# Fine Sediment Parameter Measurement for Sedimentation Studies

T. M. Parchure, T. M. Sobecki and T. C. Pratt
US Army Engineer Research and Development Center
Coastal and Hydraulics Laboratory, Vicksburg, MS 39180
e-mail: parchut@wes.army.mil

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## Abstract

Various types of sediment studies are conducted by the US Army Engineer Research and Development Center (ERDC) on projects that may have single or multiple objectives. Such studies include collection of field data, laboratory analysis, and numerical or analytical modeling. Field data consists of bed samples, water samples, and measurement of tides and currents. Analysis of sediment and water samples consists of determining a large number of parameters depending upon the type of sediment and objectives of study. The process of sediment analysis is called sediment characterization. Characterization of fine, cohesive sediments is more important than that of coarse, non cohesive sediments because of the large number of parameters (beyond particle size and density) that affect the mechanical properties of cohesive sediments and hence their erosional and depositional behavior. Sediment characterization consists of determining important properties, parameters and indices that describe sediment, sediment bed, eroding fluid, and pore fluid. The large number of parameters may be grouped in several ways. In the present paper 59 parameters / indices are combined under 9 groups. A list of parameters and the corresponding instrument or measuring technique is given for each. In addition, a list of special equipment and devices used for laboratory and field parameters is given. Research results have shown that properties and behavior of fine sediments are greatly influenced by several parameters. With the current knowledge on the fine sediment properties and processes, the most important factors can be determined only by conducting laboratory experiments on representative site-specific sediment samples collected from field. There is a need to identify a few selected parameters from the large number of known parameters that must be measured. There is also need for development of inexpensive equipment and procedures for testing of fine sediments.

## Introduction

Sediments occurring in nature at most project sites consist of a wide range of sediment types. Sediments from the size of boulders down to sand are called coarse or non-cohesive sediments whereas small-size sediments in the range from fine silt down to clay-size are called fine sediments or cohesive sediments. Often times, the fine sediments contain organic matter, which may have considerable influence on the behavior of the sediment, particularly in regard to dispersion / flocculation phenomena and ultimately sediment settling, deposition and resuspension. These processes are critical to an understanding of the fate and transport of fine sediment in natural and anthropogenic environments. Mathematical expressions that describe the transport processes of the cohesive and the non-cohesive sediments are significantly different. Hence the two types of sediments need to be analyzed separately.

The primary parameters to be considered for the non-cohesive sediments consist of particle size, particle density, and critical shear stress for incipient motion. These parameters are used in the equations for bed load and suspended load computations. For fine sediments, the processes of erosion, transport, deposition, consolidation and resuspension are very complex and quite different from those for the coarse sediments. In a typical estuarine environment, these processes take place in a cyclic order (Mehta et al., 1982). Due to self-weight compaction, fine sediment beds have bed density and shear strength increasing with depth below interface. Under certain natural circumstances, the time available for the sediment consolidation process may be relatively very small. Hence a very thin and easily erodible layer (on the order of a few-centimeters thick) is formed at the surface of the sediment bed. This thin layer between the water column and firm bed is in the form of fluid mud. Fluid mud is a suspension, which by definition is essentially fluid-supported and does not have any effective shear strength. The parameters and indices related to fine sediments along with common and special instrumentation used for measuring several of these parameters have been listed in this paper.

A distinction needs to be made between the fundamental properties and test parameters or indices used for describing the sediments, sediment beds or fluids. For instance, salinity of water (expressed as percent weight of total dissolved solids or as specific conductance) is a basic property whereas the Sodium Adsorption Ratio (SAR) is a derived index property that expresses the relative abundance of sodium versus calcium plus magnesium ions in a fluid. Moisture content is a basic parameter whereas liquid limit and plastic limit are soil mechanical indices that can quantitatively predict the expected behavior of soil or sediment.

## SEDIMENTATION STUDIES

The Coastal and Hydraulics Laboratory (CHL) at the US Army Engineer Research and Development Center (ERDC), Vicksburg, MS has two groups involved in sedimentation studies. One group undertakes field data collection and their analysis in order to characterize and document sediment behavior in field settings. . Field data consists of bed samples, water samples, and measurement of tides and currents. Analysis in a sediment laboratory includes determination of particle size distribution, total organic contents, erosion rates of sediment beds, and fall velocity of sediments. The second group conducts analytical computations, desktop studies and numerical hydrodynamic, sediment and water quality modeling that attempts to understand and predict sediment behavior in the field and validate these predictions against field data.

Sediment studies for typical US Army Corps of Engineers (USACE) projects may have single or multiple objectives, such as: 1. Predict change in shoaling in harbors and navigation channels resulting from project modification. 2. Estimate effects of a new project on bank erosion. 3. Design sediment traps and bank protection structures. 4. Reduce or eliminate sediment shoaling from areas of interest through structural and non-structural methods. 5. Estimate sediment resuspension caused by vessel-induced waves. 6. Selection of open water site for placement of dredged material.

## Fine Sediment Erosion and Deposition

Freshly deposited fine sediment beds are easily erodible under small (0.1 Pa or less) flow-induced or wave-induced bed shear stress. Highly compacted cohesive sediments may have very high shear strength (more than 10 Pa) and are difficult to erode. Fine sediment beds are classified as (a) uniform, which has a constant shear strength over depth, (b) stratified, which has layers of varying shear strength, and (c) fluid mud, which has negligible shear strength. The erosional properties of these are quite different, requiring use of correspondingly different mathematical equations for each. The entrainment of sediment due to hydrodynamic instability at the interface resulting in the generation and breakup of fluid mud has been described in terms of the balance between production of turbulent kinetic energy, buoyancy work in entraining sediment, and viscous energy dissipation (Kranenburg 1994). This process is distinct from surface erosion of sediment flocs, which occurs over a consolidated cohesive sediment bed. In describing such behavior it is therefore essential to determine the type of sediment bed and select an appropriate mathematical formulation.

## Sediment Characterization

Field observations of Sanford (1994) have shown that the estimated shear stress that resulted in the largest resuspension was about four times smaller than the estimated shear stress that produced a lower resuspension at the same site. This apparently contradictory result has been explained by the fact that the sediments were less erodible during the period of higher stress than they were during lower stress. Hence characterization of fine, cohesive sediment beds is more important than that of coarse, non cohesive sediment beds because of the large number of parameters (beyond particle size and density) that affect the mechanical properties of cohesive sediments and hence their erosional and depositional behavior. Sediment characterization consists of determining important properties, parameters and indices that describe sediments, sediment bed, eroding fluid, and pore fluid. This requires extensive laboratory testing, which can be expensive and time consuming. Methods for analysis of water and sediment are given by Black (1965), US Army Corps of Engineers (1970), Bowels (1980), and Plumb (1981). 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) is required if void ratio-effective stress relationships are required for consolidation modeling.

## Fine Sediment Parameters and Measurement

A very large number (close to about sixty) parameters and indices have been identified by researchers that influence the properties and behavior of fine sediments. Teeter (1990) suggested 14 parameters grouped under three levels for fine sediment characterization, namely a) Basic sediments, b) Basic fluids, and c) Extended analysis. Mehta (1992) grouped 32 of these parameters under three categories, namely a) Physicochemical properties of fluid, b) Physicochemical properties of the mud, and c) Water-mud exchange processes. However, all the parameters can be grouped in many different ways. The important parameters and instrumentation / methods used for their measurement / determination are listed below.

1. <u>Sediment (i.e. properties independent of fabric)</u>

   1. Mineralogical composition
      X-Ray diffraction, Differential thermal analysis (DTA), total elemental analysis, cation-exchange capacity (CEC), specific surface area
   2. Particle Size Distribution
      Sieve analysis, Coulter counter, Laser particle size analyzer, Sedimentation techniques using Hydrometer
   3. Median and Mean Diameter
      From the plot of particle size distribution
   4. Percentage of clay (sediment finer than 4 micron size)
      Laser particle size analyzer, sedimentation
   5. Percentage of silt and clay (sediment finer than 64 micron size)
      Wet sieving through 64 micron (200 mesh) sieve
   6. Surface reactivity parameters
      a. Braun-Emmet-Teller (BET) for CEC,
      b. Inert gas adsorption for surface area,
      c. Organic molecule retention for interlayer surface area,
      d. Anion/cation retention reactive surface area,
      e. Zeta-potential for Zero-point of charge,
   7. Particle Density
      Pycnometer
   8. Total carbonate contents
      Acid dissolution, evolved gas detection, thermogravitetric analysis

2. <u>Sediment Bed</u> (i.e. sediment properties imparted by fabric)

Some of these parameters are measurement techniques as opposed to fundamental properties, for example electrophoretic mobility.

   1. Type of bed: deposited / compacted / fluid mud
      Infer from bed shear strength
   2. Total Organic Content
      Loss on ignition (LOI), wet oxidation
   3. Bulk Density
      Compute from moisture content, Weight and volume measurement, Water displacement of coated natural fabric samples, Gamma ray techniques
   4. Moisture Content
      Gravimetric, time-domain reflectometry, capacitance
   5. Void Ratio
      Derived from bulk density
   6. Vertical density and shear strength profile
      Calibrated X-Ray scanner, Penetration resistance
   7. Redox potential
      Electrodes, Dissolved Oxygen measurements, Chemical composition
   8. Viscosity
      Viscometer, Rheometer
   9. Bingham Strength and Yield Strength

Viscometer or Rheometer plots

10. Liquid Limit
    Liquid Limit Device with grooving tool / Fall Cone
11. Plastic limit
    Atterburg Limits Procedure
12. Plasticity Index
    Liquid Limit minus Plastic Limit
13. Shrinkage Limit
    Shrinkage Limit Equipment, Linear Extensibility
14. Dispersability/Stability
    Zeta potential, zero-point of net salt effect, exchangeable sodium percentage and sodium adsorption ratio of saturated paste extract
15. Shear strength
    Shear Box Apparatus, Vane Shear Apparatus

3. <u>Eroding Fluid</u>
   1. Salinity profile as a function of water depth
      Use of Salinometer on the field water samples
   2. Chemical / ionic Composition
      Ion probes
   3. pH
      pH Meter
   4. Temperature
      Mercury Thermometer
   5. Sodium Adsorption Ratio (SAR)
      Strength of Sodium Potassium and Magnesium ions
   6. Fluid turbulence intensity
      Compute Reynolds number from flow velocity, flow depth and kinematic viscosity of fluid
   7. Turbidity
      Nephelometer
   8. Fluid density
      Pycnometer

4. <u>Pore Fluid</u>
   1. Salinity
      Salinometer
   2. Chemical / ionic Composition
      Ion probes
   3. pH
      pH Meter
   4. Temperature
      Mercury Thermometer

5. Erosion
    1. Critical shear stress for erosion
       Erosion apparatus such as flume or PES
    2. Rate of erosion
       Erosion apparatus such as flume or PES
    3. Mode of erosion, namely floc erosion, layer erosion and mass erosion
       Visual observation during erosion tests and measured erosion rates under different bed shear stresses
    4. Erosion rate constant
       Conduct erosion experiments and plot results
    5. Sediment flux rate
       Compute from erosion test data

6. Dispersion and Transport
    1. Suspended sediment concentration
       Total suspended sediment concentration determined from water samples
    2. Sediment influx rate
       Computation of sediment budget
    3. Sediment-induced density profiles with depth
       Determine suspended sediment concentration in water samples

7. Settling and Deposition
    1. Critical shear stress for deposition
       Flume experiments
    2. Median settling velocity
       Owen Tube
    3. Settling velocity as a function of suspension concentration
       Settling column measurements
    4. Settling velocity as a function of salinity
       Settling column measurements
    5. Potential for floc formation
       Infer from data on clay minerals and fluid properties

8. Consolidation
    1. Consolidation rate
       Measurements in calibrated cylinders
    2. Bed density profile as a function of time and depth
       Calibrated X-Ray scanner
    3. Permeability
       Constant head method
    4. Pore pressure
       Pore Pressure Apparatus

9. Natural Factors Influencing Sedimentary Processes
    1. River / Lake Water Level

Water level gages
2. Tidal Level
Tide gages
3. Currents
Current meters, Acoustic Doppler Current Profiler (ADCP)
4. Waves
Wave gages, Wave Buoys, Ship Reports, Data from Internet
5. Wind
Anemometers, Weather station data, Internet data
6. Vessel Traffic
Data from navigation controlling authority
7. Estuary type: Fully stratified, Partly stratified or well mixed
Interpretation of vertical salinity profiles

## SPECIAL EQUIPMENT AND DEVICES

Considerable research has been conducted worldwide to measure influence of various parameters on the most important properties of cohesive sediment beds, namely the critical shear strength for erosion, shear strength of bed and the erosion rate. Measurable parameters are very site-specific and show a large variation in their values. Results of laboratory and field experiments are available, which offer correlations of these parameters with the measurable properties of sediments, beds and fluid. However, as of now, the above-mentioned three parameters cannot be analytically calculated based on any of the measured parameters. Hence the only way to get them is by conducting laboratory experiments. Special equipment and devices have been custom-made by researchers all over the world for determining the erosional and depositional properties of cohesive sediments. Lee et al., (1994) have conducted a comprehensive literature review and have described many such devices that have been used in laboratory and field all over the world. A list of device types is given below. The same type of device used in different laboratories has considerable variation in the dimensions and operational methods.

Laboratory Devices

1. Straight flume
2. Rotating annular flume
3. Race track flume
4. Rocking flume
5. Close conduit sediment water tunnel
6. Rotating cylinder apparatus
7. Vertical grid oscillator, also called as Particle Erosion Simulator (PES)
8. Settling columns used for measuring fall velocity

Field Devices

1. Submerged jet
2. Field inverted channel
3. Field rotating annular flume
4. Field probes for measuring parameters such as bulk density and shear strength
5. Fluid Mud Sampler
6. Water sampler
7. Surface bed sediment sampler
8. Bed coring tubes

## CONCLUDING REMARKS

Research results have shown that properties and behavior of fine sediments are greatly influenced by several parameters. With the current knowledge on the fine sediment properties and processes, it is not possible to predict the most important factors such as the shear strength, critical shear stress for erosion, erosion rate, settling velocity and so on. These can be obtained only by conducting laboratory experiments on representative site-specific sediment samples collected from field. There is a need to identify a few selected parameters from the large number of known parameters that must be measured. There is also need for development of inexpensive equipment and procedures for testing of fine sediments.

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