# Summary

A one-day symposium on "Geotechnical Aspects of Ocean Waste Disposal" was held at the winter meeting of ASTM in Orlando, Florida on 26 Jan. 1989. The symposium was cosponsored by ASTM Committee D-18 on Soil and Rock, the National Oceanographic and Atmospheric Administration Office of Marine Pollution, and the Sea Grant Programs of California and Connecticut.

The 1-day symposium was comprised of 17 individual presentations on both laboratory research and field experiences related to excavation and disposal of wastes in the marine environment. Each half-day session was begun with an invited state-of-the-art presentation. These were by W. F. Bohlen on Shallow Water Disposal (morning) and A. J. Silva on Deep Water Disposal (afternoon). The program concluded with a discussion of research needs by I. Noorany. About 80 individuals attended the symposium.

The objective of this summary paper is to survey briefly the findings of the presentations made at the symposium, supplement these findings with the results of nonsymposium researchers, and incorporate the comments of paper reviewers and symposium attendees to provide a balanced review. It is hoped that this symposium will help identify new test methods and procedures that require standardization by ASTM as well as define research areas that require further investigation.

Note that the topic of ocean waste disposal is very complex in nature and an understanding of even the simplest problem often requires the interaction of specialists from many disciplines. The multidisciplinary nature of this topic is apparent in the authors represented as well as the topics covered in this summary. However, the focus of this symposium is geotechnical engineering which deals with one small facet of the overall problem and involves site selection, material placement, containment, and monitoring of a seabed waste disposal site.

## Magnitude of the Problem

Annually, millions of tons of waste materials are disposed in the oceans by the United States and other coastal industrial countries. This ocean dumping has recently led to stressed conditions off heavily populated areas. Many of these observed problems are a result of uncontrolled storm runoff and sewage discharges at the coast and have little relationship to the objectives of this book. Yet, there are a number of opportunities for the geotechnical engineer to be involved.

The waste types and volumes disposed of in the oceans by the United States in 1983 are summarized in Table 1. A review of it shows that dredged materials constitute, by far, the largest volume of waste. Bohlen has noted that dredged materials are the waste of primary concern in ocean geotechnics because their density is greater than seawater and they can be deposited on the seabed as an engineered material. Less than 10% of the dredged material is contaminated with heavy metals or organic compounds and constitute a threat to the environment.

The U.S. Army Corps of Engineers [2] currently proposes that contaminated dredged materials be disposed of at shallow ocean sites where they can be placed on the seabed and capped with clean sediments to isolate it from the water column. Shallow ocean capped disposal has been used in the United States since 1978; however, the process of placing the

TABLE 1—*Ocean dumping in the United States in 1983* [1].[a]

| Waste Type | Amount, $10^3$ Tons[b] |
|---|---|
| Dredged material | 65 160 |
| Industrial waste | 304.5 |
| Sewage sludge | 8 312 |
| Construction debris[c] | 0 |
| Solid waste[c] | 0 |
| Explosives[c] | 0 |
| Wood incin. | 31 |
| Chemical incin.[c] | 0 |
| Total | 73 807.5 |

[a]Source: dredged material: U.S. Army Corps of Engineers. All other materials: U.S. EPA.
[b]1 ton = 0.002916 kg.
[c]While no materials in this category were dumped in 1983, they have been in prior years.

dredge and cap material is difficult [*3*]. Surveys show that as little as 20% of the contaminated waste material is effectively isolated by capping [*4*].

Sewage sludges and industrial wastes are less voluminous than dredged materials but may be highly toxic by comparison. Sludges and chemicals have densities approximately equal to that of seawater and have been disposed of in deep water by barge [*5*]. The primary mechanism to reduce the toxicity of sludges and chemicals to acceptable environmental levels using this technique has been through dilution by rapid mixing. However, dispersed contaminants in seawater will probably become adsorbed to the surface of sediment and organics particles or ingested by plankton—both processes which will reconcentrate the contaminants at the microscopic level of the food chain. As a result, all dilute forms of contamination including storm runoff from urban and agricultural areas may constitute a long-term threat to coastal areas.

Because of an Act of Congress in 1988, ocean disposal of wastes (excluding dredge materials) will be banned effective 1 Jan. 1992. This Act will affect nine municipalities around the New York City area which currently dispose of sewage sludge in the ocean, and it will limit all U.S. disposal to either landfilling or incineration or both which have their problems. Consequently, it is not unreasonable to expect ocean disposal to return to use in the next decade or two but limited to concentrated chemical wastes. At that point, new technologies will be available to place the wastes on or within the seabed and will not rely solely upon dilution to treat the waste. These technologies will include containerization and solidification to handle the waste and penetrometers for drilling or pumping for placement. Many of these techniques will involve geotechnical design and analysis.

## Site Survey and Monitoring

An ocean waste disposal site, according to Silva, should exhibit geological stability, beneficial sediment properties, and remoteness from land or specific seabed resources. Bohlen has further noted that the hydrodynamic conditions should also be stable to minimize sediment erosion/deposition and ship-positioning problems. An ideal seabed location should be flat or slightly depressed with adjoining slopes less than 1°. The seabed sediment should be a silt to clay which would indicate good hydrodynamic stability but also, low strength, low permeability, and high compressibility. The properties of the seabed are very important for defining the waste disposal plan and, thus, the site survey and monitoring needs.

Acoustic measurements are most important for defining site conditions before and after deposition. During the Disposal Area Monitoring System (DAMOS) program, the Army Corps of Engineers used a high frequency bathymetry (200 kHz) along with a microwave position system to obtain replicate bathymetric profiles and maps of dredged material mounds in Long Island Sound [*3*]. The surveys were performed before and after deposition of dredged or capped material to assess deposited volumes and this data has been subsequently used to measure consolidation settlements [*6*] and geological and erosional stability (Bohlen).

Other acoustic surveying techniques that have been used in DAMOS with considerable success[1] are the high-resolution (3.5-kHz) profiler for defining subsurface geology and mound/seabed deformation and the side-scan SONAR for identifying geologic hazards and site irregularities.

A new and promising tool for seabed site selection and monitoring of a disposal site is the REMOTS camera and imaging technology (Rhoads and Germano). This camera system uses a prism to photograph a cross section of the upper 20 cm of seafloor sediment; the photos are analyzed with the aid of a computer-imaging system. This system has been successfully used for several years at dredge material disposal sites to measure disposed sediment thickness on the flanks of disposal mounds for mass balance analysis and study benthic infauna and recolonization of dredged material deposits, as well as sediment texture, bed forms, and event monitoring such as off-site transport of sediment. This analysis is likely to become a required part of all site selection and monitoring studies associated with a waste disposal project.

Baldwin et al. have proposed the use of real-time in situ monitoring of dredged material at waste disposal sites. These authors note that current sensors and telemetry are sufficiently advanced for continuous monitoring before, during, and after disposal. This approach would be particularly useful and cost-effective during short-term events that influence a waste disposal site such as discharge of a dredge material from a scow, impact with the seabed, and dissipation of excess pore pressures during consolidation or storm wave interaction at a disposal site to name a few.

### Sediment Sampling

Sediment sampling requirements at an ocean waste disposal site (Smits) fall into two general categories: shallow and deep. In general, shallow sampling involves the recovery of the top 1.5-m (5-ft) or less of sediment using a grab sampler or box corer. Deep sampling involves recovery of sediment cores of lengths greater than 1.5 m and often up to 15 to 30 m (50 to 100 ft) or more using devices such as gravity cores. Presently available sampling equipment appear to be adequate for both shallow and deep sampling. Yet, efforts are ongoing to improve sediment sampling capability (Smits), such as a new fixed piston hydrostatic corer capable of taking a 270-mm (11-in.) diameter continuous core up to 10 to 15 m (35 to 50 ft) long.

According to Bohlen, shallow grab samplers are particularly useful for acquiring thin, diffuse types of contaminated sediment. At dredged material disposal or excavation sites, a diffuse layer of contaminated sediment always forms, and grab samplers provide a means of estimating mass balance to account for contamination loss and for further estimating erosion and transport potential. However, the grab samplers must be equipped with a top cover to prevent erosion and loss of sediment during recovery from the seafloor to the ship's deck.

For deep samplers, sediment disturbance is an important factor controlling the selection of the specific sampling equipment (Silva, Smits, and Freeman and Schüttenhelm). Deep sediment samples are used in laboratory tests to determine the variation of geotechnical properties such as Atterberg limits, gradation, shear strength, permeability, and consoli-

[1]R. W. Morton, unpublished material.

dation with depth. This information is used to predict and evaluate the short-term and long-term interaction of the waste material with the seabed which alter the disposition of the waste product such as slope stability, consolidation, or percolation.

## Laboratory Testing

There is a general consensus that existing laboratory tests, when performed on undisturbed marine sediments, provide an excellent measurement of in-place physical and engineering properties (Silva, Bohlen, and Freeman and Schüttenhelm). However, it is sound engineering practice to make in-place measurements for comparison with laboratory values when possible. Silva notes most seafloor deposits are normally consolidated and that the surfical 1 m (3 to 4 ft) of sediment is very soft and difficult to handle and trim into laboratory test specimens. He notes that this soft surface layer often behaves like an overconsolidated material which he attributes to a combination of cementation and aging. However, this behavior could also be a result of disturbance from sampling and handling.

Pamukcu et al. have performed some interesting settlement and property tests on natural and fabricated marine sediments in which different contaminants are mixed into the sediments. The test results show that the properties of the natural material vary significantly with the type and quantity of contaminant. They note that the mixing of a disposed waste into the natural seabed material should be considered in disposal site design and construction since it will significantly alter the seabed's properties and behavior.

Burkett et al. examined the microfabric of deep-sea illitic clays adjacent to a heater probe using electron microscopy. After heating to about 300°C, the clay exhibited a very minor change in microfabric compared to unheated specimens.

## In-Place Testing

A number of new and interesting in-place geotechnical tests have been developed primarily in support of the proposed subseabed disposal of high-level nuclear waste for the U.S. Department of Energy, but they may be used for almost any seabed waste disposal program. Details about the geotechnical problems associated with heat-generating nuclear waste disposal may be found in the papers by Silva and Freeman. In general, the concern is to insure the containerized waste package penetration into the seabed achieves an adequate protective cover to prevent contaminant migration for an extended period of time.

For high-level nuclear waste, several mechanisms may lead to contaminant (radionuclide) migration within the porewater of the deep seabed. While the seabed is composed of thick impermeable clays, long-term porewater migration may occur as a result of both thermal or porewater pressure gradients. Bennett et al. and Valent et al. described a deep-sea piezometer probe which was developed for measurement of excess pore pressure dissipation as a result of insertion of a simulated waste canister in the seabed which experiences subsequent heating (300°C in prototype) by a 600-W heat source. Excess pore pressures were measured with a precision of less than 0.14 kPa (0.02 psi) in both the laboratory and in situ at water depths of 5500 m (18 000 ft). An analytical model was concurrently developed (Riggins and Valent) which compares favorably with the observed pore pressure response and dissipation.

Schultheiss also developed and tested a piezometer for use in the deep ocean at water depths greater than 5000 m for time periods up to a year in duration. His probe uses differential pressure transducers which are capable of measuring excess pore pressures as low as 15 Pa to a subbottom depth of up to 6 m (25 ft). He was interested in natural advective porewater flows which result from a combination of thermal and porewater pressure gradients related to base rock (geologic) cooling, seabed consolidation, and tidal waves. Insertion pore pressures developed in deploying the device had to decay for up to a week before measurements could begin. Using piezometer probes, (1) permeability, (2) horizontal coefficient of consolidation, and (3) undrained shear strength can be potentially determined. To date, piezometer probes have not been used on any waste disposal projects but offer great promise to understand better waste/seabed interaction such as in the mounding and capping of dredge materials in the shallow ocean.

Marine in situ chemical sensing techniques are currently being developed (Tokar and Pugh) for use in the water column and subseabed using a penetrometer probe. At present, fiber optic sensors offer great promise to measure water quality parameters and trends with time. Fiber optic sensors are particularly useful for measuring pH, carbon dioxide, and dissolved oxygen which are indicators of certain types of marine pollution and can be coupled with the real-time monitoring systems proposed by Baldwin et al. The entire area of in situ chemical sensing and real-time electronic monitoring is vital to the evaluation of waste disposal sites and the remediation of contaminated sites in the ocean.

## Modelling and Prediction

Most of the ocean waste disposal activities have relied upon dilution or isolation as the primary chemical mechanisms for disposal of a waste product. For a sound engineering and scientific evaluation, there is a need to develop a number of analytical or stochastic models to predict the impact of disposal activities on the environment. Bohlen notes that "a coherent base of information" is needed to deal with potential long-term effects of ocean waste disposal and permit the resource manager to develop reasonably accurate quantitative estimates of the effects associated with continued use of available disposal areas. The available information base is presently very small and is lacking in predictive models.

Hickox et al. show how a model can be developed and used to predict thermal-induced convection adjacent to a heat-generating nuclear waste package. These predictive models are invaluable for defining the parameters that influence disposal activities and for performing order-of-magnitude simulations to evaluate disposal alternatives. They are also essential for design of both survey and monitoring operations during and after waste disposal and provide a basis for comparing measured values.

## Conclusions

Geotechnical engineering has a very important role in the problem of waste disposal on or within the seabed but has received little attention in the efforts to date. New ASTM standards will be needed in support of disposal activities, particularly in the areas of remote sensing, chemical sensors, and penetrometer probes. The following conclusions are justified from these symposium papers:

1. Ocean waste disposal projects are multidisciplinary in nature and the geotechnical engineer has an important role in selecting, designing, and developing the disposal site.
2. Site surveying and monitoring with the REMOTS camera and acoustic profilers have been invaluable in dredge material disposal studies of mass balance, consolidation settlement, and slope stability.
3. There is an urgent need to develop chemical sensors, such as the fiber optic sensor and the telemetry for real-time continuous monitoring before, during, and after disposal.
4. A number of new piezometer probes have been developed that should improve our understanding of waste/seabed interaction but have yet to be deployed on a waste disposal project.
5. For a sound engineering and scientific evaluation, there is a need to develop a number of analytical and stochastic models to predict the impact of disposal activities on the marine environment.

**References**

[1] NRC, *Dredging Coastal Ports: An Assessment of the Issues,* National Academy Press, Washington, DC, 1985, 212 pp.
[2] "Long Island Sound Dredged Material Containment Feasibility Study," U.S. Army Corps of Engineers, New England Division, Waltham, MA, Feb. 1983, 330 pp.
[3] Morton, R. W. and Karp, C. A., "Disposal Area Annual Report," DAMOS Contribution 17, New England Division, U.S. Army Corps of Engineers, Waltham, MA, 1983.
[4] Long, R. P. and Demars, K. R., "Shallow Ocean Disposal of Contaminated Dredged Material," in *Proceedings of the ASCE Conference on Geotechnical Practice for Waste Disposal,* Ann Arbor, MI, 1987, pp. 655–665.
[5] Reed, Q. W., *Ocean Waste Disposal Practices,* Noyes Data Corporation, Park Ridge, NJ, 1975, 341 pp.
[6] Demars, K. R., Long, R. P., Stanton, S., and Charleton, W., "Settlement and Stability of Ocean Disposal Mounds," in *Proceedings of the ASCE Conference on Dredging '84,* Clearwater Beach, FL, Vol. 2, 1984, pp. 1040–1049.

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