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Environmental Effects of Dredging Technical Notes

MONITORING DREDGED MATERIAL CONSOLIDATION AND SETTLEMENT AT AQUATIC DISPOSAL SITES

PURPOSE: This technical note provides information on methods for monitoring the consolidation and subsequent settlement of dredged material deposited at aquatic disposal sites. Information is given on methods that have been used by the Corps of Engineers (CE) at various aquatic disposal sites around the United States. Other methods are discussed that may prove useful in monitoring the consolidation and subsequent settlement of subaqueous dredged material deposits.

BACKGROUND: Each year approximately 120 million cu yd of dredged material are deposited at designated aquatic disposal sites around the United States. Placement of uncontaminated dredged material is typically conducted at level-bottom subaqueous disposal sites and results in the formation of a mound of material on the floor of the water body. Contaminated dredged material placed in aquatic disposal sites may be chemically and/or biologically isolated from the overlying water column by capping with clean dredged material.

Placement and subsequent capping of contaminated dredged material may be accomplished either at level-bottom disposal sites or in contained aquatic disposal (CAD) sites. CAD sites are natural or constructed depressions into which contaminated dredged material is placed and subsequently capped. The CAD disposal may be more effective in containment of contaminated material since lateral movement of the material is restricted and less surface area is exposed to the water column. Level-bottom disposal and CAD concepts are illustrated in Figures 1 and 2, respectively. Aquatic dredged material disposal sites have typically been located in water depths of 20 to 150 ft.

In conjunction with any of these aquatic disposal options for confining contaminated material, postdisposal monitoring of the dredged material deposit should be conducted. Monitoring of the behavior of constructed aquatic deposits is necessary to evaluate and predict the long-term physical and chemical stability of the deposit and to assist in determining the remaining disposal site capacity. Several methods are available for monitoring the settlement characteristics of subaqueous deposits of dredged material.

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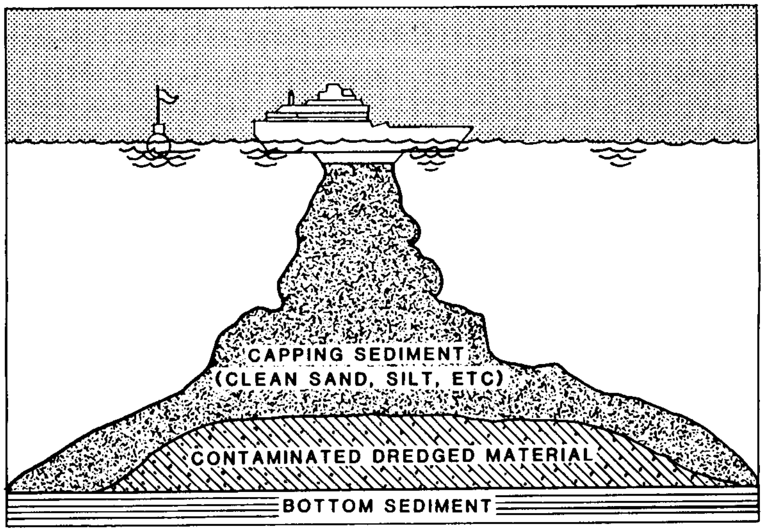

Figure 1. Schematic of typical level-bottom capping operation

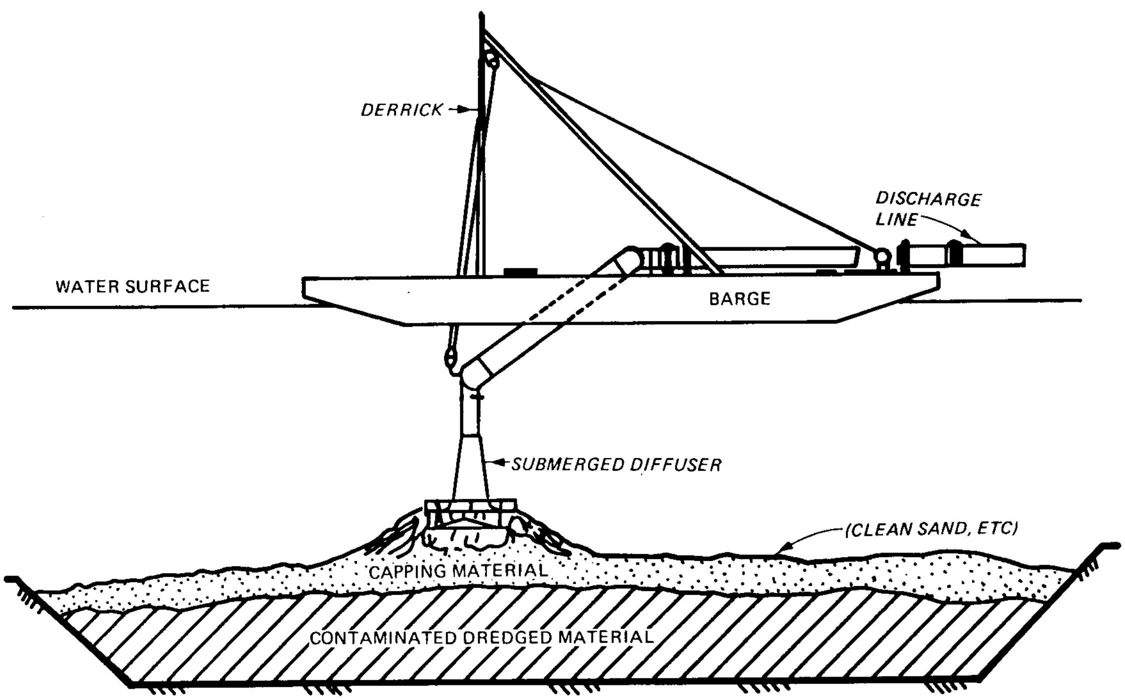

Figure 2. Schematic of CAD project showing use of a submerged diffuser for placement

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Postdisposal Behavior

After the dredged material and cap, if one is used, are placed at an aquatic disposal site, the material will undergo consolidation and may be exposed to erosion and transport from the disposal site (Poindexter 1988). Consolidation can occur in any one of or all three materials (if they are compressible): the capping material, the dredged material, and/or the underlying bottom sediments. As consolidation occurs in these materials, pore water is extruded from the deposit, and the shear strength of the material is increased. Extrusion of pore water results in a volume decrease of the deposited dredged material; this volume reduction is exhibited by settlement of the mound's upper surface. The increase in shear strength results in a deposit less susceptible to slope instability and to erosion.

During an investigation of the consolidation behavior of a dredged material deposit, the behavior of all compressible soil layers at that particular site should be considered and evaluated. Not only must the dredged material and any capping material be investigated and monitored, but any compressible foundation soil must also be evaluated. This is necessary so that any changes in elevation of the deposit's surface can be accounted for. It is not adequate to merely assume that a particular amount of consolidation will occur in the foundation soil. Instead, field and laboratory investigations should be conducted to determine whether compressible foundation or capping materials are present, and, if they are, consolidation tests should be run to enable prediction of the amount of consolidation that can be expected. The disposal site should then be monitored to discriminate any foundation consolidation from dredged material and/or cap consolidation.

Erosion and transport of the deposit's exposed surface material may occur if the disposal environment is such that current velocities exceed the critical shear stress for the material. The more cohesive an exposed material is, or the larger individual exposed particles are, the more resistant a material is to erosive/transport forces and, therefore, the more stable the mounds or deposits are. When planning for an aquatic disposal site deposit, the disposal site environment should be considered; e.g., bottom surface, depth of water, currents, and eroding versus accreting location, as well as properties of the material that will be on the surface of the deposit, whether it is dredged material or capping material (Shields and Montgomery 1984; Truitt 1986a, b, c; Dortch 1986; and Randall 1986).

Methods of Monitoring

A number of methods are available for monitoring the postdisposal behavior of subaqueous dredged material deposits. The various methods provide different types, quantities, and accuracies of information. The monitoring method(s) used should be selected to provide the required information and the desired level of accuracy for a particular disposal project.

The three most common methods of monitoring that have been successfully used by the CE (hydrographic surveys, settlement plates, and sediment sampling) are discussed in the following paragraphs. The type of equipment needed, its installation and use, the data provided, and the advantage/limitations of each monitoring method are included. Other commercially available monitoring techniques are then briefly mentioned.

Hydrographic surveys

By far, the most commonly used technique for monitoring settlement of subaqueous deposits is the hydrographic survey. Surveys of this type are typically used to monitor the changes in and condition of subaqueous features. Within the CE, this technique is most often used to evaluate the need for dredging and to verify the effectiveness of the dredging process in shipping channels, harbors, and turning basins. The technology of the hydrographic survey can be applied directly to monitoring the settlement characteristics of dredged material deposits.

Hydrographic surveys measure the depth of water between the survey boat and floor of the body of water. These surveys are usually conducted along parallel transects with equidistant spacing between the transects. The distance between readings taken on the transects and the spacing between adjacent transects determines the resolution of the grid of data collected. By correctly accounting for tidal fluctuations during the survey, elevation of the subaqueous sediment surface can be monitored and changes in elevation over time can be documented. More detailed information on planning and conducting hydrographic surveys can be found in another WES document (Fredette et al. in preparation).

The advantages of using the hydrographic survey are that the necessary equipment is generally available and the technique is applicable in the depths of water that may be encountered at aquatic dredged material disposal sites. A major disadvantage is the level of accuracy that can be attained. The typical accuracy of depth measurements from hydrographic surveys using standard CE equipment is ±6 to 12 in. at best (Clausner and Hands 1988). With this level of accuracy, it is difficult to make reliable measurements of changes in height of dredged material when the changes in height may range from a few inches to 1 to 2 ft. Horizontal positioning accuracy of the survey vessel is another factor which may affect the quality of the survey data.

An additional disadvantage is that hydrographic surveys provide only the total change in elevation of a deposit. The surveys give no indication of the consolidation of individual layers (foundation, dredged material, and capping material) present at a disposal site. Also, the method cannot be used to delineate between changes in mound height due to consolidation and those resulting from surface erosion of the deposited material.

Settlement plates

Settlement plates have been used for a number of years to monitor changes in thickness of various layers of dredged material in confined upland disposal sites. Periodically, settlement plates have been incorporated into the monitoring plans for aquatic disposal sites. The settlement plates described in the following paragraphs were used at an aquatic disposal site that was part of a capping demonstration project on the Duwamish Waterway in the Seattle District (Truitt 1986a, Poindexter 1988).

Telescoping settlement plates were used to measure changes in height of individual material layers at an aquatic dredged material disposal site (Figure 3). The lower tier plate was placed on the foundation soil before the dredged material was deposited. After dredged material disposal, the second tier settlement plate was slipped over the riser pipe of the lower tier and came to rest on the surface of the dredged material. After placement of the cap, the third tier settlement plate was placed over the riser pipe of the second tier, and the plate rested on the surface of the cap. Readings were subsequently made to determine changes in individual layer thicknesses. This provided settlement data for both the dredged material and the capping material. Since the elevation of the lower tier riser pipe had not been determined relative to a

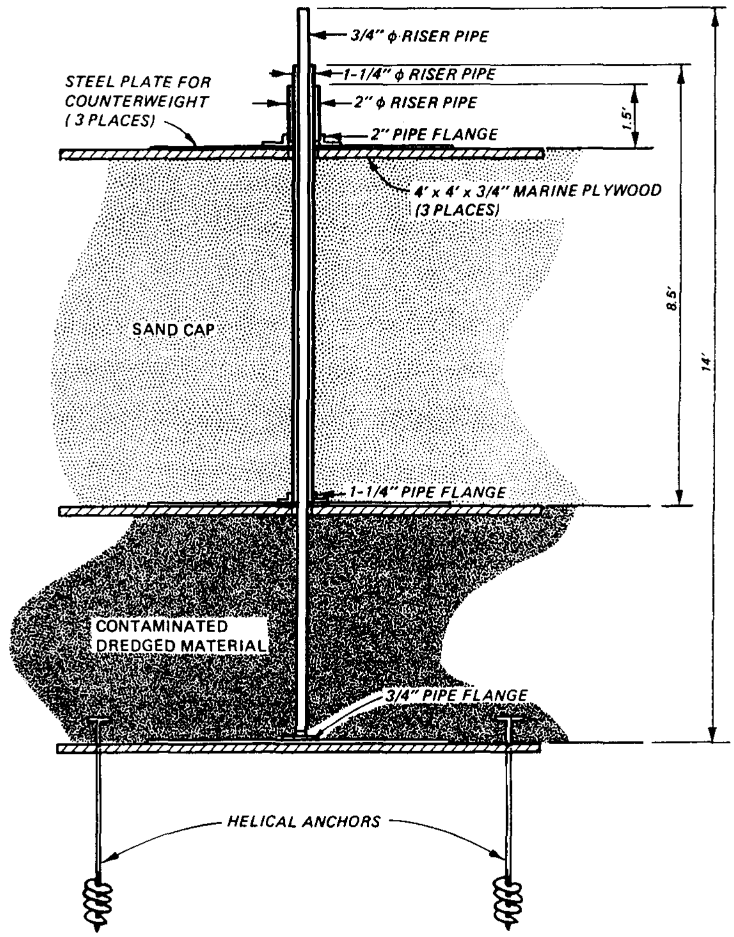

Figure 3. Tiered settlement plate that measures changes in height of individual layers of material (design 1)

stationary benchmark outside the disposal site boundaries, settlement of the foundation soils could not be determined.

Two telescoping settlement plate designs were used at the Duwamish Waterway Site (Poindexter 1988). The major difference in the settlement plates was in the diameter of the riser pipes. Design 1 used a 3/4-in.-diameter pipe as the center pipe, while design 2 used a 2-in.-diameter pipe in the center. Design 2 also used polyvinyl chloride (PVC) pipe on the second and third tier settlement plates since the required diameters of these risers were large and weight of the entire settlement plate assembly needed to be kept to a minimum. Settlement plates in the second and third tiers were designed and fabricated to have a unit weight approximating that of water so that the plates would not sink through the soft dredged material or cause consolidation of the underlying material by acting as a surcharge load.

The two settlement plate designs were used to evaluate the effectiveness of each with regard to withstanding the forces of dredged material disposal and minimizing surface scour after material deposition. Design 1 pipes performed satisfactorily in both aspects. Because of problems encountered during settlement plate installation, no definitive information was obtained on Design 2 pipes.

The advantage of using tiered settlement plates is that exact changes in thickness (settlement) of the various layers of deposited material can be obtained. Furthermore if the elevation of riser pipe from the lower tier settlement plate is related to a known elevation outside of the disposal site, then settlement of compressible foundation soil can also be monitored. When noncompressible material is used as the cap, any changes in cap thickness can be attributed to erosion. Disadvantages of this method are that divers must be used to place the plates and to obtain the settlement readings and the riser pipes/settlement plates may be accidentally disturbed or removed by anchors, cables, or fishing nets. They may also be damaged by the disposal process.

Sediment sampling

After placement of dredged material and capping material, core borings can be taken at specified time intervals to determine profiles of engineering properties. This provides a means of monitoring temporal changes in physical characteristics at the capped site.

Core borings of the sediment to be dredged and deposited dredged material provide information concerning types of material involved in the disposal operation; this information is useful in predicting anticipated behavior of the material as well as in interpreting and understanding observed field behavior (e.g., rate of consolidation and possible erodibility of the material). Sampling also provides data on water contents/void ratios of the material at various times during the dredging/disposal operation; this will allow determination of the effect of various dredging/disposal activities on sediment characteristics. Void ratio data provide needed information about conditions during the consolidation process.

Several methods are available for obtaining samples of sediment before dredging or after deposition of the dredged material at the disposal site. The most commonly used sampling devices are the Vibracore sampler and the gravity piston sampler (also known as the drop tube sampler). However, the sampling method that provides the best undisturbed sample is the Osterberg sampler.

Vibracore sampler. The Vibracore sampler is a device that has been used successfully to obtain samples of sediment from aquatic or open-water environments. Typically 3-in.-diameter cores are taken. The individual sample length is typically 20 ft, although some small devices are only capable of taking 5- to 10-ft samples. Some larger devices may be modified to take samples of 30- or 40-ft lengths. The Vibracore is generally used to sample sands; it has been used to sample some fine-grained material, but the success rate has not been as great for these materials.* A typical Vibracore sampler is shown in Figure 4.

The Vibracore consists of a steel barrel with a plexiglass liner for sample collection and a vibratory driving mechanism mounted on a four-legged tower guide and platform (US Army Engineer District, Savannah 1967). The entire assembly is lowered through the water to the substrate surface by a crane/cable hoist system. After the device has been accurately positioned on the bottom through

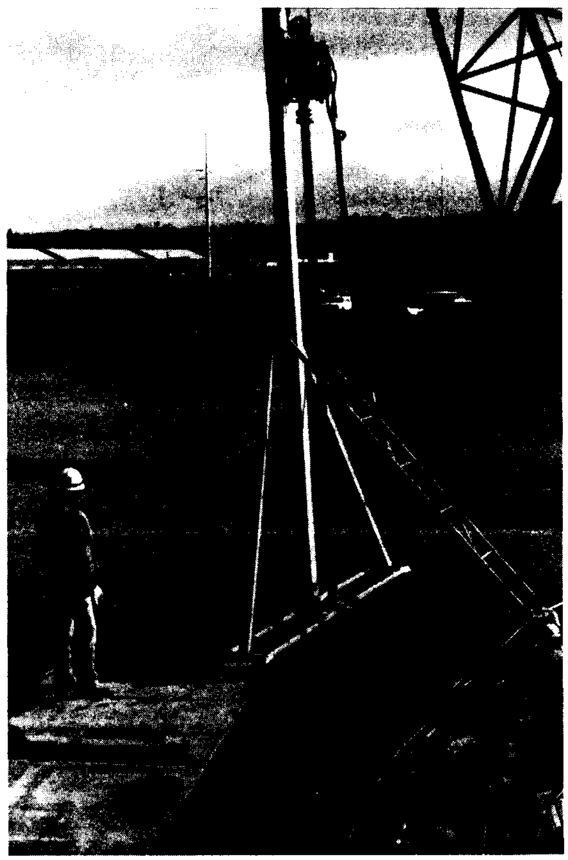

Figure 4. Typical Vibracore sampler being lowered to a subaqueous sampling site

* Patrick A. Douglas, US Army Engineer District, Mobile, personal communication.

the use of standard surveying equipment or navigation-positioning equipment, compressed air is supplied to the vibratory unit through flexible hoses extending from the floating plant down to the Vibracore. Upon application of the compressed air, the oscillating hammer (vibrator) propels the core barrel into the subbottom material. The Vibracore can be equipped with a penetration-recording device that provides a record of the penetration depth and time. After the core barrel has been extended to its full length or until it resists further penetration, the sampler is retracted from the substrate and returned to the floating plant deck. The plastic core barrel containing the sample is then removed from the sampling device, and the ends are capped for sample preservation. The core barrel is later cut open longitudinally to expose the material for visual inspection and collection of specimens for laboratory testing.

Advantages of the Vibracore sampler are the ease, speed, and low cost of sampling by this method. Typically eight to twelve 20-ft cores may be obtained in one day by an experienced sampling crew (US Army Engineer District, Savannah 1967). The major disadvantage is that the vibratory method of driving the sample tube can cause changes in the density of materials sampled: loose sand and silt may be densified while dense material may be loosened during sampling. An additional problem may be encountered if a soft material is overlain by a firmer stratum. In this case, the soft material will be pushed aside instead of entering the sample tube if the shear strength of the soft material is less than the force required to overcome the friction between the firmer material and the sample tube. If a Vibracore sampler is to be used to collect samples from aquatic disposal sites, it is recommended that the penetration-recording device be acquired and used to provide definitive information on depth of penetration.

Gravity core sampler. The gravity core sampler has been used on a number of disposal area monitoring projects. The diameter of the sample typically varies from 3 to 6 in., with the 3-in. diameter being more common. The length of sample retrieved can range from 3 to 20 ft, depending upon the particular equipment used (Stanton, Demars, and Long 1985).

The gravity core sampler consists of a core barrel, penetration weights, and stabilizing fins. The core barrel is equipped with a plastic liner and has a cutting head on the lower end. As the sampling device is lowered through the water, a triggering device is held in place by the tension in a line that is attached to a weight. When the weight reaches the substrate surface, the tension in the line is released and the sampler drops to the bottom and penetrates the

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Other methods

Several remote methods of sampling may prove to be useful in monitoring aquatic disposal sites. These methods include side-scan sonar, subbottom profiling, and various other settlement/pore-pressure monitoring techniques.

In side-scan sonar systems, acoustic energy is projected laterally from a pair of transducers mounted in a cylindrical body (called the "fish") that is towed behind a boat. Electrical energy applied to the piezoelectric transducers in the fish causes them to vibrate, creating pressure waves that travel out through the water. The energy is reflected back from the seabed or structure, picked up by the transducers, and recorded to produce a sonograph. Transducers typically vibrate at 50 to 500 kHz, with 100 and 500 kHz being most common. The 100-kHz frequency provides greater range, up to 1,500 ft on either side, and is most often used for sea-bottom mapping and locating objects. A frequency of 500 kHz gives a shorter range, up to 300 ft on either side, but provides greater detail (Clausner and Hands 1988; Truitt 1986; Coastal Engineering Research Center 1983).

A subbottom profiler operates in the same manner as the side-scan sonar, but it uses a lower frequency acoustic pulse which penetrates the sediments on the bottom. A 3.5- to 14-kHz frequency pulse is typically used for these instruments. The subbottom profiler is pointed straight down and produces an image that delineates the sediment surface and the sediment layers below the surface. In order for the various layers to be distinguishable, there must be a significant difference in material types and the various layers must be at least 2 ft thick. Additional detailed information on acoustical surveying and monitoring techniques may be obtained from Clausner and Hands (1988).

Various techniques have been used on land to investigate both the stratigraphy of an area and the consolidation settlement that occurs. Some of these techniques might be applicable to aquatic dredged material disposal sites. Techniques that might prove useful include settlement probes, liquid settlement systems, and pore-water pressure probes.

Settlement probes of various types can be used as a downhole tool in a borehole. When inserted into a borehole, a settlement probe measures the depth/location of particular objects outside the borehole or attached to the casing; these objects are stationary relative to the adjacent soil. Periodic monitoring can be used to document the consolidation of various layers.

Liquid settlement systems monitor changes in pressure head in a closed system to measure any settlement that occurs. A transducer would normally be installed at the point of interest within the disposal site and the reference liquid reservoir would be installed in a stable location outside the site. Hydraulic lines are needed to connect the transducer to the reference reservoir. A separate system would be required for each point to be monitored within the dredged material deposit.

A pore-pressure probe measures the pore-water pressure existing with depth throughout a soil deposit as the probe is pushed through the soil. Instantaneous readings provide accurate data in sand or other free-draining deposits. In fine-grained materials, probe-induced pore pressures will build up during the process of pushing the probe to the desired location for a reading; therefore, a short time delay must be allowed before the pore-pressure reading is taken in order to obtain an accurate reading.

Summary

When an aquatic site is used for disposal of dredged material, a postdisposal monitoring program should be established to evaluate the stability of the deposit, provide site-capacity data, and expand the available knowledge of the behavior of these deposits for future predictive purposes. The consolidation behavior of all compressible materials, including the dredged material, cap, and foundation soil, should be monitored. A number of monitoring techniques are available. The most commonly used methods are the hydrographic survey, settlement plates, and sediment sampling. Other methods are available but have not been proven in the aquatic dredged material disposal site environment.

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