Classification and Disposal of Dewatered Sediments

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ABSTRACT: Two of the major costs in sediment remediation projects are dewatering and disposal of the dredged sediment. When evaluating dewatering methods, the shear strength of the dewatered sediment must be considered because it can influence the disposal technique and unit cost. If the sediment strength will be lower than required for regular disposal, additional dewatering or sediment amendment may be required to avoid slope stability issues, which results in greater disposal cost per ton. This paper discusses shear strength testing, specimen preparation, and strength criteria for classifying dewatered sediments prior to landfill disposal. Dewatered sediments are usually unsaturated and thus are not directly amenable to traditional saturated shear strength parameters, such as, undrained shear strength and total stress friction angle and cohesion. Recommendations for shear testing and strength parameters for unsaturated sediment and landfill handling, placement, and operations are presented to assist with proper waste classification and landfill slope stability.

INTRODUCTION

Landfill disposal facilities typically specify minimum strength requirements and testing procedures for acceptance of dewatered sediment during negotiation of a disposal contract. The contract typically includes different unit rates for disposal of the sediments that meet and do not meet this strength requirement, with the latter usually referred to as “low-strength waste” (LSW) and having a unit disposal rate that is \$15 to \$20/short ton (\$16.50 to \$22/metric ton) more than the regular or “direct disposal rate” (DDW). Therefore, it is advantageous to have a reliable means to estimate strength of the dewatered sediments from the planned dewatering method to determine if LSW will be produced. This is tricky because dewatered sediment strength can vary based on sediment composition, moisture content after sediment pressing, landfill placement conditions, e.g., rainfall, and placement techniques, such as lift thickness and compactive effort.

OBJECTIVES

The objectives of this paper are: (1) discuss how sediment composition and dewatering methods affect the strength of the dewatered sediment; (2) review requirements for landfill slope stability and how they relate to waste strength requirements; (3) provide guidelines for reasonable sediment strength parameters for disposal contracts; (4) describe a waste classification and testing program that is appropriate for unsaturated dewatered sediment; and (5) advise generators and landfills on disposal contract language to avoid.

SEDIMENT COMPOSITION AND DEWATERING

Options for dewatering of dredged sediments generally include gravity drainage, pumping through geotubes, use of filter presses, and/or amendment with various natural materials (straw, wood chips, etc.) or pozzolans (lime kiln dust, Portland cement, etc.). Sediment composition will have a significant effect on the success of the selected dewatering method and resulting shear strength of the dewatered sediment. Sediment with a higher sand content will tend to dewater more quickly than clayey sediment. Unfortunately most sediment is primarily comprised of silt to clayey-silt particles and organic material that drain slowly, making dewatering a challenge.

Gravity drainage may be performed on a drainage pad or in a confined disposal facility that also provides long-term disposal of the sediment. When sediment is dewatered by gravity drainage on a dewatering pad, it typically requires some form of amendment to avoid classification as LSW. The same is true for sediment dewatered using geotubes for drainage, after which the percent solids in the dewatered sediment is expected to range from 40 to 45 percent. Sediment that is dewatered using filter presses typically has a higher percentage of solids and lower moisture content than sediment dewatered on a drainage pad or using geotubes. As a result, filter presses usually produce sediment that exhibits higher shear strength than other methods and should be acceptable for disposal without further dewatering or amendment. The following sections discuss considerations for dewatered sediment that meet strength requirements for disposal as it is delivered to a landfill and how that strength can be documented to protect the owner/generator from additional costs or a higher disposal rate.

SEDIMENT DISPOSAL AND LANDFILL PERMITTING REQUIREMENTS

Permitted hazardous and non-hazardous disposal facilities have the same basic operational requirements related to waste placement, compaction, and slope stability. The waste strength requirements should be specified in a Waste Acceptance Plan or Operating Plan, as well as in design calculations performed to document stable landfill slopes during and after waste placement at the designed slope angle and fill height. Sediment strength requirements should be based on slope stability calculations for interim and final landfill slope configurations because the interim condition is frequently critical (Stark et al., 2000a and b). The final slopes are typically not steeper than 4 horizontal to 1 vertical (4H:1V), with a designated maximum fill height. However, interim slopes may exceed the final slope inclination and/or height because of limited placement capacity or equipment and anticipated waste settlement.

When the design slope inclination and/or maximum slope height is achieved for a certain slope length, a bench may be included to increase stability as subsequent slopes are constructed above. In addition, a sediment setback distance should be specified so high moisture content sediment is not placed on exposed slopes which can lead to shallow or surficial slope failures that become a maintenance issue. For example, Figure 1 shows shallow slope movement that may occur if high moisture content sediment slumps down an exposed slope. Figure 2 shows a rotational slope failure that extends the full slope height, with a bulge at the slope toe. These slope movements are not deep seated and would not likely impact the liner system, but do require maintenance and can trigger regulatory concerns and actions. As a result, a contract specification that requires sediment to be placed at least 10 feet (3.1 m) from the intermediate waste slope face should be included in the contract requirements. A horizontal distance or setback from an intermediate waste slope is recommended because the slope movement in Figure 1and Figure 2 will likely have a depth of less than ten feet (3.1 m). If the weak material is placed at a deeper depth and covered with a low hydraulic conductivity cover soil, slope movements may be avoided because of the buttressing effect of the cover soil and reduced infiltration.

These filling requirements should be included in the contract and shown in a series of waste fill sequence drawings for a facility that plans to place multiple lifts of dewatered sediment. The slope stability and sediment strength requirements must reflect the planned waste fill sequence and slope design for waste stability.

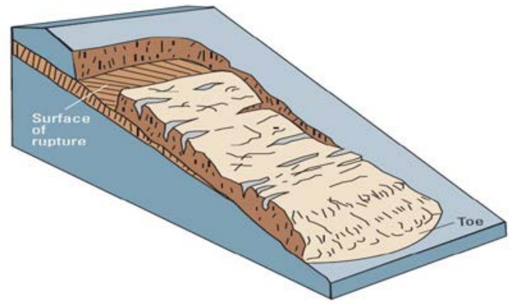

FIGURE 1: Schematic of translational movement in exposed sediment (Source: US Geological Survey).

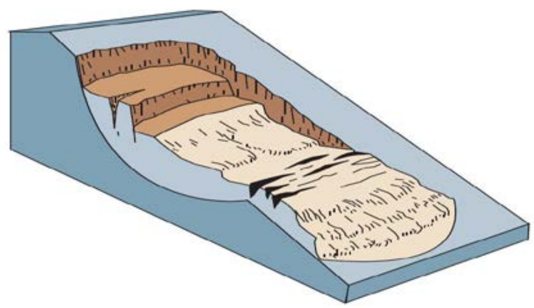

FIGURE 2: Schematic of rotational slope movement extending to slope toe (Source: US Geological Survey).

Landfill operations also can impact the strength of the sediment during and after placement. For example, dewatered sediment that initially meets the required strength for regular placement in a landfill can become weaker before and after disposal if it is subjected to precipitation and/or not compacted properly. Sediment should be compacted in relatively thin lifts using a sheepsfoot roller, or similar compaction equipment, to ensure uniform and significant compaction. If not properly compacted, rainfall and surface water runoff can infiltrate and cause the dewatered waste to decrease in strength and possibly classify as LSW, essentially reversing the benefits of dewatering. In addition to proper compaction, the surface of the waste at the working face of the landfill should be compacted using a smooth-drum roller or covered with a tarp prior to a major rainfall event, to minimize infiltration and an increase in moisture content. After the final slope configuration has been achieved, the sediment should be covered with low hydraulic conductivity soil to reduce precipitation infiltration to the disposed sediment.

Dewatered sediment typically has high moisture content but is not saturated, so it is therefore in a drained condition. However, after the waste has been placed in a landfill and subjected to overburden pressure and some infiltration, the degree of saturation can approach 100% and cause pore-water pressures to develop that weaken the waste. Some state regulatory agencies have recognized this potential problem and require landfill operators to install drainage measures within the fill, such as prefabricated drains or granular drainage layers that facilitate dissipation of pore-water pressure from the sediment. It is the responsibility of landfill owners/operators to keep sediment in a drained or unsaturated state so the shear strengths measured before shipping of the sediment are still applicable and control slope stability.

DEWATERED SEDIMENT TESTING STRATEGY

Prior to contract negotiations for waste disposal, a plan should be developed for sampling, testing, and classifying dewatered sediment to determine the disposal unit cost. This plan should include methods to obtain representative samples of dewatered sediment, sample preparation, test methods, and interpretations to be used for shear strength testing. Facilities disposing of large volumes of dewatered sediment may have additional permit requirements for testing of dewatered sediment, but this testing may not be appropriate for sediment strength at the time of disposal. Testing that provides immediate results are beneficial to the owner and/or generator because these results can be used to establish sediment strength, classification, and disposal cost prior to shipment.

Representative Composite Samples. Dewatered sediment samples should be formed to be representative of the sediment to be disposed for a given volume. The testing plan should specify the sampling frequency and sample compositing procedures to obtain a representative sample of the volume to be disposed. At sites where large volumes of dewatered sediment are planned for disposal, sampling may need to be performed multiple times each day to establish the strength for sediment to be shipped off site that day or the following day for disposal.

Geotechnical Testing of Dewatered Sediment. Composite samples should be compacted at a moisture content and dry unit weight that approximates field conditions at the time of waste placement in the landfill, which is difficult because the sediment can be subject to moisture during transport, unloading, and placement. The following describes recommended test methods for classification and testing to determine waste strength:

- ***Sediment Grain Size*** - grain size using the American Society of Testing and Materials (ASTM) D-422.
- ***Percent Solids/Moisture Content* –** The representative composite sample should be tested for percent solids and moisture content using ASTM D 2216 or D 2974.
- ***Compaction*** – After thoroughly homogenizing the composite sample, a portion of the dewatered sediment sample should be collected and compacted to at least 80 percent of the maximum dry unit weight based on Standard (ASTM D698) or Modified Proctor Compaction (ASTM D1557) depending on the landfill compaction equipment and techniques. To achieve this sample, a Proctor Compaction Curve or relationship must be developed to determine the optimum moisture content and maximum dry unit weight for the composite sample.
- ***Drained Shear Strength*** – Shear strength of the to be delivered sediment should be tested using a method that provides rapid results, so these results are known prior to loading for off-site transportation and disposal because the results determine the disposal unit cost. For cohesive soils, an unconfined compression (ASTM D 2166), a laboratory vane shear (ASTM D 4648), or direct shear (ASTM D 3080) test can be used to estimate the shear strength of the unsaturated sediment as discussed below.
- ***Undrained Shear Strength* –** Undrained shear testing may be required by the disposal permit but should not be used for sediment classification and acceptance if the dewatered sediment is in an unsaturated or drained state. This strength may be relevant *after disposal* because there is a possibility the waste will become saturated

after during or after disposal. If required by the disposal permit, the type of testing and methods to be used should be provided by the disposal company. However, it should be specified that these test results are not representative of the waste as it is delivered because the sediment is not saturated. Therefore, the strength criteria should not use undrained strength parameters as discussed below.

Testing frequencies for the above tests should be specified by a professional engineer prior to commencement of remediation, and be reflected in the contract requirements. Bench-scale testing is recommended to be performed in advance of remediation to obtain information on the expected strength, and thus unit disposal cost, of the dewatered sediment prior to negotiating a contract for disposal. The resulting contract should specify the testing frequency, sample and specimen preparation, test method, and shear strength criteria that matches the test method proposed, e.g., direct shear, triaxial compression, or vane shear.

CLASSIFICATION OF DEWATERED SEDIMENT

This section discusses shear strength parameters that can be used in disposal contracts to classify the dewatered sediment as DDW or LSW because a higher unit disposal cost is usually required for the LSW. It is recommended that specific values of shear strength be used to determine whether the dewatered sediment classifies as DDW or LSW instead of qualitative criteria such as:

- "Medium" consistency, i.e., "penetrated several inches (many cm) by thumb with moderate effort" (Peck et al., 1974)
- Support its own weight;
- Support the weight of material placed over it;
- Capable of being worked and managed by low ground pressure bulldozers; or
- Stable on 3:1 slope.

These qualitative criteria are difficult to quantify and thus prove if a dispute over unit disposal cost for sediment disposal develops. As a result, specific values of shear strength that reflect as delivered conditions are preferred so a disposal facility knows how to manage the incoming sediment and the generator has some predictability of total disposal cost. A sediment classification scheme could require the dewatered sediment to meet one or more of the following shear strength values that have been used in prior projects to identify DDW:

1. A minimum compressive strength of 1,600 pounds per square foot (psf) (7,812 kilogram per square meter [kg/m^2]); or
2. A minimum cohesive strength of 800 psf (3,906 kg/ m^2); or
3. A minimum undrained or short term frictional strength of 20 degrees; or
4. A minimum drained or long term frictional strength of 25 degrees; or

When the dewatered sediment is unsaturated, only the first and fourth criterion are viable for identifying DDW because the second and third criterion correspond to total stress strength parameters obtained from a Consolidated-Undrained (CU) (ASTM D4767) or Unconsolidated-Undrained (UU) (ASTM D2850) triaxial compression test, i.e., a total stress cohesion and friction angle.

If the dewatered sediment was fully saturated, the short term frictional strength would be zero and the cohesive strength would correspond to the undrained shear strength (S_u) or 800 psf (3,906 kg/ m^2). Therefore, the first and second criterion would be equal if the sediment was fully saturated. The first and second criterion would be equal because S_u is one-half of the unconfined compressive strength, q_u. Figure 3(a) illustrates the results of three UU triaxial compression tests on saturated clay that results in the short term frictional strength (ϕ) being equal to zero degrees. The strength envelope is horizontal because the three specimens are saturated so there is no change in void ratio when the confining stress is applied before shearing of the specimen. If the three specimens have the same void ratio, they exhibit the same strength, i.e., same size Mohr's circle (see Figure 3(a)), which results in a horizontal strength envelope or ϕ equal to zero. The vertical axis intercept corresponds to S_u. If an unconfined compression test was conducted on saturated sediment, the resulting Mohr's circle would start at the origin and be tangent to the horizontal strength envelope and also correspond to S_u .as shown by the left most circle in Figure 3(a). Therefore, the first and second strength criterion would be equal if the sediment was fully saturated.

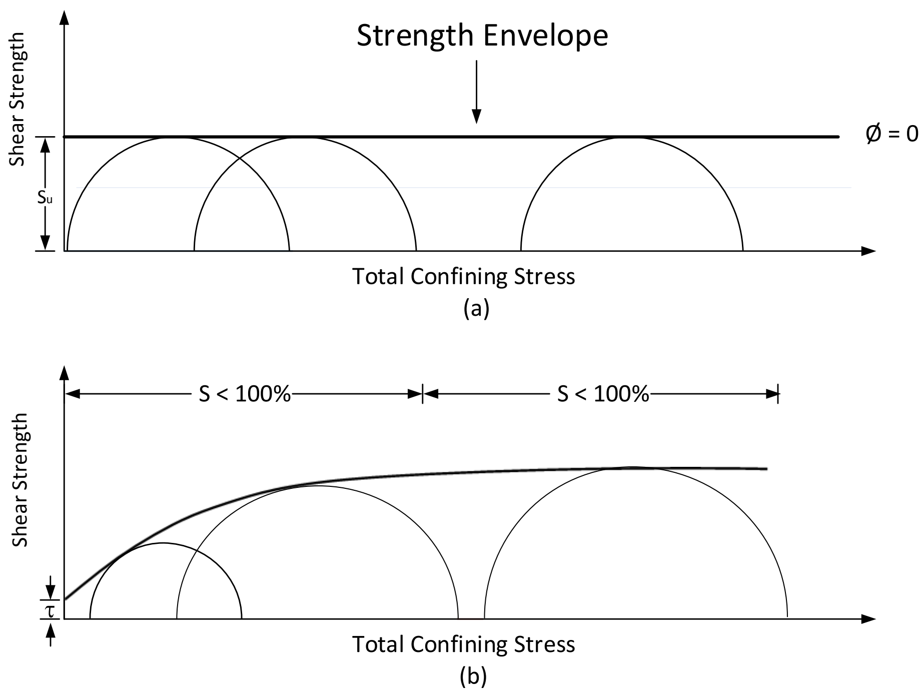

Figure 3: Strength envelopes from UU triaxial compression tests on: (a) saturated clay and (b) unsaturated clay (figure adapted from Holtz and Kovacs, 1981).

Conversely, Figure 3(b) illustrates the results of three UU triaxial compression tests on unsaturated clay that results in a stress dependent strength envelope, i.e., a non-constant friction angle. The strength envelope is stress dependent, i.e., increases with total confining stress because the three specimens are unsaturated so there is a decrease in void ratio when the total confining stress is applied before shearing of the specimen. The void ratio decreases because the total confining stress compresses some of the voids causing a decrease in void ratio. As a result, the three specimens have different void ratios prior to shearing and thus exhibit different strengths, i.e., different size Mohr's circles (see Figure 3(b)). The smallest decrease in void ratio occurs at the lowest confining stress and yields the smallest circle whereas the largest decrease in void ratio occurs at the highest confining stress and yields the largest circle. This results in different size Mohr's circles and a stress dependent strength envelope. Therefore, a compressive strength corresponding to a certain point on this stress dependent strength envelope can be used a strength criterion. For example, a total confining stress representative of landfill placement conditions can be selected and corresponding shear stress or shear strength used as the strength criterion. Of course an unconfined compression test with zero confining stress is easier and quicker to perform than applying a confining stress. If an unconfined compressive test is used instead of a UU triaxial compression test with a confining stress, the value of unconfined compressive shear stress (τ) shown in Figure 3(b) can be used for the strength criterion. However, an unconfined compression test will result in a conservative estimate of shear strength as shown in Figure 3(b) because the strength envelope increases rapidly with confining stress. Because the sediment should not be placed on an exposed slope as discussed above, the sediment will be subjected to some confining stress in the field so using an unconfined compressive shear stress will underestimate the field strength.

The fourth criterion is viable for DDW because it utilizes a drained frictional angle (ϕ') which is applicable to unsaturated soils. The value of ϕ' can be determined from the results of drained direct shear tests performed in accordance with ASTM D3080. Because the material is unsaturated, a drained direct shear test (ASTM D3080) can also be performed to measure the shear resistance because drainage is not controlled during shearing and the test is performed at a slow enough displacement rate that shear-induced pore-water pressures do not develop.

TESTING OF DEWATERED SEDIMENT

The main objective of laboratory testing is to estimate engineering properties of dewatered sediment under field conditions. As a result, it is important to simulate field conditions in the laboratory to accurately estimate the field shear strength and other engineering properties of the dewatered sediment. Given dewatered sediment will be transported to a landfill in an unsaturated condition, the laboratory testing must simulate the unsaturated condition to properly evaluate shear strength and landfill slope stability. If the landfill operator or generator anticipates the sediment will become saturated during transport, handling, and placement, the sediment should be hydrated to saturation prior to shear testing. Unconfined compression, direct shear, and vane shear tests can be performed on unsaturated and saturated materials to measure field shear strength values.

The next issue is which one of these shear test procedure(s) and test conditions should be used to determine whether or not the strength criteria proposed above are satisfied. A common laboratory test procedure is the unconfined compression test (ASTM D 2166) which yields values of q_u. An unconfined compression test involves testing a right circular cylindrical specimen of filter cake under no confinement. This is analogous to testing concrete cylinders to measure the compressive strength of concrete. During the test, the cylindrical specimen is compressed at an axial strain rate of about 1% per minute until the peak shear resistance is measured. Shortly after mobilizing the peak shear resistance, the test is stopped and the specimen removed from the apparatus. This test is easy and quick to perform and differs from CU and UU triaxial compression tests in which the specimen is encased in a membrane and a total confining stress is applied using either water or air as shown in Figure 3(a). However, the values of unconfined shear stress will be conservative and underestimate field strength because a confining stress will be applied in the field as discussed above. As a result, other types of tests were considered for testing unsaturated sediment or filter cake.

Another common laboratory test procedure is the direct shear test (ASTM D 3080) which yields values of ϕ'. A direct shear test involves testing a circular or square specimen of sediment under a representative normal stress. During the test, the specimen is sheared on a horizontal plane at a shear displacement rate that ensures positive pore-water pressures do not develop during shear. This can result in a slow displacement rate, e.g., 0.5 to 1 mm/minute, which can result in each test taking about 25 to 50 minutes. This is significant because the test results need to be complete before the sediment is transported to a disposal facility so the landfill operator knows how to handle and dispose of the material and the generator knows the classification and unit disposal cost.

A laboratory vane shear device (see Figure 4) also can be used to measure values of S_u instead of an unconfined compression test if the specimen is saturated. If the specimen is unsaturated, the laboratory vane test will yield a shear stress similar to an unconfined compression or UU triaxial compression test. The lab vane test will not yield a stress dependent envelope as shown in Figure 3(b) because a confining pressure is usually not applied to the specimen so it has zero confining stress like in an unconfined compression test. The laboratory vane shear test (ASTM D 4648) is easy and quick to perform and does not require reconstitution of a slender right circular cylinder specimen with a height to diameter ratio of two as the unconfined and UU triaxial compression tests require. The laboratory vane shear test also utilizes a reconstituted specimen but the specimen is in a small container and is easier to prepare than an unconfined and UU triaxial compression specimen. The vane shear reconstituted specimen has a diameter that allows clearance of at least two blade diameters (0.5 inches or 12 mm) between all points on the circumference of the vane and the outer edge of the specimen container. This also results in larger diameter (2.5 inches or 62 mm) specimens for the vane shear testing than unconfined and UU triaxial compression testing, which facilitates preparation of a representative specimen. During the test, the specimen is sheared on horizontal and vertical planes along the vane at a shear displacement rate that ensures positive pore-water pressures do not develop during shear. The lab vane also yields faster results, and thus waste classification, than unconfined or triaxial compression tests and tests a larger specimen which helps assess sediment variability.

Other devices that might be adequately calibrated to determine shear strength parameters for sediment classification purposes are the pocket penetrometer and torvane. If the specimen is saturated, both devices provide an estimate of S_u. If the sediment is unsaturated, these two devices provide a value of penetration resistance and shear stress, respectively. The pocket penetrometer and torvane test procedures are a little easier and could provide slightly faster test results than the laboratory vane shear. The pocket penetrometer and torvane results could be calibrated with the vane shear test and/or triaxial compression tests to reduce some of the more time consuming testing and speed up sediment classification.

In summary, a laboratory vane shear and unconfined compression tests are reasonable tests to quickly measure the shear strength and classify dewatered sediment. Laboratory pocket penetrometer and torvane tests also could be used if properly calibrated but would require similar specimen reconstitution and preparation as the lab vane and unconfined compression tests.

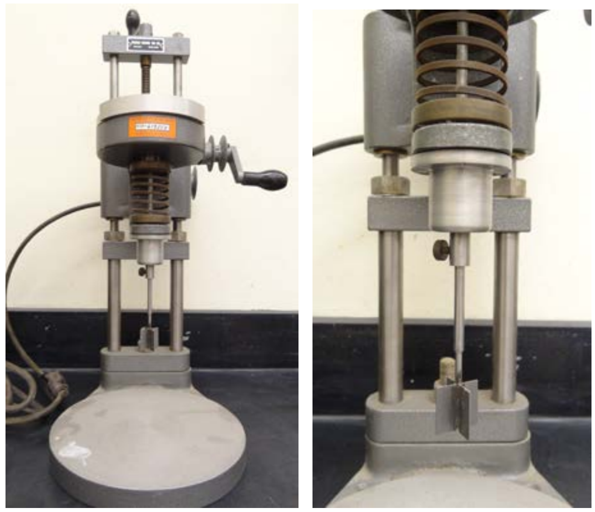

Figure 4: View of: (a) laboratory vane shear device and (b) close-up of laboratory vane.

RECOMMENDATIONS FOR DISPOSAL CONTRACT LANGUAGE

Some disposal firms have proposed disposal contract language that can be unfavorable to sediment owners or generators. The most commonly-observed language relates to the following disposal concerns:

- ***Slope stability*** **–** some disposal companies contractually require the waste or sediment generator to provide material that "ensures a stable slope". This language should not be used because slope stability is affected by many factors other than sediment strength, such as, surface water management, slope inclination, compaction, and cover material. For example, if an operator places sediment at a steeper slope than is recommended by stability calculations, a slope failure could occur even if the waste placed met the strength requirement. Such requirements essentially make generators responsible for landfill handling, placement, and operations.
- ***Sediment strength*** **–** some contracts require shear strength testing be performed for the *undrained* waste condition rather than for the *drained* condition. While this may be required by the disposal permit, it may not be relevant for dewatered sediment because it is unsaturated. If the sediment arrives at the landfill in an unsaturated state, it should be tested for acceptance using drained conditions, such as direct shear or lab vane tests. It is the operator's responsibility to keep the waste in a drained or unsaturated state during handling, placement, and storage.
- ***Generator notification*** **–** the disposal facility must immediately notify the generator upon waste acceptance at the landfill if it has a dispute regarding the dewatered sediment meeting the strength criteria. Otherwise, a disposal facility may accept waste and then decide months later that the sediment did not meet the DDW strength criteria and demand compensation at the LSW rate. Because the difference in disposal rates range from $15 to $20/short ton ($16.50 to $22/metric ton), a difference of millions of dollars can occur quickly. For example if 300,000 short tons (272,154

metric tons) of sediment is classified as LSW instead of DDW, the disposal fees could increase by $4.5 to $6.0 million dollars.

RECOMMENDATIONS

For waste generators involved in sediment remediation projects that involve sediment dewatering and disposal, we recommend careful consideration of the testing program and contract language that applies to acceptance of unsaturated dewatered sediment at the landfill. Strength testing should be performed under drained conditions if the dewatered and/or amended sediment will be unsaturated when it is shipped and/or placed. Testing that provides immediate strength results, prior to shipping, is also recommended so landfill personnel understand the material characteristics and the owner/generator understand the classification and disposal unit cost. The testing that applies to waste acceptance and classification for determining disposal unit rates should be carefully specified in the contract and generators should avoid language that places responsibility for impacts caused by transport, handling, and landfill placement of the sediment on the generator.

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