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Standard Practice for Field Pneumatic Slug (Instantaneous Change in Head) Tests to Determine Hydraulic Properties of Aquifers with Direct Push Groundwater Samplers[1]

This standard is issued under the fixed designation D7242/D7242M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

ε1 NOTE—Designation was editorially corrected to match units information in December 2013.

1. Scope*

1.1 This standard practice covers the field methods used to conduct an instantaneous change in head (slug) test when pneumatic pressure is used to initiate the change in head pressure within the well or piezometer. While this practice specifically addresses use of pneumatic initiation of slug tests with direct push tools these procedures may be applied to wells or piezometers installed with rotary drilling methods when appropriate.

1.2 This standard practice is used to obtain the required field data for determining hydraulic properties of an aquifer or a specified vertical interval of an aquifer. Field data obtained from application of this practice are modeled with appropriate analytical procedures (Test Methods D4104, D5785, D5881, D5912, Ref (**1**)[2]).

1.3 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.5 *This practice offers a set of instructions for performing one or more specific operations. This document cannot replace education or experience and should be used in conjunction with professional judgment. Not all aspects of this practice may be applicable in all circumstances. This ASTM standard is not intended to represent or replace the standard of care by which the adequacy of a given professional service must be judged, nor should this document be applied without consideration of a project's many unique aspects. The word "standard" in the title means that the document has been approved through the ASTM consensus process.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D2434 Test Method for Permeability of Granular Soils (Constant Head) (Withdrawn 2015)[4]

D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D4104 Test Method (Analytical Procedure) for Determining Transmissivity of Nonleaky Confined Aquifers by Overdamped Well Response to Instantaneous Change in Head (Slug Tests)

D5084 Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter

D5092 Practice for Design and Installation of Groundwater Monitoring Wells

D5521 Guide for Development of Groundwater Monitoring Wells in Granular Aquifers

D5785 Test Method for (Analytical Procedure) for Determining Transmissivity of Confined Nonleaky Aquifers by Underdamped Well Response to Instantaneous Change in Head (Slug Test)

D5856 Test Method for Measurement of Hydraulic Conductivity of Porous Material Using a Rigid-Wall,

[1] This practice is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.21 on Groundwater and Vadose Zone Investigations.

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[2] The boldface numbers in parentheses refer to the list of references at the end of this standard.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[4] The last approved version of this historical standard is referenced on www.astm.org.

***A Summary of Changes section appears at the end of this standard**

Compaction-Mold Permeameter

D5881 Test Method for (Analytical Procedure) Determining Transmissivity of Confined Nonleaky Aquifers by Critically Damped Well Response to Instantaneous Change in Head (Slug)

D5912 Test Method for (Analytical Procedure) Determining Hydraulic Conductivity of an Unconfined Aquifer by Overdamped Well Response to Instantaneous Change in Head (Slug) (Withdrawn 2013)[4]

D6001 Guide for Direct-Push Groundwater Sampling for Environmental Site Characterization

D6282 Guide for Direct Push Soil Sampling for Environmental Site Characterizations

D6724 Guide for Installation of Direct Push Groundwater Monitoring Wells

D6725 Practice for Direct Push Installation of Prepacked Screen Monitoring Wells in Unconsolidated Aquifers

3. Terminology

3.1 Terminology used within this practice is in accordance with Terminology D653 with the addition of the following:

3.2 *Definitions:*

3.2.1 *direct-push (DP) sampling*—sampling devices that are directly inserted into the soil without drilling or borehole excavation. **D6001**

3.2.2 *two-tube system*—a system whereby inner and outer tubes are advanced simultaneously into the subsurface strata to collect a soil sample, sometimes referred to as dual-tube. The outer tube is used for borehole stabilization. The inner tube for sampler insertion and recovery. **D6282**

3.2.3 *single-tube system*—a system whereby single extension/drive rods with samplers attached are advanced into the subsurface strata to collect a soil sample. **D6282**

3.2.4 *slug test*—a single well test to measure aquifer properties such as transmissivity and hydraulic conductivity. A slug test is conducted by inducing a near instantaneous change in the static water level in a well and observing the recovery of the water level to static condition over time. Also called an instantaneous change in head test.

4. Summary of Practice

4.1 This practice describes the field procedures used to conduct an instantaneous change in head (slug) test in a direct push (DP) installed groundwater sampling device or monitoring well using air pressure to cause a sudden change in the water level. A pneumatic manifold is installed on a developed well or DP installed device to control the pressure in the wellhead. Positive pressure or vacuum may be applied with the pneumatic manifold to induce a rising head test or falling head test, respectively. The changing water level in the well is monitored with a transducer and data acquisition device and the data is saved for curve fitting and analysis.

4.2 Appropriate well design and construction is necessary to obtain representative slug test results. Furthermore, without adequate development (Practice D6725, Guide D5521, Refs (**1, 2**)) of the well or groundwater sampling device slug tests may yield biased data. Field quality control may be monitored by conducting replicate tests after development and visually comparing the replicate data sets.

4.3 Aquifer response data obtained from the pneumatic slug tests are modeled with the appropriate analysis method (Test Methods D4104, D5785, D5881, D5912, Refs (**1, 3**)) to calculate the transmissivity and/or hydraulic conductivity of the screened formation.

5. Significance and Use

5.1 Combining slug test methods with the use of direct push installed groundwater sampling devices provides a time and cost-effective method that was previously not available for evaluating spatial variations of hydraulic conductivity (K) in unconsolidated aquifers. Current research (Ref (**4**)) has found that small (decimeter) scale variations in hydraulic conductivity may have significant influence on solute transport and therefore design of groundwater remediation systems. Other investigators (Ref (**5**)) report that spatial variation in K is believed to be the main source of uncertainty in the prediction of contaminant transport in aquifers. They found that increasing the data density for K in model input noticeably reduced the uncertainty of model prediction. Because of increased efficiency and reduced costs, the combination of slug test methods with DP groundwater sampling devices makes it possible to obtain the additional information required to reduce uncertainty in contaminant transport models and improve remedial action design.

5.2 The data obtained from application of this practice may be modeled with the appropriate analytical method to provide information on the transmissivity and hydraulic conductivity of the screened formation in a timely and cost effective manner.

5.3 The appropriate analytical method selected for analysis of the data will depend on several factors, including, but not limited to, the aquifer type (confined, unconfined, leaky) well construction parameters (partially or fully penetrating), and the type of aquifer response observed during the slug test (overdamped or underdamped). Some of the appropriate methods may include Test Methods D4104, D5785, D5881 and D5912. A thorough review of many slug test models and analytical methods is provided in Ref (**1**).

5.4 Slug tests may be conducted in materials of lower hydraulic conductivity than are suitable for pumping tests. Slug tests may be used to obtain estimates of K for aquitards consisting primarily of silts and clays. Special field procedures may be required.

5.5 The pneumatic slug test provides some advantages when compared to pumping tests or slug tests conducted by other methods.

5.5.1 Some of the advantages relative to pump tests include:

5.5.1.1 No water added to or removed from the well. An important consideration when water quality must not be altered for purposes of environmental sampling.

5.5.1.2 Large volumes of water not removed from the well as during a pumping test. An important consideration if the groundwater is contaminated and will require disposal as a regulated waste.

5.5.1.3 Slug tests usually require only a fraction of the time needed to complete a pump test.

5.5.1.4 No large diameter pumping well or down well pump required.

5.5.1.5 Slug tests provide information on K for the formation in the vicinity of the well.

5.5.2 Some advantages relative to slug tests using water or a mechanical slug include:

5.5.2.1 No water added to or removed from the well or DP sampler to conduct the test. Generally does not change water quality for sampling. Use of vacuum to induce a falling head test could result in loss of volatiles from water in the well column. Additional purging may be required before sampling for volatile contaminants.

5.5.2.2 Pneumatic initiation of the slug test provides clean, high quality data with minimal noise, especially important in high hydraulic conductivity formations and small diameter wells.

5.5.2.3 In small diameter DP tools, inserting a mechanical slug or adding water may be difficult or even preclude accurate measurement of changing water levels.

5.5.3 Some disadvantages of slug tests as compared to pumping tests include:

5.5.3.1 Slug tests provide information on K for the formation only in the vicinity of the well, not a large scale average value as obtained from a pumping test.

5.5.3.2 Most slug test analytical methods can provide information only on aquifer transmissivity and hydraulic conductivity. Pumping test analysis can provide additional information on aquifer parameters such as specific storage, etc.

5.5.4 Some disadvantages of the pneumatic slug test relative to slug tests using water or a mechanical slug include:

5.5.4.1 Airtight seals needed on the well casing or drive rods.

5.5.4.2 The screen must remain below the water level throughout the slug test. Wells screened across the water table cannot be slug tested with the pneumatic method.

5.5.4.3 Pressure transducers and electronic acquisition methods usually required for pneumatic slug testing. Not always needed for manual methods.

5.5.4.4 Equilibration of water level after pressure (or vacuum) applied to the wellhead increases time required to complete the slug test, especially important in low-K formations.

5.6 Direct push methods provide some advantages as compared to conventional drilling methods for the installation of wells and temporary groundwater monitoring devices to be used for slug testing. Some of the advantages include:

5.6.1 DP methods minimize generation of soil cuttings reducing waste handling and disposal costs at contaminated sites during the installation of permanent wells (Guide D6724, Practice D6725) and temporary groundwater monitoring devices (Guide D6001).

5.6.2 Several types of temporary groundwater monitoring devices may be installed by DP methods (Guide D6001). These tools may be installed at various depths and various locations for slug testing and groundwater sampling in unconsolidated materials. Most of these tools are extracted for decontamination and multiple re-use, and can minimize the need for permanent well installations.

5.6.3 Short screens may be used to slug test discrete depth intervals to document vertical and lateral variations of K within an aquifer in a cost and time effective manner.

5.6.4 Equipment required to install DP wells and temporary groundwater samplers are often smaller and more mobile than conventional rotary drilling equipment. This can make site access easier and more rapid.

5.6.5 Other direct push screening and sampling methods, for example Guide D6282 on soil sampling, can be used to detect test zones in advance of slug testing, which helps with knowledge of test location.

5.6.6 Direct push tests are minimally intrusive.

5.6.7 Direct push tests are generally more rapid and less expensive than other drilling methods.

5.7 Some disadvantages of DP methods as compared to conventional rotary drilling include:

5.7.1 DP methods generally provide a smaller diameter bore hole than traditional rotary drilling. This may limit the size of equipment than can be placed down hole.

5.7.2 Direct push tools are designed to penetrate unconsolidated materials only. Other rotary drilling methods will be required to penetrate consolidated rock.

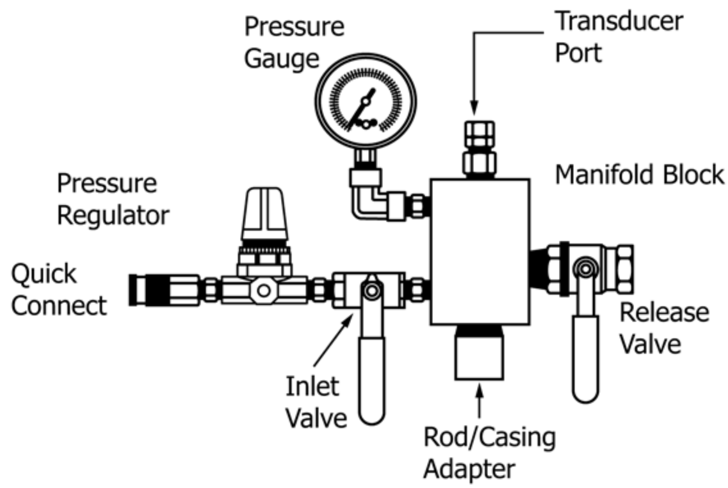
5.7.3 Some subsurface conditions may limit the depth of penetration of DP methods and tools. Some examples include thick caliche layers, cobbles or boulders, or very dense materials, such as high density glacial tills.

NOTE 1—The quality of the result produced by this standard is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D3740 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with Practice D3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of those factors. Practice D3740 was developed for agencies engaged in the testing or inspection of soils and rock, or both. As such, it is not totally applicable to agencies performing this practice. However, users of this practice should recognize that the framework of Practice D3740 is appropriate for evaluating the quality of an agency performing this practice. Currently there is no known qualifying national authority that inspects agencies that perform this practice.

6. Apparatus

6.1 *General*—The following discussion provides descriptions and details for one pneumatic slug test system. Many geologists and hydrologists have fabricated their own pneumatic slug test equipment. While the descriptions below are specific to one particular system other pneumatic systems may be suitable if they can provide appropriate data quality and data density for the aquifer response to be monitored in the field. Professional experience and judgment should be used to evaluate whether the pneumatic slug test system is adequate for the aquifer and well conditions to be tested. Not all wells or temporary groundwater monitoring devices are appropriate for pneumatic slug testing.

6.2 *Pneumatic Manifold*—The pneumatic manifold is an airtight system to allow for control of air pressure inside the wellhead. The primary features of a pneumatic manifold are depicted in Fig. 1 and include:



NOTE 1—Various rod and casing adapters are used to connect to different size casing or DP drive rods. Inside diameter of the release valve should be the same or larger than the diameter of the well casing to be tested.

FIG. 1 Example of a Pneumatic Manifold Used to Conduct Slug Tests on DP Groundwater Samplers or Conventional PVC Wells

6.2.1 Inlet valve connecting to an air or vacuum source.

6.2.2 Pressure regulator to modulate the rate of pressurization of the well head.

6.2.3 Pressure/vacuum gauge to monitor pressure in the wellhead. May be graduated in centimetres [inches] of water pressure. Used for leak testing and monitoring the amount of water level change in the wellhead.

6.2.4 Air tight fitting (transducer port) that allows the transducer and cable to move up and down for placement at various depths within the well. An additional airtight fitting may be available for a second transducer to monitor the air pressure inside the wellhead.

6.2.5 Release valve that may be opened rapidly to allow for quick exchange of air between the wellhead and ambient atmosphere. The release valve opening should be approximately the same diameter or larger than the well casing to be tested. This will provide for unhampered airflow and minimize generation of any noise as the pressure in the wellhead changes rapidly.

6.2.6 Casing adapter that will allow the pneumatic manifold to attach to the well casing with an airtight connection. The casing adapter should attach to the well casing or drive rod in such a way as not to reduce the ID below that of the ID of the casing to be tested.

6.3 *Pressure Transducer*—Several pressure transducers suitable for use in slug testing are commercially available. Pressure ratings may be reported in kiloPascal (kPa) [pounds per square inch (psi)]. Be sure that baseline noise levels and hysteresis characteristics of the transducer are suitable for the range of pressure change to be monitored. Pressure transducers rated at 35 to 70 kPa [5 to 10 psi] are generally suitable because the transducer is placed approximately 1 to 1.5 m [3 to 5 ft] below the water level for most test conditions. Pressure ratings of 140 kPa [20 psi] or higher may be acceptable, but if small head changes are used, resolution of higher pressure transducers may be inadequate. The diameter of the transducer and cable should allow its insertion down hole without interference. Dark cables on pressure transducers are subject to heating when exposed to sunlight. This may cause fluctuations in transducer response (Ref (**6**)) and errors in slug test data analysis. Minimize exposure of transducer cables to sunlight. Also allow pressure transducer to equilibrate to ambient water temperature as specified by manufacturer before initiating slug tests.

6.4 *Data Logger/Analog to Digital Inverter*—Several portable data loggers are commercially available that may be used to capture the transducer signal and store it for later down load to a computer for plotting and analysis. Some systems use an analog to digital inverter to acquire the analog signal from the pressure transducer and convert it to digital format for direct upload to a portable computer. Some data acquisition systems allow the user to observe the slug test response as the test is conducted in the field. Be sure the data acquisition system will provide for sufficient sampling rate to capture fast recovering water levels or oscillatory responses if these conditions are anticipated. Sampling rates of 5 to 10 Hz may be needed when oscillatory responses occur.

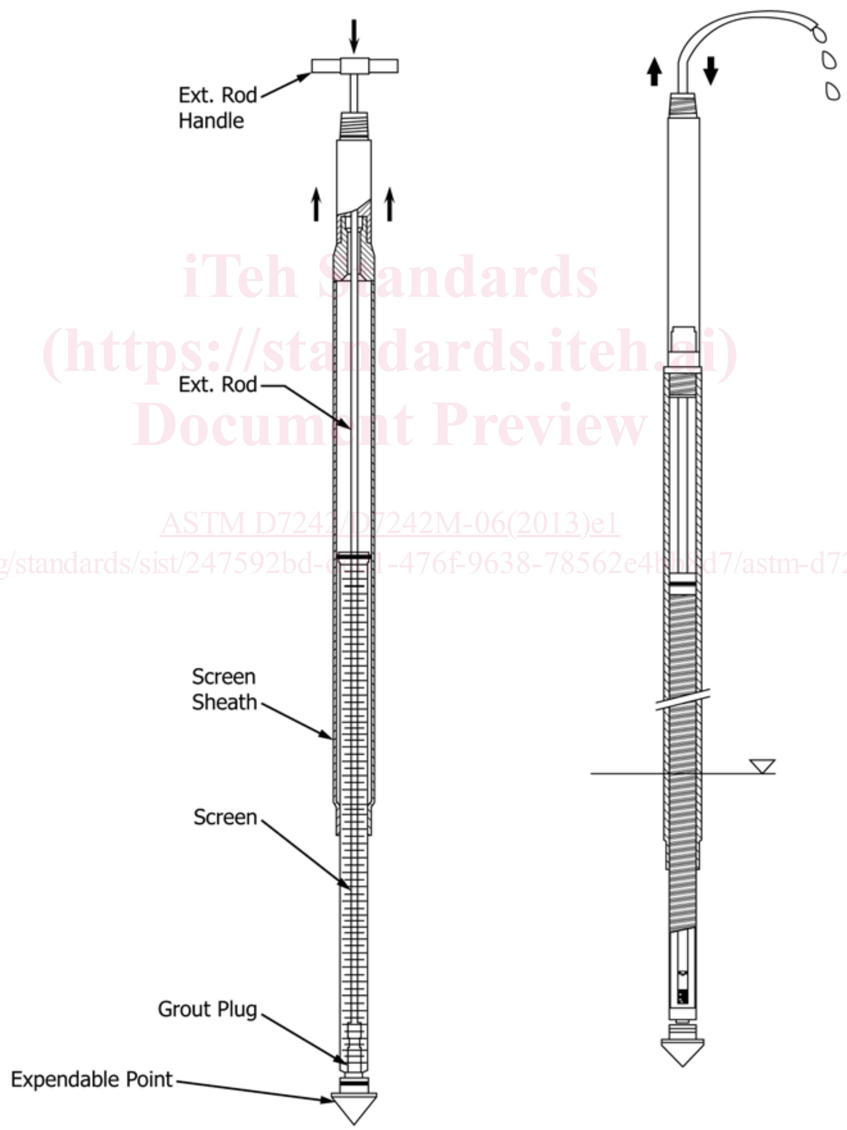
6.5 *Air/Vacuum Supply*—As the pressure inside the well head required to depress the water level a sufficient amount to conduct a slug test is not more than 3 to 7 kPa [1 to 2 psi], a large compressor is usually not required, especially for wells of 50 mm [2-in.] diameter or less and the smaller DP tools. For larger diameter wells and wells with deep water levels a compressor or other clean gas supply may be preferred. In the smaller wells and tools, a foot-operated pump or manually operated pump can be used to provide sufficient air pressure or vacuum with minimal effort. Small 12 Volt electric pumps are available and may be used if desired. Some field technicians prefer to use cylinders of compressed gas. This is suitable, but does present some additional safety hazards for transportation of the compressed gas cylinders. Whatever the source of air for pressurization of the wellhead, ensure the air is clean and will not contain potential contaminants. If a compressor is required, use an oil-less compressor.

6.6 *Casing Adapters*—Verify the pneumatic manifold is specifically designed to provide an airtight fitting for the casing diameter on the well(s) to be tested. Adapters may be used to attach the pneumatic head to larger or smaller casing sizes if necessary. Be sure the adapters do not obstruct the ID of the well casing.

6.7 *Miscellaneous Supplies and Accessories*—Various hand tools, supplies and accessories will make field activities more efficient and easier. Plumber's tape and O-rings may be required to make up airtight fittings. A soapy liquid to conduct leak testing on exposed fittings and connections will help if system leaks do occur.

7. Preparation/Conditioning

7.1 Well construction (Practice D5092, Guide D6725) and DP groundwater sampler installation (Guide D6001, Refs **(7, 8)**) must be completed appropriately to assure that representative data is obtained from slug tests. In general, PVC monitoring wells with filter packs are installed and developed some time before slug testing is conducted. Alternatively, DP groundwater sampling tools (Fig. 2) may be installed and developed immediately before slug tests are conducted. If the well screen and/or filter pack are improperly designed for the



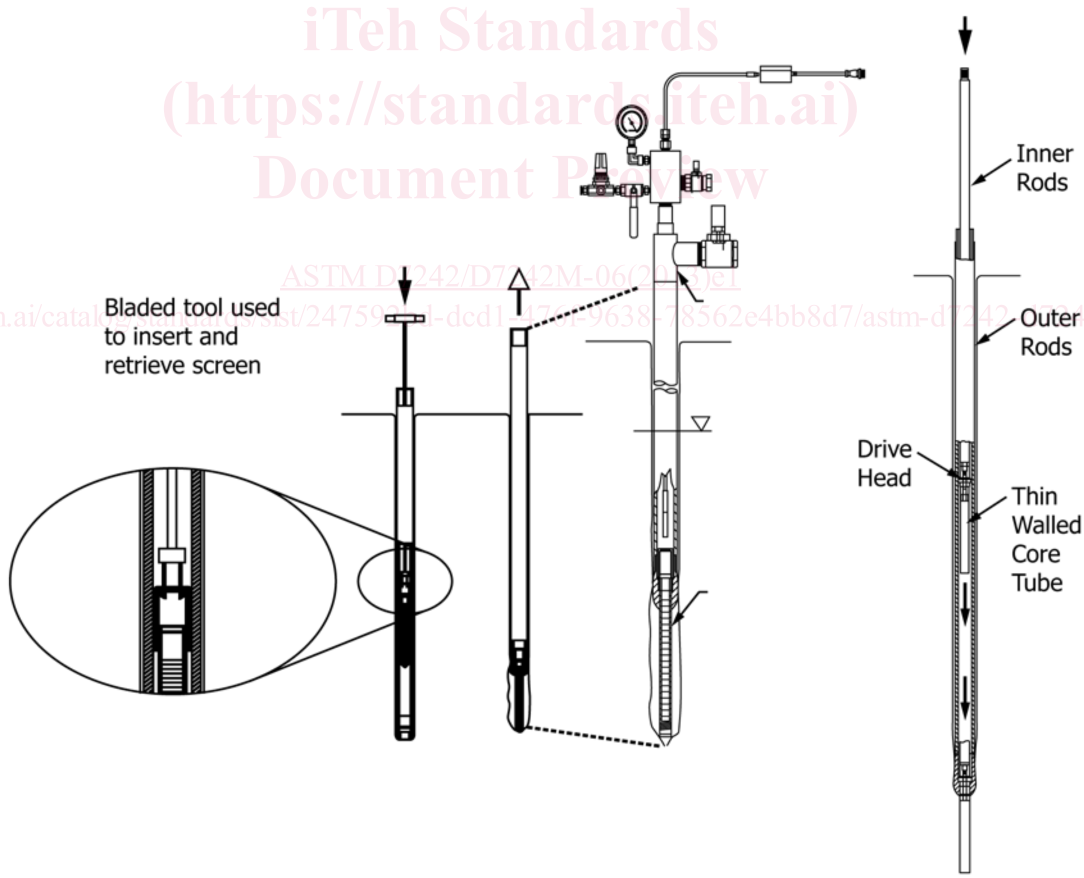
NOTE 1—Screen is protected with a sheath during advancement. Small extension rods inserted after driving (a) to expose screen desired amount for slug testing and sampling. Development must be conducted (b) to assure that natural flow is established between the formation and sampling device. Simple inertial pump often effective for surging and purging to develop the sampler.

FIG. 2 Direct Push Installed Single Tube Groundwater Sampling Device

formation monitored it may be difficult or impossible to achieve good well development. Boring logs and well construction diagrams should be reviewed prior to mobilization to evaluate possible well design problems. Alternatively, cone penetration test (CPT) or coring logs could be performed near the well to verify subsurface conditions. One common problem is that the filter media and screen slot size are too large for the natural formation conditions. This may result in continued movement of fines into the well even after significant development is conducted. Such movement of fines may cause erratic recovery rate in the well or curvature of normalized data plots. This will hinder accurate modeling of the slug test response and calculation of aquifer parameters. Clearly note any suspected well design problems in the field log book and later reporting.

7.2 When slug tests are to be conducted in fine-grained formations special procedures may be required to minimize compression and damage to the natural formation. DP Dual tube methods (Fig. 3) may provide an effective means to access the formation and conduct slug tests under these conditions. A thin-walled sampler should be used to core the formation beneath the dual tube rods. A brush or other suitable means is then used to relieve smearing on the core hole wall in cohesive formations. Relief of smearing is comparable to development in coarse-grained materials. A screen is then inserted into the cored hole in preparation for slug testing. A small casing (for example, 13-mm [0.5-in.] PVC riser pipe) may be used to connect the screen to the surface. The smaller casing will help reduce the recovery time required for the slug tests in fine-grained materials. An alternative to use of the screen is to fill the cored and brushed hole with sand having a much higher permeability and K than the formation.

7.3 *Well Development*—Slug test results in granular formations are particularly susceptible to well development. If the well or temporary groundwater sampling tool is not adequately developed before slug tests are conducted the observed response will be biased and inaccurate. Use adequate well development methods (Guide D5521, Guide D6724, Practice D6725, Refs (**1, 2**)) to assure that natural flow has been established between the well and granular aquifer so that representative slug test results are obtained. Some basic well development procedures for sandy formations include over pumping, surging with a surge block followed by purging, surging and purging with an inertial pump. Older wells may require redevelopment prior to slug testing to obtain accurate



NOTE 1—Dual tube soil sampling procedures may be combined with simple groundwater sampling devices to conduct sampling and slug testing at multiple depths in one boring. After removal of the soil sample or center rod a simple slotted screen may be installed through the open bore of the casing (a). In coarse grained sediments the rods are retracted to expose the screen (b). Following development an adapter attaches the pneumatic manifold (c) to the large drive rods for slug testing. In fine grained materials a thin walled tube may be used to core below the outer rods to minimize compression of the formation (d). The screen is then set in the open core hole below the drive rods.

FIG. 3 DP Dual Tube Methods for Pneumatic Slug Tests