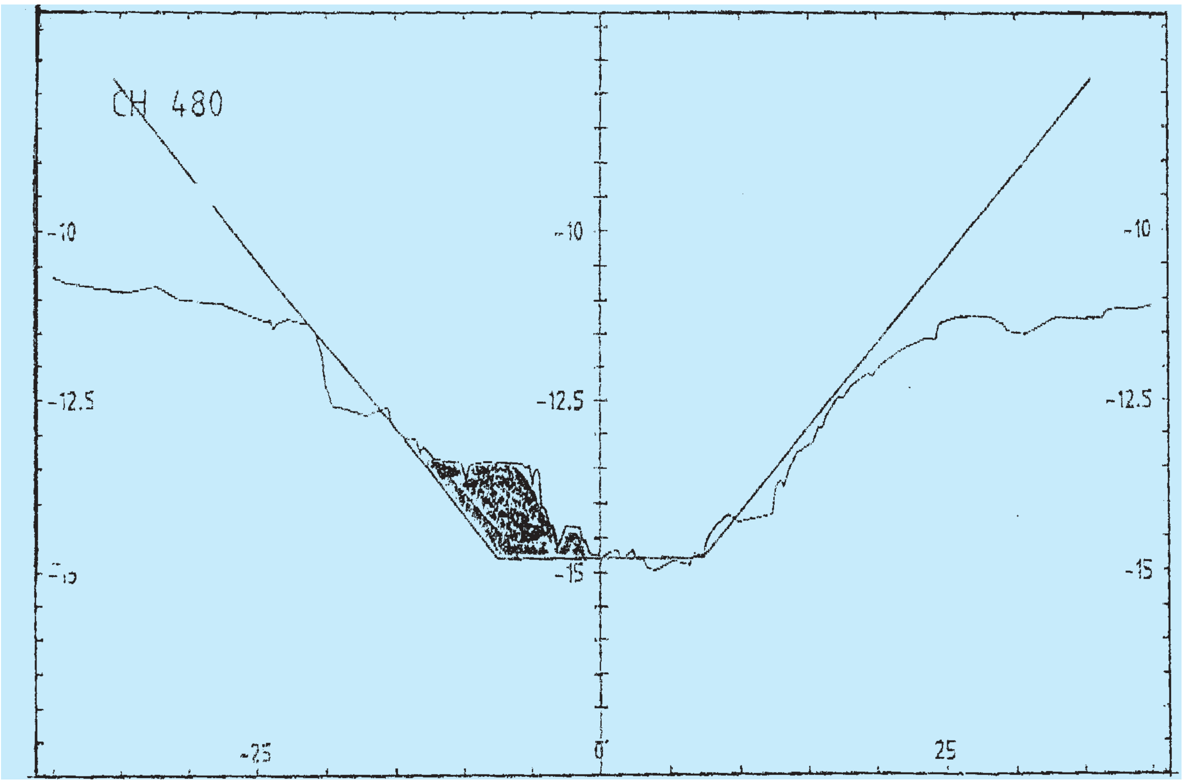


Figure 10. CH 480 cross-section. Preliminary outsurvey Kp 60-500, 15 November 1994, showing "hard spot".

row area was very limited and alternative borrow areas had to be located. The alternative sand source provided material of the grading shown in Figure 12.

Backfilling was done in two parts because of the draft restrictions of the suction hopper dredger *Poseidon* mobilised to backfill the trench. The first section was from the beach cofferdam to CH 400, and the second from CH 400 offshore.

The shallower section was backfilled using the pontoon *Kutxa* supporting a T-shaped fall-pipe which, when connected with the *Poseidon* via a floating pipeline, allowed discharge of the 3000 m^3 load over the outfall.

The offshore section was backfilled by the hopper dredger directly. This was done by pumping the hopper contents down one of the suction pipes and allowing it to discharge 5 to 10 m above the outfall.

Unfortunately, because of the fine content of the back-fill material and cross-currents, there was a significant loss of backfill material.

Figure 11. In the foreground, the pipeline is awaiting the pull. In the background is the pull barge and the pontoon dredging underneath the gas line. In the middle ground is a sewer diversion pipe crossing the pipe trench.

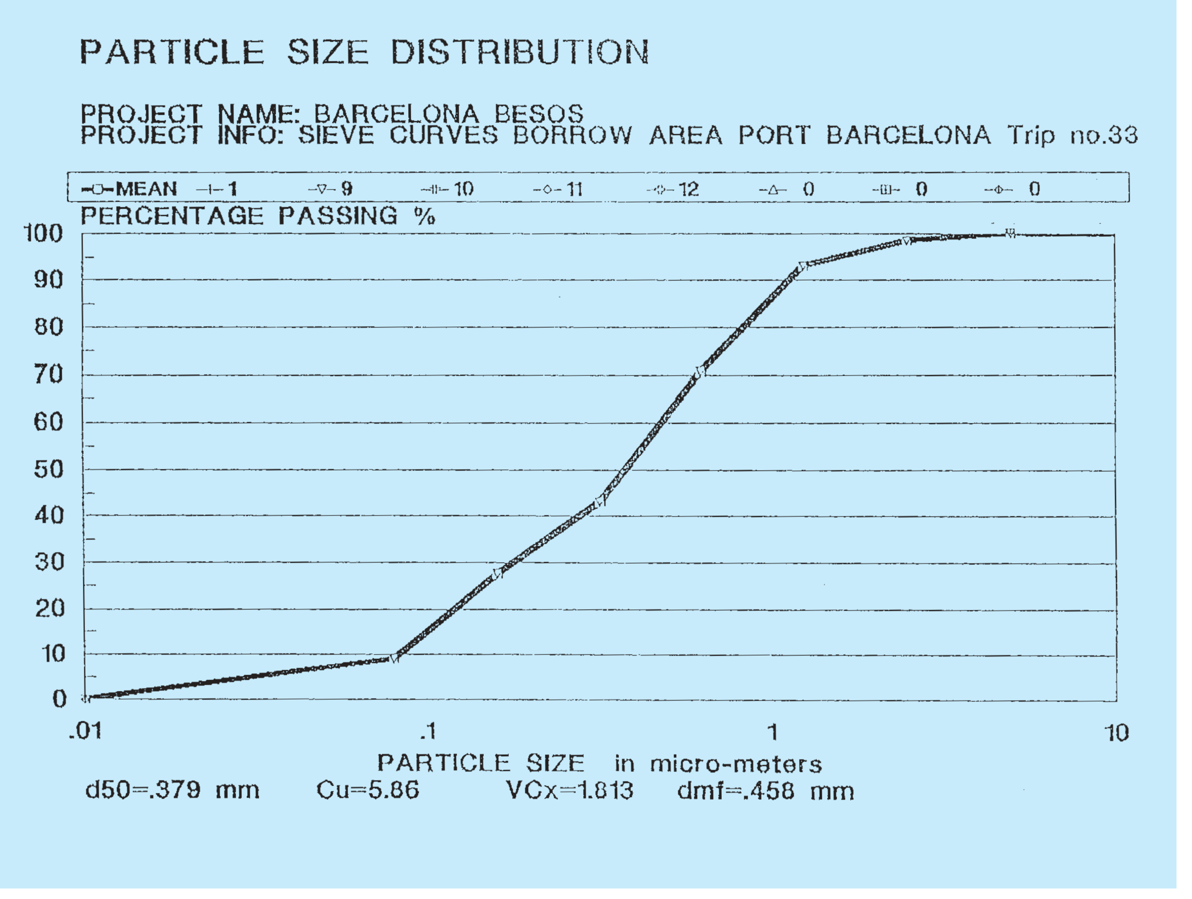


Figure 12. Particle size distribution of sand for backfilling.

Survey

The key to the successful accurate dredging of the trench was survey. The control system for the survey comprised two DGPS reference stations, seven microfix stations and an automatic tide gauge. Survey stations were installed on the survey launch *La Restinga,* crane pontoon *Kutxa,* suction hoppers *Poseidon* and *Lelystad* and the cutter dredger *Rozenburg*. In the later stages, a station was set up on the pull barge *Taklift 8* and another on the anchor handling tug *Smit Lloyd 31.*

Conclusion

The dredging activities necessary to ensure the successful construction of the new longer outfall at Besòs in Barcelona were defined by several strict requirements. For instance, dredging activities were not allowed to cause turbulence which would disturb beaches during holiday seasons. Therefore work took place during restricted periods (spring and autumn) and suction hopper dredgers had to work mostly without overflow.

In addition, utmost care was needed to cross a high pressure operational gas pipeline. This included devising contingency plans which had to be approved by Gas Natural SA. Movement of vessels was restricted and contingency plans required that suction heads were always on the surface when crossing the gas line.

Although modern engineering works are increasingly dominated by highly sophisticated technical systems, the type of precision involved in this project also relied heavily upon the close cooperation of a large number of individuals. The collective skills of the crew, the engineers and the divers allowed for the successful completion of this a significant contract within a limited time span.

Charles W. Hummer, Jr.

Books/ Periodicals Reviewed

The US Army Corps of Engineers is concluding a multi-year $25 million dredging research programme. Many fine interim technical reports have been produced periodically during the course of the programme. Presently a number of final reports are being published which are of prime interest, and four of these are abstracted below. The Dredging Research Programme (DRP) is organised into five technical areas:

Area 1 Analysis of Dredged Material Placed in Open Waters
Area 2 Material Properties Related to Navigation and Dredging
Area 3 Dredge Plant Equipment and Systems Processes
Area 4 Vessel Positioning, Survey Controls and Dredge Monitoring Systems
Area 5 Management of Dredging Projects

Development and Verification of Numerical Models for Predicting the Initial Fate of Dredged Material Disposed in Open Water, Report 2. Theoretical Developments and Verifications Results. Technical Report DRP 93-1.
US Army Corps of Engineers. February 1995.
Bibliographic references. 74 pp. Illustrated.
B.H. Johnson and M.T. Fong

This research was conducted under the DRP Technical Area 1. A numerical model called STFATE (Short Term FATE) for computing the short-term fate of dredged material disposed in open water has been developed. STFATE builds upon work of earlier researchers to provide a more realistic simulation of actual disposal operations from split-hull barges and multi-bin hopper dredges. New developments allow for multiple-connecting clouds and stripping of solids fluid from those clouds to better represent water column effects. Other developments include the use of the total energy approach for computing the bottom surge and computations that make the model more applicable at dispersive disposal sites.

STFATE has been applied to simulate disposal tests conducted at a 1:50 scale in a large laboratory facility at the US Army Engineer Waterways Experiment Station. Comparison of computed and measured results on decent and bottom surge speeds, bottom deposition, and suspended sediment concentrations have been made. The results show that STFATE can be used to reliably predict the fate of material disposed at open water disposal sites. However, an uncertainty analysis is needed to place accuracy bounds on model results.

Key words: barge, disposal, dredged material, hopper dredge, mixing zone, numerical model, sediment.

Plume Measurement System (PLUMES), Technical Manual and Data Analysis Procedures: Final Report. Technical Report DRP-95-1.
US Army Corps of Engineers. February 1995.
Bibliographic references. 94 pp. Illustrated.
M.W. Tubman

The PLUmes MEasurement System (PLUMES) was developed under the Measurement of Entrainment and Transport research work unit of the DRP Technical Area 1 to monitor the transport of suspended sediment from dredging and dredged material disposal operations. This system can monitor the transport nearly synoptically, both horizontally and vertically. The report provides technical information on the overall system, guidance on locating specific information in the standard technical manuals provided by the manufacturers of the individual system components, technical information on special features of the system components not included in the manufacturers' manuals, information on system operation and deployment procedures, descriptions of the PLUMES software, and information on the data analyses procedures.

Key words: acoustic, dredged material, monitoring, PLUMES, suspended sediment transport

Technologies for Hopper Dredge Production and Process Monitoring - Laboratory and Field Investigations: Final Report. Technical Report DRP-95-2.
US Army Corps of Engineers. February 1995.
Bibliographic references. 95 pp. Illustrated.
S.H. Scott, J.D. Jorgeson, M.B. Savage and C.B. Cox

This work unit, which falls under DRP Technical Area 3, was initiated to investigate methods for monitoring hopper dredge production and operation. Hopper dredging accounts for a significant portion of the total amount of material dredging in the United States. Operating costs for a hopper dredge are significant. Costs may vary from approximately $30,000 to $75,000 per 24 hour day, depending on the size of the dredge and support requirements. Typically, the cost of efficiency of a dredge is judged by its ability to move sediments from the project area to disposal with a minimum of pumping and travelling time. The ideal hopper load for accomplishing this is referred to as the "economic load". Better methods are needed to monitor dredge processes which will reveal the optimal operation for achieving the goal of economic load. Under this work unit, two methods were designed, fabricated, tested and evaluated for effectiveness in providing data to dredge personnel for the purpose of increasing dredge efficiency:

- A resistivity probe was developed to directly measure the vertical density profile of dredge material in the hopper.
- An instrumentation package which included acoustic and pressure sensors was developed to monitor the real time dredge displacement and hopper volume and indirectly measure the density of dredged material in the hopper.

The data resulting from the application of both systems can be used for calculating dredge production on a load by load basis. The report presents the description and method of the testing programmes and the study findings. The concept of uncertainty analysis for determining the error potential in hopper dredge production calculations is presented and discussed with an example calculation.

Key words: dredges, hopper dredge, dredge investigations, economic load, excavating machinery

A Technique to Assess the Characteristics of Bottom and Subbottom Marine Sediments: Final Report. Technical Report DRP-95-3.
US Army Corps of Engineers. February 1995.
Bibliographic references. 174 pp. Illustrated.
R.G. McGee, R.F. Ballard, Jr and D.D. Caulfield

The theoretical concept, assembly and field testing of a waterborne seismic acoustic impedance technique which has been developed to characterise bottom and subbottom sediments as they relate to removal by dredging are presented in this report. This method, developed under the DRP Technical Area 2, provides estimates of in-situ density and soil type in rapid, cost-effective manner using digital acoustic subbottom profiling methodology.

In-situ densities obtained by the acoustic impedance technique to date, when compared to those obtained by conventional means at several different sites under a wide varity of marine conditions, have statistically been within 10 percent. However, only marine sediments considered to be fully saturated, inorganic and uncontaminated have been investigated and "ground truthed". After comparisons with ground truth information and laboratory testing, a critical analysis of the acoustic impedance technique reveals it to be a valid and useful approach to bottom and subbottom material and density prediction. Athough some development is still needed to fully establish advantages and limitations, its potential usefulness warrants technology transfer now provided proper cautions are observed. This supposition is corroborated by the fact that numerous reimbursable surveys have been successfully conducted whilst products were still in the development stage. Each site surveyed provided valuable input to the R&D evolutionary processes, and enabled researchers to fine tune procedures whilst simultaneously providing a successful and timely service to clients.

Key words: acoustic impedance, acoustic subbottom profiling, bottom sediments, subbottom sediments

These reports may be obtained at no cost from:
Mr E. Clark McNair, Jr
Programme Manager, Dredging Research Programme
U.S. Army Engineer, Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, Mississippi 39180-6199, USA

or at nominal cost from:
National Technical Information Service
5285 Port Royal Road
Springfield, Virginia 22161, USA

Call for Papers

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

Gdansk, Poland
September 1-5 1996

The Marine Civil Engineering Department of the Technical Univesity of Gdansk is the site of the PIANC (Permanent International Association of Navigation Congresses) conference on inland and coastal problems in Eastern Europe.

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

Further information is available from:
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Hydro 96

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

The tenth international biennial symposium of The Hydrographic Society is being organised by The Society's Benelux Branch and will take place in September 1996. The Symposium's topics will address key hydrographic issues affecting port and other applications, including:
- port and coastal surveys;
- port and coast geodesy and navigation;
- dredging surveys;
- mapping; and
- water management.

The proceedings will be supported by an exhibition of equipment and services at which the Port of Rotterdam will be a major participant. Deadline for submission of abstracts is 1 January 1996. Notification of acceptance for presentation will be 1 March 1996. Submission of full papers for proceedings must take place by 1 July 1996.

Prospective speakers and organisations wishing to participate should contact:

Mrs P.Y. van den Berg
Hydro 96 Organising Committee
Oceanographic Company of The Netherlands
P.O. Box 7429
2701 AK Zoetermeer, The Netherlands
tel. +31 7942 8316
fax +31 7941 5084

maritime country, and water tranportation is crucial for trade. Investments are being made in the development of port facilities, deep seaports, export processing zones (EPZ), ship repair, dredging, ship and marine equipment and so on.

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International Seminar on Dredging and Reclamation

Place: Singapore
Date: January 15-19, 1996
Venue: Concorde Hotel

In cooperation with the National University of Singapore (NUS) and the Applied Research Corporation (ARC), International Association of Dredging Companies is pleased to organise, for the second consecutive year, an intensive, one-week seminar on dredging and reclamation. Last January's course met with such enthusiastic response, that IADC, building on this success, has decided to present this seminar again in 1996. The course will be held at the Concorde Hotel, Singapore. The costs are US$ 2650, which includes six nights accommodation at the Concorde Hotel, breakfast and lunch daily, one special participants dinner, and a general insurance for the week.

The seminar includes workshops and a site visit to a dredging project. Highlights of the programme are:

Day 1: Why Dredging?
The Need for Dredging/Project Phasing
Day 2: What is Dredging?
Dredging Equipment/Survey Systems
Day 3: How Dredging?
Dredging Projects
Day 4: Preparation of Dredging Contract
Day 5: Cost/Pricing and Contracts

Representatives of port authorities, companies, and individuals interested in attending are requested to complete the preliminary registration form below as soon as possible and prior to November 15 1995, and return to:

IADC Secretariat, Duinweg 21,
2585 JV The Hague, The Netherlands
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Name ....
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Do not send payment with this form. Upon receipt of this form, we will send you further detailed information about the seminar, final registration forms and an invoice for the correct amount.

11th International Harbour Congress

Antwerp, Belgium
June 17-21 1996

Organised by the Royal Flemish Society of Engineers, this five-day congress will be held together with the 8th International Harbour Exhibiton.
Topics will include all aspects of port and harbour technology such as:
- port planning: extension, renovation, future policy making, environment, financing through privatisation;
- port infrastructure design: reducing wave agitation; quality control and care; measurements, instrumention; design in third world situations;
- port construction: innovative techniques, new ship types, protection of water bottom;
- port access: approach channels, capital dredging and maintenance in rivers;
- maintenance: planning, reducing work on piers, breakwaters, etc.; maintenance dredging; emergency intervention; third world ports.

For further information contact:
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