

CHAPTER 3

LABORATORY TESTING

3-1. General.

a. Laboratory tests as described are required primarily to provide data for sediment characterization, containment area design, and long-term storage capacity estimates. The laboratory tests and procedures described in this chapter include standard tests that generally follow procedures found in Standard Methods (item 2) and EM 1110-2-1906. A flowchart illustrating the complete laboratory testing program for sediment samples is shown in Figure 3-1. Sediment characteristics and requirements for settling data and for long-term storage capacity estimates will dictate which laboratory tests are required.

b. The required magnitude of the laboratory testing program is highly project dependent. Fewer tests are usually required when dealing with a relatively homogeneous material and/or when data are available from previous tests and experience. This is frequently the case in maintenance work. For unusual maintenance projects where considerable variation in sediment properties is apparent from samples or for new work projects, more extensive laboratory testing programs are required. Laboratory tests should always be performed on representative samples selected using sound engineering judgment. The potential presence of contaminants should be evaluated when planning a laboratory testing program, and appropriate safety measures should be considered.

c. In some cases, recurring maintenance dredging is performed on given channel reaches. Laboratory test data from previous sampling efforts may be available. Under such conditions, sediment characterization tests may be the only laboratory testing required. Additional settling tests or consolidation tests are not required if it has been satisfactorily determined by prior testing that the settling and consolidation properties of the sediment to be dredged have not changed.

3-2. Sediment Characterization Tests.

a. General. A number of sediment characterization tests are required before the tests essential to design can be performed. Visual classification will establish whether the sediment sample is predominantly fine-grained (more than half <No. 200 sieve) or coarse-grained (more than half >No. 200 sieve). Tests required on fine-grained sediments include natural water content, Atterberg limits (LL), organic content, and specific gravity. The coarse-grained sediments require only grain size analyses. Results of these tests can be used to classify the sediments according to the Unified Soil Classification System (USCS) (item 33).

b. Salinity. Near-bottom water samples from the area where water will be mixed with sediment during the dredging or pump-out operation (usually dredging site water) should be tested for salinity. In estuarine environments, the salinity may vary with depth, flow, wind, tidal cycle, and season. Therefore, it is important to know the expected range of salinity during the dredging project. If the dredging site water is saline (>1 part per

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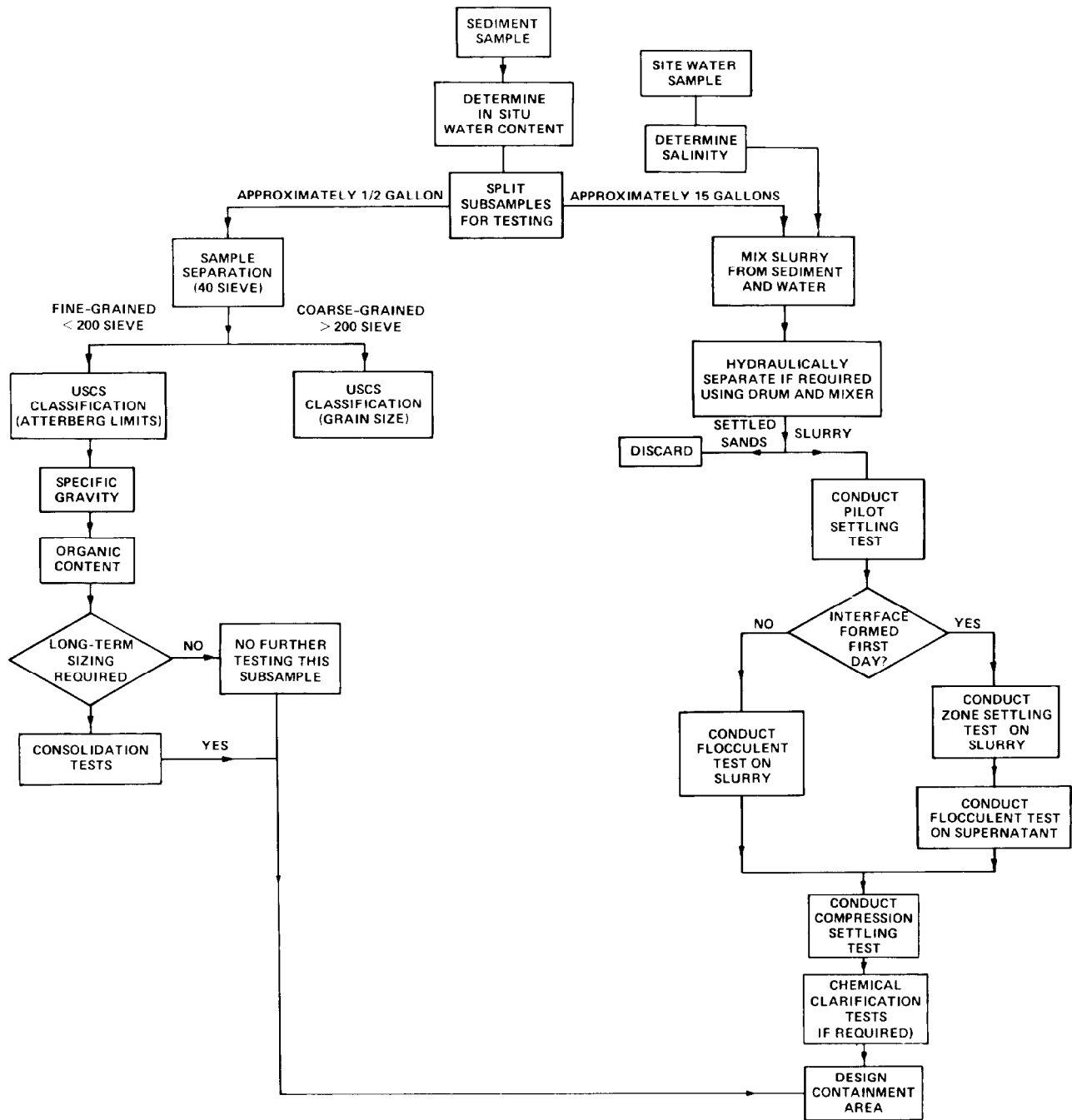


Figure 3-1. Flowchart depicting laboratory testing program for sediment samples

thousand), water gathered during the field investigation or reconstituted salt water should be used when additional water is required in all subsequent characterization tests and in the settling tests. Salinity may be measured in two ways:

(1) Conductivity. The salinity may be measured directly by a salinity-conductivity meter that electronically converts temperature-adjusted electrical conductivity into salinity.

(2) Dissolved solids or nonfiltrable residue. A detailed procedure is presented in Standard Methods for the Examination of Water and Wastewater (item 2). Briefly,

(a) Filter water through a filter that has a pore size of 1 micron or less.

(b) Pipette a known volume (about 25 millilitres) into a weighed dish and evaporate the sample 4 to 6 hours in a drying oven at 103° to 105° C.

(c) Cool the dish in a desiccator and then weigh immediately.

(d) Salinity (in parts per thousand) is equal to the residue (in milligrams) divided by the sample (in millilitres).

c. Water Content. Water content* is an important factor used in sizing dredged material containment areas. Water content determinations should be made on representative samples from borings or grab samples of fine-grained sediment obtained in the field investigation phase. The water content of the sample should be determined prior to sample homogenization and separation as described below. The detailed test procedure for determining the water content is found in Appendix I of EM 1110-2-1906. The water content is expressed on a dry weight basis as follows:

$$w = \frac{W_w}{W_s} \times 100 \text{ percent} \quad (3-1)$$

where**

w = water content, percent*

W_w = weight of water in sample, grams

W_s = weight of solids in sample, grams

d. Solids Concentration.

(1) General. The suspended solids concentration is the most frequently measured parameter in the laboratory procedures. This measurement is made during preparation of slurries and suspensions and during evaluation of settling characteristics, treatment effectiveness, etc. Three methods may be

* It should be noted that the term "water content" as used in this manual refers to the engineering water content commonly used in geotechnical engineering and may exceed 100 percent.

** For convenience, symbols and unusual abbreviations are listed and defined as appropriate throughout the text.

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used to measure suspended solids: evaporation, filtration, and centrifugation. Each is applicable under different circumstances. Evaporation (direct drying) measures total solids, i.e., the sum of both suspended and dissolved solids. The dissolved solids concentration, if significant, must be measured separately and subtracted from the total solids concentration. Filtration directly measures suspended solids. Centrifugation is a blend of the other two methods. It attempts to measure suspended solids by measuring the total solids after washing the dissolved solids out of a known volume of sample. The procedures outlined below are adapted from the methods given in Palermo, Montgomery, and Poindexter (item 26). In practice, there has been confusion concerning the method of reporting suspended solids. The terms "concentration in grams per litre," "percent solids by weight," "percent solids by volume," and "percent solids by apparent volume" have been used. These methods of reporting suspended solids concentration are discussed and compared in Table 3-1. The relationship of percent suspended solids by weight and volume, concentration in grams per litre, and water content is illustrated in Figure 3-2. Figure 3-2 does not account for salinity in the sample. Suspended solids concentration in grams per litre or milligrams per litre is used throughout this manual. If suspended solids determinations are to be made on samples with a solids concentration of 1 gram per litre or less, the centrifugation or the filtration method should be used. The total solids method or

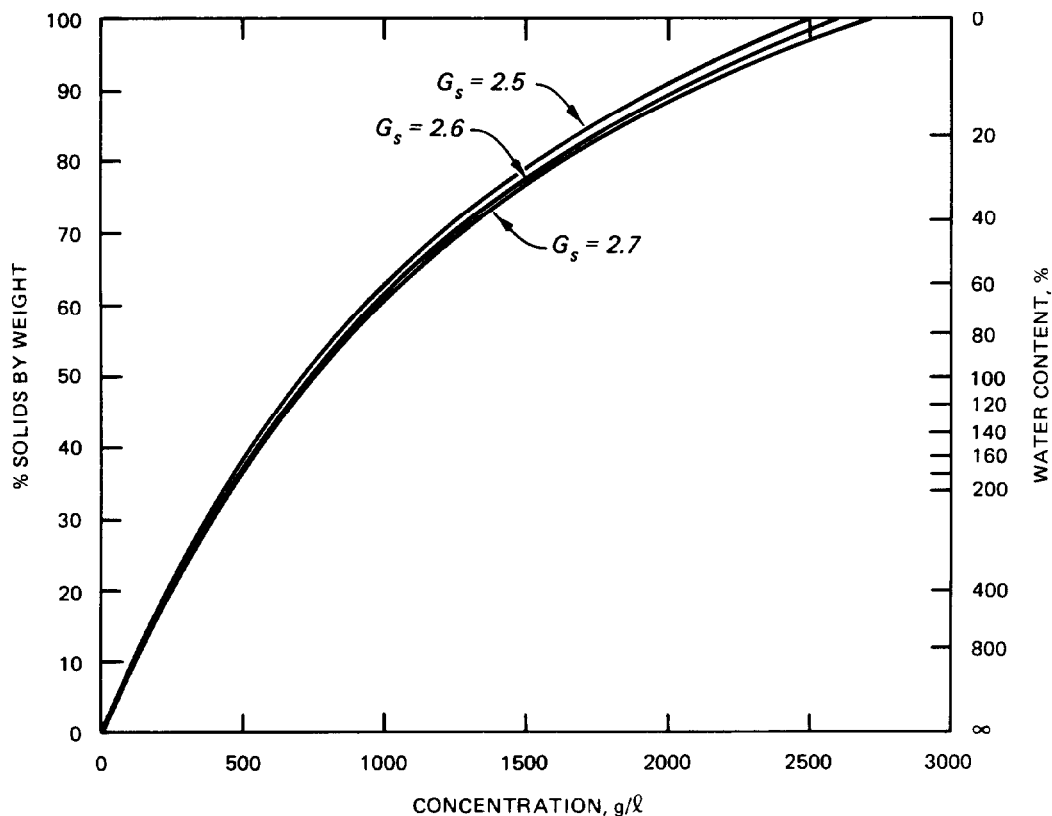
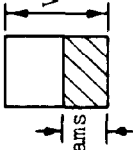
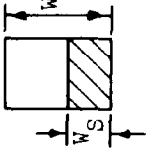
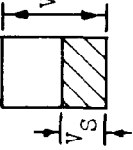
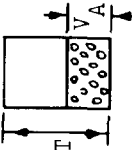


Figure 3-2. Relationship of concentration in percent solids by weight, percent solids by volume, concentration in grams per litre, and water content

Table 3-1
Methods of Reporting Suspended Solids

Method of Reporting Suspended Solids	Weight-Volume Relationship	Method of Computation	Remarks
grams per litre or milligrams per litre	 $V_T = 1 \text{ litre}$ $W_S, \text{ grams}$	<p><u>Preferred Method</u></p> $S = \frac{W_S}{V_T}$	Common method for reporting dissolved chemical concentrations. Best method for engineering purposes
percent by weight	 W_T W_S	<p><u>Other Methods</u></p> $S = \frac{W_S}{W_T} 100$	Easy to determine by laboratory test. Does not require value for specific gravity
percent by volume	 V_T V_S	$S = \frac{V_S}{V_T} 100$	Easy to determine by laboratory test. Requires determination of percent by weight and value for specific gravity
percent by apparent volume	 $V_T = V_S + V_I$ V_A V_I	$S = \frac{V_A}{V_T} 100$	Apparent volume determined by settled solids for a bottle or flask. No standardized procedure available. Void ratio of settled solids varies with type of sediment. Can lead to errors because of nonstandard test. Not recommended. Value is meaningless in engineering calculations
Note:	W_S = oven-dry weight of solid particles V_T = total volume W_T = total weight	V_S = volume of solid particles V_A = apparent volume of settled solids V_I = volume of interstitial water	

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the centrifugation method should be used for slurries with solids concentrations of 1 gram per litre or more.

(2) Definitions and conversions.

(a) The percent of total solids by weight is the weight of solids both nonfiltrable and filtrable (both dissolved and suspended) in a sample divided by the weight of the sample.

$$\%S = \frac{W_s}{W_t} (100 \text{ percent}) \quad (3-2)$$

where

$\%S$ = percent total solids by weight, percent

W_t = total weight of sample, grams

(b) The percent of suspended solids by weight is the weight of solids less the weight of dissolved solids in a sample divided by the weight of the sample.

$$\%SS = \frac{W_s - \frac{(W_w \text{ Sal})}{1,000}}{W_t} (100 \text{ percent}) \quad (3-3)$$

where

$\%SS$ = percent suspended solids by weight, percent

Sal = salinity, parts per thousand

(c) Solids concentration is the weight of solids (dissolved and suspended) in a sample divided by the volume of sample.

$$C_s = \frac{W_s}{V_t} \quad (3-4)$$

where

C_s = solids concentration, grams per litre

V_t = sample volume, litre

(d) Suspended solids concentration is the weight of suspended solids in a sample divided by the volume of sample.

$$C = \frac{W_{ss}}{V_t} \quad (3-5)$$

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where

C = suspended solids concentration, grams per litre

W_{ss} = weight of suspended solids in sample, grams

= $W_s - [W_w (\text{Sal}/1,000 \text{ parts per thousand})]$

(e) The percent of suspended solids by weight may be converted to concentrations in units of grams per litre by the following formula:

$$C = \frac{(1,000 \text{ g/l}) G_s \left[1 + \left(\frac{\text{Sal}}{1,000 \text{ ppt}} \right) \right]}{G_s \left[\left(\frac{100\%}{\%SS} \right) - 1 \right] + \left[1 + \left(\frac{\text{Sal}}{1,000 \text{ ppt}} \right) \right]} \quad (3-6a)$$

where

G_s = specific gravity of suspended solids particles

(f) Suspended solids concentrations presented in units of grams per litre may be converted to percent of suspended solids by the following formula:

$$\%SS = \frac{100\% G_s \left(\frac{C}{1,000 \text{ g/l}} \right)}{G_s \left(\frac{C}{1,000 \text{ g/l}} \right) + \left[G_s - \left(\frac{C}{1,000 \text{ g/l}} \right) \right] \left[1 + \left(\frac{\text{Sal}}{1,000 \text{ ppt}} \right) \right]} \quad (3-6b)$$

(g) Suspended solids concentrations can be calculated from total solids concentrations by the following equations if the salinity is known and the total solids concentration is presented in percent of solids by weight.

$$\%SS = \%S - \left[(100\% - \%S) \left(\frac{\text{Sal}}{1,000 \text{ ppt}} \right) \right] \quad (3-6c)$$

$$\%S = \frac{\%SS + 100\% \left(\frac{\text{Sal}}{1,000 \text{ ppt}} \right)}{1 + \left(\frac{\text{Sal}}{1,000 \text{ ppt}} \right)} \quad (3-6d)$$

$$C_{ss} = \frac{(1,000 \text{ g/l}) G_s \left[1 + \left(\frac{\text{Sal}}{1,000 \text{ ppt}} \right) \right]}{\left[1 + \left(\frac{\text{Sal}}{1,000 \text{ ppt}} \right) \right] + G_s \left\{ \left[\left(\frac{\%S}{100\%} \right) \left(1 + \frac{\text{Sal}}{1,000 \text{ ppt}} \right) - \left(\frac{\text{Sal}}{1,000 \text{ ppt}} \right) \right] \right\}} \quad (3-6e)$$

(3) Total solids method. This test is used when the suspended solids concentration is large, compared to dissolved solids. It may be used in other cases where the dissolved solids or salinity is known or measured separately. To ensure accuracy, the test should generally be used only for a suspension with a suspended solids concentration greater than 1 gram per litre. These steps should be followed:

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- (a) Obtain tared weight of a sample dish.
- (b) Thoroughly mix sample and pour into sample dish.
- (c) Weigh dish and sample and place in drying oven at 105° C until sample has dried to a constant weight (about 4 to 6 hours).
- (d) Cool in desiccator and then weigh immediately.
- (e) Calculate suspended solids concentration C , in grams per litre, as follows:

$$C = \frac{W_{ss} (1,000 \text{ g/l})}{\left(\frac{W_{ss}}{G_s}\right) + W_w} \quad (3-7)$$

from before

$$W_{ss} = W_s - [W_w (\text{Sal}/1,000 \text{ parts per thousand})]$$

$$W_s = [(\text{weight of dry sample and dish}) - (\text{weight of dish})]$$

Sal = salinity, parts per thousand, or dissolved solids, grams per litre; if unknown in freshwater environments, use zero

G_s = specific gravity of solids; use 2.67 if unknown

W_w = [(weight of wet sample and dish, grams) - (weight of dry sample and dish, grams)]

(4) Filtration method. This method should be used for suspensions having suspended solids concentrations of less than 1.0 gram per litre. Any quantitative filtering apparatus using a filter paper that has a pore size of 1 micron or less can be used for the test. The two most common setups use either a Gooch crucible with a glass fibre filter paper or a membrane filter apparatus. These steps should be followed:

- (a) Weigh the filter.
- (b) Filter a measured volume of the sample. The volume should be sufficient to contain 5 milligrams of suspended solids.
- (c) Filter 10 millilitres of distilled water twice to wash out dissolved solids.
- (d) Place the filter in a drying oven at 105° C until the sample has dried to constant weight (usually 1 to 2 hours).
- (e) Cool in a desiccator and weigh.
- (f) Calculate suspended solids concentration C , in grams per litre, as follows:

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$$C = \left\{ \begin{array}{l} \text{[(weight of filter and dry solids, grams)} \\ \text{- (weight of filter, grams)] (1,000 milli-} \\ \text{litres per litre)/(volume of sample,} \\ \text{millilitres)} \end{array} \right\} \quad (3-8)$$

(5) Centrifugation method. This method is recommended for samples from saltwater environments that have a suspended solids concentration greater than 1 gram per litre. It is particularly useful when the dissolved solids concentration or salinity is unknown but is expected to be significant (greater than 10 percent of the suspended solids concentration). This method is preferable to the total solids method when the dissolved solids concentration is several times greater than the suspended solids concentration. These steps should be followed:

(a) Centrifuge a measured volume of sample until the liquid and solids have separated, yielding clear supernatant (several minutes should be sufficient).

(b) Pour off the supernatant, being careful not to lose any of the solids.

(c) Resuspend the settled solids in distilled water by diluting the sample to its initial volume.

(d) Repeat steps (a) through (c) twice to wash out all dissolved solids.

(e) Pour the sample into a preweighed dish and then wash all remaining solids from the centrifuge tube into the dish, using distilled water.

(f) Place the dish in a drying oven at 105° C until the sample has dried to constant weight (usually 4 to 6 hours).

(g) Cool in a desiccator and weigh.

(h) Calculate suspended solids concentration C , in grams per litre, as follows:

$$C = \left\{ \begin{array}{l} \text{[(weight of dish and dry solids, grams)} \\ \text{- (weight of dish, grams)] x 1,000 millilitres per litre} \\ \text{(volume of sample, millilitre)} \end{array} \right\} \quad (3-9)$$

(6) Correlation of suspended solids with turbidity. In some cases, effluent quality standards are specified in terms of turbidity, an optical property. Relationships between suspended solids concentration and turbidity are sediment-specific and can be determined only by preparing a correlation curve. The correlation curve is developed by determining turbidity and suspended solids concentration of samples prepared over a sufficiently wide range of concentrations.

e. Sample Compositing and Separation.

(1) Following determination of in situ water content, the sediment sample(s) must be homogenized, split, and possibly separated into coarse- and

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fine-grained fractions prior to further testing. Sediment characterization tests such as plasticity, grain size determination, specific gravity and organic content may be performed on grab samples from each of several sampling locations. Other tests, such as consolidation and settling tests, should be performed on an appropriately composited and homogenized sample. The need for and methods of compositing are highly project-dependent, but should be aimed toward producing a sample for testing that is representative of the material to be dredged. If composite samples are to be used for further testing, they must be thoroughly mixed. Samples for settling tests (approximately 15 gallons) may require addition of some water to aid in mixing.

(2) Sediment character as determined from in situ samples is not indicative of dredged material behavior after dredging since the fine-grained (<No. 200 sieve) fraction will undergo natural segregation within the containment area and will behave independently of the coarse-grained (>No. 200 sieve) fraction. Therefore, the relative percentage (dry weight basis) of coarse- and fine-grained material should be determined by separation of a small portion of the sample using a No. 200 sieve and following procedures generally described in EM 1110-2-1906.

(3) If the coarse-grained fraction is less than 10 percent by dry weight, the sediment sample is considered to be fine grained and is treated as though all the material passed the No. 200 sieve; separation for further characterization tests is not required. If the coarse-grained fraction is greater than 10 percent by dry weight, the entire sample should be separated into coarse- and fine-grained fractions prior to further testing. Separation can be accomplished for small sample volumes (e.g., those intended for classification or consolidation testing) by using the No. 200 sieve as described above. However, the larger sample volume required for sedimentation tests makes the use of a sieve impractical. For such volumes, slurry (sediment plus water) can be thoroughly mixed in a large barrel and then allowed to separate by differential settling. After initial mixing is stopped, coarse material will quickly accumulate on the bottom. The slurry remaining above the coarse material can be pumped into a second barrel, where it can be remixed and loaded into the testing column.

(4) In conducting the various tests and during sample separation and preparation activities, it will be necessary to make up slurries of various solids concentrations. In doing so, it is advisable to begin the testing sequence with slurry of higher concentration and add the required volume of water to obtain the desired lower concentration. The following simple relationship is useful in calculating the volume of additional water required:

$$C_1 V_1 = C_2 V_2 \quad (3-10)$$

where

C_1 and C_2 = solids concentrations
 V_1 and V_2 = slurry volumes (water plus solids)

f. Grain Size Analyses. Grain size analyses should be performed on coarse-grained samples or on the coarse-grained fraction of samples that are mixtures of coarse- and fine-grained material. These analyses are used to classify the coarse-grained portion of the sediments. The fine-grained

material (passing the No. 200 sieve) should be used in the other characterization and consolidation tests if required. Grain size analyses should follow the procedures contained in EM 1110-2-1906. Hydrometer analyses can be used to define the grain size distribution of the fine-grained fraction if desired.

g. Plasticity Analyses. In order to evaluate the plasticity of fine-grained samples of sediment, the Atterberg liquid limit (LL) and plastic limit (PL) must be determined. The LL is that water content above which the material is said to be in a semiliquid state and below which the material is in a plastic state. Similarly, the water content that defines the lower limit of the plastic state and the upper limit of the semisolid state is termed the PL. The plasticity index (PI), defined as the numerical difference between the LL and the PL, is used to express the plasticity of the sediment. Plasticity analyses should be performed on the fine-grained fraction (<No. 200 sieve) of sediment samples. A detailed explanation of the LL and PL test procedures and apparatus can be found in Appendix III of EM 1110-2-1906.

h. Organic Content. A knowledge of whether significant organic matter is present is required. The following dry-combustion test procedure is recommended to determine the organic content expressed as the percentage of weight lost on ignition:

(1) Dry a 40-gram sample at 105° C until there is no further weight loss (usually 4 to 6 hours).

(2) Place it in a desiccator to cool for 15 minutes.

(3) Weigh the sample and place it in the oven at 440° C for 4 hours.

(4) Place it in the desiccator to cool for 15 minutes.

(5) Weigh the sample and determine the organic content by dividing the weight lost by the sample while in the oven at 440° C by the total weight of the sample at the time it was placed in the oven.

i. Specific Gravity. Values for the specific gravity of solids for fine-grained sediments and dredged material are required for determining void ratios, conducting hydrometer analyses, and consolidation testing. Procedures for conducting the specific gravity test are given in Appendix IV of EM 1110-2-1906.

j. USCS Classification. When classifying sediment samples, the fine-grained portion that passes the No. 200 sieve should be classified separately from the coarse-grained portion retained on the No. 200 sieve, regardless of which fraction comprises the greatest percentage by weight. Additional information regarding the USCS classification may be found in WE'S Technical Memorandum No. 3-357 (item 33).

3-3. Settling Tests. Dredged material placed in disposal areas by hydraulic dredges or pumped into disposal areas by pump-out facilities enters the disposal area as a slurry (mixture of dredged solids and dredging site water). Settling refers to those processes in which the dredged material slurry is separated into supernatant water of low solids concentration and a more

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concentrated slurry. Laboratory sedimentation tests provide data for designing the containment area to meet effluent suspended solids criteria and to provide adequate storage capacity for the dredged solids.

a. Settling Processes.

(1) Settling types. The settling process can be categorized according to four basic classifications: discrete settling where the particle maintains its individuality and does not change in size, shape, or density during the settling process; flocculent settling where particles agglomerate during the settling period with a change in physical properties and settling rate; zone settling where the flocculent suspension forms a lattice structure and settles as a mass, the high solids concentration partially blocks the release of water and hinders settling of neighboring particles, and a distinct interface between the slurry and the supernatant water is exhibited during the settling process; and compression settling where settling occurs by compression of the lattice structure. All of the above sedimentation processes may occur simultaneously in a disposal area, and any one may control the design of the disposal area.

(2) Governing factors. Discrete settling describes the sedimentation of coarse particles. The important factors governing the sedimentation of fine-grained dredged material are the initial concentration of the slurry, salinity of the carrier water, and the flocculating properties of the solid particles. Because of the high influent solids concentration and the tendency of fine-grained particles to flocculate, either flocculent or zone settling behavior normally describes sedimentation in containment areas. Sedimentation of freshwater sediments at slurry concentrations of 100 grams per litre can generally be characterized by flocculent settling properties. As slurry concentrations or salinity is increased, the sedimentation process may be characterized by zone settling properties. Compression settling occurs in the lower layers of settled material for both the flocculent and zone settling cases. As more settled material accumulates, excess pore pressures develop in the lower layers and further consolidation occurs as water is expelled and the excess pore pressures dissipate.

(3) Zone versus flocculent settling as a function of salinity. The tendency of a fine-grained dredged material slurry to settle by zone or flocculent behavior in the initial stages of settling is strongly influenced by the presence of salt as a coagulant. If salinity is less than 1 part per thousand, indicative of freshwater conditions, flocculent processes normally describe the initial settling, and no clearly defined interface is seen. If salinity is greater than 1 part per thousand, indicative of brackish or salt-water conditions, zone settling processes normally describe the initial settling, and a clear interface between the clarified supernatant water and the more concentrated slurry is evident. For the zone settling case, some of the fine particles remain in the supernatant water as the interface falls. Flocculent processes then describe the settling of these fine particles from the supernatant.

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b. Testing Equipment and Procedures.

(1) Test objective. The objective of running settling tests on sediments to be dredged is to define their settling behavior in a dredged material containment area. The tests provide numerical values for the design criteria that can be projected to the size and design of the containment area. Procedures for computer-assisted plotting and reduction of settling column data are available as discussed in Chapter 8.

(2) Settling column. The settling column shown in Figure 3-3 should be used for dredged material settling tests. The column is constructed of 8-inch-diameter Plexiglas tubing and can be sectioned for easier handling and cleaning. Ports are provided for extraction of samples at various depths during sampling. A bottom-mounted airstone is also provided for agitation and mixing of slurries in the column by using compressed air. Shop drawings of the column with bills of materials are shown in Appendix B.

(3) Samples. Samples used to perform settling tests should consist of fine-grained (<No. 200 sieve) material. Any coarse-grained (>No. 200 sieve) material present in the sample would normally be hydraulically separated when the sample is mixed prior to sedimentation testing. A composite of several sediment samples may be used to perform the tests if this is thought to be more representative of the dredged material. Approximately 15 gallons of sediment is usually required for the tests. Water used to mix the slurries can be taken from the proposed dredging site or can be prepared by mixing tap-water and salt to the known salinity of the dredging site water.

(4) Pilot test. A pilot test conducted in a graduated cylinder (4 litres is satisfactory) is a useful method for determining if flocculent or zone process will describe the initial settling. The pilot test should be run at a slurry concentration of approximately 150 grams per litre. If an interface forms within the first few hours of the test, the slurry mass is exhibiting zone settling, and the fall of the interface versus time should be recorded. The curve will appear as shown in Figure 3-4. The break in the curve will define the concentration at which compression settling begins. Only lower concentrations should be used for the zone settling test in the 8-inch column. If no break in the curve is evident, the material has begun settling in the compression zone, and the pilot test should be repeated at a lower slurry concentration. It should be emphasized that use of a small cylinder as in the pilot test is not acceptable for use in design. Wall effects for columns of small diameter affect zone settling velocities, and data obtained using small-diameter columns will not accurately reflect field behavior. If no interface is observed in the pilot test within the first few hours, the slurry mass is exhibiting flocculent settling. In this case, the pilot test should be continued until an interface is observed between the turbid water above and more concentrated settled solids below. The concentration of the settled solids (computed assuming zero concentration of solids above) is an indication of the concentration at which the material exhibits compression settling.

(5) Required number of column loadings for tests. Three types of settling tests in the 8-inch column may be needed to fully define the settling properties of the dredged material. However, in most cases the 8-inch

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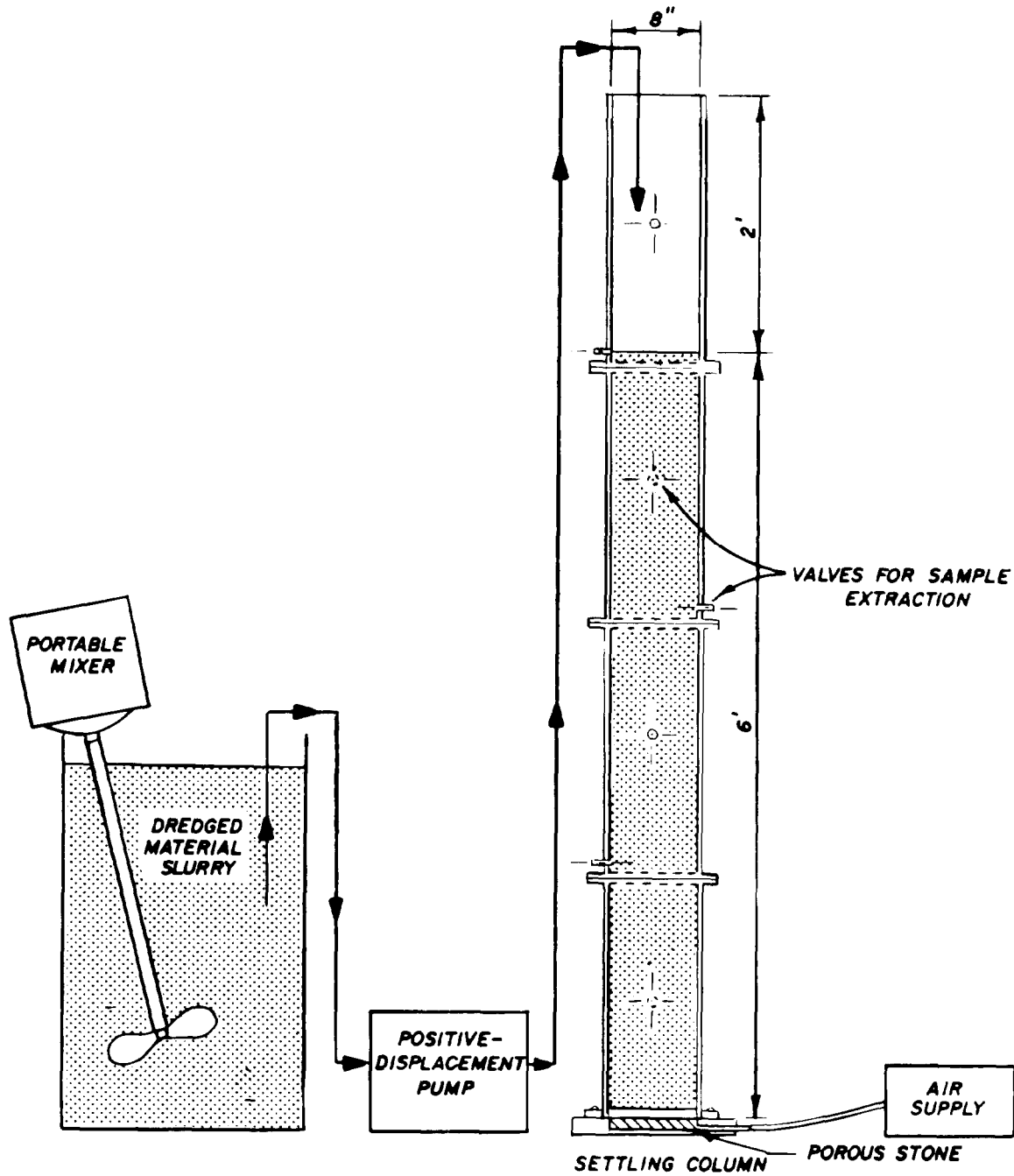


Figure 3-3. Schematic of apparatus for settling tests

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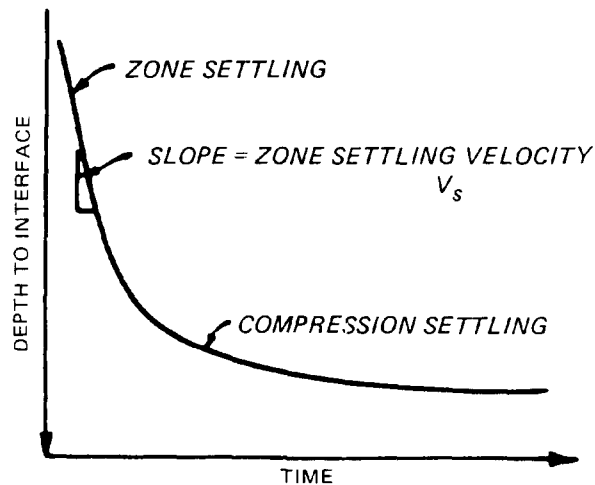


Figure 3-4. Conceptual plot of interface height versus time

settling column used for the settling tests needs to be loaded with slurry only once. A compression settling test is needed to define the volume that will be occupied in the disposal area by a newly deposited dredged material layer at the end of the disposal operation. A flocculent settling test for either the slurry mass or for the supernatant water above any interface is required to predict effluent suspended solids concentrations. A zone settling test is required to define the minimum surface area needed for effective zone settling. These tests should be conducted at a slurry concentration equal to the expected influent concentration; therefore, only one loading of the test column would be required to collect data for all purposes.

c. Flocculent Settling Test.

(1) The flocculent settling test consists of measuring the concentration of suspended solids at various depths and time intervals in a settling column. If an interface forms near the top of the settling column during the first day of the test, sedimentation of the material below the interface is described by zone settling. In that case, the flocculent test procedure should be continued only for that portion of the column above the interface.

(2) Information required to design a containment area for the flocculent settling process can be obtained using the following procedure:

(a) A settling column such as shown in Figure 3-3 is used. The slurry depth used in the test column should approximate the effective settling depth of the proposed containment area. A practical limit on depth of test is 6 feet. The column should be at least 8 inches in diameter with sample ports at 0.5 foot intervals (minimum). The column should have provisions for slurry agitation with compressed air from the bottom to keep the slurry mixed during the column filling period.

(b) Mix the sediment slurry to a suspended solids concentration C equal to the expected concentration of the dredged material influent C_1 . The

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slurry should be mixed in a container with sufficient volume to fill the test column. Field studies indicate that for maintenance dredging of fine-grained material, the disposal concentration will average about 150 grams per litre. This concentration should be used in the test if better data are not available.

(c) Pump or pour the slurry into the test column using compressed air or mechanical agitation to maintain a uniform concentration during the filling period.

(d) When the slurry is completely mixed in the column, cut off the compressed air or mechanical agitation and immediately draw off samples at each sample port and determine their suspended solids concentration. Use the average of these values as the initial slurry concentration at the start of the test. The test is considered initiated when the first samples are drawn.

(e) If an interface has not formed on the first day, flocculent settling is occurring in the entire slurry mass. Allow the slurry to settle and withdraw samples from each sampling port at regular time intervals to determine the suspended solids concentrations. Substantial reductions of suspended solids will occur during the early part of the test, but reductions will lessen at longer retention times. Therefore, the intervals can be extended as the test progresses. Recommended sampling intervals are 1, 2, 4, 6, 12, 24, 48 hours, etc., until the end of the test. As a rule, a 50-millilitre sample should be taken from each port. Continue the test until an interface can be seen near the bottom of the column and the suspended solids concentration in the fluid above the interface is 1 gram per litre. Test data are tabulated and used to plot a concentration profile diagram as shown in Figure 3-5. Examples are shown in Appendix C.

(f) If an interface forms the first day, zone settling is occurring in the slurry below the interface, and flocculent settling is occurring in the supernatant water. For this case, samples should be extracted from all side ports above the falling interface. The first of these samples should be extracted immediately after the interface has fallen sufficiently below the uppermost port to allow extraction. This sample can usually be extracted within a few hours after the beginning of the test, depending on the initial slurry concentration and the spacing of ports. Record the time of extraction and port height for each port sample taken. As the interface continues to fall, extract samples from all ports above the interface at regular time intervals. As an alternative, samples can be taken above the interface at the desired depths using a pipette or syringe and tubing. As before, a suggested sequence of sampling intervals would be 1, 2, 4, 6, 12, 24, 48, 96 hours, etc. The samples should continue to be taken until the suspended solids concentration of the extracted samples shows no decrease. For this case, the suspended solids in the samples should be less than 1 gram per litre, and filtration will be required to determine the concentrations. The data should be expressed in milligrams per litre for these samples. Tabulate the data and plot a concentration profile diagram as shown in Figure 3-5. In reducing the data for this case, the concentration of the first port sample taken above the falling interface is considered the initial concentration C_0 . Examples are shown in Appendix C.

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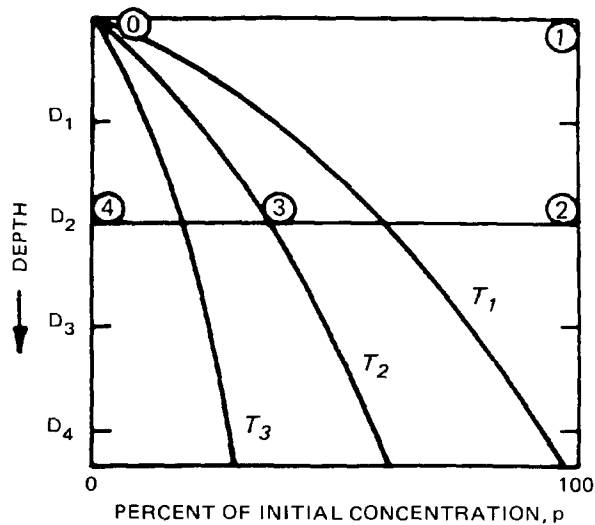


Figure 3-5. Conceptual concentration profile diagram

d. Zone Settling Test.

(1) The zone settling test consists of placing a slurry in a sedimentation column and reading and recording the fall of the liquid-solids interface with time. These data are plotted as depth to interface versus time. The slope of the constant velocity settling zone of the curve is the zone settling velocity, which is a function of the initial test slurry concentration. This test is required if the material exhibits an interface within the first day. The test should be run at the expected influent slurry concentration, or the highest expected to persist for several hours if a range is expected.

(2) Information required to design a containment area for the zone settling process can be obtained by using the following procedure:

(a) A settling column such as shown in Figure 3-3 is used. It is important that the column diameter be sufficient to reduce the "wall effect" and that the test be performed with a test slurry depth near that expected in the field. Therefore, a 1-litre graduated cylinder should never be used to perform a zone settling test for sediment slurries representing dredging disposal activities.

(b) Mix the slurry to the desired concentration and pump or pour it into the test column. Air may not be necessary to keep the slurry mixed if the filling time is less than 1 minute.

(c) Record the depth to the solid-liquid interface as a function of time. Readings must be taken at regular intervals to gain data for plotting the curve of depth to interface versus time as shown in Figure 3-4. It is important to take enough readings to clearly define this curve.

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(d) Continue the readings until sufficient data are available to define the maximum point of curvature of the depth to interface versus time plot. The test may require from 8 to 48 hours to complete.

(e) Calculate the zone settling velocity v_s as the slope of the constant velocity settling zone, as shown in Figure 3-4 (straight-line portion of curve). The velocity should be in feet per hour.

(f) Compression Settling Test.

(1) A compression settling test must be run to obtain data for estimating the volume required for initial storage of the dredged material. For slurries exhibiting zone settling, the compression settling data can be obtained from the zone settling test with interface height versus time recorded. The only difference is that the test is continued for a period of 15 days, so that a relationship of log of concentration versus log of time in the compression settling range as shown in Figure 3-6 is obtained. For slurries exhibiting flocculent settling behavior, the test used to obtain flocculent settling data can be used for the compression settling test if an interface is formed after the first few days of the test. If not, an additional test is required with the slurry concentration for the test sufficiently high to initially induce compression settling. This concentration can be determined by the pilot test.

(2) Information required to design a containment area for the compression settling process can be obtained using the following procedures:

(a) Tabulate the interface height H_t for various times of observation during the 15-day test period.

(b) Calculate concentrations for various interface heights as follows:

$$C = \frac{C_o H_i}{H_t} \quad (3-11)$$

where

C = slurry concentration at time t , grams per litre

C_o = initial slurry concentration, grams per litre

H_i = initial slurry height, feet

H_t = height of interface at time t , feet

Neglect solids in the water above the interface to simplify calculations.

(c) Plot concentration versus time on log-log paper as shown in Figure 3-6.

(d) Draw a straight line through the data points.

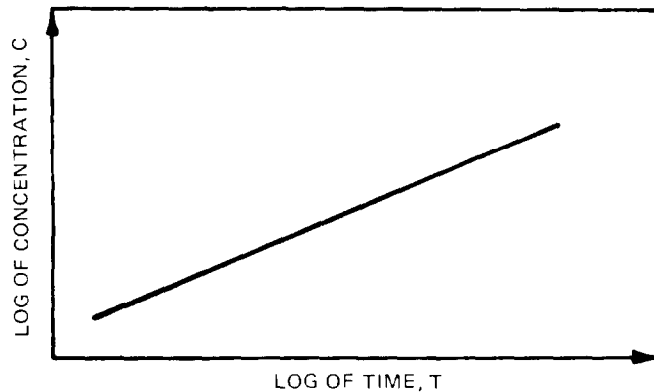


Figure 3-6. Conceptual time versus concentration plot

3-4. Chemical Clarification Tests.

a. General. If for a given disposal area, gravity sedimentation does not remove sufficient suspended solids to meet effluent standards, chemical clarification may be required. This may be especially true when a freshwater sediment with a significant clay fraction is dredged. The effluents from such sites may contain several grams per liter of suspended solids after gravity settling prior to chemical clarification.

b. Jar Tests.

(1) Jar tests have traditionally been used to evaluate the effectiveness of various flocculants under a variety of operating conditions for water treatment, and these procedures have been applied to the disposal of dredged material. Jar tests are used to provide information on the most effective flocculant, optimum dosage, optimum feed concentration, effects of dosage on removal efficiencies, effects of concentration of influent suspension on removal efficiencies, effects of mixing conditions, and effects of settling time.

(2) The general approach used in the jar test procedures is as follows:

(a) Using site-specific information on the sediment, dredging operation, containment areas, and effluent requirements, select mixing conditions, suspension concentration, settling time, and polymers for testing. Test a small number (four to six) of polymers that have performed well on similar dredged material.

(b) Prepare stock suspension of sediment.

(c) The tests should be run on 2-grams-per-litre suspensions of sediment, which is a typical concentration for effluents from a well-designed containment area for freshwater clay sediments. If good removals are obtained at low dosages (10 milligrams per litre of polymer or less), then select the most cost-effective polymer. If good removals are not obtained, examine the

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polymer under improved mixing and settling conditions and test the performance of other flocculants.

(d) After selecting a polymer and its optimum dosage, examine the effect of polymer-feed concentration over the range of sediment concentrations of 1 to 30 grams per litre, typical concentrations found in the field, at the optimum dosage.

(e) Determine the dosage requirements for the expected range of suspended solids concentrations to be treated at the primary weir.

(f) Examine the effects of the range of possible mixing conditions on the required dosage of flocculant for a typical suspension.

(g) Examine the effects of settling time on the removal of suspended solids from a suspension of average suspended solids concentration using the selected dosage and likely mixing conditions.

(3) The purpose of the approach described is to select an effective polymer for a suspension of a standard suspended solids concentration, 2 grams per litre, which is a typical effluent solids concentration. In this manner, the effectiveness and dosage requirements of various polymers are easy to compare. The other test variables are set to simulate anticipated field conditions. After a polymer is selected, other variables are examined: polymer-feed concentration, solids concentration of suspension to be treated, mixing, and settling time. The approach may be changed to fit the needs and conditions of the specific study. Detailed jar test procedures are found in Appendix E.

3-5. Consolidation Testing. Determination of containment area long-term storage capacity requires estimates of settlement due to self-weight consolidation of newly placed dredged material and due to consolidation of compressible foundation soils. Consolidation test results must be obtained, including time-consolidation data, to estimate the average void ratios at completion of 100 percent primary consolidation.

a. Consolidation tests for foundation soils should be performed as described in EM 1110-2-1906.

b. Controlled-rate-of-strain tests or fixed-ring consolidometers should be used for consolidation testing of sediment samples because of their fluid-like consistency. The only major modifications for the conventional fixed-ring testing procedure concern the sample preparation and the method of loading. Detailed procedures are found in Appendix D.