BUILD UP OF SABLE ISLAND

by

Marie C. Rockwell

ABSTRACT

Sable Island is the only visible part of the Sable Island Bank. Until 1971 this island was of little significance except perhaps for its unique environment. In that year significant quantities of oil and natural gas were discovered. Since 1971 several other significant hydrocarbon deposits have been located; the largest to date of which is the Venture structure located just offshore Sable Island and in water depths of less than 20 meters.

The Venture Structure is the first scheduled for production and engineering is currently underway addressed to providing necessary facilities to recover the gas and move it to the mainland. Two proposals have been put forward for Venture gas production. The first by Mobil Oil utilizes an offshore production platform method with emergency back-up facilities on Sable Island. More recently a proposal has been put forward by Beaver Dredging Company to construct an artificial island on the Venture site. This island would contain all the necessary support facilities for gas production.

A third proposal which I am advocating for study is the selective build-up of Sable Island, resulting in a larger land mass. Enlarging of Sable Island will have two major benefits. It will permit the recovery of gas utilizing on shore technology at lower costs and less hazard to the environment and, secondly, it will stabilize the Island and reduce the effects of erosion. Sable Island has been eroding during the centuries, as is shown since discovery and use by man, and may disappear if this trend is not reversed.

INTRODUCTION

The shelf off Nova Scotia is characterized by the existence of several banks; the largest and most easterly of which is the Sable Island Bank approximately 250 km long, 100 km wide and with water depths of up to 100 meters. Since the discovery of America, these banks have proved to be rich in fish and have provided a stable income to fishermen during several centuries.

1Associate Professor, Department of Mining and Metallurgical Engineering, Technical University of Nova Scotia, Halifax, N.S., Canada.
Sable Island is the eroding remnant of a one-time land mass of now Sable Island Bank. The island is located 190 km off shore, is nearly 43 km long and 1.4 km wide. It is surrounded by shoals which are particularly hazardous to navigation. These shoals and bars extend nearly 5 km southwest of the island and 13 km northeast of it as shown in Figure 1. (Mobil Oil Canada Ltd., 1983).

Until 1971 Sable Island was relatively unknown and ignored except for its reputation as a hazard to navigation. More than 200 shipwrecks are listed in known and recorded history. However, in 1971, a combination of the impending "Oil Crisis" and the announced discovery of hydrocarbons by Mobil Oil sparked a new interest in the island and its banks.

Extensive drilling has been carried out, on and near Sable Island, since 1967 with several wells showing significant quantities of hydrocarbons, mainly natural gas.

RECENT HISTORY OF SABLE ISLAND

The ultimate fate of Sable Island is still under some debate. However, records during the past 500 years indicate that the island is not only diminishing in size, but is also moving northeastward. Early records, going back to 1505, indicate that Sable
Island was once much larger than at present. At that time the island was also heavily vegetated. Various domesticated animals were introduced to Sable Island in the 16th century and thereafter.

In 1775 charts compiled from French records indicated that Sable Island was approximately 64 km long, 3.6 km wide with sand hills over 60 meters high. By 1799 the island had not only been reduced to a length of 50 km and a width of 3.3 km, but it had also migrated eastward by 21 km.

By 1815 Sable Island was only 46.4 km in length. At present the island is 42.5 km long, 1.4 km wide and has sand hills of less than 20 metres. During a period of 200 years the island has been reduced in length by 33% and has an area of less than 59 sq. km. One also observes that Sable Island is only 22 km south west of a deep seabed canyon. This canyon, known as "The Gully", has water depths of over 200 metres. As Sable Island moves eastward, sand is irreversibly lost to this deep canyon. Should this erosion continue Sable Island may cease to exist as anything other than a shoal and hazard to shipping. It is also readily apparent that Sable Island is very fragile.

PHYSICAL DESCRIPTION OF SABLE ISLAND

Sable Island is structured from sand dunes, of which less than 39% are vegetated as shown in Figure 2. (Martec, Ltd., 1980). The sand grains are fine with 84% of the particles between .25 mm and .5 mm. The soil is of poor quality lacking in both organic matter and nutrients.

There are still over 150 species of plants on Sable Island. In past centuries crops were raised successfully; however, the attempt to grow trees on the island in 1901 failed. At that time some 80,000 trees were planted on the island, most of which disappeared by 1913.

Mammals on Sable Island were quite extensive at one time and included horses, cattle, pigs, sheep, rats, mice, cats, dogs, foxes and rabbits. All have disappeared excepting the unique Sable Island ponies that have adapted to the environment. The introduction of animals probably speeded the erosion of the island. Over-grazing of land and the reduction in vegetation cover left exposed sand vulnerable to the forces of erosion, thus leading to a degenerating situation which has not been halted.

Other life on Sable Island includes several hundred species of birds which are routinely sighted, or nest, on the island,
herds of seals, various types of fish, insects, etc. All of these will be lost should the island continue to eroded.

Figure 2: Stabilized Terrain on Sable Island (Martec Ltd., 1980)

GEOLOGY OF SABLE ISLAND

The geology of the Scotian Shelf has been well studied, particularly since 1967. The Sable Island Bank near Sable Island has been the focus of much of this attention, especially since the advent of the extensive drilling program for hydrocarbons.

The Scotian Shelf consists of unconsolidated quarternary sediments overlying older bedrock strata as summarized by King & MacLean (1974, 1976). 50 km off the coast of Nova Scotia the rocks which form the acoustical basement are overlain by sediments. These mesozoic and cenozoic sediments thicken seaward and reach a thickness of 8 km in the Venture Gas Field near Sable Island. The strata then dips seaward.

Figure 3 (Jansa and Wade, 1975) shows a cross section of the Scotian Shelf stratigraphy.
Figure 3: Diagramatic Cross Section of Scotian Shelf Stratigraphy. (Jansa and Wade, 1975)

Figure 4: Thickness of Offshore Surficial Sediments
(Jacques/McClelland Geosciences Inc., 1982)
The thickness of the surficial sediments is shown in Figure 4 (Jacques/McClelland Geosciences Inc. 1982). The sediments near Sable Island have been worked and reworked over the years by ocean currents.

CURRENTS AND SEDIMENT TRANSPORT

Sable Island is located in an area under the influence of two major and several minor ocean currents as shown in Figure 5. (McLellan, 1957; Sutcliffe et al., 1976; Smith, 1978; Houghton et al., 1978).

![Figure 5: Scotian Shelf Currents](image)

The major current flows are the north-east flowing warm Gulf Stream and the southeast flowing cold Labrador current. In addition there are several minor currents, particularly the Cape Breton current. These currents influence the Sable Island Banks and generally affect both water and air temperatures and cause extensive fog over the region. The interaction of these currents place Sable Island in an area where current velocity and direction vary considerably.

Within the immediate vicinity of Sable Island, the local currents are determined by waves, tides, wind and major ocean currents.

The direction of waves on Sable Island is from the open ocean approaching the island from the south west. Little investigation has been carried out to determine the volume of sediment transported by this mechanism acting alone.

Tides generate significant current flow on the banks of Sable Island. The ebb tide flows south toward the island at magnitudes of approximately 75 to 100 cm/sec. This tidal current changes direction as it approaches the island flowing eastward along the northside of Sable Island. The flood tide flows northward at approximately 50 to 75 cm/sec and as it nears Sable Island flows toward the northwest over the west bars.

Winds also induce current flow near Sable Island. Although it is difficult to separate wind driven currents from other sources, the direction of the winter wind is toward the southeast while the summer wind is toward the northeast. The net effect of these winds is eastward; however, the influence of other current sources make this difficult to identify.

Although there has not been extensive studies of the sources, magnitudes and direction of the currents near Sable Island, the limited information available (Evans-Hamilton, 1977-1978 & others) supported by past observations of drift bottles and other objects, indicate that there is a net clockwise current around the island of approximately 5 to 8 cm/sec. These result in a net sediment transport toward the east as shown in Figure 6. The magnitude and direction of this sediment transport requires confirmation by much needed additional measured data.

Sable Island is structured from sand dunes. There are several small freshwater and brackish ponds and various types of vegetation on the island; however, the majority of the island is exposed sand. These open sand dunes form a ridge of sand on each side of the island contribute to the erosion of the island from the wind forces. These winds, particularly during storms, result in significant sand transport as shown in Figure 7, (Owens, 1973). During the winter months the wind tends to blow toward Sable Island from the north-west transporting sand toward the southeast part of the island. In contrast, during the summer months, the wind tends to come from southwest transporting sand toward the northeast. The net effect of these wind forces over the long term is to transport sand toward the eastern end of the island; the same direction as current induced sediment transport. The combined effect of all forces, as records for the past several centuries confirm, is to move Sable Island eastward.
Figure 6: Current Induced Sediment Transport. (James and Stanley, 1968; Evans-Hamilton, Inc. 1975; Martec Ltd., 1980).

Figure 7: Subaerial Sand Transport on Sable Island (Owens, 1973)
HYDROCARBONS EXPLORATION ON THE SABLE ISLAND BANK

The hydrocarbon drilling program commenced in the Sable Island area in 1962 with the first well drilled by Mobil Oil in 1967. A gas show came in 1967 and an oil show in 1970. In 1971 significant oil and gas appeared from a well drilled on the western end of Sable Island. By August of 1983 a total of 88 wells had been drilled on or near the island, of which 12 showed significant gas and 6 significant oil. Most are on or near Sable Island and in water depths of less than 20 meters. Figure 8 (Nova Scotia Department of Mines and Energy) shows the location of these wells.

Figure 8: Hydrocarbon Structures on Sable Island Banks
(Nova Scotia Dept. of Mines and Energy)

There are twelve major structures in this area:

- The Venture structure located just off the east bar of Sable Island has had four wells drilled on it, the deepest being 5960 meters. This structure is estimated to have 72 billion cubic meters of natural gas and is scheduled for production in 1988.

- The South Venture Structure is 5 km southwest of the Venture field. One well drilled to 6176 meters tested 2,645,000 cubic meters/day of gas.
- The Olympic Structure is located 13 km west of the Venture Field. One well at a depth of 6064 meters tested at 1,598,000 cubic meters/day of gas.

- Citnalta is located 16 km northeast of the eastern tip of Sable Island. One well drilled to 4575 meters tested a flow rate of 555,000 cubic meters/day of gas.

- Intrepid located 12 km south of Sable Island has one well at 4162 meters which showed a flow rate of 513,000 cubic meters/day of gas.

- Cohasset is located 48 km west of the western tip of Sable Island. Of two wells drilled, one was dry and the second tested at 2719 cubic meters/day of gas and 249 cubic meters/day of oil at a depth of 4427 meters.

- Thebaud Structure is 7 km southwest of the western tip of the island. Two wells drilled to 4115 meters and 3962 meters tested at 849,800 cubic meters/day of oil and 387,984 cubic meters/day of gas.

- Eagle is located 20 km southeast of the eastern tip of Sable Island. One well at 4660 meters tested at 4248 cubic meters/day of gas.

- Primrose is 80 km east of the eastern tip of Sable Island. Three wells were drilled, two were dry and one tested at 1,430,000 cubic meters/day of gas at 1714 meters.

- West Sable E 48 is located on the western tip of Sable Island. The well was drilled to 3603 meters and tested at 1,812,000 cubic meters/day of gas and 649 cubic meters/day of oil. Seven delineation wells have been drilled on this structure.

- West Sable 0-47 well was drilled to 4199 meters. It tested at 172,752 cubic meters/day of gas and insignificant oil.

- Petro Canada Banquereau C21 is 96 km east northeast of Sable Island. Of two wells, one was dry and one drilled to 4991 meters tested 642,864 cubic meters/day of gas.

The Venture field, off the east spit of Sable Island, is expected to be developed with a production rate of 11 million cubic meters/day.

The exploration and development of oil and gas near Sable Island may have a severe impact on the environment of the island. Much of the data presented has indicated a fragile environment which may be
seriously affected by both the exploration and production of hydrocarbons. Some of the common concerns are:

- destruction of dunes by traffic and roads.

- erosion of the land base from wind and water.

- spoiling of fish spawning and feeding grounds by drill cuttings, drilling fluids and muds, debris and garbage.

- damage to fishing equipment by drill and supply ships and debris.

- disruption of fishermen's traffic and routes with limited access to traditional fishing areas.

- mechanical damage to sea bottoms by anchoring and drilling.

- destruction of habitats of fish, birds, and mammals by oil leakage, spills, sewage, deck drainage, wash waters, producing formation water and well treatment materials.

- pollution from spills and blow-outs, leading to loss of flora and fauna, and irreparable damage to the island.

- concern for appropriate cleanup facilities in case of spills.

- social disruptions on the mainland because of influx of oilfield workers and support people.

- competition with fisheries for crews.

- competitions with fishery for wharf space and services.

- lack of compensation fund for damage to fish nets and for fishing time lost during accidents or spills.

- localized inflation caused by the petroleum industry demands on goods, services, amenities and people.

GOVERNMENT LEGISLATION

To help reduce the possible negative aspects of hydrocarbon exploration and development, legislation has been enacted at both the federal and provincial levels of government to protect the
environment and residents of the area. The significant federal legislation includes:

- **Fisheries Act, 1970.** This defines Canadian fisheries waters, deleterious substances, and provides for penalties for violations.

- **Canada Shipping Act.** Defines pollutants in all-embracing terms, prohibits the discharge of pollutants from ships and provides for ship inspections.

- **Canada Water Act.** Provides for the Federal Government to enter into agreements with Provincial Governments to establish bodies to undertake comprehensive water resource management programs.

- **Migratory Birds Convention Act, 1970.** Prohibits the killing or injuring of migratory birds and the destruction of their eggs or nest.

- **Navigable Water Protection Act, 1970.** Provides that no work shall be placed in, upon, over, under, through or across any navigable water unless the plans have Ministerial approval. It prohibits the depositing of any stone, earth, or substance that is liable to sink to the bottom of any navigable water less than 20 fathoms deep.

- **Ocean Dumping Control Act. 1974-75.** Prohibits the dumping of any substance at sea, from aircraft, ships, platforms, or other man made structures. The Act exempts disposal of material incidental to normal operations, explorations, exploitations and processing of seabed mineral resources. Permits may be issued for discharges considered harmless to human and animal health.

- **Canada Oil and Gas Act (Bill C-48, March 1982).** This act establishes a resource management regime for the "Canada Lands" which include the East Coast of Canada. Companies must actively explore the land they hold and all activities must be environmentally sound.

- **The Canada - Nova Scotia Agreement 1982.** This agreement establishes an organization that could manage the offshore oil and gas resources. The agreement is for 42 years and guarantees petroleum revenues to the Province of Nova Scotia.
Provincial legislation covering offshore development includes:

- Nova Scotia Environmental Protection Act. Defines various terms and provides for a permit for any plant or facility that affects the environment.

- Nova Scotia Water Act. Regulates exploration, development and production of petroleum and provides for exploration agreements, drilling permits, production leases, etc.

- Nova Scotia Energy and Mineral Resources Conservation Act. Establishes a board to regulate the conservation of and to prevent the waste of energy and mineral resources.

- Nova Scotia Pipeline Act. Regulates the transmission of oil and gas from the wellhead to the consumer. It also selects routes for pipelines with due regard for the environment and the safety and convenience of the public.


- Nova Scotia Beaches Protection Act. Prohibits the removal of any sand, gravel, stone or any other material without a permit from the Minister of Lands and Forests.

- Petroleum and Natural Gas Act. Provides for notification to the Minister of intention to drill and provides for granting of a licence or lease and for payment of fees, rentals, royalties, etc. It also makes the licensee or lessee responsible for ensuring the proper disposal of wastes.

These Federal and Provincial Acts are intended to encourage the timely and effective development of resources with the greatest benefit to the public while reducing the environmental risks to a minimum.

PROPOSED HYDROCARBONS PRODUCTION

The hydrocarbon exploration phase at Venture near Sable Island is almost complete in that sufficient gas has been discovered to warrant planning of production facilities. These production facilities are undergoing the required engineering and other studies directed to
delivery of gas via pipeline to the mainland for distribution to customers in Nova Scotia and elsewhere. Although production will be complicated by the weather, sea, and bottom conditions, the area is free of ice and does enjoy a fairly moderate climate with minimum temperatures seldom falling below freezing.

The production of gas from Sable Island will centre in early years on the Venture Field located from 6 to 16 km east of the island and in places less than 3 km from the east bar. The water depths range from 14 to 28 meters.

Mobil Oil is proposing to develop the Venture gas field utilizing two offshore production facilities. Each will consist of two wellhead platforms, one accommodation platform and one production platform. Gas will be shipped to the mainland by undersea pipeline.

This production method will necessitate the use of Sable Island for some facilities such as an emergency base for personnel employed on the offshore, including housing, storage of supplies, water, and other necessary support facilities. Additional helicopter handling and navigational installations will be required. Although the use of Sable Island will be limited, some environmental damage may occur and steps must be taken to minimize or eliminate these.

A second alternative has recently been proposed by Beaver Dredging Company for the Venture field. This proposes the construction of an artificial island at the Venture site. This island would be approximately 700 meters long and 350 meters wide at the surface. The base of the island would be nearly 1200 meters by 900 meters. This island would contain an airstrip for fixed wing aircraft, storage facilities for such aircraft, a harbor for service vessels, production facilities for gas, and all required support installations for staff. This island would be completely self sufficient and not dependent on the use of Sable Island.

The construction of this island would be mainly from rock and sand fill. The rock would be shipped to the island site from the mainland while sand would be dredged from the nearby bottom. The construction time is estimated at 5 years with a cost approaching $300,000,000.

Although this island approach may have merits, it may also present several problems other than cost. This artificial island would be located in 15 meters of water and within 3 to 4 km of the shallow east bar of Sable Island. With a base of 1.2 km by .9 km, this artificial island could significantly influence the current flow and sediment transport around Sable Island. The result of this change in sediment transport patterns could possibly lead to a change in the island and its associated bars. The end result may be beneficial,
harmful, or effect no change. There must be extensive study prior to the construction of such an island. Should accelerated erosion of Sable Island occur after construction of an artificial island, additional costs may be incurred in stabilizing Sable Island.

The third alternative to gas production on Sable Island is to induce sedimentation on the Sable Island Bank; building up the banks and effectively enlarging Sable Island itself. The stabilizing of Sable Island has been a problem and although some limited success has been realized by land management under the Sable Island Environmental Advisory Committee established in 1975, its activities have been relatively small compared with the magnitude of the problem. Land management to date has had limited success, partially stabilizing some of the sand blowouts which have threatened to erode the island at further locations.

In spite of these land management efforts, the fragility of Sable Island has not been reduced and the island is certainly not environmentally or physically stable.

The concept of building up the Sable Island Banks may be the least expensive and best long term solution to guaranteeing the future of the island. These banks would be built-up through utilizing natural sediment transport mechanisms combined with structures or devices which will cause this sediment to be selectively deposited and stabilized in the desired locations. The first step in this process is to obtain and correlate additional information on the currents flowing around Sable Island along with the volume and direction of sediments transported by the currents.

More aggressive methods of stabilization and vegetation must be exercised on Sable Island. This may include more extensive use of fencing, nets or other stabilizing devices placed on the island. Additional planting and upkeep, including fertilization, must be undertaken. This will reduce the sand drift and erosion caused by winds.

Sediment is probably being transported via currents to Sable Island from all directions; however, the net transport of this material is eastward. Figure 1 shows the extensions of the west and east bars and the 20 - 25 meter water depth boundary representing the area of Sable Island which could potentially be built up.

The actual build up of the Sable Island banks may be accomplished in several ways. These include the construction of groynes along the coast, the construction of headlands near the coast and the selective placing of nets or other sediment trap devices along or near the coast.
The construction of groynes along the coast of Sable Island would be relatively inexpensive. Material would be transported from the mainland; however, the volume would be small in comparison to an artificial island. The effectiveness of groynes would require further investigation; however, work published by Silvester, R. M. and S. K. Ho indicates this may not be the most effective approach and might prove counter productive in this environment.

The second approach, found effective by Silvester and Ho in Singapore, is to construct artificial headlands along the coast of Sable Island. These headlands could be constructed from rock fill, structures or possibly, sand trapping devices constructed from nets or metal webbs. These would be spaced at intervals of several hundred meters along the coast and perhaps 50 to 200 meters offshore. Their size would be in the order of 50 meters long and 10 meters wide. Sand would accumulate between these headlands and the shore effectively moving the shoreline south and east. Extending these headlands along the west and east bars may possibly lengthen the island. Once sand has been built up along the east shore of Sable Island, stabilization techniques would be applied to this sand and new headlands constructed further offshore.

Several cycles of the above techniques could eventually lead to building up the Sable Island bank to cover the Venture gas field. Once this gas field has been covered by built up banks, its development into production would be simplified and relatively inexpensive through utilizing onshore technology.

The potential benefits of a built up Sable Island are many, the major being:

- The larger island would be inherently more stable and easier to protect from further erosion.

- The island would provide a more stable home for its unique plant and animal life.

- Sable Island would become a base for offshore operations providing space for the construction of workers' accomodations, storage, recreation, production and communication facilities, an airstrip for fixed wing aircraft, etc.

- The larger island would provide for easier access to oil and gas fields from onshore sites on Sable Island rather than utilizing offshore facilities. This would make the recovery of hydrocarbons from Sable Island more economical and would provide access to some of the smaller fields through the use of onshore technology.
There may also be a change in the relationship between federal and provincial roles in the Sable Island area by making gas production an onshore rather than an offshore program.

CONCLUSIONS

The production of gas from Sable Island has not yet reached the stage where it will definitely proceed to full possible production in the near future. Substantial gas has been found; however, the difficulties in bringing this gas to market are extensive. The building up of the Sable Island Banks will make the development of production facilities more attractive and will also ensure the continued existence of this island with its uniqueness. Research is continuing into the technology which can lead to the build up of these banks. Much work remains in this field and more data must be gathered.

The cost benefits of this approach are potentially large and financial and technical investment into this project could provide a substantial return. Should the demand for gas in eastern North America decline or the technical difficulties in bringing the gas ashore increase, the build up of the Sable Island Banks may prove to be the only viable solution to the development and production of east coast natural gas.

REFERENCES


BRIEF PERSONAL HISTORY

Marie C. Rockwell

M.Eng. in Metallurgy from the Technical University of Nova Scotia, 1972.
B.Eng. in Mining from the Technical University of Nova Scotia, 1965.

Experience: Presently, Associate Professor in the Department of Mining and Metallurgical Engineering of the Technical University of Nova Scotia, Halifax, N.S., Canada, teaching undergraduate and graduate courses in mining, petroleum and mineral economics. Also, supervising several graduate student research projects.

Prior to joining the teaching staff in 1979, I spent over ten years in industrial research, the last five with the Atlantic Industrial Research Institute as a senior research associate.

Contributed to engineering profession with several papers on R&D and as a TV guest speaker on various occasions on issues of advanced technology in engineering.

The research topics undertaken vary in nature from new creative ideas to applied research in mineral handling and processing, mining and petroleum technology, offshore drilling and production engineering and electronic ceramics.

Professional Affiliations: Member of the Association of Professional Engineers of Nova Scotia; SPE & SME; Canadian Mining and Metallurgical Society; Canadian Petroleum Society; American Ceramic Society; NICE & CEC.

Personal: Married to a biomedical engineer and have two teenage children.
FAHRLC REINFORCED DIKES FLOATED ON SOFT DREDGED MATERIAL FOUNDATION

by

Jack Fowler

QUANDARY: How do you build a dike over a dredged material foundation that must have prompted the quote "too thin to walk on and too thick to swim in"? An innovative technique to do just that, tested at the Craney Island Disposal Area in the Corps' Norfolk District, is described in the following article.

The Craney Island Disposal Area, a 2500-acre confined dredged material disposal site, is one of the largest such sites in the United States (Figure 1). The Corps' Norfolk District constructed the site in the mid-50's for long-term disposal of material dredged from ports and channels in the Hampton Roads area near Norfolk, Virginia. Almost continuous use for disposal from direct pipeline discharge and hopper dredge pumpout has deposited over 147 million cubic yards of material within the containment.

In the early 70's, an attempt was made to construct two interior dikes using woody debris and end-dumped or hydraulically placed sand. The dikes were designed to create subcontainment areas that would improve sedimentation in the containment area being used and allow the other two containment areas to dry out. Construction was halted when very soft dredged material, encountered about midway between the perimeter dikes, prevented the progress of end-dumping.

Public Law 94-587, enacted in 1976, authorizes use of containment-area management practices that will increase the capacity and extend the useful life of dredged material disposal areas. In 1980, the Norfolk District, assisted by the U. S. Army Engineer Waterways Experiment Station, developed a plan to ensure good management of the remaining resources of the Craney Island Disposal Area (see Information Exchange Bulletin 1980 and Palermo, Shields, and Hayes 1981).

The 1980 management plan identified early completion of the two interior dikes as a key element. Dike closure would form three subcontainment areas that would improve the sedimentation process, improve weir performance, and increase the storage capacity of the disposal area. Overall benefit would be to postpone the need to acquire scarce, expensive real estate for another disposal area.

SITE DESCRIPTION

Extremely poor foundation conditions existed along the interior dike alignments for about 5000 ft for closure of the north dike and 3500 ft for the south dike. Soft dredged material, which extended to depths of 30 to 40 ft, had undrained shear strengths that ranged from 25 to 100 psf. The predominant underlying in situ material was very soft marine clay (CH and OH). The land surface enclosed by the completion of the perimeter dike in 1957 was at el -10 ft mean sea level (msl) with the

1Assistant to the Chief, Engineering Studies Branch, U.S. Army Engineers, Waterways Experiment Station, Vicksburg, MS.
very soft marine clay extending to el -90 ft msl.

Approximately 40 percent of the alignment area had a dried 3- to 4-in. crust. The other 60 percent was covered by recent deposits of dredged material, and there was surface water near the weirs.

**DESIGN CONSIDERATIONS**

Site conditions dictated a wide shallow-sloped dike (1 vertical: 10 horizontal) to be raised incrementally as filling of the containment area progressed. Previous experience indicated that the magnitude of dike displacements would be 8 to 10 volumes down for one volume above the surface of the dredged material. To provide the necessary initial containment area capacity, the dikes were to be 11 ft above present surface at the embankment center line.

**CONSTRUCTION ALTERNATIVES**

End-dumping of displacement sections is an accepted method of dike construction where marginal foundation conditions exist. Clean sand dredged material was available near by, but the large quantities required to construct an unreinforced displacement section were not economically feasible. Also, engineering judgment led to the conclusion that it would be difficult if not impossible to control displacement dike sections to achieve the desired width and stable base for future dike raising anticipated at the Craney Island facility.

Analysis of the use of conventional dike construction without any reinforcement indicated that the factor of safety in bearing would be less than 1.0. Unreinforced dikes constructed on the soft foundation in the disposal area could exceed the foundation bearing capacity and result in one of three types of failure:

- Localized foundation failure with propagation of a rotational failure through the dike.
- Lateral splitting and outward spreading and sliding of the dike.
- Bearing failure caused by excessive subsidence caused by excessive consolidation and displacement.

A design concept developed by Dr. Fowler and the late Dr. T. Allan Haliburton of Haliburton Associates, Stillwater, Oklahoma, supported by the Dredged Material Research Program (DMRP) and the Dredging Operations Technical Support (DOTS) Program, was considered: floating a dike on the soft foundation by using a civil engineering fabric (also called geofabric, geotechnical fabric, and filter cloth) for tensile reinforcement (Fowler 1981). The fabric would be placed on the soft foundation transverse to the dike alignment, followed by placement of a sand layer for a working table with a wide-base shallow-sloped dike to be raised as soon as pore water pressure dissipated and the dredged material foundation consolidated.
The design considerations and construction techniques are described by Fowler (1981). Test Sections 1 and 2 were designed by the late Dr. Haliburton and Dr. Fowler, author of this article. Test Section 3 was built as a worst-case exercise.

Design analyses indicated that the fabric would provide the reinforcement necessary to prevent rotational foundation failure or embankment spreading and splitting until the soft foundation consolidated sufficiently to support the embankment. A similar system was used successfully to construct a multi-purpose dike at Pinto Pass in the Mobile District (see Information Exchange Bulletin 1979).

Experience from prior end-dumped dike construction at Craney Island and from fabric-reinforced dike construction at Pinto Pass indicated that the latter could be accomplished for about 40 percent of the cost of end-dumping and that better control of the desired section could be maintained with the fabric-reinforced dike. Based on these two factors, the fabric-reinforced construction was selected for installation of three dike sections to determine the feasibility of using floating dikes at Craney Island. Construction began in mid-July 1982 and was completed in mid-November 1982.

CONSTRUCTION TECHNIQUES

The planned construction sequence was essentially the same as that used for the dike at Pinto Pass (Fowler 1981). Fabric was laid on the dredged material surface in 16-ft-wide panels placed transverse to the longitudinal axis of the dike (Figure 2), and the panels were sewn together (Figure 3) with very strong polyester thread (breaking strength approximately 80 lb).

As the fabric placement progressed, sand was end-dumped and then spread with small wide-track dozers with 2.3-psi contact pressure (Figure 4). The sand layer was 2.0 to 2.5 ft thick. Where the dredged material was very soft, the weight of the sand caused a small surface mud wave that launched the fabric forward. Laborers used 16-ft-long poles to assist in launching and spreading the fabric (Figure 5). The low ground pressure dozers pushed sand onto the in-place fabric, creating a wave in the underlying mud that stretched the wrinkles from the newly placed panels.

Initially, all dump truck traffic was confined to the outside edges along the toe of the test section to provide lateral spreading that would pretension the fabric. After the fabric was placed and the sand was spread for the working table, the dikes were raised in increments to a height of 11 ft for Test Sections 1 and 2 and 8 ft for Test Section 3.

On-site construction was directed by Dr. Fowler assisted by personnel of the Norfolk District: Mr. Matthew Byrne, geotechnical engineer; Mr. Rivers Westcott, manager of the Craney Island Disposal Area; and Mr. T. J. Szelest, Project Manager for implementation of Craney Island Management Plan. The project was under the general supervision of
FIELD TEST SECTIONS

Test Section 1

Test Section 1 was a 750-ft-long dike designed to begin at the west end of the existing north interior dike. There had been very little disposal into the area since April 1982, and a 3- to 4-in.-thick crust of dried material covered the alignment of the dike. The in situ undrained shear strength of the foundation was about 100 psf.

The crust provided a good working surface that supported the laborers as they spread the fabric across the center line of the dike and sewed the panels together. The spreading of the sand working table closely followed the fabric-laying operation. This sequence progressed rapidly for 600 ft with no evidence of the anticipated mud wave, and the decision was made to construct the remaining 150-ft dike section without the fabric reinforcement.

The embankment was raised incrementally. There was complete failure of the unreinforced section when the dike approached a height of 6 ft. The fabric-reinforced section was raised to 11 ft without failure. Figure 6 shows the completed dike section.

Test Section 2

A 400-ft-long dike section was to begin at the west perimeter dike and be constructed eastward on the same alignment as Test Section 1. Foundation materials were very soft on the west side of the containment area; the in situ undrained shear strength was about 50 psf. No crust had formed in the area because dredged material had recently been deposited. Disposal operations continued in the northwest corner during the construction of Test Section 2.

Construction proceeded as planned (Figure 7). A very shallow mud wave was created and was used to advance the fabric. The dike was completed without any major construction problems and a stable embankment was built.

Test Section 3

A 300-ft-long dike was projected eastward from the west perimeter dike on the same alignment as the south interior dike. The elevation was the lowest of the entire disposal area. Records showed that water had ponded there continuously since construction of the perimeter dikes was completed in 1957. Needless to say, no crust had developed. In situ tests showed the undrained shear strength of the foundation dredged material in the area was 25 psf. Construction in the area would be under worst-case foundation conditions.

The planned construction sequence was used for laying the fabric and raising the dike (Figure 8); however, the dike did not float on the
soft material, but displaced downward about two volumes for each volume of sand raised above the surface. (This was a vast improvement over the previous experiences of site personnel, who had consistently observed downward displacements of 8 to 10 volumes below the surface for one volume above.) The embankment was successfully raised to a height of 8 ft.

General

An equipment rental contract was used by the Norfolk District rather than a performance contract because specific items in the construction process, such as construction sequence, fabric placement, and sewing techniques, were considered critical to satisfactory performance of the test sections. The low construction bid for the three dikes was about $280,000 and the 92 rolls of fabric used for reinforcement cost approximately $141,000.

SUMMARY

The reinforced embankments at Test Sections 1 and 2 were finished to design width and grade without excessive lateral spreading or rotational bearing failure in the foundation despite excessive pore water pressure of about 20 ft that developed above the dredged material surface. The embankment of Test Section 3 experienced a downward displacement of about two volumes for one volume raised above the surface during construction, but no embankment failure occurred.

The fabric performed satisfactorily when the fabric warp fibers were oriented perpendicular to the long axis of the dike, but failure occurred in the fabric fill fibers which were oriented in the longitudinal direction at Test Section 3 (which is the inherently weaker orientation of the fabric fibers). Nonetheless, the fabric provided sufficient reinforcement to support rapid dike construction to the desired height and to maintain the structural integrity of the embankment.

Foundation pore pressures are dissipating gradually. After the excess pore pressures have been reduced, the height of the dikes can be increased to provide additional storage area.

Long-term settlement and pore pressure data are being collected and evaluated to determine the performance of the dikes and to refine the design and construction procedures and criteria. Results of the long-term study will be published in a technical report.

LESSONS LEARNED

When time constraints will permit, construction of a floating dike will progress with a minimum of difficulty if construction is delayed until a crust is formed that will support the fabric-laying activities. Crust formation can be accelerated by drainage/dewatering techniques such as progressive trenching with the RUC (Riverine Utility Craft, see Skjei 1976). The crust along the alignment of Test Section 1 was 3 to 4 in. thick and supported fabric laying and construction of the initial sand
layer, eliminated the mud wave construction technique, and reduced the fabric fill fiber strength requirements.

For detailed information concerning the Craney Island project or the construction technique, contact Dr. Fowler (Commercial 601 634-2703 or FTS 542-2703); Mr. Charles C. Calhoun, Jr., Program Manager for the DOTS Program (Commercial 601 634-3428 or FTS 542-3428); or Mr. Szelest, Norfolk District (Commercial 804 441-3503 or FTS 827-3503).
REFERENCES


List of Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Aerial view showing December 1982 configuration of Craney Island Disposal Area, looking north</td>
</tr>
<tr>
<td>2</td>
<td>Unrolling fabric across the center line of the dike</td>
</tr>
<tr>
<td>3</td>
<td>Sewing fabric panels together</td>
</tr>
<tr>
<td>4</td>
<td>Dumping and spreading sand on in-place fabric</td>
</tr>
<tr>
<td>5</td>
<td>Launching and spreading fabric on advancing mud wave</td>
</tr>
<tr>
<td>6</td>
<td>Test Section 1 during construction (viewed from east to west)</td>
</tr>
<tr>
<td>7</td>
<td>Test Section 2 during construction (viewed from south to north)</td>
</tr>
<tr>
<td>8</td>
<td>Test Section 3 during construction (viewed from east to west)</td>
</tr>
</tbody>
</table>
Figure 1. Aerial view showing December 1982 configuration of Craney Island Disposal Area, looking north

Figure 2. Unrolling fabric across the center line of the dike
Figure 3. Sewing fabric panels together

Figure 4. Dumping and spreading sand on in-place fabric
Figure 5. Launching and spreading fabric on advancing mud wave (viewed from north to south).

Figure 6. Test Section 1 during construction (viewed from east to west).
Figure 7. Test Section 3 during construction
(viewed from south to north)

Figure 8. Test Section 3 during construction
(viewed from east to west)
BRIEF PERSONAL HISTORY

Jack Fowler

Education: B.S., Civil Engineering from the University of Mississippi 1961
M.S., Civil Engineering from Mississippi State University, 1972
Ph.D., Civil Engineering from Oklahoma State University, 1979.
Major field of study: Soil Mechanics

Experience: Mr. Fowler worked for the Soils Conservation Service for one year while attending the University of Mississippi. After receiving his BS degree in 1961, Mr. Fowler was employed by the Corps of Engineers Ballistic Missile Construction Office, Inglewood, California, as a construction inspector at the Jacksonville, Arkansas, Field Office. This work involved construction of 18 Titan II Missile Bases. Mr. Fowler was on Military leave of absence for 3 months in 1962 at Fort Polk, Louisiana, during the Berlin Crisis. Since 1962, Mr. Fowler has been employed at the U.S. Army Engineer Waterways Experiment Station as a Research Civil Engineer, participating in the Dredge Material Research Program as a Senior Project Engineer on numerous projects involving dewatering of dredged materials and design and construction of fabric reinforced containment levees and construction haul roads. He has also participated on a streambank erosion inspection team that is responsible for providing new guidelines for streambank protection. He is currently a principal assistant to the Chief, Engineering Studies Branch, and is responsible for planning, executing, and analyzing the results from research and development studies and preparation of engineer manuals on construction control for earth and rock-fill dams and levee design.

Professional Licenses: Registered Professional Engineer in the State of Mississippi

Professional Memberships: ASCE, NSPE, ASTM, MES, Vicksburg Engineers Club and Chi Epsilon

Publications: Mr. Fowler has authored or co-authored 25 technical publications, 5 unpublished technical publications, and 7 papers. He has also been technical contributor to 16 technical publications. These publications were in the field of geophysics, dynamics, soil mechanics, soil and structural interaction and pile supported foundations, and seismic wave propagation phenomena.
EFFECT OF A LADDER PUMP ON THE CAVITATION CHARACTERISTICS OF A CUTTERHEAD DREDGE

by
Giulio Venezian

INTRODUCTION

A cutterhead dredge system of fixed geometry is analyzed to determine the head required to achieve a given discharge of mixture for various concentrations. These relationships determine the characteristics of the pumping system needed for the operation of the dredge in the given configuration.

Other parameters calculated are the power required, the weight of solids delivered per unit time, and the net positive suction head available at the pump.

The optimal design would have the best efficiency of the pump coinciding with the highest weight of delivered solids per unit of energy expended. There are various limitations on this optimization: the maximum power available, the minimum permissible suction head for the pump, the maximum concentration of solids that can be carried, and the characteristics of the cutterhead and seafloor which combine to give a relationship between discharge rate and concentration of sand.

Of these four limitations, only the suction head limitation can be avoided easily. The power limitation will be taken as an absolute one, limited by capital cost, size and weight. The maximum permissible concentration of solids that can be pumped is unknown, but in the context of this paper it will be assumed to be 35 percent which is the approximate limit of validity of the Durand-Gibert relations used in the analysis. While higher concentrations can undoubtedly be pumped, the head requirements increase rapidly so that this limitation becomes similar to the power limitation. Finally, the characteristics which determine the concentration for a given flow rate are not known at this time. This is an area where further studies are needed if a rational design of a dredging system is ever going to be carried out.

DESCRIPTION OF THE SYSTEM

An idealized dredging system is shown in Figure 1. It consists of a suction pipe, one or more pumps, and a discharge line. The system is basically the one analyzed by Basco (1973) except that the system geometry is kept fixed, and some details of the analysis have been changed.

In the configuration shown, \( l_s \) is the length of the suction line, \( l_d \) is the length of the discharge line, \( d \) is the water depth and \( e \) is the elevation of the pump and discharge above the water surface. An alternative configuration is also considered, in which an auxiliary pump is placed on the ladder at a distance \( l_a \) from the inlet.

1Associate Professor, Ocean and Civil Engineering, Texas A&M University, College Station, TX 77843.
In analyzing the system, it is assumed that the fluid in the lines is a slurry containing a concentration $C$ of solids (volume of solids/volume of mixture) while the fluid surrounding the pipe is clear fluid of specific weight $\gamma_1$.

The pressure at a point $P$ having the same elevation as the inlet is thus $\gamma_d$, and if it is assumed that slurry is drawn into the inlet starting from rest at point $P$, the Bernoulli equation between $P$ and the discharge point $O$, where the pressure is atmospheric is

$$\gamma_1d + \Delta p_p = \frac{1}{2} \rho_m V_D^2 + \Delta p_s + \Delta p_d + \gamma_m (d+e)$$

(1)

where $\Delta p_p$ is the pressure increase across the pump, $\Delta p_s$ and $\Delta p_d$ are the pressure drops due to frictional losses in the suction and discharge lines, and $V_D$ is the velocity of the fluid at the discharge.

If the flow rate is given, the velocities in the suction and discharge lines can be found, and hence the pressure drops can be calculated for any given concentration. The Bernoulli equation then gives the pressure rise required across the pump to achieve the desired flow rate, and the power can then be calculated.

The stagnation pressure at the suction inlet of the pump is given by

$$p_{ss} = \gamma_d - \gamma_m (d+e) = \Delta p_s$$

The available positive suction head relative to the vapor pressure of the liquid (expressed in feet of mixture) is

$$h_s = (p_{ss} + p_a - p_v)/\gamma_m$$

(2)

where $p_a$ is the local atmospheric pressure and $p_v$ the vapor pressure of the liquid.

**LOSSES**

The literature on losses in a pipe when slurry is flowing traditionally expresses the losses as a head of clear liquid, so that $\Delta p = \gamma_1 h_L$.

The formulation used here will follow the results of Durand (1953) and Gibert (1960). The head loss in a horizontal pipe carrying mixture $(h_L)_m$ is expressed in terms of the corresponding head loss for the same conditions carrying clear fluid $(h_L)_f$ as follows:

$$(h_L)_m = (1 + C\phi)(h_L)_f$$

(3)

where $C$ is the concentration and $\phi$ is a function which does not involve the concentration and is given by
Here \( D \) is the pipe diameter, \( d \) the median particle diameter, \( s \) the specific gravity of the sediment (relative to the conveying fluid), and \( v_s \) is the settling velocity of the particles.

This equation applies only when there is no settling of the sediment to the bottom of the pipe, a condition which holds only when the velocity is larger than a critical velocity \( V_c \) which Durand expressed as

\[
V_c = F_L (2yD(s-1))^{1/2}
\]

where \( F_L \) depends on the concentration and median sediment diameter.

Gibert found that the relation could be applied to a partially blocked pipe by assuming that the blockage would decrease the effective diameter of the pipe and thus the critical velocity until the point would be reached when the velocity became equal to the critical velocity for that blockage and no further blockage would then occur. Expressing the effective diameter as 4 times the hydraulic radius, this equilibrium blockage would be reached when

\[
\frac{V^2}{4R_h} = \frac{v_c^2}{D}
\]

For inclined pipes, Gibert found that \( \phi \) should be replaced by \( \phi \cos \theta \) in Equation (3). Worster and Denny (1955) proposed that \( \phi \) should be replaced by \( \phi \cos \theta \), and this relation was used in the calculations presented here.

It should be noted that in the case of an inclined pipe the question of partial blockage does not arise, unless the slope is very small.

CALCULATIONS AND RESULTS

Calculations were performed for a system described as follows:

- length of suction line: 100 feet
- length of discharge line: 2000 feet
- suction pipe diameter: 33 inches
- discharge line diameter: 30 inches
- median particle diameter: 0.5 mm
- settling velocity: 0.21 ft/sec

Concentrations were varied from 0.02 to 0.25, and digging depths of 40 and 70 feet were considered.
Figures 2(a) and 2(b) show the head versus discharge curves for different concentrations for digging depths of 40 and 70 feet respectively. The horsepower requirement is also indicated on the curves. There is no significant variation of the curves with digging depths, indicating that the frictional loss is dominant for this geometry. The head loss increases with concentration and the power requirements increase both with flow rate and concentration. There is thus a limitation on the system imposed by the maximum power available.

Figure 3(a) shows curves of available NPSH at the pump superposed on the head versus discharge curves for a digging depth of 70 feet. These curves are nearly parallel to the concentration curves, indicating that there is a maximum concentration that can be conveyed by the system.

Of course the NPSH alone is not a suitable criterion, since the NPSH required by a pump to avoid cavitation varies with flow rate and rotational speed. Nevertheless, the curves do indicate that the available NPSH decreases with concentration.

The efficiency of the system in terms of energy cost per unit weight of solids delivered increases with concentration, so that if the NPSH limitation can be removed, the efficiency of the system can be improved.

Figure 3(b) shows the effect of a ladder pump on available NPSH. The calculations were done with an auxiliary pump halfway up the ladder, assuming that the pressure increase across the auxiliary pump is 20% of the total head. As it can be seen from the resulting curves, the available NPSH at the main pump is virtually constant over the range of values computed. The auxiliary pump thus eliminates the NPSH limitation.

It must be pointed out, however, that the Durand-Gibert formulation does not hold for large concentrations, so that the increase in efficiency with concentration has a limit also. Moreover, the concentration itself is not a controllable variable since it depends on the inlet conditions and the characteristics of the sediment. Optimization of the process is still an operator function, although calculations of the type described here can be of value in the design of the dredging system and in indicating desirable operating conditions.
Figure 1. Schematic diagram of dredging system.
Figure 2. Head vs. discharge curves for different concentrations
(a) digging depth = 40 ft; (b) digging depth = 70 ft.
Figure 3. Available NPSH at a digging depth of 70 feet.
(a) Single pump; (b) with auxiliary pump on ladder.
REFERENCES


BRIEF PERSONAL HISTORY

Giulio Venezian

Personal:
Birthday: 12-9-38 Birthplace: Torino, Italy
S.S. No.: 569-60-0236 Marital Status: Married
Security Clearance: None Children: Two
Citizenship: Italy: Permanent Resident of U.S.

Education:
Ph.D., Engineering Science, California Institute of Technology, 1965
B.E., Engineering Physics, McGill University, 1960

Experience:
Associate Professor, Civil and Ocean Engineering, Texas A&M University, College Station, Texas, 1979-present
Assistant and Associate Professor, Ocean Engineering, University of Hawaii, 1968-1979
Visiting Associate, California Institute of Technology, 1974-75

Registrations:
Registered Professional Engineer, Texas No. 47439

Professional Interests:
Ocean Engineering
Numerical Modelling in Fluid Mechanics
Fluid Mechanics Perturbation Methods

Selected Publications:
"Wave energy as a resource for wave power in Hawaii," Preprints, Symposium on Chemistry and Economics of Ocean Resources, 177th Meeting of the American Chemical Society, Division of Chemical Marketing and Economics, pp. 280-291, 1979.
ENGINEERING ASPECTS OF CAPPING DREDGED MATERIAL

by

Raymond L. Montgomery

ABSTRACT

A technique known as capping has been used in the Long Island Sound and the New York Bight during recent years to contain contaminated dredged material in subaqueous disposal sites. This technique involves placing contaminated material in the disposal site and then covering it with clean sediments to prevent spread of the contaminated material in the aquatic environment. The capping technique is attractive as a means of controlling the potential harm of contaminated sediments. The Convention on the Prevention of Marine Pollution by Dumping of Waste and Other Matter (known as the London Dumping Convention) has accepted capping of contaminated sediments in open water disposal sites, subject to careful monitoring and research.

There has been a significant amount of research performed on stability of cap materials and biological activity in cap materials. However, there has been little research devoted to the equipment and operational aspects of capping. This paper provides information on past capping practices, capping materials, placement techniques and research and development needs for improved capping techniques.

INTRODUCTION

Great strides have been made in recent years in determining the effects of open-water disposal of dredged material. Research performed under the Corps' Dredged Material Research Program (DMRP) and by others have indicated that disposal of clean dredged material in open water is not of major concern. A major concern, however, is the disposal of highly contaminated sediments that are found in many of our harbors and waterways. The contamination of these sediments is a result of man's activities including industrial expansion, widespread use of pesticides in agriculture, and intentional or inadvertent dumping of pollutants. Disposal alternatives for material dredged during the maintenance of these harbors and waterways are often quite limited. The traditional method of disposing of contaminated sediments is confinement in upland disposal areas. However, a new disposal alternative is emerging in the Long Island Sound and New York Bight areas. This disposal alternative involves placing the contaminated dredged material in open water and capping it with a clean sediment to prevent the spread of contaminated sediments at the subaqueous disposal site and isolating them from benthic organisms. The cap material is thick enough to protect the underlying contaminated material from disturbances by waves and currents and keep the contaminated

1Environmental Laboratory, USAE Waterways Experiment Station, Vicksburg, Mississippi 39180.
particles buried beyond the reach of burrowing organisms.

A significant amount of research has been performed on stability of cap materials and biological activity in cap materials (Bokuniewiez, et al, 1981) (Freeland, et al, 1983) (Morton, 1983). However, there has been little research devoted to the engineering design, construction, and management of capping activities. This paper provides information on past capping practices, capping materials, placement techniques, and research and development needs for improved capping techniques.

EXISTING CAPPING PRACTICES

Capping is currently being carried out as a means of controlling the potential harm of contaminated or otherwise unacceptable sediments. The London Dumping Convention has accepted capping, subject to careful monitoring and research, as a means of rapidly rendering harmless by physical means, contaminated material dumped into the ocean. The physical means are essentially to seal the unacceptable material from the biosphere by a covering of acceptable material. In the United States, the capping techniques have only been used in the Long Island Sound and the New York Bight. The contaminated sediments have been dredged by mechanical dredges (bucket dredges) and transported to the designated disposal site by scows or barges (Figure 1). The contaminated sediments are dumped at points marked by taut-wire moored buoys. Towboat operators are instructed to hold each scow at a complete halt before and during the dumping operation. Precision disposal of the contaminated sediments is necessary so that discrete mounds can be created prior to capping.

Figure 1. Dredged material discharged from a barge/scow.
It is important that a taut-wire bouy be used to mark the discharge point. In cases where regular bouys have been used, the scows were positioned only within a circle of about a 200 yd radius of bouys. The method of placement of contaminated dredged material on the bottom should be chosen to minimize the surface area of the mound of deposited material. In the future, disposing of contaminated dredged material may require the use of electronic positioning equipment by each transport scow with the data being recorded and later provided to the contracting agency. This would allow verification of accurate placement of each scow load of contaminated sediments.

The sediment discharged from a scow descends to the bottom in a downward directed jet and upon impact spreads radically outward in a density surge. Bokuniewiez, et al. (1977) reported that 99 percent of the material discharged from scows containing more than 1000 cu yds would be transported to the bottom in the jet. Gordon (1974) reported that during one disposal activity in Long Island Sound, all of the material in the density surge settled within 170 yds of the impact.

Capping activities in Long Island Sound and the New York Bight have been carried out in about 60 ft of water. The contaminated sediments include fine-grained materials such as silts and clays. Both sand and clean fine-grained sediments have been used to cap the contaminated sediments. Generally the capping material has been obtained from clean sediments removed from nearby navigation projects. In most cases the capping material has been obtained using bucket dredges and transported in scows to the capping site. However, some experience was gained using hopper dredges to dredge the cap material and to transport it to the site. There appears to be an advantage in using the hopper dredge to place the cap material (Figure 2). The advantage involves the spreading characteristics of the cap material dredged hydraulically by the hopper dredge. This material flows over the contaminated sediments resulting in a more uniform coverage. There has been no special-purpose equipment used in past capping activities. These activities have been carried out using conventional dredging equipment developed for and used on routine dredging projects. Many researchers feel that there are improvements needed in equipment and capping techniques to ensure accurate placement of the cap material.

CAPPING MATERIALS

There has been a significant amount of research devoted to cover materials for burial of hazardous spills in lakes and waterways. This research has been summarized by Hand, et al. (1978). This work also applies to capping contaminated dredged material. Materials, both naturally occurring and man-made, that can be used to cover contaminated dredged material are divided into three categories: inert, chemically active, and sealing agents.

Inert materials include coarse- and fine-grained soils. Research is being performed at the Waterways Experiment Station (WES) to determine covering depths required to inhibit biological activity in the contaminated materials and to retard leaching of contaminants into the water column. When natural soils are used as capping materials they should be thick.
enough to protect the underlying deposit from disturbances caused by storm-generated waves and to bury the contaminated sediments out of the reach of benthic organisms. The nature of the capping material will influence the depth and character of burrowing. Myers (1979) reported that a sand cap will attract suspension feeding organisms that should not be expected to be deep burrowers, while deep burrowing deposit feeders will colonize a fine-grained cap. Therefore, site-specific biological populations are important in designing the cap thickness. Bokuniewicz (1981) reported that for disposal sites in relatively protected near shore waters a cap thickness of less than a meter should be sufficient, but site-specific studies should be done to evaluate biological populations and erosion potential.

Stability of the capping material is a major concern in the design of capping projects. Factors influencing cap erosion include: (1) the particles (size, uniformity, shape, size distribution, texture, etc); (2) the hydrodynamics of the system; (3) slope of the mound; and, (4) the degree of cap material cohesiveness. Therefore, the prediction of erosion potential of a capping material should be made on the basis of site specific data. The inert materials used for capping can be classified as cohesive or noncohesive. For given erosive forces, movement of noncohesive particles depends on shape, size, and density of discrete particles and on the relative position of the particle with respect to surrounding particles. The movement of cohesive particles depends on those factors cited above for noncohesive particles as well as on the strength of the cohesive bond between particles. This latter resisting force can
be much more important than the influence of the characteristics of the individual particles. Cohesive capping materials excavated by mechanical dredges will be more resistant to erosion than those excavated by hydraulic dredges. Once the cohesive bond has been broken during the hydraulic dredging process, the individual particles and flocs behave essentially as noncohesive particles until they gain strength through the consolidation process. The degree of consolidation, which is inversely proportional to the interstitial water content, has a significant effect on the ease at which the fine-grained particles will erode. The time required for the complete consolidation of fine-grained capping material will take many years if the material is predominantly clay.

Chemically active materials involves the placement of a chemical compound over the contaminated dredged material that would react with the contaminants to neutralize or otherwise decrease toxicity. The active covering strategy differs from the inactive covering strategy using inert materials because each contaminated dredged material must be dealt with on a case-by-case basis. In the capping of dredged material, the active material should be combined with an inert stabilizer to provide stability to the cap. Another approach would be to cover the active covering layer with an erosion-resistant inert layer. The inert layer would also provide protection for the benthic organisms. While the inert covers have little or no chemically related impact on the organisms, the chemically active covering agents could be harmful to some organisms. Also greater accuracy would be required for placement of the chemically active materials.

Sealing agents include grout, cements, and polymer films. The unique feature of the grouts and cements is that, when placed on top of contaminated sediments, they will harden and form a crust, preventing erosion and resuspension of the contaminated material. A Japanese firm (Takenaka Komuten, 1976) has done work in dredged material stabilization and deep-mixing of sediments using grouting compounds. Also, grouting is often used in the off-shore oil industry for stabilization of oil producing facilities. The technology for using grout in the salt water environment is well developed and it could be adapted for use in capping contaminated dredged material. However, there are some disadvantages associated with the use of grout in capping dredged material. The thin layer of grout placed over the contaminated dredged material cannot be considered as the permanent cap material. It should be used with a covering of inert material to provide additional stability and habitat for benthic organisms. There could also be problems with the grout cracking as the contaminated dredged material consolidates with time.

Polymer film systems have been the subject of a report by Widman and Epstein (1972). They proposed barge-mounted deployment systems for either hot or cold application of polymer film overlays. The application systems included those for placing coagulable polymers, hot melt materials, and performed commercially available films. The application system for the performed overlay limited its application to water depths of 25 to 30 ft. Roe, et al (1970) reported on a chemical overlay system which included 2000-sq ft/hr coverage and availability for water depths up to 120 ft.
Concepts for the use of polymer film overlays for cover of contaminated dredged material were developed from early erosion control efforts related to marine salvage work. None of the concepts have been field tested for dredged material. The major limitation to these concepts involves the capital equipment requirement to place them.

PLACEMENT TECHNIQUES

Several methods for placement of capping materials have been identified as having potential in further improving the capping technique. The first effort was to identify existing methods of dredged material placement. These methods included point dumping from scows/barges and hopper dredges, and open-pipe discharges from hydraulic dredges. Although, these methods are readily available and capable of placing a cap, they were found to have some drawbacks requiring further research and development (uneven cover, turbulent impact on bottom, etc). Several alternatives to these techniques, such as hopper dredge pump-down or sand spray systems, and submerged diffuser system for hydraulic dredges, have potential for both placement of the contaminated sediments and inert capping materials. These methods, however, will result in an increased cost for new equipment. Borrow pits and submerged dikes have been mentioned in the literature as possible methods for confining the contaminated sediments and could be capped using the methods outlined above.

Accurate placement of both contaminated sediments and capping materials are concerns from two points of view. First, the materials may tend to disperse during placement. This concern would apply to the fine-grained materials, which may flow in the form of fluid mud capable of traveling great distances underwater. Second, resuspension caused by placement could result in contaminated sediments spreading outside the capping area.

Point dumping both by hopper dredge and barge/scow is a straightforward application of traditional dredging disposal operations to the capping operation. One important problem associated with this technique is precision in material placement. The taut-wire buoy procedure has improved the precision of dumping but additional work is needed to control the operational aspects. Complete coverage of the contaminated material by point dumping is often not achieved. Figure 3 shows the results of three surveys made along a transect over a disposal site produced from the point dumping method. The first survey was made prior to disposing of the contaminated dredged material and the second survey was made immediately after point dumping of the contaminated material. The third survey shows the mound of silt cap material. In this case the point dumping method did not produce a complete cover over the contaminated material. A technique used in the New York Bight is to point dump the contaminated dredged material and to cap it with material dumped at a number of discrete points. This method of placing the cap improves the coverage of cap material over the contaminated sediments.

The JBF Scientific Corporation (1975) performed tank evaluations of point dumping of silts and clays. These observations of simulated dumps
showed that low moisture content silt and clay materials would tend to mound on the bottom, the dumping being characterized by a rapid descent phase, little dispersion in the water column, and little spreading of the material on impact. High moisture content materials were characterized by a slow descent phase, dispersion in the water column, and a rapid flow of material across the bottom after impact. Little or no mounding was evident in the tests on high moisture content material. The low moisture content materials would represent sediments excavated by mechanical dredges and the high moisture content materials represent sediments excavated by hydraulic dredges.

Sustar and Ecker (1972) performed a comprehensive study of point dumping of hydraulically dredged sands. Using a variety of techniques including divers, they found that on bottom contact sand surged radically outward so rapidly that a thin layer was produced over a large area. Scouring of the bottom was observed at the point of contact.

It appears that point dumping of mechanically dredged contaminated sediments is an attractive option because the material tends to mound. However, point dumping of cap materials may not be the best practice. Improved techniques are needed to ensure that the cap material is placed uniformly over the contaminated material with a minimum of disturbance.
The pump-down concept may be a means of avoiding the potential scouring and turbulence associated with point dumping. This is a concept for use with hopper dredges where the dragarms could be used to place the material near the bottom. Sand or other cover material could be pumped out of the hoppers, down the dragarms, and deposited in thin layers over the contaminated material. Discharge of the cover material could be accomplished while the hopper dredge is sailing at a low speed. The material would settle in layers reducing turbulence on the bottom. This technique would ensure good coverage and reduce the potential for displacement of the soft fine-grained contaminated sediments under the heavy load of the cap material. There is some speculation that point dumping of sands on the soft contaminated materials results in displacement of the soft materials and poor coverage of cap material.

The most promising equipment development related to placement of both contaminated sediments and cap material is the submerged diffuser system (Figure 4). This system was designed under the DMRP (Neal, et al, 1978) and it has recently been built by a Dutch dredging form and is presently being used in a capping project in Rotterdam harbor (1983). The diffuser system operates on the principle of radial divergence of flow to slow discharge velocity to acceptable levels. Diffuser systems like this are well tested and present few technological problems to development for use in capping projects. The diffuser system could be used with existing hopper dredges, hydraulic pipeline dredges and barges with hydraulic pump out capability. In these cases the barge mounted diffuser (Figure 4) would be to the discharge pipe. Sediment flow characteristics during placement will vary with the nature of sediment and current, as well as slurry discharge rate and height of diffuser above the bottom. In all cases, however, the use of the submerged diffuser system will increase control over placement of capping material, as well as reduce turbidity and scouring during placement. Complete cover of the contaminated material can be ensured by repositioning the discharge barge throughout the area as necessary. It is expected that the need for repositioning will be greater when sand is being used as the capping material because of its tendency to mound. The submerged diffuser could also be used to place the contaminated sediments. It would minimize the release of contaminated sediments in the water column during placement and provide better control of the placement operation. However, the hydraulically placed contaminated sediments would likely spread over a larger area than mechanically dredged and point dumped sediments. The use of the submerged diffuser in conjunction with subaqueous confinement such as borrow pits, depressions, and dikes is an attractive option. Advantages of the submerged diffuser system include increased control over location of both capping and contaminated sediments, decreased scouring of the bottom upon impact, and less release of contaminated materials into the water column.
Figure 4. Submerged diffuser system.
SUMMARY

Dredged material capping practices have evolved from existing dredging and disposal practices. Little research effort has been devoted to the operational aspects of placing the contaminated sediments in a controlled manner to minimize spread of contaminated sediments into the water column. Techniques and equipment for placing capping materials have not been developed to the point that accurate placement can always be assured.

There has been some research devoted to evaluating the types and thicknesses of capping materials required to protect the underlying contaminated sediments from wave disturbances and to bury the sediments out of the reach of benthic organisms. However, the results of these studies and others being performed at the WES have not been presented in the form of specific guidance. This guidance should be forthcoming in the near future.

There is equipment available now that would improve the accuracy of both cap and contaminated sediment placement. Such equipment includes automated systems for positioning during placement and the submerged diffuser for control of cap and contaminated material placement. Research is underway at the WES to evaluate equipment, capping materials, and operational procedures required to improve the capping technique. Guidelines will be produced from this work for designing, constructing, and managing capped dredged material disposal areas.
REFERENCES


