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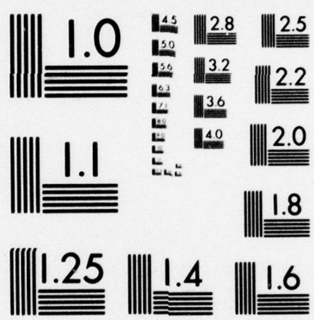

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EUROPEAN DREDGING -- A REVIEW OF THE STATE OF THE ART

DR. JOHN F. HOFFMAN*

15 NOVEMBER 1978

*Liaison Technologist from United States Naval Academy, Annapolis, MD

UNITED STATES OF AMERICA

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The state-of-the-art of dredging in Europe is described. The details are on a three-month on-site investigation in the countries of Belgium, England France, Germany, Holland and Scotland. Information was obtained during conferences involving more than 40 persons. Visited were two dredging firms, one manufacturer of dredging equipment, three universities, six laboratories concerned with the hydraulics and/or sedimentation in harbors, eight port authorities, and three miscellaneous federal agencies. New dredging technology- modifications to old dredging technology as well as dredging practices cont

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CONT → in selected European ports in discussed. The facilities and capabilities of the hydraulic laboratories visited are described.

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EUROPEAN DREDGING

A Review of the State of the Art

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EUROPEAN DREDGING

A Review of the State of the Art

INTRODUCTION

The US Army Corps of Engineers has the responsibility for maintaining the depth of the main shipping channels of the harbors of the United States, while the US Navy has the responsibility for the maintenance dredging of the slips in which its ships are berthed. The investigation summarized below was made in order to determine the state-of-the-art of European dredging technology with a view towards improving slip maintenance. This investigation, which took place over the three-month period from August to November 1978, was sponsored jointly by the Naval Facilities Engineering Command-R & D (Washington, DC) and the Office of Naval Research Branch Office, London.

One of the difficulties that had to be overcome in the various conferences was the fact that the person(s) being visited didn't quite know where to begin. Accordingly, the following questions were used as stimuli, where appropriate.

a. What methods are being used presently to dredge the subject waterway?

b. What new methods, equipment, or techniques are in use or are contemplated to be put into use?

c. What slip maintenance problems, from a dredging aspect, have been or are being encountered?

d. What environmental problems, from a dredging aspect, have been or are being encountered?

Where these questions were not applicable because of the mission of the activity, some of the dredging problems encountered by the US Navy were discussed initially.

The agencies or activities with which successful contact was made can be categorized as follows: dredging firms (2), dredging equipment manufacturers (1), port and river authorities (8), governmental departments (other than those included elswhere) (3), laboratories concerned with sedimentation and/or dredging in harbors (6), universities (3), and miscellaneous (6).

The names and addresses of the individuals contacted and their affiliations are listed in Appendix A. Conferences were held with more than 40 people in Belgium, England, France, Germany, Holland, and Scotland.

Inasmuch as the "miscellaneous" category does not appear directly in this report, the items included in it are listed below:

1. Attendance at the 16th International Conference on Coastal Engineering, Hamburg, Germany.

2. Attendance at NATO Conference on Long Term Scientific Study on Coastal Engineering, Sylt, Germany.

3. Visit with the Executive Secretary of the International Association of Dredging Companies, The Hague, Holland.

4. On-site review of the engineering works for the closure of the East Scheldte River, the last part of the Delta project, Zierickzee, Holland.

5. On-site review of the harbor expansion being undertaken at Zeebrugge, the second largest harbor in Belgium. This expansion, to be completed in 1982, is to enable tankers carrying LNG from Algeria to be berthed in the harbor. When completed the harbor will extend 2000 meters into the North Sea.

6. Attendance at the Eighth World Conference on Dredging, Amsterdam, Holland and the Europort '78 Equipment Exhibition. At least one-third of the Exhibition was related to dredging equipment (13-16 Nov 1978).

This is a summary report; however, additional information can be obtained from the 28 trip reports on file with the Naval Facilities Engineering Command (R&D), Alexandria, VA (Mr. Stephen Hurly), and with the Foundation Engineering Division, Naval Civil Engineering Laboratory, Port Hueneme, CA (Mr. Richard Malloy).

European Dredging Technology

In the United States dredging is usually accomplished using the hopper dredge, the hydraulic cutterhead dredge, and the clam shell bucket and scow. In some cases the trailing suction hopper dredge and the suction hopper dredge are used. Described below are some modifications of this technology as well as several other approaches observed on the European scene. Existing dredging practices in the US could very well change in the next few years. Two Dutch dredging companies are in the process of becoming affiliated with American dredging companies. These are:

1. The Adriaan Volker Group is becoming affiliated with the Bean Corp. on a 25%/75% basis. The venture will retain the name of the latter corporation.

2. The Amsterdam Ballast Co. is becoming affiliated with the Great Lakes Dredging Corp. on a 25%/75% basis. The name of the venture is North American Trailing Co., Inc.

The following types of dredges have been observed or discussed as being in use on the European scene:

Trailing Suction Hopper Dredge. The following is based on an inspection of one of Adriaan Volker's largest trailing suction hopper dredges, "Geopotes IX."

The trailing suction hopper dredge consists basically of a 10-ton head with projections to scarify the bottom. The head is literally dragged along the bottom. A long pipe connects the head to a centrifugal pump which discharges the spoil to a hopper that contains the dredged spoil. After the hopper is filled, the dredge steams to a dump site, the bottom doors open and the material stored in the hopper is released through the bottom. There is one complete drag head unit on either side of the ship; thus, two units fill the hopper concurrently.

The dredge "Geopotes IX" is 412 ft long, 69 ft wide, and has a hopper capacity of 8360 yd^3, and it can dredge to a depth of 110 ft. The total installed horsepower in the dredge is 11000 hp.

Positioning in a Rotterdam channel is accomplished within one meter of the desired position by use of a Motorola system with a series of transponders located along the shipping channel. In the North Sea, navigating to and positioning the same dredge at the dump site is by means of a Decca system with two transponders located on the coast. A government inspector accompanies the ship to be sure that the spoil is dumped in the designated area of the North Sea.

Besides the sophisticated gear described above, other equipment includes indicators of the slurry level in the hopper, indicators for the positions of the trailing heads in relation to the bottom, an automatic compensator for swell that keeps the trailing heads on the bottom at all times, a system of lights to indicate whether the hopper doors are open or closed, a system of lights to indicate the position of the various valves, and an automatic pilot to steer the ship on a straight course to the dump site.

Some of the newer trailing suction hopper dredges (later than Geopotes's) have water jets at the drag heads to fluidize the sediment and thereby increase productivity in dredging. There seems to be a difference of opinion as to their effectiveness. Improvements to appear in the near future are increased computerization in the dredging operation and the placement of the centrifugal pumps on the drag head to reduce the suction lift on the dredge pump.

Self-Propelled Cutterhead Suction Dredge. This is perhaps one of the latest developments in the dredging field. The commonly encountered cutterhead dredge depends upon spuds (or pile-like legs) driven into the bottom to provide the resistance against which the cutterhead can push. The dredged spoil is pumped to shore, in many cases, using a pipeline supported on pontoons. To prevent rupture of the exposed pipeline, the dredge must work in relatively quiet water.

The self-propelled cutterhead suction dredge observed in operation at Zeebrugge, Belgium through the courtesy of the dredging firm "de Cloedt et Fils" still uses a spud, but a steel piston pushing against the spud advances the dredge 6 m before repositioning of the spud is required. The pipeline is of nylon and rubber and floats on the water thus making the operation of the dredge less dependent on the sea conditions. It can work in a relatively heavy sea and can cross the ocean for transoceanic work.

Bucket Dredge. This type of dredge, also called a ladder-bucket dredge, utilizes an endless chain of buckets moving between two ladders or guides that extend into the water at an angle to the deck. In some instances the buckets have teeth welded to the cutting edge. The buckets scoop up the bottom material and dump it into a chute that overhangs a barge. The material slides along the chute into the barge. To the writer's knowledge there are no bucket dredges in the US. Two kinds of barges were observed in use: one self-propelled, the other towed. Both can dredge in depths of water up to about 38 m. Rates of dredging can be up to about 800 m^3/hr.

Multi-Grab Hopper. The Multi-grab hopper dredge is largely used in the United Kingdom although it is used supplementally in maintaining the harbor at Antwerp, Belgium. Good for close-in work such as dredging at bulkheads, alongside piers, and in pier slips, this type of dredge can be used in water depths up to 60 ft. In construction the multi-grab hopper dredge is a ship. It can be likened to a self-propelled hopper barge (bottom dump) on which is mounted from one to five cranes having clam-shell buckets attached. The cranes, using the clam-shell buckets, fill the hopper which then moves to a dump area where bottom doors are opened. The hopper can also be emptied by mean of a centrifugal pump.

Backhoe-Dredge. This type of dredge is of relatively minor importance. However, inasmuch as it has been used successfully in Europe, it is briefly described here. Photographs and models were viewed at the Europort '78 Exhibition, the equipment manufactured by shipyard De Donge, was not inspected in operation. Basically, it consists of a backhoe mounted on a barge that has three or four spuds penetrating the bottom to secure it. In one type the bucket cuts downward; in another type the bucket is rotated 180° so that it cuts upward.

Split-Hull Trailing Suction Hopper Dredges. This is a new approach to the rapid dumping of spoil. It is one step beyond the split hopper barge. Its concept has not changed from that of a trailer suction hopper dredge. The main feature of the design is that the entire hopper splits open at the dump site for a more rapid and a more complete dumping of spoil. The main part of the ship with controls, etc., remains in an upright position. Such a design eliminates much of the complicated off-loading mechanism. This dredge was not observed in operation, however, photographs and models were viewed at the Europort '78 Exhibition and it was discussed at several of the conferences.

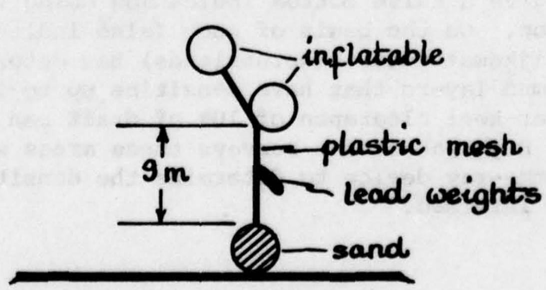
Vertical Bucket Wheel. This was in the process of development by the IHC Company (Netherlands) in the early fall of 1978 and was inspected in operation at the Europort '78 Exhibition. Basically it is a round hollow cylinder with a diameter very much greater than its height. On the peripheral wall of the cylinder are mounted small scoop-like buckets. The cylinder is mounted vertically at the end of guides and is powered by a hydraulic motor axially mounted at the axis. A centrifugal pump is connected to the hub of the cylinder.

The operation is as follows: As the peripheral buckets of the vertically-mounted cylinder cut into the sediment, the centrifugal pump sucks the spoil into the cylinder and discharges it under pressure in a continuous action.

Dredging technology, other than that involving equipment, is discussed below.

Silt Curtains. The cost of dredging pier slips in some cases can be reduced through the use of silt curtains stretched across the entrance to a slip. The Office of Chief Engineer of the Port of Rotterdam has studied this problem. In a report examined by the writer, 26 different methods of the construction of silt curtains across harbor entrances were evaluated. The plan selected for use in one of Rotterdam's harbors involves a curtain that will be about 925 ft in length and will cost about $3,250,000 to construct. It is much more elaborate than that shown below and is expected to reduce the dredging in the harbor by 30%, at annual saving of $1,000,000.

The figure is a cross section of the silt screen design that was proposed for the above use but was discarded for fear that ships dragging their anchors in Rotterdam harbor for navigational purposes would tear it up.



The operation is as follows: When a ship comes into a harbor, one inflatable tube is evacuated (the other is maintained in an evacuated condition) and the plastic screen, weighted with lead weights, collapses to the bottom. After the ship has passed over, the tube is reinflated and the plastic silt screen returns to an upright position. Should it be desired to inspect the screen, the second tube is inflated and the entire curtain floats to the surface. The mesh of the screen is of such a size that water can pass through it but not silt.

Sedimentation Basins. Dredging efficiency can also be increased by increasing the density of the fine-grain sediment. There are two ways of accomplishing this in a waterway:

1. Leave the sediments on the bottom for a longer time period to allow consolidation.

2. Allow the sediments to accumulate to a greater depth to allow consolidation before dredging. This requires overdredging to accommodate the increase in accretion and still maintain a satisfactory under-keel clearance.

Sedimentation basins in the bottom of waterways are used at Europort, Holland and in the River Clyde at Glasgow, Scotland. In the latter three basins each 300 ft by 3300 ft and 8 ft below channel depths are used to trap the sediments that, according to the Conservancy Engineer (Sinclair, 1978), would settle in pier slips.

Miscellaneous Technology. Excessive transportation of spoil to insure 100% disposal can be expensive and time consuming. On-site studies made by the Hydraulic Laboratory, Wallingford, England using radioactive gold in the River Plate in Argentina indicated that sidecasting of the spoil only a short distance from the dredge resulted in 93% of the spoil being removed from the dredged area. This has also been found to be true in the case of the Mersey River at Garston, England (see following section).

During the same study, this Laboratory also evaluated the effectiveness of overfilling the hopper of a trailing suction hopper dredge. The results of this field study showed that there was no increase in the density of the material in the hopper in spite of overfilling.

Sometimes sonar can give a false bottom indication owing to a fluid-like silt accumulation. On the basis of such false indications dredging may be specified. Rijkswaterstaat (Netherlands) has determined that ships can penetrate mud layers that have densities up to 1.2. Accordingly, the conservative under-keel clearance of 10% of draft can be eliminated. Where known to occur Rijkswaterstaat surveys these areas weekly using a back-scattering gamma-ray device to determine the densities so that mariners can be kept informed.

In order to make dredging estimates realistic the Delft Soil Laboratory has been conducting dynamic resistance tests in various sediments using a cone penetrometer moving at the rate of 1 m/s, which is the estimated speed at which the bucket of a bucket dredge moves through bottom sediments.

A novel method of spoil disposal was pointed out by the Department of Environmental Affairs of the Rijkswaterstaat (Netherlands). This Department is conducting studies concerning the disposal of dredge spoil from a selected portion of Europort into Lake Oostvoorne. The lake is 40 m deep, too deep for recreation. The plan is to fill the lake to an acceptable level (5 to 10 m) and cover the spoil with a plastic sheet. This sheet is then to be weighted down with sand to provide a suitable bottom for the water recreation area. Involved is a computer model to study seasonal turnover of the lake water and measurements of the concentrations of toxic compounds in the sediment to be dredged and those in the interstitial water. Use of a floating pipeline for the onshore disposal of spoil during dredging operations was observed in operation at Zeebrugge, Belgium as well as at the Europort '78 Exhibition as an exhibit. This type of pipeline, which is wrapped with a buoyant material, eliminates the need for cumbersome pontoons usually used to support the discharge pipeline.

Finally, at the WODCON VIII Conference a dredging formula continually stressed by Dutch engineers was:

Price x Production = a constant

while generally true, it was specifically related to setting limits allowable for overdredging. A contractor anticipating adherence to say a one-half fast payable overdredge may estimate such a slowdown in production that the price bid for the job would be higher than if a payable overdredge of one-foot were specified.

DREDGING PRACTICE IN SELECTED EUROPEAN WATERWAYS

Described below is the current (1978) dredging practice in selected waterways in Belgium, England, France, Germany, the Netherlands, and Scotland. The term waterways includes harbors, rivers, canals, and channels.

BELGIUM

Belgium has only 67 km of coast and therefore has a limited number of harbors. These are located either along the North Sea or on the West Scheldte River.

A shipping channel parallels the North Sea Coast of Belgium. This extends past the Netherlands and continues up through the West Scheldte River to Antwerp. Although the West Scheldte River passes through Dutch territory, its entire length is maintained by Belgium inasmuch as this is the only outlet for the Port of Antwerp. About 12 to 15 million m^3 are dredged annually to maintain the channel-water depth of 11 m below mean low water. About six million m^3 of this quantity is dredged from that portion of the channel located in the North Sea, the remainder being from the West Scheldt River.

The Port Authority of Antwerp, the largest port in Belgium, utilizes both bucket and multi-grabber hopper dredges to maintain pier slips and main channels. The latter dredge is used to dredge close to bulkheads and piers.

The spoil, which amounts to about 2.5 million m^3 annually is pumped to industrial sites to increase the land area. The method by which this is done is as follows: A barge with a pump and pipeline attached is moored against the shore. Hopper barges and multi-grabber hopper dredges are offloaded to the moored barge from which the spoil is then pumped inland.

The Port Authority of Zeebrugge, the second largest port in Belgium, utilizes a trailer suction hopper dredge to dredge the main channel and a small Ellicott cutterhead suction dredge to dredge the bottom adjacent to the bulkheads and in areas too confined for the use of the larger dredge. The spoil from the Ellicott dredge is pumped to the channel about 25 m away where it is ultimately removed during channel dredging. The spoil from channel dredging is dumped in the waterway in areas of accretion rather than in the North Sea. Such areas have been determined by hydraulic model analysis.

In dredging the small harbors of Niewport and Blankenburg, a small cutterhead suction dredge is used, and the spoil is pumped directly to the beach for beach replenishment.

It is interesting to note that for 50 years all of the Belgian harbors were dredged by bucket dredges.

Only one harbor in Belgium has spoil that contains toxicants. This is the harbor of Ghent. Amounting to about one million m^3 annually, the spoil from dredging this harbor is pumped to an onshore disposal site 10 hectares in area. In order to prevent the leachate from contaminating the ground water a water-tight membrane seals the bottom of the disposal area.

ENGLAND

Two port authorities in England were interviewed; the Port Authority of London and the British Transport Docks Board. A third agency, the British Ports Council was also interviewed.

All of the maintenance dredging in the Thames River is done using the bucket and scow dredge. Where special dredging jobs occur, outside contractors are used employing bucket dredges and trailing suction hopper dredges.

The amount of spoil dredged annually from the Thames River is about 600,000 m^3 along a rather extensive reach. The cost of dredging is about $\$2/m^3$ of dredged and offloaded spoil.

The Port Authority of London has a land spoil disposal program that started in 1969. It is estimated that the site will be filled by 1981. Essentially the spoil disposal site is a diked area with overflow weirs spilling to a peripheral drain. The water in the drain flows back into the Thames River. The site is basically underlain by relict riverine sediments and is in the vicinity of a range used for artillery practice. Evaporation from soil surfaces and transpiration due to plant growth dries the spoil fairly rapidly to the point that cracks develop on the surface.

An approach to the pier slip problem in the case of very deep-draft ships is to dredge a box up to 5 m deep in the pier slip. The ship is brought in at high tide and moored to the pier. At low tide its keel is about 2 ft above the bottom of the box. A sill exists between the bottom of the box and the channel thus reducing the movement of sediment into the slip.

The British Transport Docks Board is the port authority that regulates 19 nationalized ports in England and in Scotland. It is comparable in responsibility to the Port of London Authority. Basically, these ports are dredged by trailing suction hopper dredges and bucket and scow dredges. Careful evaluation has led to the conclusion that sharing equipment between ports enables economies of sufficient magnitude that private dredging is eliminated essentially from the competitive picture. Dredging is the single largest expense ($8 million in 1977) in their annual budget ($54 million in 1977).

Port Talbot in South Wales is the Board's largest problem. This port was built in 1970 in cooperation with the nationalized British Steel Industry to accommodate vessels up to 150,000 DWT displacement. Each year prior to 1975 three million yd^3 are handled by one trailer suction hopper dredge with a hopper capacity of 2000 yd^3 and one bucket and scow dredge with a hopper capacity of 2500 yd^3. Until 1975 there was no problem with siltation. Since then, storms have caused additional silting and to maintain a depth of 31 ft below the Admiralty Datum (the lowest low water), the employment of private contractors has been necessary.

Another port of interest from a dredging standpoint is Garston on the Mersey River. Dredge spoil had been dumped previously 30 miles downstream from the harbor. However, studies have shown that dumping spoil only three miles downstream has resulted in a minimal return of the spoil, therefore, spoil from channel dredging is now dumped at this latter site. Spoil from dredging pier slips, however, is still dumped 30 miles downstream.

The philosophy of the Board regarding spoil disposal is not to remove the spoil from the system but to dump it just far enough away from the dredge site to minimize its return. Studies have shown that this produces optimal economic benefits.

The function of the National Ports Council is to coordinate activities of, give guidance to, and provide engineering consultation for the various port authorities in England, Wales, and Scotland. By an act of Parliament these port authorities must belong and contribute to the Council's support. Belfast, Ireland (Protestant), however, voluntarily belongs to the Council.

In general, the UK has learned to adopt a philosophy concerning the silting problem, termed "beneficial neglect", and has learned to live with this philosophy. Even with this philosophy an underkeel clearance of 10% of a ship's draft can usually be maintained.

FRANCE

Dredging in the major harbors of France is undertaken by port authorities. Although they work independently, they still are under the jurisdiction of the federal government. Time precluded visiting any French ports; however, the subject was discussed in depth with M. Jean Chapon, Inspector-General of Public Works (formerly Director of Harbors and Navigable Waterways and the author of a text on dredging).

The equipment utilized for dredging harbors and channels in France includes dipper, bucket, grabber, cutterhead suction, stationary suction, and trailing suction hopper dredges. It has been found that bucket dredges are better utilized in harbors where the bottom sediments are cohesive. The latest trailing suction hopper dredges utilize water jets to loosen the sediment.

The spoil is disposed of in two ways. Offshore dump sites and onshore spoil areas for creating additional land near expanding ports. Offshore disposal requires, by law, an analysis of the spoil and an environmental impact study. However, according to Chapon (1978), environmental control is less rigorous than in the US.

A new feature encountered was the design of the inlet to hopper dredges. The design was instituted because it was felt that the spoil in the hopper was of low density because the pump discharge caused turbulence in the hopper resulting in a resuspension of settled material. A diffusion device, much like a lady's fan, whose plane is parallel to the deck of the dredge is attached to the centrifugal pump discharge. A rapid settlement of particulate matter takes place and relatively clear water overflows the hopper into the water surrounding the dredge. The result is a greater weight of sediment per load in the hopper.

GERMANY

Three waterway authorities were interviewed: The agency supervising the maintenance of the Elbe River and those supervising the maintenance of the ports of Hamburg and Kiel.

In Germany, the Federal Government maintains shipping channels only. The Federal States maintain their own harbor channels and slips. The German Navy maintains its own channels within the naval base.

Dredging in the Elbe River is accomplished by means of two trailing suction hopper dredges; one has a hopper capacity of 2500 m^3, the other 4500 m^3. Each has a draft of 6.7 m and the capability of bottom dumping. The smaller hopper-capacity dredge dumps the spoil in the North Sea; the larger one has the spoil pumped off to form small artificial islands. Any dumping on marshland is resisted by the environmentalists.

Artificial islands are formed by outlining a shoal area with a single layer of copper slag rock. The sand is pumped into the middle of the area outlined, and when the land surface is above the water surface, a bulldozer spreads the material. One island, pointed out on a map, is 5 km long and 1 km wide. To date (1978), these islands have not be been utilized.

About eight million m^3 are dredged annually from the Elbe River in the 110 km reach from Hamburg to the North Sea. Half of this is dumped in the North Sea within 20 km of the shore; the other half is used to build artificial islands.

During the period following WW II, the channel was deepened from 10 m to 13.5 m. It is felt that once the channel stabilizes, the amount of future dredging will be 50-60% of the quantity presently dredged.

The material dredged is basically one-third very fine sand, one-third medium sand, and one-third coarse to very coarse sand. All this material originates from the river channel bed and river banks. There is a 30-km reach of river where flocculation has caused silt to be deposited.

The chemical content of the sediment is not the concern of this authority but is under study by the University of Hamburg. As of the time of writing, no report has been issued. Monitoring the quality of the water column is the problem of the State Government.

The operating costs of dredging eight million m^3 in the Elbe River is about $9 million. Taking into account the depreciation of the equipment results in doubling this cost to about $17 million. This amounts to roughly $2/m^3$.

Dredging problems are as follows:

a. The costs of overdredging excessively to maintain the minimum depth. Under development is sophisticated sounding equipment to display the bottom graphically and permit excavation to closer tolerances.

b. Spoil disposal areas for future use.

The Port Authority of Hamburg maintains all slips and channels within the Port of Hamburg. About 58 million tons of shipping pass annually through this port. The shipping channel is 13.5 m below mean low water; the tidal range is about 2.8 m. With this depth of channel vessels as large as 250,000 DWT can enter the port allowing for an underkeel clearance of 10% of draft. In order to maintain the shipping channels at the desired depth about 3 million m^3 are dredged annually. This sediment consists of sand and loose silt. Bucket dredges are usually used. Where a bucket dredge cannot operate safely (i.e., adjacent to piers), a bucket and scow is used. The Port Authority owns three bucket and five clamshell bucket dredges. Both load onto scows which, when filled, are moved to an unloading area where a centrifugal pump unloads the scow through a pipeline and deposits the spoil onto land.

Sand spoil is used to build up land adjacent to the harbor. Inasmuch as there are no ground water wells in the vicinity, leaching of toxicants to the water table is no problem.

Silt spoil, on the other hand, is deposited on farmland rented for a period of about five years. Where the land is sandy and ground water wells are close by, a 1-m layer of clay is placed first. Where the silt has poor bearing capacity, a 1-m layer of sand is placed over the layer of silt to facilitate drainage.

About 100 hectares of land are presently used for the disposal of sand and silt. However, for optimum efficiency and economy, it is estimated that between 100-200 hectares are required. Annually, this area should be increased by 20 hectares to cope with the removal of land that has been filled to capacity.

Federal Government dredges are used to perform maintenance dredging in the Kiel harbor and the Kiel Canal. New work is performed by private contractors with cutterhead suction dredges. Private contractors claim they cannot do maintenance dredging as cheaply as the Federal Government.

Maintenance dredging of Kiel harbor utilizes the following equipment: three trailing suction hopper dredges (1950 vintage), two trailing suction hopper dredges with water jets to fluidize the mud during the dredging, and one old hopper dredge unit. Bucket dredges were used formerly but the Federal Government felt that trailing suction hopper dredges were more efficient and economical for their type of work.

The NETHERLANDS

About 20 million m^3 are dredged from the Netherlands' waterways annually. Fifteen million m^3 of the spoil is dredged from the Port of Rotterdam where dredging is accomplished by means of trailing suction hopper dredges, bucket dredges, and bucket and scow dredges. The spoil dredged from the various inner harbors of the Port is discharged onto polders. There are five permanent off-loading pump stations to accomplish this. The capacities of the pumps vary from 1000 to 2000 cubic meters per hour. Fine material that adheres to the barge is loosened by a jet of water pumped from the river.

Prior to 1960, the dredged spoil was pumped onto farmland to increase its fertility and hence crop production. However, sediment in the middle of the Port of Rotterdam was found to be contaminated by inflow from the Rhine River. Investigation by the Institute of Soil Fertility determined that the crops were absorbing the heavy metals in the spoil. Therefore, at present, land devoted to spoil disposal is used only for parks, houses, golf courses, etc.

Inasmuch as the water content in the spoil contains a sufficient amount of sodium to be deleterious to vegetative growth, the runoff is collected carefully and drained to the river. In order to prevent any leachate from contaminating the deep ground water supply, shallow wells are installed to skim the infiltration and return it to the river.

Sediment dredged from Europort, seaward of the Port of Rotterdam, is dumped in the North Sea. This is supervised by Rijkswaterstaat, Nordzee Division. This Division has three functions: Supervising the disposal of spoil in the North Sea, evaluating the movement of the spoil after dumping, and studying the concentration and effect of any contaminants that may be a problem on the Dutch portion of the Continental shelf. They issue permits for spoil disposal in the North Sea and maintain a staff of inspectors whose function is to board the trailing suction hopper dredges to be sure that the spoil is deposited in the proper place offshore.

Their monitoring programs consist of:

1. A monitoring program in which an array of 70 surface stations is sampled every two weeks. The area extends from the shore out to 70 km.

2. A biological monitoring program that consists of suspending from structures bags of uncontaminated "filter feeder" organisms obtained from the Irish Sea and analyzing them periodically for the uptake of contaminants.

Based on the investigation of the offshore movement of spoil in dumping areas, it is estimated that 50% of the silt in the coastal areas has as its source the dump site.

SCOTLAND

The Clyde River Authority is responsible for 400 square miles of water in the Port of Glasgow. Dredging of both main channels and slips is carried out by the Authority using the following equipment: one bucket dredge, four self-propelled hopper barges, and one multi-grabber hopper dredge. Four hopper barges are necessary to keep the bucket dredge working continuously. Some idea can be obtained as to the time consumed in the maintenance dredging of pier slips from the following. Dredging a berth 100 ft x 650 ft removing 2 ft of material in a water depth of 25 ft, takes 3 days of dredging. Two days are spent dredging with the bucket dredge, and one day is spent dredging with the multi-grabber dredge. The bucket dredge requires an additional day for mobilization and demobilization. Before and after each berth is dredged, the bottom is mapped by sonar in order to determine the volume of material removed. The frequency of dredging slips varies from 10 to 15 months depending upon the siltation rate.

Three siltation basins in the bottom of the harbor are in use in the Port of Glasgow. The dimensions are 300 ft wide, 3300 ft long, and 8 ft deep below the channel bottom. These basins trap the silt and allow compaction before dredging. There is no doubt in the Conservancy Engineer's mind (Sinclair, 1978) that this approach prevents siltation in berths.

LABORATORIES CONCERNED WITH SEDIMENTATION and/or DREDGING

Six major laboratories were visited in Europe, one each in England, France, and Germany and three in the Netherlands. A second hydraulic laboratory in Germany had been scheduled, but time did not permit the visit: However, its facilities are described below.

ENGLAND

The Universities of Strathclyde and Manchester have noteworthy hydraulic and coastal engineering laboratories, but their orientation is academic. Understandably these laboratories do not compare in size or activity with the laboratories described below.

Hydraulics Research Station, Wallingford— The Hydraulics Research Station with a staff of 260 and an annual budget of about $4 million, investigates problems in the field of civil engineering and hydraulics for organizations in the UK and overseas and does research in support of this work. A charge is normally made for carrying out investigations, but advice is given free when a substantial amount of staff time is not involved. Those for whom investigations are carried out include engineering consultants and contractors, industrial concerns, multinational companies, port trusts, water authorities, and British and foreign government agencies.

Numerical and physical models are often used for examining the effects of proposed schemes. The method of approach depends on the type of examination required. Sometimes both numerical and physical models are used in a single investigation, and these may be preceded by a site visit or a field survey.

FRANCE

The Laboratoire Central d'Hydraulique de France (LCHF) — Geohydraulique, Maisons-Alfort - This is a private group of consultants acting on behalf of public or private organizations who deal with hydraulic engineering or water management. The Laboratoire Central d'Hydraulique de France was founded in 1939, and Geohydraulique was founded in 1967, at which time they were combined.

The group provides research and technical skill in the fields of: harbor engineering, maritime structures, offshore structures, coastal protection and planning, river and estuary planning, field observation and measurement programs, water pollution, water survey and management, agricultural and rural hydraulics, urban hydraulics, and underground hydraulics. Its services cover all stages from planning and preliminary studies to the supervision of site work and the training of qualified personnel. The staff consists of more than 100 persons, half of whom are engineers. The various fields involved are: mathematics, hydraulics, hydrography, oceanography, hydrology, geology, hydrogeology, and sedimentology.

Scale-model testing laboratories cover about 15,000 m^2 and include wave tanks, fixed or variable-slope glass-sided waves flumes, and a large flume for offshore structures towing or hull studies. Facilities also include the following: electronics laboratory, water and rock analysis laboratory, sedimentology laboratory, and a laboratory for the study of noise propagation.

LCHF-GEOHYDRAULIQUE has its own computer center that includes: a PDP 11 computer (128K) for real time treatment of physical data recorded on laboratory scale-models, and an INTERDATA 8/32 computer (256K) for scientific calculations, together with the appropriate peripheral equipment: printer, display terminal, plotter, etc. Also, LCHF-GEOHYDRAULIQUE ahs access to exterior centers equipped with IBM 360/125 of CDC 6600 and 7600 computers.

GERMANY

Federal Institute of Waterways Engineering, Hamburg— This Institute was founded in 1948 as a centralized institute of waterways engineering with the purpose of conducting scientific and practical hydraulic research. Some of the studies include: river training and canalization (weirs, locks, power stations), interactions between ships and waterways, bank defense, morphology of rivers and estuaries (sedimentation and erosion), transport mechanisms of suspended sediment, effect of inlets and outlets on navigation, mathematical modeling, harbors, maritime structures, ground water flows, soil mechanics and foundations, field measurements at maritime and inland structures and of hydro- and soil-mechanical units, and geological studies. Governmental funds (Ministry of Transport) and consulting activities by contract (public and private orders) amounted to about $10.5 million in 1977. The staff numbers more than 300.

Franzius-Institut for Hydraulic Research and Coastal Engineering, Hanover— This Institute is part of the University of Hanover. The Director simultaneously holds the Chair of Inland Waterways and Coastal Engineering. In addition to the teaching, the tasks of the Institute cover basic scientific research as well as applied research. In addition, the Institute advises state institutions (Federal, State, and Municipal authorities) and private firms (e.g., industry and engineering companies), and supports them in the planning and construciton of hydraulic projects and coastal works in Germany and abroad.

The Institute's methods are basically concentrated on investigations of hydraulic models, mathematical and theoretical studies, and field investigations. The Institute, with roughly 60 staff members employed by the State of Lower Saxony, is a nonprofit-making organization under the supervision and control of the Ministry of Arts and Science of the State of Lower Saxony.

Reports on the most important projects completed by the Franzius-Institut are to be found in the information periodicals published by the Institute approximately twice a year (since 1952).

The NETHERLANDS

The Delft Hydraulics Laboratory, Delft—The DHL has the following facilities: windwave flumes, current and wave basins, testing setups for pumps and for sand-watermixture (dredge pumps), calibration rigs for flow meters (free surface and closed conduit) and control valves, density current provisions with warm water and climate control (cooling water problems) and saline water supply for salt intrusion and waste water problems, morphology basins, sediment transportation flumes, sediment mixing plant, remote-controlled ship maneuvering, hydrographic instrumentation, and computer programs.

The scope of the activities include: theoretical studies; mathematical model investigations; hydraulic model investigations in the fields of hydraulics, hydrodynamics, and hydrology; providing data for the design of hydraulic structures, river, coastal, and ocean engineering works; carrying out surveys *in situ*; processing and interpreting observations. Fundamental research, is also carried on in cooperation with educational and other scientific research institutes, and as support to consulting work.

Funding to support this facility (amounting to about $33 million annually [1978]) comes from the proceeds of consulting activities and revenues from special services.

De Voorst Hydraulic Laboratory, Kampen— The "De Voorst" laboratory began operation in 1951. The available area of this site, located between the Vollenhover Kanaal, Zwolse Vaart, and Voorsterweg, amounts to about 300 acres. About 225 staff are employed in the area.

The open-air models (about 35 sites available) can be supplied with water originating from the Vollenhover Kanaal. An intake sluice supplies a balance basin from where the water is distributed over the laboratory by a network of open channels all connected to the models. The water flows through the models, controlled by weirs, racks and gates, and through the lower discharge channels to the Zwolse Vaart. The total fall between the Vollenhover Kanaal and the Zwolse Vaart is about 4 m, being equal to the static head of the pumping station "Smeenge" that pumps the surplus polder water (and the water discharged by the Laboratory as well) back to the Vollenhover Kanaal. From this point of view the water used circulates continuously.

There are three main types of models according to the phenomenon studied: flow, wave motion and navigation. Often these types are used in combination.

Model studies on flow problems (e.g., rivers, coast, estuaries, closure gaps, and sluices) have their supply of water controlled by Romijn-sluices, and water levels controlled by adjustable flap gates. Wave models (e.g., harbors and coasts) are equipped with wave generators of the flap-type.

In the navigation models, ship models are applied to study the nautical problems encountered in hydraulic engineering projects (e.g., harbor entrances, canals, river crossings). These ships can be steered in different ways. Depending on model scales and other considerations, they can be steered electronically (by cables interconnecting ship and shore), by a real helmsman aboard the shipmodel, or by remote control radio.

Some large models are covered by a shed. The largest building has an area of 6 acres and accommodates the tidal model of the Oosterscheldte region (main part of Delta plan).

For detailed studies on the effect of wind or wind waves, a wind-wave flume (width 4 m, height 2 m, effective length 100 m) is available in which a giant blower can generate high velocity winds.

For studies requiring high velocity flow, a discharge flume (cross section 3 x 3 m, length 100 m) is available. This flume has a capacity of about 10 m^3/s.

Besides model studies commissioned by governmental authorities, contractors and consultants, the Laboratory carries out fundamental research. In addition to experimental work, much attention is paid to the theoretical approach to hydraulic problems. In this the mathematics section plays an important part.

Delft Soil Mechanics Laboratory, Delft—Liaison in the field of dredging is carried on between the Delft Hydraulics Laboratory and the Delft Soils Laboratory. This is one of the most complete soils laboratories this writer has ever seen. Furthermore, it is geared for mass analysis of sediment and rock samples.

Among the various devices viewed was a dynamic resistance test on various sediments using a cone penetrometer moving at the rate of 1 m/s which is the estimated speed at which the bucket of a bucket dredge moves through bottom sediments. The purpose of the test is to enable *in situ* testing of bottom sediments in order to make a better estimate timewise for a specific dredging job.

Manufacturer, IHC Holland, maintain a complete soil mechanics laboratory for the design of its equipment. For a bottom sample, a complete analysis of the properties are examined (various shear strength tests, density, grain size distribution, etc.). Once determined, these properties are typed into a computer program. One output that appears on a cathode ray tube (CRT) display is the required horsepower. Other information needed for equipment design are additional outputs.

Recommendations

1. Owing to the large costs involved in mobilization and demobilization of equipment, an economy may be effected if a number of slips in US Navy harbors were dredged in the same time period even though some individual slips could go a little longer without dredging. Therefore,

it is recommended that the dredging procedures and frequency for slips of all US Navy harbors be reviewed.

2. Consideration should be given to overdredging US Navy slips to permit greater consolidation of the sediment and therefore permit more efficient dredging operation. This would prolong the time between dredging operations.

3. Investigation should be made into the possibility of specifying equipment other than that presently used, such as bucket dredges, to maintain US Navy slips. Discussion with American dredging companies that are affiliated with Dutch dredging companies may be necessary.

4. A review of all regulations concerning dredging equipment is recommended. Currently, US Code (46-292) imposes the following limitation:

"Dredging by foreign-built dredges"

> "A foreign-built dredge shall not, under penalty of forfeiture, engage in dredging in the United States unless documented as a vessel of the United States." May 28, 1906, c. 2566, §1, 34 Stat. 204.
>
> "Historical Note
>
> "Codification. Section 2 of Act May 28, 1906 provided for documenting as vessels of the United States certain named foreign-built dredges. It was omitted from the Code as special only."

According to the foreign dredging firms interviewed, it is not possible to obtain documentation as a US Vessel for dredging equipment. Besides the above regulation European dredging firms also refer to restrictions imposed by the Jones Act (1921). The writer has not researched this latter regulation.

The state-of-the-art of dredging in the United States may be improved by the utilization of equipment available on the foreign market but not available on the American market. For example, bucket dredges which are useful in dredging slips would be too expensive to build in the US because of the tooling-up procedure and the relatively limited market. However, there are second-hand bucket dredges in Europe available for purchase by American dredging firms if it were permitted.

5. Membership on the committee composed of members of the Corps of Engineers and selected foreign engineers that has been formed for the purpose of improving dredging in the United States could be advantageous to the US Navy. It is recommended that such membership be requested.

6. It recommended that the Japanese dredging industry be reviewed in the same manner that the European dredging industry was. Most of the engineers interviewed agreed that the Japanese have a firm posture in the dredging field.

7. The lack of time precluded visits to a number of agencies concerned with dredging, dredging problems, and/or harbor sedimentation problems. Some of these had been scheduled initially; some have been recommended by contacts made while in Europe. It is recommended that these be followed up. The agencies are:

a. The Ports of Bordeaux, Marseille, Nantes, Dunkerque, Rouen, and Le Havre, France

b. SOGREAH at Grenoble, France

c. The Biological Station at Roscoff, France

d. Centre National pour l'Exploitation des Oceans, Brest, France.

e. Franzius Laboratory, Hanover, Germany (described in text, but not visited)

f. Port Authority of Antwerp, Belgium

g. University of North Wales, Marine Science Laboratories, Anglesey, North Wales.

h. The River Mersey Dock Board, Liverpool, England

i. The British Transport Dock Board Hydraulic Laboratory, London, England

j. The National Hydraulics Laboratory of Belgium

k. The Institute of Soil Fertility, Groningen, Netherlands

l. The Institute of Oceanographic Sciences, Taunton, England

REFERENCES

Chapon, J. P., 1978, Personal Communication

Sinclair, A., 1978, Personal Communication

APPENDIX A

PERSONNEL CONTACTED IN COURSE OF INVESTIGATION

BELGIUM

Mr. Jean-Jacques DeCloedt,
Managing Director,
DeCloedt and Sons S.A.
Franklin Roosevelt Ave., 11
1050 Brussels

Mr. Hugo Devleiger,
Civil Engineer,
DeCloedt and Sons S.A.
Franklin Roosevelt Ave., 11
1050 Brussels

Mr. Jean G. DeWilde,
Manager of Overseas Dept.,
DeCloedt and Sons S.A.
Franklin Roosevelt Ave., 11
1050 Brussels

Mr. Phillip Jacobs,
Civil Engineer,
Engineer in Charge of the "Vlanderen XIX"
DeCloedt and Sons S.A.
Franklin Roosevelt Ave., 11
1050 Brussels

Mr. M. Spaenhoven, Director
Chemin de Fers et Entreprises
Square Fr. Orban 10
1040 Brussels

Mr. Jan Theuns, Inspector-generaal
van Bruggen en Wegen
Ministerie van Openbare Werken
Bestuur der Waterwegen
Wetstraat 155
1040 Brussels

ENGLAND

Mr. Fraser Clift,
Deputy Chief Engineer,
Port of London Authority
London Dock House Annexe
1 Thomas More St.
London E1 9AZ

Mr. K.A. Heathcote, Joint Secretary,
National Ports Council
Commonwealth House
1-19 New Oxford St.
London WC1A 1DZ

Mr. D. Jones,
Chief Engineer,
British Transport Docks Board
Melbury House
Melbury Terrace
London NW1 6JY

Dr. Don McDowell,
Simon Engineering Laboratories
Univ. of Manchester
Oxford Road
Manchester M13 9PL

Dr. B.A. O'Connor,
Senior Lecturer,
Dept. of Civil Engineering
University of Manchester
Oxford Road
Manchester M13 9PL

Mr. J.R. O'Donnell,
Chief Engineer,
Port of London Authority
London Dock House Annexe
1 Thomas More St.
London E1 9AZ

Mr. W.A. Price,
Head of Coastal Division,
Hydraulic Research Station
Wallingford, Oxon

Mr. Michael Thorn,
Principal Scientific Officer,
Hydraulic Research Station
Wallingford, Oxon

Mr. J.T. Williams,
Director of Engineering,
National Ports Council
Commonwealth House
1-19 New Oxford St.
London WC1A 1DZ

FRANCE

M. Jean P. Chapon
Inspector General of Public Works
(formly Director of Harbors and
Navigable Waterways)
246 Boulevarde Saint Germain
Paris

M. George Moguilny,
Chief Engineer
Laboratorire Central d'Hydraulic de France
10 Rue - Renault
94700 Maisons - Alfort

GERMANY

Dr. Ing. Heinz Giszas
Freie und Hansestadt
Behorde für Wirtschaft
Verkehr und Landwirtschaft
Amt für Strom- und Hafenbau
Dalmannstrasse 1-3
2000 Hamburg 11

Mr. Hans H. Nagel,
Chief Engineer,
Wasser- und Schiffahrtsdirektion Nord
Ausenstelle Hamburg
Postfach 240
2000 Hamburg 4

Prof. Dr. Ing. Dr. Phys. H.W. Paternascky
Director
Franzius Institüt
University of Hannover
Neinburger Strasse 4
D-3000 Hannover 1

Mr. G. Schroeder,
Civil Engineer,
Wasser- und Schiffahrtsdirektion Nord
Kiel

Mr. J. Sindern,
Kuratorium für Forschung und Kusteninggenierrurwesen
Wasser- und Schiffartsdirektion Nord
Hindenburger 247
2300 Kiel 1

Mr. D. Spengler,
Freie und Hansestadt
Behorde für Wirtschaft
Verkehr und Landwirtschaft,
Amt für Strom- und Hafenbau
Dalmannstrasse 1-3
2000 Hamburg 11

Mr. H.H. Waibel,
Chief Engineer,
Wasser- und Schiffartsdirektion Nord
Kiel

The NETHERLANDS

Mr. J. Al, Geochemist,
Delta Department-Rijkswaterstaat
Environmental Division
Grenadierweg 3 (P.O. Box 439)
4330 AK Middelburg

Ir. J. Asselbergs
Manager of Development Department
IHC DE KLOP
P.O. Box 3
4 Industrieweg-Sliedrecht

Ing. H. Bijl
Deltadienst-Rijkswaterstaat
Informatie en documentatie
Van Veelan 1
Postbus 5005
4300 KA, Zierikzee

Prof. Dr. Ir. E.W. Bijker,
Professor of Coastal Engineering,
Delft University of Technology
Stevinweg 1, Delft

Mr. Kees d'Agremond
Head of Development Dept.
Adriaan Volker Huis
71 Oostmaaslaan
Rotterdam

Mr. Jaap de Nekker
Head, Harbor Department,
Municipality of Rotterdam
Vee Markt 2
Rotterdam

Mr. Jan Hagmeyer,
Dredging Engineer,
Adriaan Volker Huis
71 Oostmaaslaan
Rotterdam

Ir. W.J. Heijnen, Director,
Laboratorium voor grondmechanica
Delft Soil Mechanics Laboratory
Stieltjesweg 2
P.O. Box 69
2600 AB Delft

Mr. H.J. Jansen
Publicity Manager
IHC HOLLAND
P.O. Box 6141-2 Marconistraat
Rotterdam

Dr. J.G.Th. Linssen, Executive Secretary
International Assn. of Dredging Companies
Duinweg 21
2585 JV The Hague

Ir. P.C. Lunstroo
Manager Shipbuilding Dept.
IHC SMIT
P.O. Box 1
Kinderdijk

Mr. R. Misderp,
Land Planner--Rijkswaterstaat
Delta Dept.
Environmental Division
Grenadier 31 (P.O. Box 439)
4330 AK Middelburg

Mr. A. Paape,
Head, Delft Laboratory,
Rotterdamsweg 185
P.O. Box 177
2600 mh Delft

Mr. D.C.W. Slieker,
Public Relations Officer,
dosbounw
Burg-Haastede
Postbus 5003

Captain Peter Snieders
Adriaan Volker Huis
71 Oostmaaslaan
Rotterdam

Mr. P. Tanis, Civil Engineer,
Adriaan Volker Huis
71 Oostmaaslaan
Rotterdam

Mr. J.D. Van Den Bunt
Deputy Head, Delft Laboratory
Rotterdamsweg 185
P.O. Box 177
2600 mh Delft

Mr. A. van Gent,
Deputy Managing Director,
Adriaan Volker Huis
71 Oostmaaslaan
Rotterdam

Mr. W. Viemmix, Civil Engineer
Rijkswaterstaat
Directie Noordzee
Nijverheidsstraat 2
Rijswijk

Mr. J.J. Vinje,
Head, de Voorst Laboratory
Repelweg 10, Marknesse, noordoostpolder
P.O. Box 152
8300 ad Emmeloord

Mr. Jan Visser,
Land Planner--Rijkswaterstaat
Delta Dept.
Environmental Division
Grenadierweg 31 (P.O. Box 439)
4330 AK Middelburg

Mr. J. Wiersma
Rijkswaterstaat
Directie Noordzee
Nijverheidsstraat 2
Rijswijk

SCOTLAND

Dr. John Riddell,
Professor of Coastal Engineering,
Dept. of Civil Engineering
Univ. of Strathclyde
Glasgow

Mr. Andrew Sinclair,
Conservancy Engineer,
River Clyde Port Authority
16 Robertson St.
Glasgow

APPENDIX B

PROGRAM OF THE 8TH WORLD DREDGING CONFERENCE AMSTERDAM, NETHERLANDS

Tuesday 14th November 1978

08:30 Registration of delegates

10:00 Opening Europort '78 by Dr. J.M.A.H. Luns, Secretary General NATO.

10:30 Introductory address

10:45 Coffee break

11:15 The influence of industrial requirements on project specifications. Ir. J.M. Langeveld, Managing Director, Shell International Petroleum Company.

12:00 Project specifications in the light of reality. Ir. H.A. Ferguson, Retired Managing Director Delta Works, National Public Works Department.

12:45 Lunch break

14:00 The contractors response to the complexity of present projects. Mr. E.H. James, President of the International Association of Dredging Companies. Co-author, Ir. J.F.R. Andraea, Vice president administration Ocean Minerals Inc.

14:45 The dredging contract and the cooperation of the parties involved. Mr. J.G. Drabbe, Chairman of the Board of Directors Associated Marine Consultants Amsterdam.

15:30 Coffee break

16:00 Discussions

Wednesday 15th November 1978

09:00 Science and design of navigation channels and offshore trenches. Prof. Dr. Ir. E.W. Bijker, Delft University of Technology.

09:45 The influence of recent advances in data gathering and processing on project design. Mr. P. Couprie, Director of Research and Development, Soletanche S.A. Co-author, Ir. C. Stigter, Managing Director Hydronamic, Port and Waterway Engineers, Project Development.

10:30 Coffee break

11:00 Developments in the design of dredging equipment. Speaker to be invited.

11:45 Customer's requirements, dredging operations and equipment development. Prof. Ir. J. de Koning, Delft University of Technology.

12:30 Lunch break

14:00 Discussions

15:30 Conclusions: Mr. W.R. Murden, Prof. Eng. Mech. Eng. Chief Plant and Supply US Army Office. Chief of Engineers.

16:00 Ceda Inaugural Meeting

Commander
Naval Facilities Engineering Command
Department of the Navy
200 Stovall Street
Alexandria, VA 22332
Codes 032D, PC-4, 0453

Commanding Officer
Western Division
Naval Facilities Engineering Command
P.O. Box 727
San Bruno, CA 94066
Codes 09PA, 09BE

Commander Atlantic Division
Naval Facilities Engineering Command
Norfolk, VA 23511
Code 90P2

Commanding Officer
Southern Division
Naval Facilities Engineering Command
P.O. Box 10068
Charleston, SC 29411
Code 90

Commanding Officer
Northern Division
Naval Facilities Engineering Command
Philadelphia, PA 19112
Code 1038

Commander
Pacific Division
Naval Facilities Engineering Command
Pearl Harbor, HI 96860
Code 402

Commanding Officer
Chesapeake Division
Naval Facilities Engineering Command
Washington Navy Yard
Washington DC 20374
Code 03L

Commander
Naval Ocean Systems Center
San Diego, CA 92152
Code 406

Scripps Institution of Oceanography
University of California, San Diego
La Jolla, CA 92037
Code A-009

Commander
Mare Island Naval Shipyard
Vallejo, CA 94592
Code 460

Chief of Naval Research 800 North Quincy St. Arlington, VA 22217	Code 462
Commander and Director Waterways Experiment Station P.O. Box 631 Vicksberg, MS 39180	H. G. Simmons Chief, Hydraulics Laboratory
Commanding Officer Charleston Naval Shipyard Naval Base Charleston, SC 29408	
Commanding Officer Naval Air Station Pensacola, FL 32508	
Commanding Officer Naval Station Norfolk, VA 23511	
Commanding Officer Naval Ordnance Test Unit Patrick Air Force Base, FL 32925	
Chief of Naval Material Navy Department Washington, DC 20360	Code 044P Code 08T241
Oceanographer of the Navy Hoffman II 200 Stovall St. Alexandria, VA 22332	Codes N4 and N5
District Engineer U.S. Army Engineer District 211 Main Street San Francisco, CA 94105	Mr. John Sustar
Virginia Institute of Marine Sciences Gloucester Point, VA 23062	Dr. Maynard M. Nichols
Environmental Quality Laboratory California Institute of Technology Pasadena, CA 91125	Dr. Brent Taylor Code EQL, 314-40
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KANSAS CITY, MO. 64106

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NORFOLK, VA. 23510

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