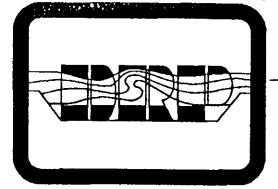


Dredging Research Technical Notes



Fine-Sediment Erodibility Characterization

Purpose

The purpose of this technical note is to set forth a set of characterization test parameters or descriptors for evaluating the erodibility of fine-grained, cohesive sediments at open-water disposal sites.

Background

To establish or manage open-water disposal sites, assessment of the "dispersion" of disposed materials from the site is often required. Dispersion includes both the relatively small losses of material carried away at the time of placement, and the main effect of erosion and transport from the bed under the action of waves and currents. The erodibility of fine-grained sediments depends on a number of parameters. Erodibility and the correlations between erodibility and sediment parameters are both highly variable and difficult to predict. Characterization parameters are a way to key in on erodibility.

This technical note describes tiered laboratory tests which can be applied to provide some characterization parameters and, therefore, an indication of the erodibility of fine-grained dredged material. References are provided for test methodology.

Additional Information

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Scope

This is the first of several DRP technical notes on the erodibility of fine-grained, cohesive sediments. The characterizations described herein provide a relative, rather than an absolute, gage for sediment erodibility. As such,

published values and experience must be used to make the connection between sediment characteristics and specific erodibility values. Erodibility encompasses the threshold flow conditions for erosion, and the erosion rate about the threshold value.

Erodibility characterization is one aspect of an overall study which might include bathymetric, current, wave, and sediment surveys of the site, plus possible contaminant screening of the material to be dredged. These study methods and their planning are important, but difficult to generalize for all situations. Direct methods of assessing sediment dispersion from existing sites (including erosion), such as bathymetric and density surveys, will not be described, but should be considered. In addition to sediment properties, water column conditions, mound formation, slumping, and micro-topography may all be important to sediment dispersion from a disposal site.

Characterization provides basic information on the transport behavior of the fine-grained sediment (Mehta and others 1989). A suite of tests is required because no single parameter can be used to predict transport behavior. Erodibility is the main transport process under consideration here. However, if the initial dispersion of sediments in suspension is of concern, then certain deposition characteristics come into play. Also, in critical situations such as those involving contaminated sediments or in sensitive environmental settings, direct testing of erodibility may be indicated. Therefore, to cover the expected range of study concerns, three levels of characterization are proposed here. Characterization tests are described in three sections: basic, extended, and complete. Analytical methods will be cited, but details will not be presented.

Basic Sediment Characterization

The erodibility of fine-grained, cohesive sediments is related to interparticle cohesion, and hence on the physicochemical characteristics of the sediments and the fluids involved. Cohesive sediments form electrochemical bonds which must be broken before erosion can take place. For field-wet sediment samples, the following characterizations are recommended: grain size distribution, density or related parameters, cation exchange capacity, and total organic content. Analytic methods can be found in Plumb (1981), Black (1965), and US Army Corps of Engineers (USACE) (1970).

Use hydrometer, pipette, or other fine-sediment sizing method to extend grain size determination to the silt-clay fraction. Avoid chemical and physical alterations to samples. Analyses should be conducted on dispersed sediments which have never been dry or lost substantial moisture.

The erodibility of fine-grained sediments is strongly related to its bulk wet density (Teeter 1987). Bulk density should be measured in dredged and in situ materials using reliable devices such as nuclear probes, or gravimetric analyses should be performed on representative samples. Sediment density, or related parameters such as solids content, is an important indicator of the

sediment structure. Proposed power law relationships between solids content and erosion threshold have exponents of 2 to 3.5 (generally 2.5). Settled sediment aggregates are progressively crushed by overburden into more compact orientations with greater erosion resistance.

The ability to exchange positive salt ions, or cation exchange capacity (CEC), is a measure of the activity of the cohesive fraction of the sediment. CEC, usually expressed as milliequivalents (meq) per 100 g dry sediment, depends on surface charge density and surface area per unit dry weight of clays and fine silts. A meq is one-thousandth of a gram-equivalent weight or mole.

Clay content and mineral type are the principal factors affecting CEC. Organic matter also affects CEC and is normally removed before analysis. If organics are not removed, then the CEC reflects the total material. CEC provides a measure of the potential interparticle bond strength, depending on the ions actually available in the sediment or eroding fluids, and on the presence of colloidal organics. Typical ranges of values for CEC (Teeter and Pankow 1989) found in the literature are:

<u>Mineral Fraction</u>	<u>CEC, meq/100 g</u>
Kaolinite	1-15
Illite	10-40
Montmorillonite	50-150
Chlorite	10-40
Vermiculite	100-150
Organic fraction of solids	150-500

In general, the greater the CEC, the more erosion resistant the material.

Characterizations on fluids should include in situ sediment pore fluids and the receiving water column, including major cations and anions, total salt content, pH, temperature, and dissolved oxygen and oxidation/reduction potential.

Dissolved salts compress the ionic layer surrounding particles. Higher salt content makes particle collisions (as from Brownian or settling motions) more effective at forming interparticle bonds. Major cations usually include sodium (Na⁺), calcium (Ca⁺⁺), and magnesium (Mg⁺⁺). Major anions include chloride (Cl⁻) and sulfate (SO₄⁻⁻).

The ratio of Na⁺ to other major cations can be used to compute the sodium adsorption ratio (SAR):

$$SAR = \frac{[Na^+]}{\left\{ \frac{1}{2} [Ca^{++}] + \frac{1}{2} [Mg^{++}] \right\}^{1/2}}$$

where the variables inside the square brackets indicate concentration in meq per liter. SAR is used to predict when a suspended particle in equilibrium with the surrounding fluid will become cohesive. Both SAR and concentration of salts in pore fluids have a significant effect on erosion threshold. The higher the salt content and lower SAR, the greater the threshold value. Salt content and SAR of the eroding fluid also affect erosion threshold.

The pH and redox potential of a fluid also affect particle surface charge and cohesion. Temperature inversely affects interparticle attraction.

Extended Sediment Characterization

A more in-depth characterization of erodibility and an assessment of transport characteristics involved in deposition can be made by performing the basic tests plus the following: mineral composition determination, rheological testing, consolidation testing, and settling testing. Mineral composition tests should include both clay and nonclay components. See Black (1965) for X-ray diffraction methods of identification.

Rheological testing gages the stress-strain relationships of the material and should concentrate on low-shear viscosity and apparent yield stress. Researchers have related rheologic and erosion properties of fine-grained sediments. The Bingham Plastic model can be applied to the data to estimate yield stresses at various sediment concentrations. Other models can be used to estimate a limiting low-shear viscosity, related to the Bingham yield stress.

Consolidation testing should identify vertical density profiles as well as settling rates. Methods are described by USACE (1970) and Teeter and Pankow (1989). Special laboratory testing (Cargill 1982) will be required if void ratio-effective stress relationships are required for consolidation modeling (Poin-dexter-Rollings 1990).

Although settling is unrelated to erosion, the dispersion of suspended material from the disposal site may be an issue that would require estimates of settling rates and critical shear stresses for deposition. The former can be determined by settling tests. Settling rates depend on suspension concentrations, indicating that a representative range should be tested. Native water should be used (Teeter and Pankow 1989).

The critical shear stress for erosion of newly deposited sediments approaches the critical shear stress for deposition. Therefore, the critical shear stress for deposition can be estimated from the aggregate yield strength obtained by rheological tests at low suspension concentrations.

Complete Sediment Characterization

Basic and extended characterization tests are recommended before proceeding with direct laboratory erosion testing. Several erosion processes or modes have been previously identified, most involving critical or threshold shear stresses, and erosion rate constants of various forms. The first problem will be to identify the most important erosion mode for the particular situation and to design a test plan accordingly. Erosion modes include: entrainment, particle, significant particle, mass, and abrasion.

Static fine-grained suspensions undergo entrainment into the flow depending on local velocity and density gradients. Static suspensions are defined as having no interparticle bond strength nor effective stress. Particle and significant particle erosion modes are bed-surface erosion phenomena. Interparticle bonds are disrupted individually or in small groups (respectively) by the local applied hydraulic shear stress. Mass erosion occurs if the bed is subjected to sudden large shear stresses, and the bed fails at some plane below the bed surface. Dense clays which can withstand extreme clear-water flows can be abraded by saltating sands in much milder flows.

There are no standard methods for erosion testing. Sediment beds are either deposited from suspension or molded into an apparatus for erosion testing. If the bed is deposited, a suitable time for settling, gelling, and consolidation must be allowed. Gelling requires about one day, and consolidation times of a few days to a week or two are typically allowed.

Future DRP technical notes will discuss erosion testing and cohesive sediment erodibility more completely.

Summary

Characterization of fine-grained, cohesive sediments for erodibility was recommended at three levels as follows:

Level	Tests
Basic - sediments	grain size density or related parameters CEC
- fluids	total organic content major ions, total salts pH, temperature, dissolved oxygen / redox
Extended	mineralogy rheology consolidation settling
Complete	all of the above direct erosion observation

Conclusions

Cohesive sediment erodibility varies widely depending on sediment composition, condition, and other factors. Judgments and interpretations of reported erodibility values should be based on the important parameters presented earlier.

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