Poking the Bear: Drilling and Sampling for Embankment Dams

Subsurface investigations that include drilling and sampling are often used to obtain geotechnical information about embankment dams and their foundations. However, performing these intrusive investigations does not come without risk and unique considerations. Drilling could connect existing seepage paths or weak zones within the embankment, or create such by fracturing or disturbing the material. As such, drilling with fluids within embankment dams is particularly adverse. Drilling a hole in or near a dam to collect in situ information and samples should therefore only be performed if warranted, under supervision of a driller and field engineer with experience drilling in embankment dams, and executed based on a well thought-out plan. The plan should include the purpose and goals of the investigation and address concerns associated with drilling through an embankment dam. Intrusive drilling and sampling are usually conducted after other non-intrusive investigations have been completed, including review of existing information, mapping of rock and soil exposures, and perhaps geophysical surveys. Intrusive methods are prescribed after it has been determined that analyses requiring site-specific geotechnical information are warranted.

In the last issue of the Western Dam Engineering Technical Note, we discussed ways to evaluate stability and determine whether more in-depth analyses are warranted. In this edition, we include some methods of drilling and sampling embankment dams typically used to support those studies. The purpose of this technical note is to discuss general guidelines for evaluating and selecting the drilling and sampling methods that are currently available in most parts of the United States. Additional, less common, methods exist that have not been included. The discussion begins with general sampling and drilling methods for embankment dams, followed by guidelines for drilling and sampling in the core of the embankment, the embankment shell, and the foundation.

Importance of Investigation Plans

A geotechnical investigation for an embankment dam that involves drilling and sampling in test holes should begin with a carefully thought-out plan that addresses the objectives and purpose of the work and lays out detailed specifics of the drilling and sampling approach. Most projects will have existing information available about the dam and foundation that can be used to provide an estimate of the type and location of materials that might be encountered. This information will be helpful to determine appropriate drilling methods, the estimated depth, inclination, and diameter of test holes, and the types of samples that should be obtained. The contents of this article should be carefully considered when selecting the hole location and drilling method. In particular the reasons to not drill with fluid through the embankment (and with it in the foundation) should be heeded.

Drilling and sampling usually forms only a part of the investigation plan. The investigation plan should also consider site access conditions, utilities, health and safety requirements, test hole completion and abandonment, installation of instrumentation, in situ testing, sample handling, storage of samples, transportation of samples, and laboratory testing. The investigation plan should also consider the target drilling and sampling depths and expected phreatic surface.

Perhaps the most important part of the investigation plan is to be flexible and have contingencies for unknown conditions often encountered in the subsurface. Flexibility can be achieved by having several different drilling and sampling methods available with the drill rig selected for the investigation. An example contingency for drilling would be to have extra drill rods on the rig, should the test hole(s) need to go deeper or have a string of casing available for caving hole conditions. An example contingency for sampling would be to have a variety of samplers on the rig to select the one most appropriate for the soils encountered.

Drilling and sampling in an embankment dam has associated risk of damaging the embankment; therefore, the investigation plan should include procedures to arrest damage if it is observed or suspected. Drains, embankment slopes, and piezometers can be monitored to observe changes during the drilling and sampling. If the embankment is considered particularly sensitive to potential changes (i.e., the dam has shown signs of instability, seepage, or piping) materials such as gravel, sand, bentonite, etc. can be stockpiled near the test hole with equipment for transport to the test hole, should damage become apparent. Signs of embankment disturbance may include increased seepage downstream of the test hole, seepage turning turbid, or sinkholes/depressions forming on the surface of the embankment. At a minimum the accessibility of the nearest source of emergency materials should be identified. The investigation plan might also include phone numbers to communicate events, written procedures to help promptly deal with unusual conditions or damage, and guidelines for the work associated with the drilling and sampling.

Typical Sampling Methods

Appropriate sampling methods vary based on the target strata being investigated. This is a general summary of typical methods for obtaining samples to characterize embankment dam materials. Refer to the referenced ASTM standard for detailed information on each sampling type and method.

Photo 1. Example Samplers *(Photo Courtesy of CME)*

Split spoon sampling using Standard Penetration Test procedures (SPT) (ASTM D1586): A split spoon sample is a driven-sample generally obtained using the SPT method. This provides both an in situ test of the relative consistency (density/stiffness) of the material and obtains a disturbed sample. Split spoon samples can be performed in most soil types and weak rock, but are not appropriate for strong rock. If the material is non-cohesive (sandy), then various catchers may be used at the sampler tip to help retain the sample; however, these may affect SPT results is low strength material. The resulting sample is appropriate for index testing (gradation, plasticity, moisture content, etc.). Samples should be removed from the sampler and placed in sealed plastic baggies to retain moisture. (Laboratory testing of samples will be discussed in a subsequent issue.)

Thick-walled split tube sampling (i.e., modified California sampler, ASTM D3550): is a driven-sampling method using a ring-lined barrel that provides a slightly less disturbed sample of soils and weak rock, but is not appropriate for strong rock. This sampling method is also often used following SPT procedures. It is preferred over the split spoon when a less disturbed sample is desired and the material has sufficient cohesion to be retained in the sampler. The ring sample should be carefully sealed with wax or taped plastic caps. The ring samples can best be used for index property characterization (gradation, plasticity, moisture content, etc.). Use caution performing tests on these samples, when they are intended to represent in-place properties such as density and strength, as some disturbance of the soil likely occurred.

Thin-walled sampling (i.e., Shelby tube, ASTM D1587): Shelby tube sampling is a push-sample method that provides a relatively undisturbed sample of fine-grained, cohesive material. It may be difficult for sampling non-cohesive or granular material such as sands or gravels, as they are difficult to retain in the tube, although special procedures have been developed for thin walled sampling of sands using fixed piston samples, which provide for development of vacuum in the soil pores during sample extraction. Tube sampling of sands requires great skill and care and special precautions must be taken to limit disturbance of these samples during transportation. Quality Shelby tube samples are appropriate for testing index properties as well as in-place characteristics such as density, consolidation, and strength properties, as this method generally results in the least disturbance of soil sampling when performed properly. Samples should be retained within the tube to allow the laboratory to carefully extrude the sample. Sample disturbance and change in sample condition is likely if the sample is extruded in the field. The tube should be carefully sealed with wax or o-ring packers. Care should be taken to avoid sample disturbance during transportation to the laboratory, especially for soft soil samples.

Core sample: A “core” sample refers to a relatively continuous sample recovery of the drilled material. Core samples are obtained through the drilling process itself. Sample cores can be relatively undisturbed or disturbed based on the drilling method used. Core samples can be obtained using diamond coring, sonic drilling, and even auger drilling when a plastic-lined auger string is utilized. Undisturbed core samples are appropriate for testing index properties as well as in-place properties such as density, consolidation (in the case of soil cores), rock quality (in the case of rock cores), and strength properties.

Typical Drilling Methods

Six general methods of drilling are presented herein that are typically considered in the investigation of embankment dams. The methods include auger drilling, core drilling, mud rotary drilling, Odex drilling, sonic drilling, and Becker drilling. A number of other methods exist; however, these six have been found to be most commonly used in the United States. Refer to the referenced ASTM standard for detailed information for each drilling method.

Auger Drilling

Auger drilling is one of the most commonly used methods of drilling, and for embankment dams should be the preferred method, if possible due to its low risk of embankment damage, cost, versatility and availability. Many drill rigs can be set up to use solid flight auger (ASTM D1452) and hollow stem auger (ASTM D6151) strings. Auger drilling requires a high torque and low revolution speed rig, and with care depths of 200 to 300 feet can be drilled. Auger drilling does not require the use of drilling fluid; however, in some materials water may be poured into the test hole to aid in removing cuttings. Auger drilling is appropriate for fine-grained soils, granular soils, and weak rock, but may have difficulty advancing in very dense and/or very coarse-grained granular material due to friction. It is not appropriate for strong rock. Auger drilling allows for split spoon (SPT), Shelby tube, and thick-walled tube sampling.

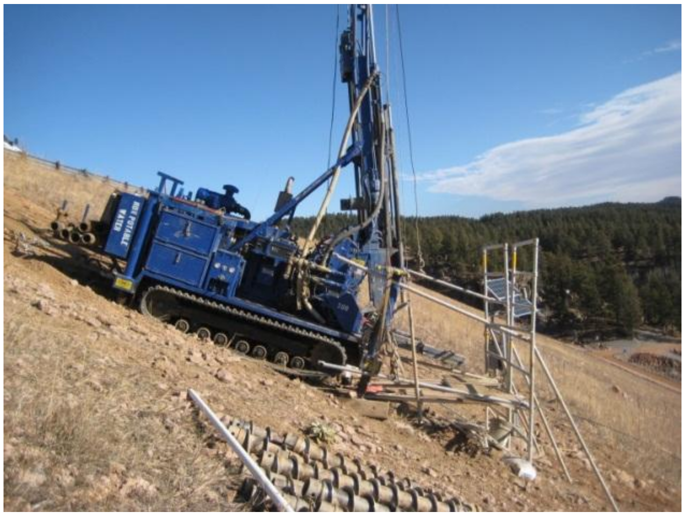

Photo 2. Auger Drill Rig

A track mounted drill rig using a 6-inch hollow stem auger (HSA) is shown in Photo 2. The string of 6-inch HSA has an inside diameter of 3 ¼ inches. This configuration allows use of the auger string as casing. Sampling and deepening the hole below the lead auger can be accomplished by switching to mud rotary or core drill strings. Note the added precautions necessary, particularly access and safety, when drilling on the steep incline of an embankment slope.

Auger Drilling Considerations

Pros	Cons
Can drill through loose/soft to dense/hard material and possibly weak rock	Not suitable for strong rock or some larger diameter granular material (i.e., cobbles and boulders)
HSA casing provides some embankment protection	Auger string may deviate more easily than other drilling methods
Drilling fluid not required	
Generally less expensive; available in most parts of the US	
HSA casing allows easy access for most sampling techniques including core barrel [although test hole not filled with mud per ASTM standard of SPTs (ASTM D1586)]	

Core Drilling

Core drilling (ASTM D2113), also referred to as diamond core drilling, can be used to obtain continuous sample cores of soil and rock, although this method is most commonly associated with drilling and sampling in rock. Drilling fluid, if required, can be air, water, or mud. SPT samples can be obtained from the inside of the drill string when the core barrel has been removed; however, this presents a risk of damaging the diamond bit. Because drilling fluid (water, mud, or air) is used, this method should not be used within embankments. If used within a rock foundation below an embankment, the hole should be cased within the embankment zone with the casing seated in the underlying bedrock, and preferably drilled through an outer shell zone.

In Photo 3 below, a track mounted core rig is shown advancing a test hole at an angle of 25° from vertical. The drill rod on the pipe rack is "HQ" size (4-inch diameter hole) from a wireline core string, which allows retrieval of the core samples as the test hole is deepened without having to trip out the drill string.

Photo 3. Core Drill Rig

Core Drilling Considerations

Pros	Cons
Can drill through almost all soils and rock; however, typically used in rock	Drilling fluid such as air, water, or mud is likely required
Casing can be used to provide embankment protection	Generally more expensive; but widely available in the US
Yields a continuous core	Core sample may be disturbed and recovery may be low in some materials
	Performing SPT tests are time consuming

Mud Rotary

Mud rotary (aka rotary wash) drilling (ASTM D5783) is probably the most common soil and rock drilling method used in the United States for a wide range of purposes; however, it is not recommended for drilling in and around dams. Air can be used as a drilling fluid (ASTM D 5782); however, some type of drilling mud is typically used. Mud rotary is appropriate for drilling in almost all soil and rock materials. It is different from diamond core drilling in that it uses a rock or tricone-type bit at the tip of the drill string and therefore only produces cuttings during drilling rather than a continuous core.

Mud is generally used to stabilize the hole rather than casing. As the test hole is drilled, mud inside the hole is maintained at a level near the collar of the hole to help keep the hole open and form a mud cake on the walls of the test hole. Drilling with a casing advancer (ASTM D 5872) is a method related to mud rotary drilling and uses casing as the drill string, with a wireline tri-cone bit in the lead casing. A casing advancer drill string is often used for materials such as flowing sands or loose gravels that may not allow the test hole to remain open with only the drill fluid. In some parts of the country (the northeast for example), this method is sometimes used with water instead of mud as the fluid – commonly called cased wash borings. Similar to that described for core drilling, mud rotary should not be performed through embankment dams due to the use of drilling fluid and the potential to hydraulically fracture any encountered weaknesses, even if a casing advancer is used. Similar to auger drilling, mud rotary drilling itself does not produce a sample, only cuttings. However, most sampling methods can be used in mud rotary-drilled holes by removing the drill string from the hole and lowering the sampler. This includes the potential use of diamond core strings to obtain continuous core samples.

In Photo 4, a truck mounted CME-75 drill rig is equipped with a string of "N" rod and a tri-cone bit to drill into alluvium. A string of "A" rod was used to conduct in situ testing and obtain SPT samples.

Mud Rotary Drilling Considerations

Pros	Cons
Can drill through almost all soil and rock and a wide range of drilling conditions	Drilling fluid such as air, water, or mud is required.
Generally least expensive and most widely available method in all parts of US	Should not be performed through embankments due to fluid pressure, even if cased
Easy to switch out drill string to obtain samples, although the drill method itself only produces cuttings	

Photo 4. Mud Rotary Drill Rig

Odex Drilling

Odex drilling (also known as TUBEX) is a percussive drilling method that uses an air powered down-the-hole hammer to advance a casing string. Odex casing can be driven through almost all soil and rockfill materials and weak rock in the foundation. SPT and core samples can be obtained through the inside of the casing by changing the drill string and other methods of drilling can be used to deepen the test hole, if required. Drill fluid consists of air and a large air compressor is required. During drilling cuttings from inside the casing are carried to the surface using air. Odex drilling is generally not advisable within the embankment portion of the dam due to the potential damage that can be induced by the percussive action of the hammer and the high pressure air used for cuttings removal.

Odex Drilling Considerations

Pros	Cons
Can drill through loose/soft to very dense/hard material, and rock fill	Not suitable for strong rock
Casing provides embankment protection	Generally more expensive and less widely available
Samples can be obtained after the hammer is pulled from the casing	Performing SPTs are more difficult/costly than with HSA
	Air required as a drilling fluid

Photo 5. Odex Drill Rig

Sonic Drilling

Sonic drilling (ASTM D6914) uses an oscillating hammer in the drill head to vibrate and advance the drill casing. This drilling method provides almost continuous sample recovery of drilled material in the form of a continuous, albeit disturbed, core. Sonic drilling can be used to efficiently advance through almost all soil and weak rock; however, slow drilling and refusal may be encountered in strong rock or large boulders. Flowing sands and gravels may be problematic and fall out when pulling the core barrel. Drill fluid is not required for sonic drilling; however, some water may be poured into the casing to reduce friction and to keep the sample cool. Samples other than the sonic core (i.e. SPT, Shelby tube, etc.) can be obtained through the casing after the wireline core barrel has been retrieved; however, sampling is time consuming.

The test hole can be deepened into rock upon refusal using mud rotary or core drilling methods. Sonic drilling is generally preferred for drilling through coarse or dense embankment materials over Odex due to the limited potential disturbance. However, it is generally one of the most expensive drilling methods.

Photo 6. Sonic Drill Rig

Sonic Drilling Considerations

Pros	Cons
Can quickly drill through loose/soft to very dense/hard material	Slow and inefficient for strong rock with a potential for refusal
Casing provides embankment protection	Generally more expensive and less widely available
Yields a continuous core	Core sample is disturbed
Drilling fluid not required	Performing SPT tests is more difficult/costly
Limits embankment disturbance compared to percussive methods or mud rotary methods	May result in disturbance of loose in-place material, and therefore care should be taken when performing SPTs

Becker Drilling

Becker drilling (ASTM D 5781) uses an AP-1000 diesel hammer to drive double walled casing. Becker casing can be driven through almost all materials within the embankment dam and weak rock in the foundation. SPT and core samples can be obtained through the inside of the casing and other methods of drilling can be used to deepen the test hole, if required. Drill fluid is not required for this drilling method; however, some water may be poured into the casing to reduce friction. During drilling cuttings from inside the casing are carried to the surface using reverse circulation air and separated using a cyclone.

In Photo 7 below, a truck mounted AP-1000 Becker rig and required pipe truck is shown set up on a test hole. The Becker casing on the pipe truck is 9-inch diameter, with an inside diameter of about 4 inches (with a crowd in bit). Note the drill pad size required for the Becker rig and pipe truck, which is about 120 feet long and 20 feet wide. The pipe truck is typically set up behind the Becker rig to allow safe handling of the heavy casing.

Becker Hammer Drilling Considerations

Pros	Cons
Can drill through loose/soft to very dense/hard material, and rock fill	May not suitable for strong rock
Casing provides embankment protection	Generally more expensive and less widely available
Yields continuous cutting samples	Performing SPT are more difficult/costly than with HSA
Drilling fluid not required	
Becker blow count can be correlated to SPT blow count	

Photo 7. Becker Drill Rig

The drilling and sampling descriptions above provide limited information about the equipment. Refer to the ASTM standards for detailed descriptions and considerations to use when selecting drilling and sampling methods. ASTM D 6286 (Standard Guide for Selection of Drilling Methods for Environmental Site Characterization) may be useful for comparing drilling methods and selecting a preferred method for the investigations. Often the best source of information when selecting drilling and sampling methods is drilling company employees familiar with the equipment they use. If possible discuss your proposed drilling and sampling plan with the driller you plan to work with before heading into the field. If multiple drilling and sampling methods are to be used, it will be important to check the feasibility of the investigation plan with the driller.

Drilling and Sampling the Core Zone

The core zone of the dam refers to the generally fine-grained, low permeable zone of the embankment that is the primary seepage barrier. Drilling and sampling in the core zone of an embankment dam risks damage to the core. If possible, drilling and sampling in the core should be avoided. Alternatives should be considered to obtain the same or similar information by doing investigations at locations outside the core. For example, drilling through the shell or toe area is preferred if the primary objective is obtaining information on the foundation. If no alternatives are available, the preferred method of drilling in the core zone should be auger drilling. Auger drilling can be done without the use of drilling fluid (air, water, or mud) and therefore limits the risk of hydraulic fracturing of materials comprising the embankment core that could lead to internal erosion and piping damage. If drilling with water or mud must be conducted, limit the effective head to 0.5 psi per foot of vertical depth to reduce risk of hydraulic fracturing. Never drill in the cut-off trench, adjacent to outlet works or conduits, in or near known areas of seepage, and at locations above abrupt changes in the shape of the foundation. These may be areas of low stress that are more susceptible to damage due to drilling-induced disturbance or may be areas in which a drill hole could connect concentrated seepage paths.

Drilling and Sampling the Shell Zone(s)

Drilling and sampling in the shell(s) of an embankment dam may require the same considerations as drilling and sampling in the core, especially if the shell was constructed from fine-grained material. Shells constructed of coarse-grained earth fill or rock fill can be drilled and sampled using any of the appropriate methods described above. Risk of contaminating and plugging filters and drains should be considered; therefore, if possible use an auger drilling method because drilling mud is not required. If auger drilling is impossible due to flowing ground conditions, consider using a casing advancer method and keep the casing full of water or drilling mud at all times. If gravel, cobbles, and boulders are encountered, consider using the sonic drilling method or the core drilling method. Embankment shells constructed with rock fill may contain large boulders in which refusal may be encountered when using auger or even sonic drilling methods in some cases. A flexible investigation plan with contingencies for potential problems should be considered. For example, in the case of refusal, a pilot hole can be made with a core drill string to investigate whether refusal is due to a discrete boulder, in which case the auger string or sonic string could then ream the pilot hole and advance the test hole through the boulder.

Drilling and Sampling the Foundation

Subsurface investigations of the foundation material can be performed either through the embankment or outside the dam footprint. Either location has precautionary considerations. We have discussed the care needed to drill through the embankment and that is also reiterated in the paragraph below. Investigations within the foundation outside the dam footprint also need to consider the risk of blowing out foundation material. Drilling or excavating test pits near the toe, especially when the reservoir is near full pool, could provide an easy exit for foundation pore pressures, resulting in the potential for heave or blowout of the foundation. Larger excavations such as test pits, especially those below the water table, could exacerbate this risk. Offsetting borings a distance away from the toe, lowering the reservoir if possible, and drilling borings using fluid or mud help reduce the risk. This should be evaluated based on the specific foundation conditions expected at the site.

In cases in which the test hole will extend through the embankment (hopefully the shell) and into the underlying foundation, the materials to be drilled and sampled will likely vary and may require different drilling and sampling methods with depth. The investigation plan will need to address how to safely drill through the embankment and continue into the foundation. An example might be to use the hollow-stem auger drilling method to advance the test hole to the top of a rock foundation, then use the auger as casing and seat the lead auger into the foundation, then advance the test hole into the foundation using the core drilling method. The investigation plan, especially the drilling and sampling approach, should be discussed with the driller prior to start of the work so that potential equipment problems can be identified. In many cases, the driller will offer good ideas for conducting the drilling and sampling if they are well-informed of the objectives of the investigation.

SPT Sampling for Liquefaction

SPT sampling for liquefaction evaluation is very specialized procedure. Special care is required when sampling very loose sands. By standard procedure, water or mud is required in the hole when performing SPT sampling. This limits the potential of causing flowing or heaving in loose sands, which would disturb the in situ test. As mentioned earlier, fluid is not recommended in borings within embankment dams; however, compacted embankment materials are not common targets of liquefaction evaluation. Certain drilling methods may also disturb the area, especially in loose soils. Precautions should be implemented to limit drilling disturbance in the target zone for liquefaction evaluation. This may include switching drilling methods to auger methods in the target zone, which generally results in the least disturbance, and extracting drill strings at a slow rate to avoid a vacuum effect. The procedure may also require corrections for gravel content, which dictates the method to be used for blow count. The Reclamation guidance manual on SPT sampling (Reclamation 1999) should be referenced for more detail.

Test Hole Backfilling

If the test hole is not being completed as a piezometer, then it should be backfilled in such a manner to limit potential for a weak zone or seepage paths in or around the hole. Backfilling using cement/bentonite grout placed using tremie (bottom-up) methods should be required in or near the dam. Bentonite chips (also known as "hole plug") can also be used. Bentonite chips expand upon saturation, so the hole should be wetted as chips are placed. Backfilling test holes using cuttings should never be performed in holes within the embankment, foundation, abutment, or toe area of dam, as this could cause the surrounding soil to creep, deform, or result in increased seepage.

Conclusions

Drilling and sampling for embankment dams should be initiated with the preparation of a geotechnical investigation plan. The preferred method of drilling and sampling on and around dams is with the hollow stem auger drilling method, as this method best protects the embankment. Sonic drilling should be the next preferred method if the auger method will not work, such as in rockfill. If possible, avoid drilling in the core zone of the embankment. Never drill in the cut-off trench, near conduits in the embankment, or in areas that may be susceptible to damage. Prior to and during drilling, conditions at the dam should be monitored by reading piezometers and seepage weirs, and visually observing for signs that drilling and sampling might be causing damage to the embankment or foundation. Consider including procedures for dealing with damage to the embankment in the geotechnical investigation plan. Always review your drilling and sampling plan with the appropriate dam safety regulator as part of the investigation plan development process.

References

[1] ASTM D1452-09 Standard Practice for Soil Exploration and Sampling by Auger Borings.

[2] ASTM D1586-11 Standard Test Method for Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils.

[3] ASTM D1587-08 (2012) Standard Practice for Thin Walled Tube Sampling of Soils for Geotechnical Purposes.

[4] ASTM D2113-08 Standard Practice for Rock Core Drilling and Sampling of Rock for Site Investigation.

[5] ASTM D3350 01(2007) Standard Practice of Thick Wall, Ring-Lined, Split Barrel, Drive Sampling of Soils.

[6] ASTM D5781/D5781M-13 Standard Guide for Use of Dual-Wall Reverse-Circulation Drilling for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices.

[7] ASTM D5782-95 (Reapproved 2000) Standard Guide for Use of Direct Air-Rotary Drilling for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices.

[8] ASTM D5783-95 (Reapproved 2000) Standard Guide for Use of Direct Rotary Drilling with Water-Based Drilling Fluid for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices.

[9] ASTM D5872-95 (Reapproved 2000) Standard Guide for Use of Casing Advancement Drilling Methods for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices.

[10] ASTM D6151-08 Standard Practice for Using Hollow-Stem Augers for Geotechnical Exploration and Soil Sampling.

[11] ASTM D6286-12 Standard Guide for Selection of Drilling Methods for Environmental Site Characterization.

[12] ASTM D6914-04 Standard Practice for Sonic Drilling for Site Characterization and the Installation of Subsurface Monitoring Devices.

[13] U.S. Dept. of Interior, Bureau of Reclamation (Reclamation), 1999. Standard Penetration Test Driller's/Operator's Guide. DSO-98-17. Earth Sciences and Research Laboratory, Dam Safety Office.