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Recent conferences seem to have linked onto the theme of “new developments for the 21st century”. And probably not so strangely, because although the turn of the century is still two years away, the issue of new technology is clearly what keeps the motor of successful dredging turning.

Along with reliability and expertise, innovative thinking is of essential importance when tackling a dredging project. Often these technologies are related to environmental issues. But not always. Sometimes innovations are related to what seems to be the most mundane of issues – the weather. And with reason, for when you are dredging against a deadline, dealing with stormy seas or monsoons is really not so simple.

Two of our articles address issues related to the weather. One concerns the development of the Punaise, a unique sort of dredger which locates itself on the seafloor and appears to be insensitive to the heaviest of storms. The other article revolves around the challenges of controlling the Jamuna River in Bangladesh, in order to prevent it from overflowing its banks during monsoons, thereby rendering useless a newly built bridge. This achievement reflects almost 30 years of research, a large financial investment, and the inset of more than 2,000 people. It was in many respects a larger project than building the bridge.

Of course, environmental studies remain a high priority, and our third article is the 1997 IADC Award-winning paper granted in September at the ICCS in Rotterdam, which evaluates the impact of gas emissions from dredged materials.

Continuing the pursuit of advanced technologies, the CEDA Dredging Days, just held in late November in Amsterdam, focused on recent results and future trends in dredging techniques and equipment. Looking ahead, and hoping to start the new year right, several papers on innovations reported there will certainly be published in Terra et Aqua in 1998.

Marsha Cohen
Editor
Construction of the River Training Works for the Jamuna Bridge Project in Bangladesh

Abstract

Bangladesh is physically divided by several rivers, which need to be bridged over in order to develop the country’s infrastructure. One of these, the Jamuna Bridge crossing over the Bramaputra has been studied for decades and in 1993 the “Jamuna Multipurpose Bridge Project” finally was given the go-ahead. The Project comprised a number of Contracts for the bridge construction, river training works and road approaches. In May 1994, Contract 2, “River Training Works and Reclamation” was awarded to HAM-Van Oord ACZ Joint Venture (JV).

The River Training Works have to ensure that the river remains flowing underneath the bridge. This was accomplished by constructing a pair of banana-shaped guide bunds, a pair of hardpoints, flood embankments and by closure of river branches. Execution of the Works could only take place during the low water season (from 15 October to 30 April) and thus took three working seasons, from 1994 through 1997. The purpose of this paper is to give an outline of some of the construction methods used on the project. The logistics of working on a river of such vast dimensions, as well as working in remote rural area of a developing country, provided some unique challenges.

Introduction

The Peoples Republic of Bangladesh is physically divided by several rivers such as Ganges, Padma, Meghna, Bramaputra and Jamuna (see Figure 1). In order to develop the country’s infrastructure, these huge rivers have to be bridged over. A number of bridges have already been built; others are still being studied. A bridge which has been studied for decades is the Jamuna Bridge crossing over the Bramaputra, locally called Jamuna. This river runs from north to south through the country and therefore the proposed 5 km long bridge is an important link, both economic and social, between west and east Bangladesh. In 1993 the “Jamuna Multipurpose Bridge Project” finally got the green light with financial support from the International Development Association (IDA), Overseas Economic Cooperation Fund (OECF), Asian Development Bank (ADB) and the Government of Bangladesh (GOB).

The Project comprised a number of Contracts for the bridge construction, river training works and road approaches (see Figure 2). In May 1994, Contract 2, “River Training Works and Reclamation” was awarded to HAM-Van Oord ACZ Joint Venture (JV).

The complete River Training Works consist of:
- A pair of banana-shaped guide bunds, with a developed length of approx. 3.2 km, one at either side of the river at the bridge location. The main function of the guide bunds is to ensure that the approaches to the bridge will be protected against erosion by outflanking river channels.
- A pair of “hardpoints” with a length of 1.7 km, 6.5 km upstream of the bridge, at the boundary of the floodplain on either side of the river. These are to function as a first guidance of the river towards the...
bridge. The western hardpoint was a provisional item.
– Flood embankments on both river banks, constructed at the borders of the existing floodplain.
– Closure of river branches.

Summarised, the River Training Works have to ensure that the river remains flowing underneath the bridge, now and in the future. For further background on design considerations for this Project, reference is made to CUR Manual no 169, “Manual on the Use of Rock in Hydraulic Engineering”, Section 8.2, “River training works”.

The guide bunds were to be constructed by excavating a trench with a depth of 27 to 30 m below original ground level, mainly by dredging but also by some dry excavation. A clear distinction was made between the land and river side slope of the trench. The land side slope, after dredging to the design profile, had to be covered by slope protection. The underwater part of the slope had to be covered with fascine mattresses and a layer of rock, at the above water part a layer of Open Stone Asphalt on geotextile had to be applied. The river side slope was for construction purposes only, i.e. firstly it was a consequence of cutting a trench away from the main river channel to warrant current-free conditions for slope construction, secondly it was to prevent material slipping into the trench before the land side slope was covered by slope protection.

Figure 1. Overview Bangladesh with main rivers and project location.

Figure 2. Plan view (satellite image October 1995) and cross-section of the Works and river.

River Training Works for the Jamuna Bridge Project

The Jamuna River

The Jamuna River has a characteristic annual water level regime imposed by snow melt in the Himalayas and monsoon rainfall in the catchment area. The difference between mean highest water level (August) and mean lowest water level (February) amounts to 6.5 m. The river’s discharge can be as low as 3,000 m³/s during the low water stage, but amounts to 65,000 m³/s during an average flood. The river is of a braiding type. At both sides of the main stream(s) a char area with branches is present. These areas are more or less submerged part of the year. The main stream(s) and char areas are the most dynamic parts of the river with rapidly and hard to predict shifting of channels and chars. At the land sides, adjacent to the char areas, the floodplains are located. The level of the floodplains is such that they are only inundated during the highest water levels. Owing to outflanking of the river, severe erosion can take place locally which can reach up to hundreds of metres in a few weeks time. Normally a flood embankment is located on the floodplain for protection of the hinterland against flooding. Regularly the flood embankments disappear because of erosion of the floodplain.

Execution of the Works

Execution of the Works could only take place during the low water season. Such a working season was defined as being from 15 October to 30 April the following year. In total three working seasons were available with the following, contractually prescribed, order of construction (Figure 3):

- 1994-1995: Work Harbour and Bhuapur Hardpoint

As a consequence of the ever-changing river morphology, the final detailed design to be constructed and the site conditions were only known at the start of each working season.

On the Project, 41 million m³ was dredged. Also 1.6 million tonnes of (imported) rock, 1.8 million m² of geotextile, 7.2 million m³ of bamboo and many more materials were used. People of over 20 nationalities, of which, during the working season, 2,200 locally employed personnel and 100 people of other nationalities, were involved. The challenges, which inevitably accompany the execution of a work at a river of such vast dimensions and unpredictable behaviour, have been large and contributed to the uniqueness of the Project. Although the design aspects and river morphology are interesting as well, the aim of this paper is to give an outline of some of the construction methods used on the Project.

Working Season 1994-1995

Work Harbour: dredging and reclamation

During the first working season a Work Harbour, connected to the river, had to be dredged. For this job cutter suction dredger (CSD) HAM 219 (3,500 kW) was mobilised (Figure 4). The dredge material was used for reclamation of flood-free working areas for offices,
The distance of about 120 km from Dhaka to the site took two and a half hours. The JV had brought in telecommunication equipment in order to establish a micro wave link to the Dhaka exchange. However, owing to the fact that in Bangladesh a telephone line is a much desired but hard to get item, availability of the first telephone lines on site took a considerable time.

**Bhuapur Hardpoint (cellular mattresses)**

During the working season 1994-1995 also the so-called “Bhuapur Hardpoint” was constructed. An eye-catching part of the slope protection design was the use of cellular mattresses filled with sand-asphalt. Two layers of geotextile are sewn together at 0.5 m intervals, thus creating cells which can be filled with sand-asphalt. The required filling rate was minimum 300 kg/m². On site the name “sausages mat” was commonly used, which indicates best what the mattresses look like after filling.

Filling of the mattresses was carried out with specially designed twin-augers, fitted in tubes. The tubes were fed with sand-asphalt by hopper bins. The total apparatus was suspended from the boom of an excavator.

During the tender stage, tests were conducted with this filling device. Taking into account that a total area of 60,000 m² of cellular mattresses had to be made, the 6 m² which was constructed during the tests could not possibly give a guarantee for the production which had to be achieved. Also economic use of the sand-asphalt, while achieving the 300 kg/m² requirement, and temperature control during filling were an important items. Against the background of the onset of the rainy season in May and the fact that the asphalt plant was on the critical path during the first season, it was clear that this innovative construction method had to pass its learning curve as quickly as possible. In a relatively short period filling production could be boosted by a factor 4 which resulted in timely completion.

**Considerations on rock supply**

The Project required a quantity of 1.6 million tonnes of blasted rock and boulders to be used in the Works. The basic question was how the delivery of this rock could be assured and spread over various quarries in order to limit the risk of non-performance. It should be noted that inside Bangladesh no (blasted) rock is available. Only relatively small quantities of rounded boulders, fished from the river-bed, could be purchased locally. Therefore, besides quarry production, transport of rock from the quarry abroad to the Project site was of vital importance. It was decided to create a mix of transport by supplier and transport by the JV. Transport by supplier was expected to be much cheaper, but also considered to be much more uncertain for political and commercial reasons as well as to the poor transport infrastructure.

After a period of quarry investigations, a number of
quarry contracts were awarded both to inland quarries in India and Bhutan, which had to deliver the rock to site, as well as to coastal quarries in Indonesia and southern India, which had to deliver the rock to the barge at the quay, from where the JV would transport the rock overseas to site. For the overseas transport a fleet was established the extent of which was based on the expected output of the inland quarries and their ability to transport the rock to site. However, the main boundary condition was the guarantee that, if necessary, all rock required could be transported by the JV in such a way that it would be on site just in time for use in the Works. Only in this way could the pressure be kept on those supplying rock to the site.

**Rock transport**

For rock transport by sea five barges with a total capacity of 32,000 tonnes and 3,500 hp sea-going tugboats were used. Because of draft restrictions on the river, it was not possible to bring the fully loaded barges used for sea transport direct to the site. The rock had to be transshipped on to smaller barges. For this purpose a transshipment pontoon, with a conveyor system, was anchored 80 km upstream of the mouth of the lower Meghna River. For rock transport on the river four barges with a total capacity of 12,000 tonnes and two 3,300 hp pushboats were used.
West Bank: logistics
The West Guide Bund was to be constructed during the second working season 1995-1996. One of the main concerns that season was the logistic arrangement to be made. Since all accommodation, facilities and offices were located at the East Bank, additional basic facilities, such as offices, workshops, catering and fuel supply, had to be set up at the West Bank. Also the transport of people, materials and equipment had to be organised. A crew launch was used on a daily basis to transport over 150 people from one side of the river to the other and back. For transporting materials and equipment, 1,000 t barges with 1,000 hp tugboats were used. The asphalt mixes were transported from the East Bank, where the asphalt plant was located, to the West Guide Bund by 400 t barges. These were specially prepared in order to limit the loss of temperature of the asphalt mix during the trip.

West Bank: access channels
In connection with transport, obviously marine access, i.e. sufficient water depth, was required. The navigable transport route led from the Work Harbour at the East Bank via an access channel, through floodplain and char area, to the main river. Another access channel, through char area, at the West Bank connected the main river to the West Guide Bund trench. It should be noted that the char area, in which many branches are still present during the low water period, forms part of the river.

Existing river branches were used as much as possible as access channels, and if necessary enlarged/deepened and maintained by dredging. The location and lay-out of the access channels were selected taking into account the quantity to be dredged and their orientation relative to the main river. After “capital” dredging of an access channel by CSD, regular “maintenance” dredging by WID was required. Especially at the West Bank side, also regular re-dredging by CSD was required owing to the high rate of siltation (Figure 8). A good understanding of the behaviour of the river is important: dredging against nature is a game lost in advance. During the second season, 10% of the total quantity dredged was from access channels.

West Guide Bund: slope dredging
Dredging of the guide bunds required cutter suction dredgers which would be able to dredge slopes with a vertical tolerance of 0.5 m. This is not really a special situation, except for the fact that the bunds covered...
River Training Works for the Jamuna Bridge Project

maximum 153.5 m of slope length and 28 m water depth and had to be dredged in recent riverine deposits of micaceous fine sand. Moreover, the bunds had some very strongly curved sections (Figure 9). Taking into account the amount of slope dredging which had to be carried out, it was clear that only with a fully automatically controlled dredging process could the required progress and tolerances be achieved. Two more cutter suction dredgers were mobilised: CSD Zeeland II (6,212 kW) and CSD Jokra (5,086 kW). A three-dimensional model of the trench to be dredged was simulated and loaded in the survey computer on board all the dredgers. The combination of Differential Global Positioning System (DGPS), also on board all dredgers, and the three-dimensional dredge model provided that on-line dredge profiles were available.

The main parameters to be set are the dredge depth and swing width. The survey computer feeds the dredge computer which also receives on-line information on the cutter depth, which is acquired by conventional instrumentation. Via a PLC the ladder and side winches are automatically operated, taking into account the spud carrier position. The required progress of slope dredging while maintaining a constant level of high accuracy could not have been achieved by manual operation.

West Guide Bund: slope (in)stability
As a result of numerous slope failures during the first months of dredging, the Engineer decided to change the Design. The soil conditions appeared not to permit the slope gradients, 1:5 and 1:3.5, as anticipated in the original Design. Several stretches of slope collapsed after being dredged to lines and levels. The changed West Guide Bund design incorporated slope gradients of 1:5 and 1:6. Because nearly half of the working season had already passed, it was clear that the West Guide Bund, according to the new Design, could not be completed within the low water season. The dredge quantities had increased significantly and the dredging methodology had evolved to application of a reduced layer thickness (“ultra-cautious” dredging) all through the trench. In order to prevent sitation of the trench, before installation of slope protection, by slides from the river side slope, this slope had to be dredged with the same care as the land side slope. Construction of the West Guide Bund had to be accelerated in order to limit the extension of the working period into the high water season as much as possible. Also measures had to be taken to prevent exposure of the construction activities, dredging and slope protection works, and the structure itself, the West Guide Bund under construction, to river currents caused by the rising water level.
Together with the Engineer and the Employer it was decided to mobilise an additional dredger, CSD HAM 250 (1,427 kW). Protection of the trench was achieved by the so-called mitigative measures which consisted of a reclaimed bund, reinforced with groynes at the river side, around the trench. The West Guide Bund was completed in August 1996, some three months after the end of the intended working season. The additional dredger was demobilised after this.

**West Bank: closure of river branches (design)**

At the location of the bridge, the river is over 12 km wide during the high water season. Because the bridge was only 5 km long, the West Guide Bund had to be built in the char area of the Jamuna River. In order to connect the bund, or better the west end of the bridge, to the floodplain, a cross-dam had to be constructed. The dam was part of the reclamations and led through the char area thereby crossing several river branches. The size (width and depth) of and current in the branches was expected to be such that they had to be closed before reclamations could proceed. In the Contract these closures were incorporated as "design and construct", although the number and dimensions would only be known at the start of the low water season in which they were to be designed and constructed. The type, quantity and dimensions of the materials to be used followed from the flow velocities and patterns which were calculated taking into account the expected river condition during the consecutive closure operations. A complicating factor was that during the design process the water level of the river was still receding. This caused the bathymetry of the branches to change constantly and hence the river conditions during a closure operation could not exactly be known in advance. In principle, the closures had to be executed, with the materials available on site. It should be noted that last minute requirements for other materials, for instance heavy rock, could not be accommodated because of logistical limitations.

**West Bank: closure of river branches (construction)**

In general, the components of all three closures were the same. First the bottom was protected by installation of fascine mattresses. From the location of the dam to be built to a certain length downstream, a stability layer of rock was dumped on top of the fascine mattresses. Abutments at both banks were made and protected by geotextile and sand filled jute-bags. Finally the physical closure was carried out by dumping rock to build up/out the dam. In order to recover the rock used, thereby not delaying the reclamations, all closures took place outside the future reclamations.

In total three river branches had to be closed, two secondary branches and one main branch. Closure of the first secondary branch was a horizontal closure. The dam was constructed till just below the water level. Owing to the rapidly falling water level the branch closed itself. The other secondary branch and the main branch were closed vertically. During the design phase, it appeared that the differential head over the main closure would exceed the threshold value for a safe closure as contractually foreseen. Because of the low water level the distance of the points of bifurcation and confluence had increased significantly. The most economical way to limit this distance, and thereby the differential head, was to dredge a channel in east-west direction from the main river to the downstream side of the future closure location. As a contingency measure 3,500 pieces of 1 m³ geotextile "big-bags" were fabricated on site. These could be filled with sand and/or boulders to function as heavy current resistant elements, if required. Also assisted by the further decrease in water level, the dredged "short-cut channel" proved to be a sufficiently effective intervention for the successful execution of the main closure (see Figure 10) contributing to closing all river branches well within budget.

**West Guide Bund: slope protection (fascine mattresses)**

The major part of the slope protection works consisted of fascine mattresses with rock which had to be constructed using floating equipment. The length of a fascine mattress in general varied from 120 m to 140 m, to be sunk in maximum 28 m water depth. In total 140 pieces fascine mattress were fabricated and installed for the West Guide Bund.

In order to achieve the required production, the mattresses were fabricated in an "infinite" length. The length of the fascine mattress fabrication yard was approx 170 m and the components of fabrication were spread over almost the full length (Figure 11). The infinite mattress was pulled into the water in stretches of 30 m. Once the required length of mattress was floating in the water, it was cut at the water line. The continuous process of fabrication provided controlled management of the 200 labourers involved, each group with their own specific task. Maximum productions of 12,000 to 14,000 m² per day were thus achieved.

Figure 13. Rock dumping by SSDV Pompei.
Installation was carried out by sinking the mattress through dumping an even layer of 4”-8” boulders on top. This ballasting operation was carried out fully by hand. The upper part of the mattress at the above water slope was first fixed using small wooden local boats. After a sufficient length of mattress had been sunk, a small barge was brought in place. The barge was slowly shifted towards the positioning pontoon, to which the sink beam was connected, while some 60 labourers dumped boulders on top of the mattress (Figure 12). Dumping boulders by hand appeared to be an ideal rock dumping method on a 1:5/1:6 slope, and an optimum spread was achieved.

**West Guide Bund: slope protection (rock dumping)**

The fascine mattresses had to be protected by a layer of minimum 0.5 m rock 10-60 kg. At the location of the bridge abutment minimum 1.0 m rock 10-100 kg was required. Rock dumping was carried out by Dynamic Positioning (DP)-controlled, side stone-dumping vessel (SSDV) Pompei (Figure 13). Dumping of an even layer of 0.5 m using rock with an average diameter of 0.27 m required an intensive follow-up by hydrographic surveys. For this purpose a survey vessel was equipped with Real Time Kinematic (RTK) GPS “on the fly”. After extensive tests with RTK GPS on both sand and rock slopes, it followed that centimetre accuracy can be achieved with this system. Because the required layer thickness of the rock was relatively small, it was a very suitable instrument for judgement of dump results. It should be noted that only the “X” and “Y” values of the RTK GPS have been used, in other words only the position of the survey vessel was registered by this system. For accurate use of the “Z” value, which can also be obtained from RTK GPS, insufficient datum shift parameters were known in Bangladesh.

**Working Season 1996-1997**

**East Guide Bund: dredging underneath the bridge**

At the (delayed) start in 1994, part of the Works for the Jamuna Multipurpose Bridge Project had to be resched-
an accurate and reliable positioning system and automatic dredge process control were indispensable. Because the bridge deck caused an obstruction to the receipt of the signals required for DGPS, radio positioning system Axyle was used when dredging in the vicinity of the bridge. The level of the bridge deck prevented the dredgers from passing underneath the bridge. Therefore dredging took place from both sides at the same time in order to achieve a gradual lowering of the bottom level (see Figures 16 and 17). However, the dredgers had to proceed for a considerable length underneath the bridge for sufficient overlap of the (circular) dredge areas. For this purpose the ladder gantry of the dredgers was stripped of all protruding objects. During the approach and passing of a pile group the cutter to pile distance was normative. Once the cutter had passed the piles, the ladder gantry to pile cap distance and thereafter the pontoon to pile cap distance became normative. Gantry and pontoon were guarded visually by a look-out using hand-held radio.

**East Guide Bund: access channels around the bridge**

The bridge under construction intersected the trench to be dredged and, as mentioned above, the dredgers, but also the SSDV, could not pass underneath the bridge. Thus an alternative access to the dredge area north of the bridge had to be provided. During the working season 1996-1997 the bridge was expected to progress within the East Bank floodplain, so the main river could still be used to pass the bridge corridor. It was therefore decided to dredge an access channel north and parallel to the bridge corridor, connecting the main river with the dredge area north of the bridge. A disadvantage, which could not be avoided, was the fact that the trench now had an open connection to the river at a substantial distance upstream from the anticipated entrance to the south side of the trench. In other words, if the north and south sides would be physically connected, the river gradient would apply to the trench and hence cause a current. The Contract required current-free working conditions. The optimum solution could only be to minimise the distance between the inlet points of the two channels. This was effectuated by dredging an access channel just south and parallel to the bridge corridor and opening it at a late stage only (Figure 17). The anticipated southern access at the most south-side of the trench was kept closed. Eventually 20% of the quantity dredged during the season, was from access channels at the East Bank. Only by timely recognition of the access requirements and constructive discussion with Engineer and Employer, the additional quantities could be properly programmed and dredged within the available time frame.

**East Guide Bund: slope protection around the bridge piles**

Sinking of fascine mattresses around the pile groups required some creativity in order to achieve a proper protection around the piles. These mattresses were fabricated with a split. After manoeuvring them in floating condition around the pile group the split was sewn together whereafter the mattress was sunk.
The space in between the piles forming a group was filled in with gravel dumped through a chute system. Finally fascine mattresses and gravel were covered by the prescribed layer of rock, dumped by the SSDV, which had to manoeuvre with utmost caution underneath the bridge.

Conclusions

River training works for a dynamic river like the Jamuna required a flexible attitude from all parties involved: Employer, Engineer and Contractor. To be more specific:

1. The conversion of Contract Drawings into Construction Drawings, taking into account the actual site conditions after the high water season, required a very short lead-time until construction commenced (in the same low water season). Equally for unexpected and unforeseen situations, prompt action was required in order not to lose valuable time within a working season.

2. In order to anticipate the changing river morphology and relative late availability of design data, the Contractor developed various scenarios for construction. Once a scenario was implemented, the appropriate work methods were finalised and construction commenced. A strict control on work methods and planning, supported by a QA system, proved to be vital.

3. In case of unexpected and unforeseen situations, the adaptation and application of work methods required a great deal of expertise, creativity and improvisation from the Contractor’s staff and crew. The availability on site of a wide variety of high quality auxiliary equipment, in addition to the main equipment, in combination with extensive workshop facilities, contributed to the fact that the time lost within a working season because of changed circumstances could be kept to a minimum.

4. Logistics was an essential part of the execution of the Works. Not only for rock transport, where a major achievement was made, but also for uninterrupted supply of spare parts, fuel, and so on, and mobilisation of additional equipment if so required. Back-up by overseas support desks in this respect was indispensable.

5. Although much can be achieved in the manner described above (Figure 19), a Contractor should try to get the Employer to understand the realities of the situation.

References

Jamuna Multipurpose Bridge Project Contract Documents
Vol 6: “Specification”.


Figure 19. Latest available satellite image of the working area (December 1996).
Martin Kussmaul, Alexander Groengroeft and Harald Koethe

Emissions of Porewater Compounds and Gases from the Subaquatic Sediment Disposal Site “Rodewischhafen”, Hamburg Harbour

Abstract
In the year 1993 a confined and unused harbour basin was used to store 300,000 m³ of fine-grained dredged material from Hamburg Harbour. About 70% of the deposit surface was covered with water. Only the rim areas were above the water level and covered with reed. Emissions of dissolved compounds into the groundwater, as well as surface emissions of methane and carbon dioxide were measured between 1994-1997. As indicators for the water fluxes from the deposit area we used NH₄⁺ and HCO₃⁻ because of their high concentrations in sludge porewater in comparison to groundwater. The average concentrations of NH₄⁺ and HCO₃⁻ in the porewater increased during two years from 85 to 250 mg NH₄⁺ l⁻¹ and from 1.6 to 2.1 g HCO₃⁻ l⁻¹. In contrast, the groundwater from different sample sites around the deposit in 4-9 m depth showed constant concentrations of about 8 mg NH₄⁺ l⁻¹ and 0.7 g HCO₃⁻ l⁻¹. Furthermore, the average gas emissions over the water surface were 3.5 g CH₄ m⁻² d⁻¹ and 1.2 g CO₂ m⁻² d⁻¹. The land surface emission of CO₂ showed with 1.1 g CO₂ m⁻² d⁻¹ similar emission rates, but almost no methane was released from land areas. The results indicated, that there were no significant emissions of porewater compounds from the subaquatic sediment deposit into the groundwater, but there was a high emission of the greenhouse gas CH₄ over the water surface into the atmosphere. This paper was first presented in September 1997 at the ICCS, Rotterdam, The Netherlands, and was published in the conference proceedings. This revised version is reprinted here with permission.

Introduction
A confined and unused harbour basin with a surface area of 42,000 m² was used to store 300,000 m³ of fine-grained dredged material from Hamburg Harbour below the water table. The harbour sludge is polluted mainly by heavy metals and arsenic and is characterised by high concentrations of organic material between 3 and 7% TOC. The decay of carbon leads to anaerobic conditions and thus to gas production in the sludge deposit. Existing gas inclusions as well as a high content of clay and silt (50-98%) result in a low water permeability of the sludge. Production and emission rates of the greenhouse gases methane and carbon dioxide were determined. High CH₄-emissions may cause explosive gas mixtures (5-15% CH₄ in at least 11.6% O₂, Rettenberger 1994) in confined areas. This could be the case, if the deposit area would be used for construction purposes. The aim of the investigation was to find out, if the sludge deposit contributes under subaquatic storage conditions to the groundwater pollution and to the emissions of greenhouse gases.

Figure 1. Aerial view of the “Rodewischhafen” with the surrounding harbour facilities. At the time, the dam of the “Rodewischhafen” was constructed but no sludge was as yet pumped in.
**SITE DESCRIPTION AND METHODS**

Photographs of the harbour and of the harbour sediment deposit "Rodewischhafen" are shown in Figures 1 and 2. The large water surface with an average water depth of 30 cm, as well as the reed covered rim, which was up to 50 cm above the water table is visible. Figure 3 shows a sketch of the deposit with surrounding sand and low permeable estuarine loamy clay layers. The sludge was stored mainly subaquatic. About 30% of the area had a land surface which was covered with reed. The average depth of the deposit was 7 m below the water table. Throughout the year the water table changed about ± 5 cm. The groundwater flow in this harbour region was from north to south, therefore we used the monitoring well RM2 to measure porewater emissions into the groundwater layers A and B. The groundwater layer B had a broad distribution and was influenced by the tide, whereas layer A was only locally distributed and showed almost stagnant conditions. At the down-gradient position RM2 a conventional monitoring well with 20 m screen length (10-30 m below water table) was used to collect groundwater samples from layer B by pumping. In layer A a multi-tube well with three monitoring points (3 to 5 m below water table) was installed, the samples were collected by a vacuum pump device.

**Sampling techniques**

Porewater samples. Porewater samples (50 ml) were collected with suction lysimeters, permanently installed at depth of 3, 4 and 5 m below water table. To avoid precipitation of cations or phosphates, the collection bottles were prefilled with 1 ml HNO₃ (32%) or 2 ml H₂SO₄ (38%), respectively. For other anions and ammonium no prefilling was carried out. The chemical parameters were analysed afterwards in the laboratory.

**Chemical and physical analyses**

Measurement of ground- and porewater compounds. The chemical composition of the water samples were

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**IADC Award 1997**

**Presented during the International Conference on Contaminated Sediments, Rotterdam, The Netherlands September 7-11, 1997**

At the International Conference on Contaminated Sediments, held in Rotterdam from September 7-11, 1997, Dr Martin Kussmaul was presented with the annual IADC Award for younger authors. Dr Kussmaul graduated in 1991 from the University of Konstanz, Germany with a degree in Hydrology. He then moved to the University of Hamburg where in 1994 he received a PhD in microbial ecology. Since 1995 he has been employed at the Institute of Soil Science at the University of Hamburg, where he produced this paper with his colleague at the institute, Alexander Groengroeft, and Dr Harald Koethe of the Federal Institute of Hydrology, Koblenz, Germany. Each year at a selected conference, the International Association of Dredging Companies grants an award to a paper written by a young author. The paper Committee of the conference is asked to recommend an author who is younger than 35 years of age and whose paper makes a significant contribution to the literature on dredging and related fields. The purpose of the award is “to stimulate the promotion of new ideas and encourage younger men and women in the dredging industry”. The IADC Award consists of US$1,000, a certificate of recognition and publication in *Terra et Aqua*.
determined by using standard analytical procedures: titration (HCO₃⁻), anionchromatography (Cl⁻, SO₄²⁻, NO₃⁻), photometry (NH₄⁺, PO₄³⁻), AES (Na⁺, K⁺) and AAS (Mg²⁺, Ca²⁺, Fe²⁺, Mn²⁺, Zn²⁺, Cd²⁺, Cu²⁺, Cr³⁺, Ni²⁺, Pb²⁺, As).

Gas analyses

The concentrations of methane, carbon dioxide and oxygen were measured with a gaschromatograph (Fisons GC 6000). A flame ionisation detector (FID) was used to determine low concentrations of methane (< 0.5%). Higher CH₄-concentrations as well as O₂ and CO₂ were detected by a hot wire detector (WLD). The variation of the measurement was 2% for CH₄ and CO₂ and 5% for O₂.

Gas production and gas emission

Gas production

Sludge cores were taken with a beeker sampler out of the center of the deposit in 0 to 4 m depth. A gastight 130 ml flask with rubber septum was filled with 80 ml of sludge from different depth and immediately flushed with nitrogen. The increase of CH₄ and CO₂ in the headspace was measured after 12 h of incubation for the following 48 h. During that time the samples were incubated at the corresponding depth temperature of the deposit in the dark. Afterwards the flask was refilled with water. The weight of the added water corresponds to the gas volume in the bottle. Gas production rates were calculated by a linear regression in [g m⁻³ fw sludge d⁻¹].

Gas emission

Gasboxes were used to determine the gas emissions over the water and land surface (Figure 4). The increase

Table I. Average porewater concentrations of anions, cations and trace metals from 1994 to 1996.

<table>
<thead>
<tr>
<th>anions [mg l⁻¹]</th>
<th>cations [mg l⁻¹]</th>
<th>heavy metals and As [mg l⁻¹]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cl</td>
<td>40</td>
<td>NH₄⁺</td>
</tr>
<tr>
<td>SO₄²⁻</td>
<td>n.d.</td>
<td>Na⁺</td>
</tr>
<tr>
<td>NO₃⁻</td>
<td>n.d.</td>
<td>K⁺</td>
</tr>
<tr>
<td>PO₄³⁻</td>
<td>1.4</td>
<td>Mg²⁺</td>
</tr>
<tr>
<td>HCO₃⁻ measured</td>
<td>1810</td>
<td>Ca²⁺</td>
</tr>
<tr>
<td>HCO₃⁻ calculated</td>
<td>2470</td>
<td>Fe²⁺</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mn²⁺</td>
</tr>
</tbody>
</table>

n.d. = not detectable.
of CH₄ and CO₂ in the box was measured for 6 h. Every 45 min a gas vessel was replaced and afterwards analysed in the laboratory. Gas emission rates were calculated by linear regression in [g m⁻³ fw sludge d⁻¹].

**Results and Discussion**

**Chemical parameters of the ground- and porewater**

Table I shows the porewater composition as median values over time (Oct. 1994 to Sept. 1996) and sample depth (1-5 m below deposit surface). Owing to the high TOC of the harbour sludge and the absence of oxygen, nitrate and sulfate have been totally reduced. The concentration of chloride is still in the range of the water from the River Elbe, which was primarily used for flushing the dredged material in the harbour basin.

The main anionic constituent of the porewater is hydrocarbonate (90 % of the sum of anions). Part of the HCO₃⁻ is lost owing to the sampling technique (precipitation in the lysimeter tubes as Ca- or Fe-carbonates, gaseous loss as CO₂), therefore the concentration of HCO₃⁻ was calculated from ion balance.

The concentration of ammonium was high, single values varied between 66 and 300 mg l⁻¹. Phosphate behaves irregular, partly not being detectable, partly showing considerable concentrations up to 10 mg l⁻¹. Potassium, magnesium and calcium have been markedly increased in comparison to the Elbe water, whereas the content of sodium was still in the range of riverine water. The low redox potentials of the sediments resulted in increased concentrations of mobile iron and manganese. The concentrations of heavy metals were low, only the solubility of arsenic had to be considered.

Vertical differences in the porewater composition were rather small. Owing to the mineralisation of organic material and subsequent geochemical processes (carbonate buffering, cation exchange) the concentrations of HCO₃⁻, NH₄⁺, Ca²⁺, Na⁺, K⁺ and Mg²⁺ have been significantly (P < 0.05) increased from the beginning of the investigation. From regression analysis on
sediment porewater, whereas the background values of typical Elbe river concentrations are low (HCO₃⁻: 338 mg l⁻¹, NH₄⁺: 8.7 mg l⁻¹, Groengroeft and Miehlich, 1995).

Figure 5 shows the concentrations of these indicator parameters in groundwater layer A and B. The concentrations varied slightly with time but were still in the low range of bank infiltrated water. In layer A the quality was worse than in layer B, as illustrated by arsenic, but the compositions of anions and cations indicated, that there was no direct response on the sludge disposal. Thus it could be concluded, that the influence of subaquatic disposal on groundwater quality was lacking or rather small. This result corresponded with the low permeability of the disposed sludge and the observed termination of the consolidation process (Schwieger, personal comm.).

**Gas production and gas emissions**

Gas production rates of the fresh sludge with the corresponding depth temperatures from 24. April 1996.

all individual values (n = 32 to 40) the mean annual increase was calculated for HCO₃ with 9.40, NH₄⁺: 4.66, Na⁺: 0.50, K⁺: 0.15, Mg²⁺: 0.37 and Ca²⁺: 1.47 (values in mmol l⁻¹ a⁻¹). These calculated trends were nearly charge balanced (anions +9.40 mmol l⁻¹ a⁻¹, cations +9.00 mmol l⁻¹ a⁻¹).

From the measured change in porewater composition it was possible to calculate the potential release of gaseous C from mineralisation on a unit area. Using a water content of 70% fresh weight, a particle density of t = 2.55 g cm⁻³, a depth of the disposed sludge of h = 6 m and an organic carbon content of 4.1 % the unit area consisted of 2.2 t dry matter m⁻² and 5.1 m³ porewater m⁻² with the dry matter containing 90 kg organic carbon m⁻².

Using two different C/N-ratios (C/N-ratio measured = 10.5 mol mol⁻¹, C/N-ratio according to Redfield = 6.625 mol mol⁻¹) the measured increase in ammonium content in pore water (4.66 mmol l⁻¹ a⁻¹) results in a net-C-mineralisation of 3.0 kg C m⁻² a⁻¹ or 1.9 kg C m⁻² a⁻¹.

Part of the mineralised carbon leads to an increase in alkalinity (9.4 mmol l⁻¹ a⁻¹), thus the potential release of gaseous C has to be reduced to 2.4 kg C m⁻² a⁻¹ or 1.3 kg C m⁻² a⁻¹.

These calculations showed, that the daily rates of C-mineralisation may vary between 3.7 and 6.7 g C m⁻² d⁻¹. It is yet not considered, which part of the mineralised N is adsorbed as NH₄⁺-cation by matrix (leading to an increase in calculated C-mineralisation) and to which content the increase in alkalinity is caused by carbonate buffering thus not decreasing the mineralised C. The influence of the subaquatic disposal on adjacent groundwater layers should be easily detectable by a change in bicarbonate or ammonium content. As shown above, these parameters are high concentrated in the sediments of the sludge deposit from different depth are shown in Figure 6. Methane production varied between 0 and 2 g CH₄ m⁻³ fw sludge d⁻¹. No CH₄ was formed in the upper oxic layer of the deposit. However, the CH₄-production corresponds to the course of the temperature profile. In contrast, the CO₂-production ranged between 2 and 11 g CO₂ m⁻³ fw sludge d⁻¹. The lowest CO₂-production occurred in the upper deposit layer. The anoxic decay of carbon in deeper sludge layers led obviously to a higher CO₂-formation.

**Methane**

The release of methane and carbon dioxide into the atmosphere over the water and land surface is shown in Figure 6. Extremely high methane emissions between 0.2 and 7 g m⁻² d⁻¹ were measured over the water surface. The highest CH₄-emission was observed in summer. But also winter emissions rates showed high values. This indicated, that the gas emission was not only dependent on temperature but also on the atmospheric pressure or for example algae blooms in April. In summer, the methane release occurred mainly in form of gas bubbles coming out of the sludge. Therefore, the resting time of methane in oxic sludge and water layers was too short for an effective reduction of methane by methanotrophic bacteria. On the other hand, almost no significant CH₄-emission could be observed over the land surface.

**Carbon dioxide**

The emissions of carbon dioxide over the water and land surface varied between 0 and 4.5 g m⁻² d⁻¹.
throughout the year (Figure 7). But the land emissions showed more temperature dependent emission rates with highest values in summer and lowest in winter. However, the land CO₂-emissions were in the range of natural marshland emissions of 1.1 - 5.5 g CO₂ m⁻² d⁻¹ (Nyman and DeLaune, 1991). Only a small part of the produced CO₂ (see Figure 6) was emitted over the surface areas. Reasons were the good solubility of CO₂ in water and its chemical reactions with ions and surfaces. Additionally, CO₂ is fixed by autotrophic bacteria and plants for growth.

In total, the average gas surface emissions of the entire sludge deposit Rodewischhafen were approximately 140 m³ CH₄ d⁻¹ and 26 m³ CO₂ d⁻¹. However, these gas emissions were low compared to landfills of the same size (Ehrig 1994).

Conclusions

The subaquatic deposition of dredged material offers a good opportunity to store contaminated harbour sediments. No emission of contaminants into the groundwater could be observed in this case, mainly because of the low water permeability of the sludge. The concept of subaquatic disposal, as proposed by Bertsch and Knoepp (1990), can be supported with this data. The high emissions of the greenhouse gas methane over the water surface can be reduced by an oxic soil layer, which covers the deposit above the water table. The use of a plant cover promotes aeration of the upper soil and binds CO₂.

References

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Nyman, J. A. and DeLaune, R. D.

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Schwieger, F.
Personal communication. Bundesanstalt für Wasserbau Hamburg, Germany. 1996.
The Punaise: A Remotely Operated Submerged Dredging System

Abstract

The Punaise (Dutch for “thumbtack”) is a remotely operated, water-tight, submerged dredge pump system that can dredge sediments from the seafloor without impact to navigation or being affected by storms. The first Punaise was originally designed for silt removal and used in 1991 in The Netherlands. Since then, a second system has been constructed to remove sand for beach nourishment activities. PinPoint Dredging Company, a partnership of J.G. Nelis B.V., Ballast Nedam Dredging B.V. and Boskalis International B.V., operates the Punaise system and has most recently used it at beach nourishment project on the Dutch coast during the autumn of 1996. Though the Punaise has not yet operated in the U.S., PinPoint Dredging Company and the State of New York planned to demonstrate the Punaise technology for inlet bypassing, but a combination of procedural delays and limited geotechnical/geological information prevented implementation within the available environmental time frame.

This paper was written with the intention of presenting a new dredging technology to the US and is funded by the USAE Waterways Experiment Station’s Dredging Operations and Environmental Research (DOER) Program. The Innovative Technologies Focus Area within DOER is tasked with identifying new and innovative dredging Technologies for potential demonstration and monitoring to help USAE Districts conduct dredging more efficiently. This paper is not intended to be an endorsement for any particular technology or dredging company but merely to identify a technology with potential application in the US. Permission was granted by the Chief of Engineers to publish this paper.

The paper was presented at the WEDA XVIII Conference in Charleston, South Carolina, June-July 1997, and was first published in the Proceedings of the conference. It received the “Most Outstanding Paper” award from the Dredging Contractors of America. The paper is reprinted here in a slightly revised form with permission.
Introduction

Most advances in the dredging industry are modifications to existing equipment. Very infrequently, a new dredging concept is developed. One such innovation in the past seven years is the Punaise (Dutch for “thumb-tack”) dredging system designed and constructed by De Groot Nijkerk Machinefabriek and J.G. Nels Group of The Netherlands (Brouwer, Visser and van Berk 1991; Brouwer, van Berk and Visser 1992; and Brouwer, Hallie and de Looff 1995).

The Punaise is a remotely operated, water-tight submerged dredge that resides on the seafloor and pumps sediment without impact to navigation. Because it is located on the seafloor, it is tolerant of adverse surface wave action which allows it to operate in all types of weather and sea state conditions. The Punaise is connected to a shore station via an umbilical which serves not only as the communication connection but also as the discharge line through which the dredged slurry is pumped. The entire dredging process including sinking and floating (i.e. filling and emptying ballast tanks) is controlled from the shore station by one individual. The Punaise can thus operate for long periods with relatively low labor costs. Maximum flexibility in sediment removal is attained through the flexibility of repositioning the Punaise at the dredging site from time to time with the help of a tug.

Punaise Principle of Operation

The Punaise operates under the principle of the deep-dredging process (i.e. putting dredge pump as close to the sediment intake as possible). In so doing, the Punaise also requires an embedded support that must extend below the suction intake for vertical stability during dredging. Figures 1 and 2 show the two existing Punaises, PN250 and PN400, which contain a dredge pump, electric motor, instrumentation, suction intake and vertical support. Specifics for each model are shown in Table I.

Table I. Punaise Specifics

<table>
<thead>
<tr>
<th></th>
<th>PN250</th>
<th></th>
<th>PN400</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Width</strong></td>
<td>SI</td>
<td>English</td>
<td>SI</td>
<td>English</td>
</tr>
<tr>
<td></td>
<td>7.8 m</td>
<td>25.6 ft</td>
<td>8.5 m</td>
<td>27.9 ft</td>
</tr>
<tr>
<td><strong>Height (without suction pipe)</strong></td>
<td>SI</td>
<td>English</td>
<td>SI</td>
<td>English</td>
</tr>
<tr>
<td></td>
<td>3.1 m</td>
<td>10.2 ft</td>
<td>6.0 m</td>
<td>19.7 ft</td>
</tr>
<tr>
<td><strong>Height (with suction pipe)</strong></td>
<td>SI</td>
<td>English</td>
<td>SI</td>
<td>English</td>
</tr>
<tr>
<td></td>
<td>8.5 m</td>
<td>27.9 ft</td>
<td>8.7 m</td>
<td>28.5 ft</td>
</tr>
<tr>
<td><strong>Draft</strong></td>
<td>7.5 m</td>
<td>24.6 ft</td>
<td>6.5 m</td>
<td>21.3 ft</td>
</tr>
<tr>
<td><strong>Working depth</strong></td>
<td>30 m</td>
<td>98 ft</td>
<td>40 m</td>
<td>131 ft</td>
</tr>
<tr>
<td><strong>Required sediment thickness</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>initial production</td>
<td>6.0 m</td>
<td>19.7 ft</td>
<td>7.0 m</td>
<td>23.0 ft</td>
</tr>
<tr>
<td>max production</td>
<td>8.0 m</td>
<td>26.2 ft</td>
<td>10.0 m</td>
<td>32.8 ft</td>
</tr>
<tr>
<td><strong>Pump capacity</strong></td>
<td>800 m³/hr</td>
<td>1,046 yd³/hr</td>
<td>2,400 m³/hr</td>
<td>3,140 yd³/hr</td>
</tr>
<tr>
<td>@ 6 bar</td>
<td>@ 87 psi</td>
<td></td>
<td>@ 8 bar</td>
<td>@ 116 psi</td>
</tr>
<tr>
<td><strong>Discharge pipe diameter</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>26.0 cm</td>
<td>10.2 in</td>
<td>40.0 cm</td>
<td>15.7 in</td>
</tr>
<tr>
<td><strong>Weight/Mass</strong></td>
<td>47 m-tons</td>
<td>52 tons</td>
<td>95 m-tons</td>
<td>105 tons</td>
</tr>
</tbody>
</table>
During setup prior to dredging, the shore station is established and the umbilical is floated to the dredging site. The Punaise is then connected to the umbilical and positioned at the appropriate location for sinking to the seafloor. Once positioned, the ballast tanks are filled and the Punaise settles to the bottom. Fluidisers are then activated which allow the vertical support (best described as an extension of the suction pipe) to settle into the sand bottom. When the suction intake reaches the level of the bottom, dredging begins. As material is removed, a crater or pit is formed with the Punaise located at the lowest point. Dredging continues and crater/pit size grows (Punaise settles further into bottom) until either the desired dredging depth is reached or resistant bottom features (e.g. bedrock, clay) prevent further settling. A schematic showing this process is shown in Figure 3.

Punaise production depends on both the sand grain size and the pumping distance. Figures 4 and 5 show the relationship of sand grain size and pumping distance to solids production for each Punaise, respectively.

Punaise Projects in Europe

After constructing the first Punaise prototype (PN250) in 1990, a lump-sum contract was awarded to remove 600,000 m³ of silt per year for two years in Flushing Harbour in The Netherlands. The dredge was permanently positioned in the center of a turning basin where the silt was concentrated. From this position, the fresh clean silt was pumped through a submerged pipeline directly to the Schelde estuary which ends in the North Sea. The system proved to be very reliable. Minor maintenance and repair works simply required refloating of the dredge, while major maintenance required that the dredge be disconnected from the discharge pipeline and umbilical. During a continuous period of more than three months, the dredge was submerged at a depth of 16 m and regularly pumped silt to the discharge location. This two-year period also allowed for testing and improvement of various design criteria.

In 1993, a demonstration contract was signed between the Dutch Ministry of Public Works and the contractor J.G. Nelis to conduct a beach nourishment project. Owing to the effort of the Ministry of Economic Affairs, who supports innovative technology with risk loans, the decision was made to construct a bigger and more powerful dredge specially suitable for pumping sand from a borrow-pit at sea in the coastal zone. The shape of the dredge was adapted to allow dumping sand on top as from a hopper dredge. To facilitate continuous production in consolidated sand layers, the support pipe was fitted with hydraulic cylinders to raise and lower the pipe in the hull of the dredge. This allows closing of the normal suction opening halfway down the support pipe. The material to be
dredged must then enter at the bottom of the support pipe thus creating steep (unstable) side slopes in the sand layers.

Based on the experience with the Punaise PN 250, a new Programmable Logic Controller (PLC) programme was developed to control the dredge. Fiber optics were used for communication between the shore station and dredge. In 1995 a modified lay-out of the umbilical was designed, and a new “click-in” modification was implemented to the connection between the dredge and flexible discharge line to improve the flexibility of the system (Figures 6, 7 and 8).

**Punaise Technique**

**Energy and data supply**

Electrical power is supplied by two diesel driven generators located at the shore station on the beach (Figure 9). The total installed electrical power is approximately 1200 kW and is divided in 800 kW/3000 V used for the sand pump electric motor and 150 kW/660 V used for the auxiliary equipment. The umbilical is composed of 11 mm core diameter electrical cables, which provide a relatively cheap and flexible system so that future changes in working distance and/or electrical power can easily be adapted (Figure 10).

Choosing the appropriate core diameter depends upon several factors including: electrical power, distance from dredge to shore, cable handling, connector type, and cable price. For electrical power, a compound of voltage and current is limited to 3000 V (the Dutch standard for unprotected cables). In addition, there is a need for increased power for increased dredging distances offshore. Proper and effective cable handling is limited for cables larger than 11.3 mm in diameter, and inexpensive, moldable connectors for diameters larger than 11.3 mm do not exist. Therefore, the only way to exceed the 11.3 mm core diameter limit is to use parallel cables, which increases the cost. For example, the umbilical in Punaise PN400 consists of 12 separate cables of 11 mm diameter and 1,500 m long. This total 18,000 m length of cable costs approximately $250,000. Doubling this for parallel cables would have significant impacts to unit production costs. Not only does the electrical cable lead to a maximum 1,500 m umbilical, but the fiber-optic data transmission between the dredge and the on-shore control unit also has limitations. Using cable sections between 150 m and 300 m long required at least eight lens-based underwater fiber-optic connectors to prevent water penetration in the fiber tip. This type of connector has an optical signal loss of approximately 3 dB. Adding this to the signal loss of the fiber-optic fiber with a calculated spare of 4 dB results in a total loss of 30 dB along the 1,500 m length of cable, which is the maximum allowed with existing reliable LED-based light sources.

**Remote control dredging**

The unmanned dredge is controlled by one operator from the shore station using standard personal computers for visualising and controlling all the processes and PLCs for the signal input and output (Figure 11). All signals, 420 digital and 105 analog, are updated and logged every second. All processes (except diving and floating) are fully automated so the operator only tracks operation status which is visualised on a monitor.
Diving and floating remain manually controlled because the various external factors require an experienced operator that is able to react faster than a computer. The dredging process is displayed on a separate monitor which includes a window showing the last 10 minutes of operation to track trends. Additionally, the complete filling of the 1,500 m discharge pipe is shown so the operator can determine the specific “critical flow” based on the mass of sand in the pipe. The primary variable which the operator can influence is density. Using water jets at the suction mouth and 2 bypass valves located immediately before the pump entrance, the operator can easily adjust the sand/water mixture with only a few mouse clicks at the computer. Another monitor shows the status of shore based equipment (generators, air compressors and fuel supply). Finally, daily reports showing production results, equipment status, fuel consumption, and Punaise movements and location can be produced at the end of each day’s operation. In the event of a fiber-optic failure where communication between the dredge and shore station is lost, the dredge can operate autonomously via a special programme in the dredge’s PLC. If the connection fails, the dredge automatically opens all the bypass valves and pumps clean water to shore thereby removing all of the sand from the discharge pipe. To retrieve the dredge, the operator can supply air at 5 bars to the Punaise through one of two air hoses in the umbilical which allows the dredge to empty its ballast tanks and rise to the surface.

### Table II. *Punaise* Projects in The Netherlands

<table>
<thead>
<tr>
<th></th>
<th>Bloemendaal</th>
<th>Zandvoort</th>
<th>Heemskerk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>1994</td>
<td>1994</td>
<td>1996</td>
</tr>
<tr>
<td>Volume</td>
<td>255,000 m³</td>
<td>350,000 m³</td>
<td>475,000 m³</td>
</tr>
<tr>
<td>Length of replenishment</td>
<td>2,500 m</td>
<td>2,000 m</td>
<td>1,600 m</td>
</tr>
<tr>
<td>Volume/length</td>
<td>103 m³/m</td>
<td>175 m³/m</td>
<td>297 m³/m</td>
</tr>
<tr>
<td>Fill elevation</td>
<td>+3.5 m MWL</td>
<td>+3.5 m MWL</td>
<td>+4.0 m MWL</td>
</tr>
<tr>
<td>Slope</td>
<td>1:30</td>
<td>1:30</td>
<td>1:30</td>
</tr>
<tr>
<td>Maximum pumping distance</td>
<td>2,700 m</td>
<td>2,000 m</td>
<td>1,900 m</td>
</tr>
<tr>
<td>Length submerged pipeline</td>
<td>1,000 m</td>
<td>1,000 m</td>
<td>1,100 m</td>
</tr>
</tbody>
</table>
Beach Replenishment Projects in The Netherlands

The dredge Punaise PN400 was constructed primarily for three projects all on the central North Sea coast west or northwest of Amsterdam. Details of these projects are summarised in Table II.

For the 1994 projects, the Dutch Ministry of Public Works monitored the effects of a temporary sand re-handling pit in front of the coastline at -7.00 m MWL. The monitoring programme indicated that the negative effects on the coastal morphology and the macrobenthic community on the seabed adjacent to the borrow pit area were either small or immeasurable. Turbidity levels measured in the breaker zone did not exceed the usual background values and there was no evidence of any movement of the pit towards the coast or in any direction.

During the demonstrations in 1994, the Punaise was allowed to create its own pit to meet the total quantity to be dredged with no limitation placed on pit size (area). Dredging was limited to -25.00 m MWL, and the resulting pit was kidney shaped (Figure 12).

For the project conducted in 1996, the Punaise was restricted to work in an area of 100 m x 60 m and depth of 25.00 m MWL. The contours of the re-handling pit at the original depth were 250 m x 150 m. After removing 150,000 m³ from the pit, the Punaise received dredged material dumped from a hopper dredge for onshore pumping.

Production

The 1994 projects were conducted in April and May during calm/normal weather conditions. The average hourly productions per day are shown in Figures 13 and 14 for Bloemendaal and Zandvoort, respectively.

In October and November 1996, the Dutch Ministry of Public Works initiated the beach nourishment project at Heemskerk to test the performance under heavy weather conditions (Figure 15). During the two-week period from 1-13 November, the system was tested during a series of storms. A wave rider buoy located offshore recorded storm conditions approaching a 10 on the Beaufort Scale. Beaufort Scale 10 can be described as follows:

- sea specification—very high waves with long over-hanging crests; resulting foam, in great patches, is blown in dense white streaks along the direction of the wind; on the whole, the surface of the sea takes a white appearance; the tumbling of the sea becomes heavy and shock-like; visibility affected
- equivalent wind speed at 10 km—mean 52 kts, limits 48–55 kts
- probable height of waves—9.0 m

During the first days of the storm, production increased because of an increasing pit production, and the pit slopes changed from 1:3 to 1:5 as a result of breaking waves. After dredging and pumping approximately 150,000 m³ from the pit, additional material was to be supplied by a hopper dredge near the beginning of the storm period. However, owing to the adverse weather conditions, hopper dredge operations did not begin until 13 November. This test thus showed the vulnerability of a continuous production if a hopper dredge and
Punaise are used together when weather is uncooperative. Figure 16 shows the daily production of the Punaise during this time period. Figure 17 shows the hopper dredge volume placed per day, Figure 18 shows the measured wave heights, and Figure 19 shows the evolution of the pit side slopes.

Cost figures

To minimise the costs for mobilisation and installation, all of the equipment, except the hull of the dredge, is stored in containers and is transported by ship to a harbour near the dredging location. Assembling of the discharge pipeline, umbilical and establishing the units for control and power supply normally takes about 4 weeks.

The unit cost for the three demonstration projects conducted in The Netherlands was $4.71/m³ ($3.60/y³). The cost for the hopper dredge component filling the pit was $1.63/m³ (1.25/y³).

The New York “Experience”

The New York State Department of State (NYS DOS) and PinPoint Dredging Company planned to conduct a demonstration of the Punaise system at Shinnecock and Jones Inlets on the south shore of Long Island during January and February 1997. This demonstration was intended to investigate the feasibility of using the Punaise to conduct sand bypassing at structured inlets in the US. A detailed effort to monitor equipment effectiveness, crater surveys, and beach surveys near the crater and placement sites was planned.

Shinnecock and Jones Inlets each have chronic down-drift erosion problems, so the demonstration would have provided an opportunity to evaluate the technology as well as place much needed sand on the down-drift beaches. The demonstration was to have bypassed approximately 153,000 m³ from each inlet to the down-
drift beaches. Project costs included:
- $500,000 for mobilisation/demobilisation;
- $560,000 for dredging at Shinnecock; and
- $660,000 for dredging at Jones.

Assuming an equal distribution of mobilisation/demobilisation costs between inlets, total project costs were estimated at $810,000 for Shinnecock and $910,000 for Jones. These costs translate to respective unit costs of $5.29/m³ ($4.05/y³) and $5.95/m³ ($4.55/y³) at each inlet. The higher unit cost at Jones Inlet was the result of a longer pumping distance (NYSDOS 1996).

In November 1996, NYSDOS contracted for sediment cores to be taken at each dredging location to determine the sand thickness available for Punaise operations. A total of five cores (4-6.1 m long and 1-12.2 m long) were taken at each site between 19 November and 4 December.

Shinnecock Inlet
Three of the cores taken at the Shinnecock site (approximately 6.1 m water depth offshore of the updrift fillet), showed good quantities of sand to a depth of approximately 12.2 m (sand thickness of approximately 6.1 m). One 6.1 m core showed the start of a dark brown mud layer at a depth of 11.6 m (6.2 m thickness). This mud layer extended at least to -13.3 m (6.7 m bottom thickness). The 12.2 m core at Shinnecock also showed mud at the 11.3 to 12.2 m depth and then continuously from about -12.6 m to the bottom of the core at -17.9 m (Alpine Ocean Seismic Survey 1997). From Table I, one can see that the PN400 would not be an effective tool at Shinnecock because the required minimum sand thickness to begin production exceeds 7.0 m which is greater than that available at this location. If the PN250 were considered (required minimum sand thickness is 6.0 m), then only minimum production would be attained at three of the core locations.

Jones Inlet
At Jones Inlet, the 6.1 m cores indicated a relatively clean sand (one instance of mud about 0.12 m thick) to the bottom of the core. However, the 12.2 m core showed the beginning of a clay sand mix at about -12.5 m (bottom thickness of 5.7 m). Below 13.6 m depth, to the bottom of the core, material was a hard clay (Alpine Ocean Seismic Survey 1997). Implications for Punaise operations were therefore similar to Shinnecock in that the PN250 would have been mildly effective to a certain depth, but never reaching a depth for maximum production, while the PN400 would not be effective at any of the five core locations.

Because the cores taken at each site indicated that no more than a 6.1 m thick layer of clean sand was available for dredging at either site, the Punaise demonstration project was cancelled. Although the PN250 (and possibly the PN400) could probably have dredged some sand, the location of a clay layer would have required frequent repositioning thus reducing dredging efficiency and greatly increasing costs.

Punaise Operation in the US

Prior to (and since) the effort started by NYSDOS, no other project has considered using the Punaise system for dredging in the US. One reason for lack of US work has been little known legal issues associated with the Merchant Marine Act of 1920 (more commonly known as the “Jones Act” named for its author, Senator W.L. Jones) which may limit the ability of the Punaise to operate in waters of the US. The “Jones Act” is a detailed act that deals with a wide range of port and maritime trade issues. Because of section 27 of the Merchant Marine Act of 1920, which restricts US coastwise trade between the contiguous and non-contiguous states and territories to only US flagged vessels, the name “Jones Act” has become synonymous with US cabotage laws in general. The impact to dredging is related to an amendment of still another act.
which states that all dredging activity be governed by section 2 of the Shipping Act of 1916 and section 27 of the Merchant Marine Act of 1920. So even though dredging itself is not restricted to US flagged vessels in the Jones Act, per se, subsequent amendments have made the Jones Act the authority for governing dredging activities (Powers 1996). This law is reflected in Title 46 U.S.C. App. § 292. Therefore, before NYSDOS could enter into a contract to use the Punaise for bypassing at Shinnecock and Jones Inlets, they first had to seek a ruling from the US Customs Service on whether the Punaise dredging system was prohibited by the “Jones Act.”

In August 1996, the US Customs Service issued a ruling on the legality of Punaise operations in the US. The US Customs Service decision is based on two requirements from the law, namely that to be prohibited, “it must be engaged in dredging and it must be a vessel” (US Customs Service 1996). The US Customs Service showed that the Punaise was indeed involved in dredging, but since it neither carried a crew nor merchandise nor was self-propelled, it could not be considered a vessel. Therefore, the Punaise is not prohibited by the “Jones Act” from working in the US.

**FUTURE PLANS**

In 1996 the Dutch dredging companies J.G. Nelis B.V., Ballast Nedam Dredging B.V. and Boskalis International B.V. entered into an agreement for the exploitation of the PinPoint technology with the dredges Punaise PN250 and Punaise PN400. All three partners are working together in this agreement to develop and improve this innovative dredging method. Stuyvesant Dredging Company in New Orleans, a fully owned company of Boskalis International is the primary contractor of the Punaise in the US. Currently, there are plans to build a Punaise dredge (PN250) to specifically address dredging and bypass problems around the many inlets along the sandy US east coast. PinPoint Dredging expects to execute the first demonstration project in the US in early 1998.

**Conclusions**

The Punaise is a new concept in dredging technology able to conduct dredging operations in and near navigation channels with minimal impact to ongoing navigation. Some of its advantages include:
- submerged;
- remotely operated;
- shore connected by a communication/discharge umbilical;
- only one operator required;
- automated operation; and
- mobility for movement within a borrow area or to other locations for dredging operations.

Previous work in the Netherlands has proven the technology to be an effective system to dredge and pump material for traditional beach nourishment projects. The Punaise is also especially adept for working in storm conditions at relatively low costs. Because it has been ruled that the Punaise is not restricted for operations in the US by the “Jones Act,” Stuyvesant Dredging Company is actively seeking a US site to perform dredging and/or bypassing operations. PinPoint Dredging company is currently considering a design modification to allow better access to thicker sand layers in shallower waters. Possible sites for consideration include Long Island, NY, Delaware and Florida. USAE Waterways Experiment Station, through the Dredging Operations and Environmental Research Program, is assisting Stuyvesant and PinPoint Dredging Companies to locate a demonstration site and will monitor production, fuel consumption, mobilisation and demobilisation, and so on, to evaluate the equipment effectiveness. Preliminary plans are to select a demonstration site and commence dredging/bypassing early in FY 1998.

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Developing and Maintaining Operational Ports and Harbours into the 21st Century.
Edited by IADC and CEDA Secretariats

The 2nd Asian and Australian Ports and Harbours Conference was organised by the Eastern Dredging Association (EADA) and co-organised by the Central Dredging Association (CEDA), the International Association of Dredging Companies (IADC), and the Vietnam National Maritime Bureau (Vinamarine). It was a unique assemblage of port and dredging experts and administrators from the Pacific Rim and the technical papers presented covered a broad spectrum of technical, planning, and case study situations. The Pacific Rim is an area that is experiencing rapid development, particularly in the port and harbours. Vietnam is one area that typifies some of the intense planning and construction in this field which made the location of the conference especially relevant.

The proceedings (A4-sized) are voluminous. Forty papers are presented in 666 pages. Most of the papers are comprehensively presented and a few are only abstracted or slightly expanded abstracts. Many of the papers contain selected keywords supplied by the authors. This follows an initiative by CEDA and the IADC to allow for improved information retrieval by systems such as DEBBY (Dredging and Environmental Bibliography) (see Terra et Aqua, nr 62). It is hoped that this initiative will see wider adoption by the other dredging and port-related technical conferences and proceedings in the future.

For those who are interested in the forecast of port construction and dredging projects and policy issues, such as privatisation, there are five papers of particular interest; namely,
- the keynote paper presented by the Chairman of EADA, entitled, “The Privatisation of Ports in Asia”;
- “Dredging and Reclamation Opportunities in South East Asia”, by Capt. Abdul Raziz of the Malasian Port Authority;
- “The Planning and Development of the New International Container Terminal for Ho Chi Minh City”; and
- a paper by the senior United States official in charge of ports and navigation, entitled, “Navigation Channel Improvements in the United States of America”; and
- a paper by a Belgian author, Alan Lievens, concerning the privatisation of maintenance dredging in Argentina (see also Terra et Aqua, nr 68).

The remaining papers cover dredging equipment, environmental matters, operations management and monitoring, sedimentation processes, disposal issues and non-dredging solutions. This is a very good comprehensive bit of coverage from some presenters not heard from at past conferences. As one would expect, the authors are predominantly from the Far Eastern region, including Australia. There is also a good representation of dredging experts from Europe either alone or in collaboration with regional authors. Any number of papers cover some new ground and are valuable additions to the technical literature base. Some will be particularly interesting to the dredging researchers and operators in the Western Hemisphere where some of these subjects have not been found in the recent literature and may constitute innovative measures to that geographical area. Certainly, no dredging or port library should be without these proceedings. They augment and extend existing material.

This publication may be ordered from:
IADC Secretariat,
Duinweg 21, 2585 JV The Hague, The Netherlands
tel. +31 70 352 3334, fax +31 70 351 2654
Seminars/Conferences/Events

SingaPort’98
World Trade Centre, Singapore
March 24-27 1998
Organised by the Port of Singapore Authority (PSA), SingaPort is Asia's largest maritime exhibition and conference. Exhibitors cover areas ranging from ship design to cargo handling to port planning. In addition to the extensive exhibition, SingaPort is well supported by two established international conferences, the SingaPort International Maritime Conference and the SingaPort International Bunkering Conference (SIBCON ‘98). It will also feature satellite conferences on “Shipbuilding & Shiprepair” and “Logistics & Distriparks Asia ’98”, as well as technical visits.

For further information please contact:
Chandran Nair
SingaPort Enterprises Pte Ltd
1 Maritime Square, #09-72 World Trade Centre
Singapore 099253
tel. +65 321 2103, fax +65 274 0721
email: chandran@hq.singaport.gov.sg or,
Ms Christine Ng
Times Conferences and Exhibitions Pte Ltd
tel. +65 284 8844 ext 428, fax +65 286 5754
email: tcecn@corp.tpl.com.sg

ConSoil ’98
Edinburgh International Conference Centre, Scotland
May 17-21 1998
ConSoil ’98 is organised by Forshungszentrum Karlsruhe (FZK) and the Netherlands Organisation for Applied Scientific Research (TNO) in cooperation with Scottish Enterprise.

For further information about the conference contact:
Forshungszentrum Karlsruhe – PSA
PO Box 3640, D-76021 Karlsruhe, Germany
tel. +49 7247 82 3967, fax +49 7247 82 3949
e-mail: mathes@psa.fzk.de
internet: http://www.iai.fzk.de.soil98/

WODCON XV, “Dredging Into the 21st Century” and Exhibition
Las Vegas, Nevada, USA
June 28-July 2, 1998
The Fifteenth World Dredging Congress and Exhibition, hosted by the Western Dredging Association (WEDA), will include a three and a half day technical programme with the theme “Dredging Into the 21st Century”. Suggested topics include but are not limited to: infrastructure; dredging equipment and innovations; dredge automation; disposal of dredged materials; beneficial uses of dredged material; environmental issues; dredging and the economy; education and training; and dredging case studies.

The IADC (International Association of Dredging Companies) will present a prize to the best paper by a young author (younger than the age of 35). DCA (Dredging Contractors of America) will also present an award.

The conference will be accompanied by an Exhibition of dredging and marine construction-related equipment/displays which is also being organised by WEDA.

For further information about the conference or exhibition space please contact:
Lawrence Patella, Executive Director
Western Dredging Association
PO Box 5797, Vancouver, WA 98668-5797, USA
tel. +1 360 750 1445, fax +1 360 750 1445 or
tel. +1 503 285 5521, fax +1 503 240-2209

The Sixth International FZK/TNO Conference on Contaminated Soil will be taking place in May 1998. The fifth conference in 1995 in Maastricht saw an attendance of 1000 delegates from 31 countries. The series of International FZK/TNO Conferences focusses on policies, research, development, regulations, practical implementations and experiences related to contaminated sites. Legal, financial and insurance aspects of contaminated land will be included.
Seminars/Conferences/Events

BaltExpo ‘98
Olivia Hall, Gdańsk, Poland
September 1-4 1998

This ninth international maritime exhibition, organised by the Warsaw Exhibition Board of Biuro Reklamy SA and Agpol Promotion Ltd, attracts exhibitors and visitors from both Eastern and Western Europe. The register of exhibits includes shipbuilding and repair; ports and port service; offshore; maritime management; salvage and pollution control and more.

For further information please contact:
Agpol Promotion Ltd
17, Śniadeckich Street, 00-654 Warszawa, Poland
tel./fax +48 22 625 2398, +48 22 628 7295,
+48 22 628 7296

Warsaw Exhibition Board of Biuro Reklamy SA
9, Flory Street, 00-586 Warszawa, Poland
tel. +48 22 496 006, fax +48 22 493584

Expo Marítima Mercosur
Centro Costa Salguero,
Buenos Aires, Argentina
November 11-13 1998

The newly developed Expo Marítima Mercosur is being organised by Diversified Expositions, a leading publisher of marine journals including Workboat Magazine, and producer of the International Workboat Show.

This new event follows on the heels of the recent creation of Mercosur — a free trade zone developed by Argentina, Brazil, Paraguay, Uruguay and associate members Chile and Bolivia. It spotlights the construction of the Hidrovía, the inland waterway system linking the Mercosur countries, and reflects the accelerated investment and interest in this area.

The exhibition will provide an important venue for those involved in port construction, inland waterway development, oil exploration, cargo handling, vessel overhaul and other marine-related industries.

For further information contact:
Diversified Expositions Latin America
121 Free Street, PO Box 7437,
Portland, ME USA 04112-7437
tel. +1 207 842-5500/ fax +1 207 842 5503, or

Diversified Expositions Latin America
Uruguay 1134, 7o, “B”
1016 Buenos Aires, Argentina
tel. +54 1 813 1814/ fax +54 1 813 6143

Call for Papers

29th PIANC International Navigation Congress
Netherlands Congress Centre,
The Hague, The Netherlands
September 6-11 1998

The 29th International Navigation Congress of the Permanent International Association of Navigation Congresses (PIANC) will be held next autumn in The Hague. There will be two sections which will be running in parallel sessions: I, ‘inland navigation, and II, ‘marine navigation.

Two technical excursions, to the ports of Rotterdam and of Amsterdam, are also planned. In addition, the congress will be preceded by two short post-graduate courses organised by the Road and Hydraulic Engineering division of the Netherlands government agency, Rijkswaterstaat in cooperation with Technical University Delft.

The International Exhibition on Ports and Navigation, which is being held simultaneously in the Statenhal of the Netherlands Congress Centre, is directly accessible to the conference.

For further information on any of the events contact:
Lidy Groot Congress Events
PO Box 83005, 1080 AA Amsterdam, The Netherlands
tel. +31 20 679 3218, fax +31 20 675 8326
e-mail: Lidy.Groot@inter.nl.net

Hydro ‘99
University of Plymouth, UK
January 5-7 1999

Papers are now invited for The Hydrographic Society’s eleventh international symposium. Supported by an exhibiton of equipment and services, the symposium’s main theme will be “Information Management” and will deal with a wide range of global issues affecting acquisition, management and presentation of hydrographic data.

Topics include: transfer of data sets from vessels via satellite to shore-based processing centres; production of online DTM’s; visualisation of land and marine data in four dimensions; data manipulation and presentation for ECDIS and GIS.

300-word abstracts of proposed papers on designated topics and related subjects are required by December 15 1997. They should be forwarded to:

Hydro ‘99, Institute of Marine Studies,
University of Plymouth,
Drake Circus, Plymouth PL4 8AA UK
tel. +44 1752 232410, fax +44 1752 232406
e-mail: hydro99@plymouth.ac.uk
International Seminar on Dredging and Reclamation

Place: Singapore  
Date: February 9-13, 1998  
Venue: Boulevard 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 fourth 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 1998. The course will be held at the Boulevard Hotel, Singapore. The costs are US$ 2950, which includes six nights accommodation at the Boulevard 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  
(includes a Site Visit)

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 and return to:

IADC Secretariat, Duinweg 21,  
2585 JV The Hague, The Netherlands  
tel. +31 70 352 3334, fax +31 70 351 2654  
telex 31 102 (dune nl)

Place: Singapore  
Date: February 9-13, 1998  
Venue: Boulevard Hotel

(please print)

Name ..........................................................................................................................................................................

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Please send this form and your deposit by cheque or credit card for US$ 500 in order to guarantee your place at the seminar. Upon receipt of this form and your deposit your place in the seminar is confirmed. We will then send you further detailed information, final registration forms, and an invoice for the correct amount.

Without your deposit we cannot guarantee your place and accommodations at the seminar.

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