Designation: D7242/D7242M – 06 (Reapproved 2013)$^{\varepsilon 1}$

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.

ε[1] 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.

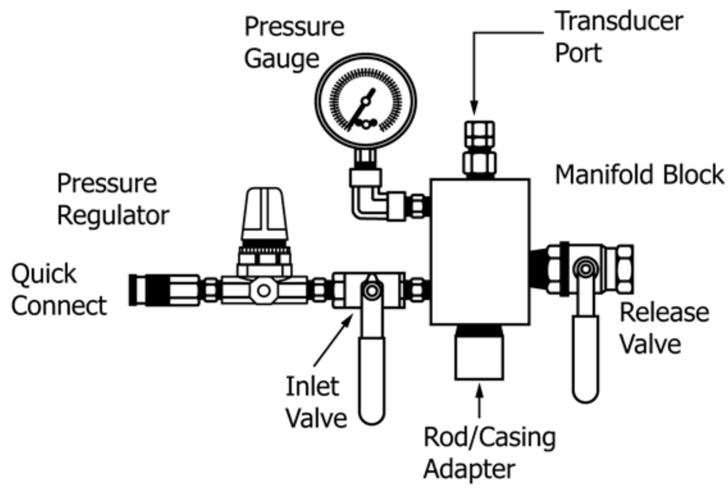
5.7.3 Some subsurface conditions may limit the depth of penetration of DP methods and tools. Some examples include thick caliche layers, cobbles or boulders, or very dense materials, such as high density glacial tills.

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.

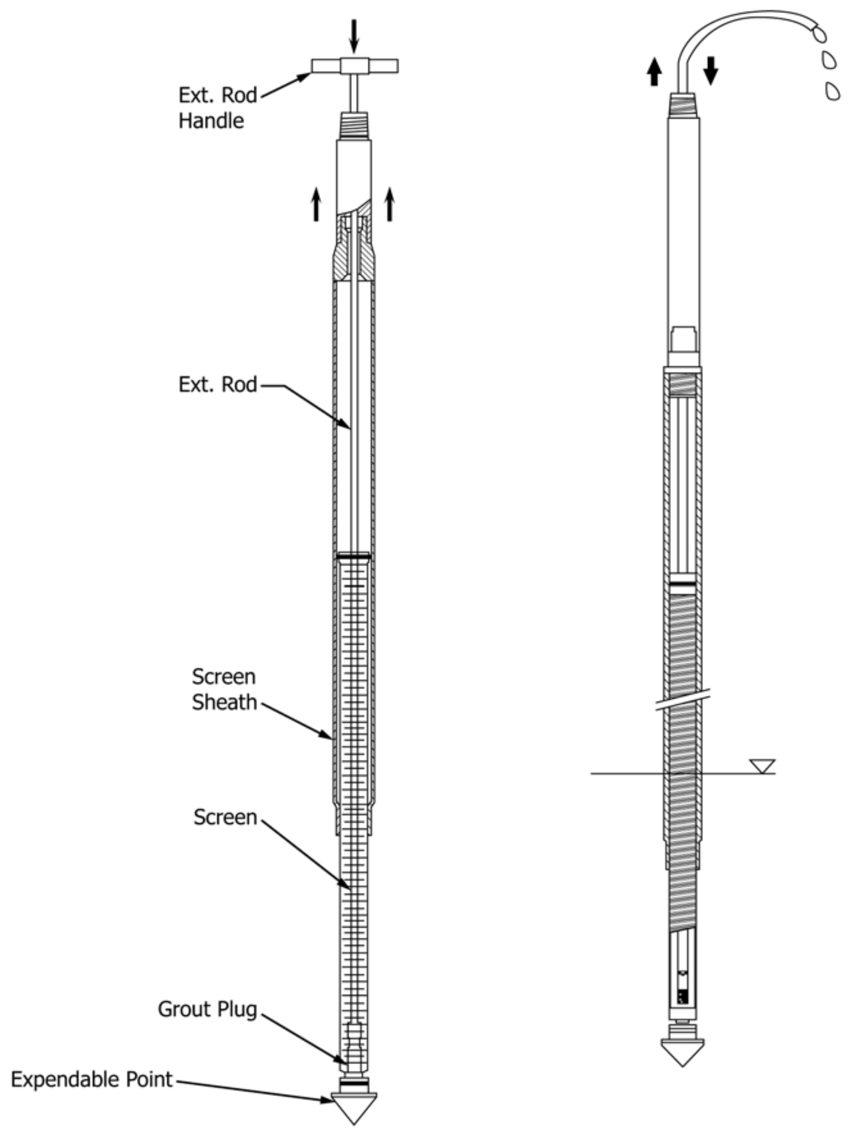
6.5 *Air/Vacuum Supply*—As the pressure inside the well head required to depress the water level a sufficient amount to conduct a slug test is not more than 3 to 7 kPa [1 to 2 psi], a large compressor is usually not required, especially for wells of 50 mm [2-in.] diameter or less and the smaller DP tools. 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



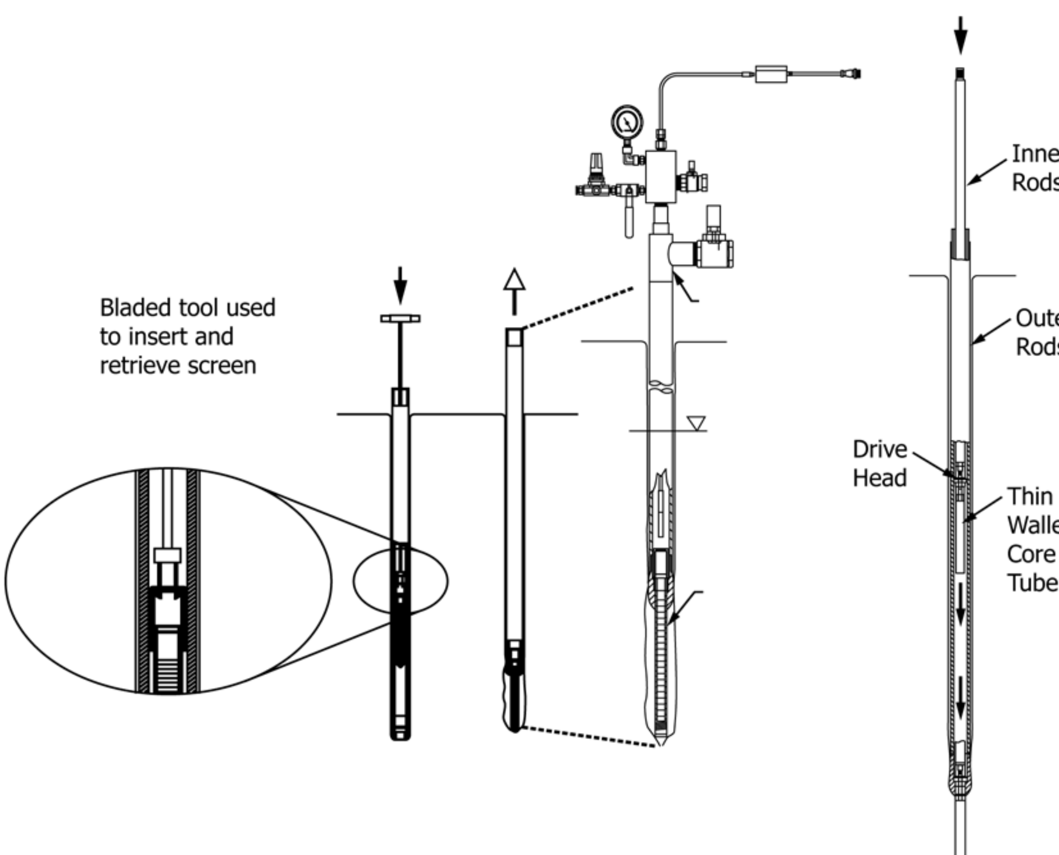
NOTE 1—Screen is protected with a sheath during advancement. Small extension rods inserted after driving (a) to expose screen desired amount for slug testing and sampling. Development must be conducted (b) to assure that natural flow is established between the formation and sampling device. Simple inertial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

results. In fine-grained formations any purging for development should be gentle and surging should be avoided to prevent damage. In cohesive formations brushing the core hole to relieve smearing from core sampling may be an integral part of the development process.

7.4 *Static Water Levels*—Measure and record the water level in the well to be slug tested before starting the tests. When possible, monitor the water level over a period of time similar to the duration of the slug test recovery. Measure and record the water level after testing is complete.

7.5 *Verify Development*—Probably the most effective way to verify that adequate development has been conducted on the well is to run preliminary slug tests. In wells that recover quickly, running three preliminary slug tests performed with the same initial head displacement are recommended. Plot the recovery curves for visual inspection (Fig. 4) or view onscreen if possible. When the well is adequately developed the initial change in head (H_o) and the symmetry of the recovery curves should be very similar. If preliminary slug tests of the same magnitude do not show a similar H_o and symmetry, further development may be required. Verification of development in fine-grained formations will be time consuming. Project objectives and economics must be considered under these circumstances.

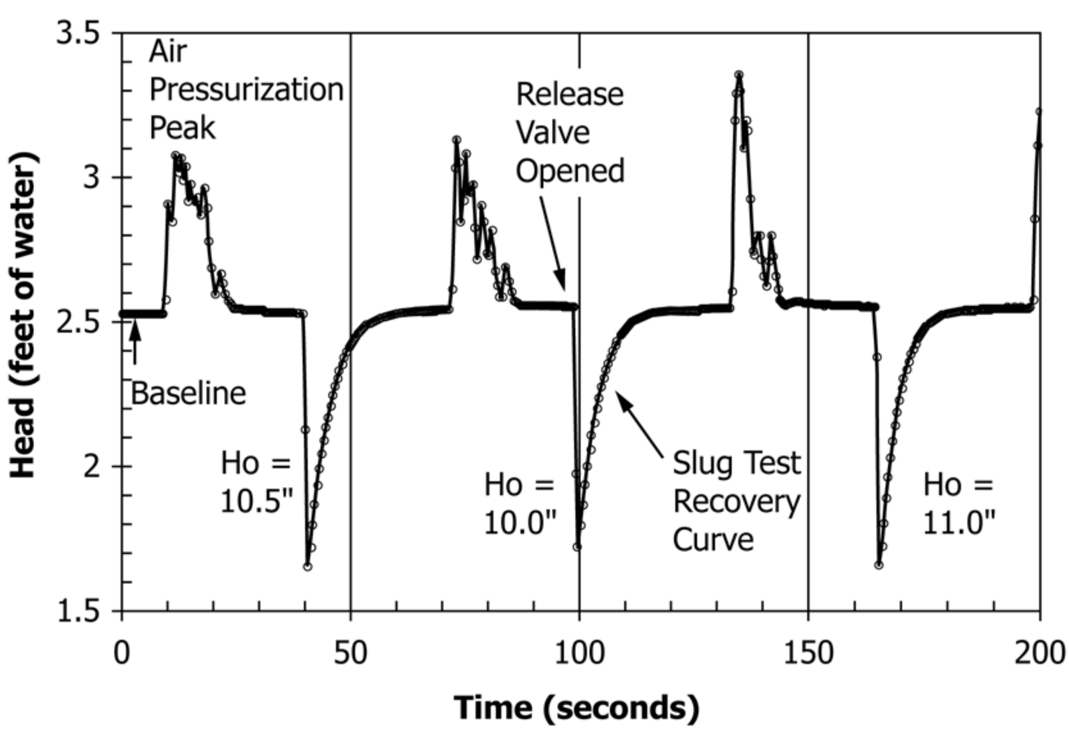
7.6 *Documentation of Well and Aquifer Parameters* —To facilitate accurate modeling of the slug test results well construction details must be known. These include parameters such as casing diameter, screen diameter and screen length. Well construction logs may provide much of this data. In addition, boring logs and water level data must be reviewed to determine the thickness of the aquifer and whether the aquifer is confined or unconfined. An easy way to assure that all of the required data is recorded is to prepare a diagram (Appendix X1) or list of the pertinent data to be gathered in the field for each well tested. This will assure that consistent and complete records are maintained.

8. Procedures

8.1 *General*—A typical field setup for pneumatic slug testing with a DP installed groundwater sampling tool is provided in Fig. 5. Refer to this figure for clarification of the procedures discussed below.

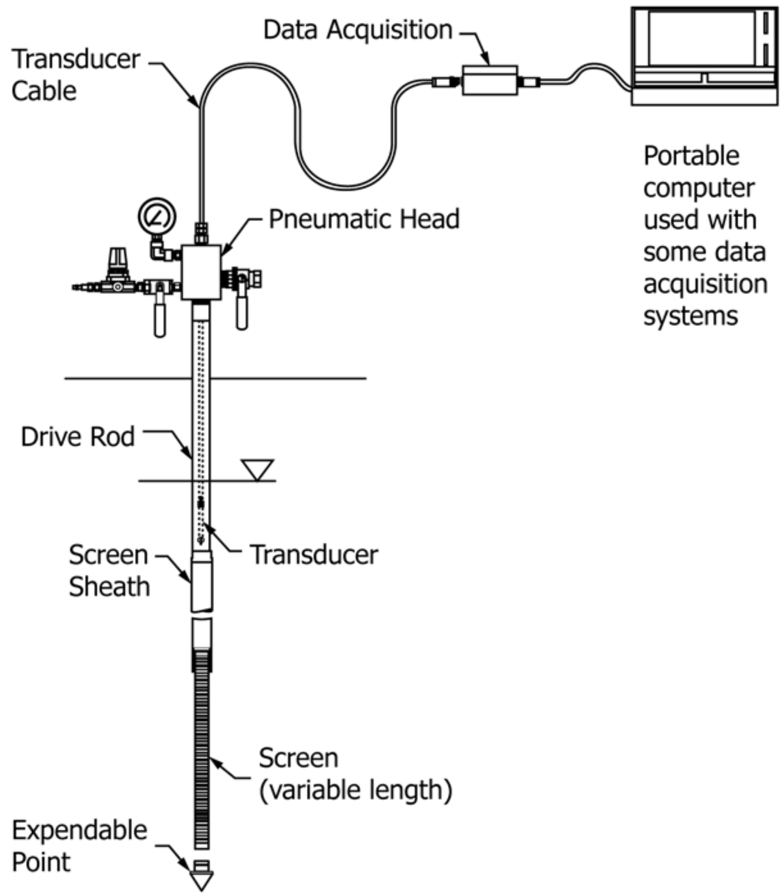
8.2 *Install Pneumatic Manifold*—The pneumatic manifold is fitted to the well casing or DP drive rod to provide an airtight fit. In some cases, adapters may be required to attach the pneumatic manifold to the casing. Use appropriate O-rings or other materials to assure an airtight seal is obtained.

8.3 *Install Transducer*—Insert transducer down the well or DP tool through airtight fitting on the manifold. Lower the transducer below the static water level to allow for temperature equilibration. The transducer should be placed below the water level further than the water level will be lowered during the slug tests, usually 1 to 1.5 m [3 to 5 ft]. Critical early time data will not be obtained if the water level is lowered below the transducer during a slug test. Follow manufacturer's recommendations to zero or set baseline on the transducer before initiating tests.



NOTE 1—Replicate slug tests with approximately the same initial head value (H_o) performed through a single tube groundwater sampler at a depth of 28 m [91 ft] with 3 m [1 ft] of screen exposed to formation. Proportional peak height and symmetry of the recovery curves for these overdamped responses indicate development is adequate and data quality acceptable.

FIG. 4 Replicate Slug Tests Displaying Overdamped Response



NOTE 1—Appropriate development must be performed before slug tests are conducted.

FIG. 5 Example of Field Setup Used for Performing a Pneumatic Slug Test with a Direct Push Installed Groundwater Sampler

8.4 *Data Acquisition*—Attach transducer to data acquisition system. This system may be a simple data logger or analog-to-digital (A-D) inverter and portable computer or other appropriate system. Prepare system for acquisition of data based on manufacturer's recommendations. From preliminary slug tests determine appropriate data acquisition rate to provide acceptable data density for recovery rate of the well. For highly permeable aquifers, especially when oscillatory responses occur, data acquisition rates of 5 to 10 Hz may be needed to provide sufficient data density for accurate modeling and curve fitting.

8.5 *Pressurize (or Evacuate) Wellhead*—Connect supply of compressed air (or vacuum pump) to the inlet valve of the pneumatic manifold. Use pressure regulator or suitable valve to regulate rate of airflow into the wellhead. Do not over pressurize the wellhead. If air is injected into the formation, non-representative results will occur during slug testing due to compressibility of air trapped in the formation. Observe the pressure (or vacuum) gauge on the pneumatic manifold to determine when the desired water level change is obtained. Adding more air (or increasing vacuum) incrementally may be done to obtain the desired initial head change value. Allow the water level in the wellhead to stabilize before starting the slug test. Initial head pressures that provide a water level change in the range of 30 to 100 cm [1 to 3 ft] are generally recommended (Ref (**1**)). Larger head changes may be suitable for under damped formations.

8.6 *Leak Testing*—Testing the pneumatic manifold and well system for leaks is often done while conducting a preliminary slug test. After pressurizing (or evacuating) the wellhead, the air pressure inside the wellhead will drift back to an equilibrium point. Observe the pressure gauge on the pneumatic head to determine when the pressure has stabilized. If the pressure in the wellhead continues to drop (or rise) until it approaches ambient air pressure then the system has a leak. Readjust pressure in the wellhead and use a suitable leak detection fluid to check each fitting for possible leaks. Make necessary adjustments to eliminate leaks. Leaks may occur not only at the pneumatic head, but down hole. PVC casing joints may be damaged, or O-rings may be missing. For DP tools, be sure to use O-rings on every rod connection and keep the tool string tightened as it is advanced to depth.

8.7 *Initiate Slug Test*—Once the wellhead is pressurized (or evacuated) to the desired level and the water level in the well has stabilized the pressure release valve on the pneumatic head is quickly and smoothly opened to start the slug test. The duration required for recovery of the water level to its equilibrium level will depend on the transmissivity of the screened formation, length and diameter of the screen and diameter of the casing where the water level change occurs. The duration of water level recovery is independent of the magnitude of the initial change in the water level (H_o) used to induce the slug test. Pressurization and slug test recovery curves for a typical over damped slug test response may occur in a matter of seconds (Fig. 4), minutes or even hours for fine-grained formations. Under damped slug test responses (Fig. 6) are typical of high hydraulic conductivity formations and are often completed in less than a minute.

8.8 *Field Quality Check*—When duration of tests permit, a minimum of three slug tests should be performed using the same initial head displacement (for example, 50 cm [20 in.]) (Ref (**1**)). Plot the results of the three tests, or observe onscreen, and compare peak height and curve symmetry (Fig. 4). If all tests have very similar peak height and curve symmetry this suggests test results are repeatable and well development adequate. For additional quality control in the field and during later data analysis, conduct tests with greater and lesser head displacement values (for example, 25 cm, 50 cm, 75 cm [10 in., 20 in., 30 in.] (**1**)). Visual inspection of peak height and symmetry should reveal all three to be proportional (Fig. 7). If the peak height for the ~75 cm [~30 in.] slug test is proportionally small compared to the other tests, it suggests that slug tests at the larger magnitude are not providing accurate responses. Recommend conducting a slug test of intermediate head (for example, 35 cm [15 in.]) to determine if the slug test response over this smaller range is accurate.

8.9 *Field Notes and Data Storage*—Save electronic data files to diskettes, compact disks, etc. for storage and archival, label appropriately. Maintain complete and accurate field notes to document methods, field quality control, anomalous results and any deviations from planned procedures.

9. Report

9.1 The following information should be included in the field report. Much of this information is included on the diagram in Appendix X1. Refer also to D5434 for further guidance and information.

9.1.1 Facility name, location and address information, site contacts.

9.1.2 Well number, location, depth, and well construction information as listed in Appendix X1.

9.1.3 Names of drilling company, driller, helper, and field technician conducting the slug test.

9.1.4 File names of slug test data files.

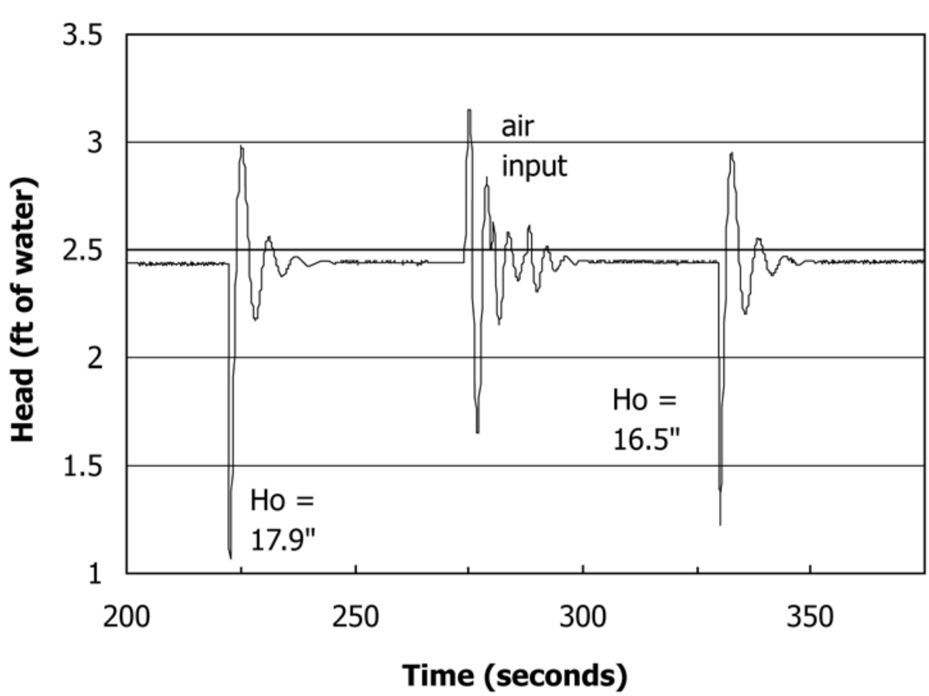
9.1.5 Specifications of equipment used to conduct the slug test (transducer, data logger, screen specifications, DP ground-water sampler specifications, etc.).

9.1.6 Rising head or falling head test, magnitude of head change used to initiate the test.

9.1.7 Recommend including copies of boring logs and well construction logs and development logs for each well tested.

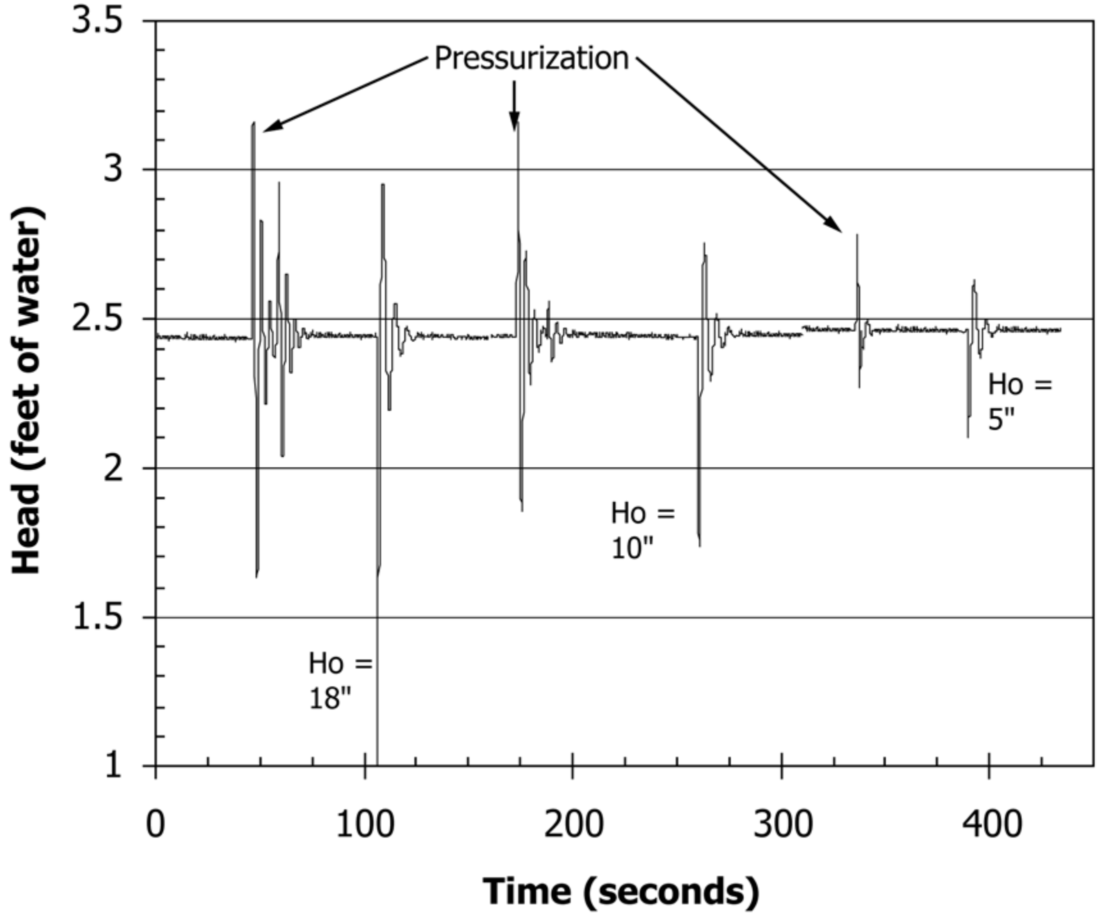
9.1.8 Field notes completed as slug tests conducted.

9.1.9 Site-specific information relevant to the project.



NOTE 1—High hydraulic conductivity formations may yield an underdamped response to an instantaneous change in head resulting in an oscillatory movement of water in the well. The slug tests in this figure were performed in a DP installed prepacked screen monitoring well with 13-mm [0.5-in.] nominal casing diameter and effective screen length of 3-m [10-ft]. A sampling rate of 10 Hz was used to provide good definition of the aquifer response so that curve fitting and determination of K could be done accurately. Visual inspection of peak height and curve symmetry for repeat tests may be used to conduct field quality control.

FIG. 6 Slug Tests Displaying the Underdamped (Oscillatory) Response



NOTE 1—A series of slug tests using different initial head values may be used in the field to provide a qualitative evaluation of the data and aquifer-well system response. Visual inspection indicating proportional peak heights and symmetry of response curves suggests system response is linear over the range of head values tested. See Fig. 8 for post acquisition QC measures.

FIG. 7 Proportional Response of Underdamped Slug Tests Conducted With Different Initial Head Values

10. Data Analysis Considerations

10.1 *Casing Radius Correction*—When conducting slug tests in smaller diameter wells or DP tools (for example, ID < 50 mm [2 in.]), the diameter of the transducer cable will displace a significant proportion of the well volume. This will result in faster recovery of the water level and an error in the determined K if the displaced volume is not corrected for during calculation. To account for the volume displaced by the transducer cable the casing radius is corrected as follows:

$$Rcc = \left(R_c^2 - r_t^2\right)^{1/2} \quad (1)$$

where:

Rcc = the corrected casing radius,
R_c = actual measured radius of the casing (or drive rod) where the measured change in water level occurs during the slug test, and
r_t = actual measured radius of the transducer cable.

10.2 *Correction for Frictional Losses in High K Media*—Field research (Ref (**8**)) found that frictional losses became significant in smaller diameter casings (ID < 50 mm [2 in.]) when under damped (oscillatory) responses were encountered. Comparison of results with tests conducted in adjacent larger diameter wells revealed that the frictional losses began to appear when the formation hydraulic conductivity exceeded about 60 m/day [200 ft/day]. Additional analysis (Ref (**9**)) resulted in development of a simple correction factor to account for frictional losses in the smaller diameter casing. The correction procedure for the calculation of hydraulic conductivity described therein should be followed when the casing diameter is less than 50 mm [2 in.] and the hydraulic conductivity exceeds 60 m/day [200 ft/day].

10.3 *Analytical Models*—Both formation conditions and the type of slug test response obtained during the slug test will determine the analytical model that should be used to calculate the formation hydraulic conductivity. Boring logs, CPT logs or similar information must be reviewed along with observed water levels to determine if the aquifer is confined or unconfined. Review of the slug test data plot will readily indicate if the aquifer response is over damped (for example, Fig. 4) or under damped (for example, Fig. 6). This information is used in conjunction with Guide D4043 to select the appropriate analytical model for calculation of hydraulic conductivity or transmissivity. A thorough review of analytical models used for determination of hydraulic conductivity is provided in Ref (**1**).

11. Precision and Bias

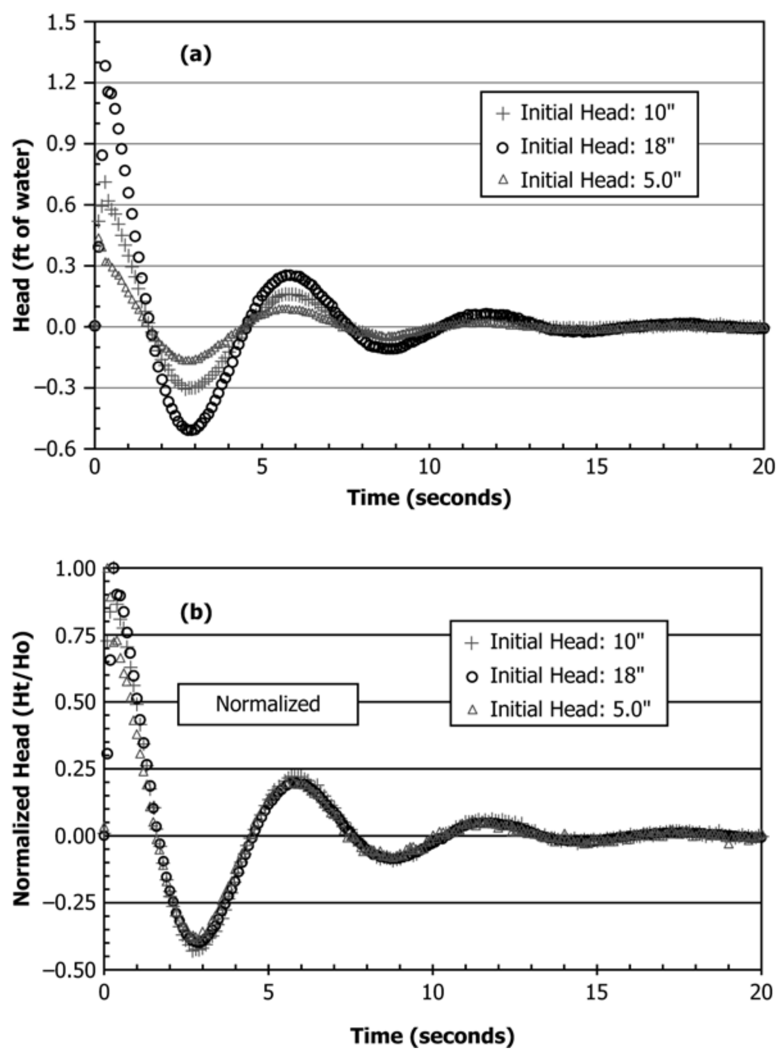
11.1 *Precision*—Test data on precision is not presented due to the nature of this test method. It is either not feasible or too costly at this time to have 10 or more agencies participate in an in situ testing program at a given site.

11.2 The subcommittee (D18.21) is seeking any data from the users of this test method that might be used to make a limited statement on precision.

11.3 Slug tests conducted in situ in the field are generally regarded as providing semi quantitative estimates of transmissivity and/or hydraulic conductivity. The results are usually considered semi-quantitative because of the heterogeneous nature of almost all aquifers and natural formations. However, methods do exist for qualitatively and quantitatively assessing precision and bias for multiple slug tests conducted in a single well using the same methods.

11.4 *Location Specific Precision*—Precision of location specific slug tests may be evaluated on a qualitative level in the field, and later, quantitatively during modeling and calculations.

11.4.1 Precision in the Field is most often evaluated by conducting several pneumatic slug tests initiated using the same initial head. Visual comparison is made of data plots from three or more slug tests initiated with the same initial head (Fig. 4). The initial change in the head for each test should be comparable. The rate of the water level recovery and the symmetry of the recovery curve should be similar for all the



NOTE 1—Three slug tests were performed in the same well using differing initial head values (see Fig. 7). Non-normalized plot (*a*) with start times aligned shows time correlation of peaks and troughs with different initial displacements. Normalized plot (*b*) demonstrates that for the range of head values tested the system responds in a linear fashion and therefore no bias of method over the range tested. These tests conducted in a nominal 13-mm [0.5-in.] diameter PVC prepacked screen well with 3-m [10-ft] effective screen interval using pneumatic methods.

FIG. 8 Example of Post Acquisition Quality Control

tests based on visual inspection of the data plots. If these qualitative measures of precision are not met in the field, corrective action should be considered. Most often the well is redeveloped to remove a well skin or to remove mobile fines from the screened interval in order to obtain repeatable results. Note any anomalous slug test response in field notes and report appropriately.

11.4.2 *Quantitative Precision*—Precision may be quantitatively evaluated after the slug test response data are obtained. Results from three or more slug tests initiated with the same initial head may be plotted over each other for graphical comparison. Furthermore, the appropriate analytical method (Test Methods D4104, D5785, D5881, D5912, Refs (**1, 3**)) should be used to calculate the hydraulic conductivity from each repeat test conducted with the same initial head in one well. The precision of the method may then be evaluated by calculation of the percent relative standard deviation (%RSD) between the calculated hydraulic conductivity values where:

$$\%\ RSD = [\{(\text{Sum}(x_i - \text{mean})^2)/(n-1)\}/\text{mean}] \times 100 \qquad (2)$$

The percent relative standard deviation for slug tests conducted in the same well with the same initial head should not exceed 10 %. This assumes the slug tests are conducted over the same screen interval, applying the same method.

11.5 *Bias*—There is no accepted reference value for this test method, therefore, bias cannot be determined.

11.5.1 Unlike laboratory analytical methods, objective standards do not exist for (pneumatic) slug tests conducted in the field. However, some methods for qualitative evaluation of bias may be applied, either in the field or later by comparison of data plots from replicate tests from the same well. Due to the influence of scale (Ref (**10**)) it is generally not appropriate to compare slug tests to pumping tests to assess bias. Additionally, comparison of slug tests to laboratory tests for K on soil cores (for example, Test Methods D2434, D5084, D5856) is generally not effective. Again the influence of scale of measurement as well as laboratory and sampling procedures will result in differences in measured values of K between lab tests and slug tests often approaching an order of magnitude. Some lab procedures measure vertical K as compared to the horizontal K measured by slug tests. Other lab methods use remolding of the sample that will change natural texture and structure causing differences between the lab measurements and field slug tests.

11.5.2 A quality check may be performed for evaluation of bias in the field by conducting three or more slug tests using differing initial head values (Fig. 7, Fig. 8). Visual comparison of the data plots may be made in the field to determine if the change in initial head used to start the tests results in a proportional change of response observed in the output data (Fig. 7). If the change in peak height from smaller to larger initial head values is not proportional corrective measures should be considered. Additional well development may be required or the magnitude of head over which the tests are conducted may need to be reduced. Use of large initial head values in small diameter wells or groundwater samplers will result in attenuation of response due to frictional losses in the well bore (Refs (**8, 9**)) causing a bias in the test result.

11.5.3 Results from repeat slug tests with differing initial head values (Fig. 8a) (for example 25, 50, and 75 cm [10, 20, and 30 in.]) may be normalized (H_t/H_o) and plotted together (Fig. 8b) for a graphical evaluation of bias. When the aquifer and well are responding appropriately the normalized results should closely overlay one another on the plot (Fig. 8b). This indicates a lack of bias in the testing method under the existing aquifer and well conditions for the range of head values tested. Use of extremely large head values (2 to 3 m [5 to 10 ft]) will often result in nonlinear results (Ref (**9**)) when compared to smaller head values, especially in aquifers that display oscillatory responses to slug testing.

12. Keywords

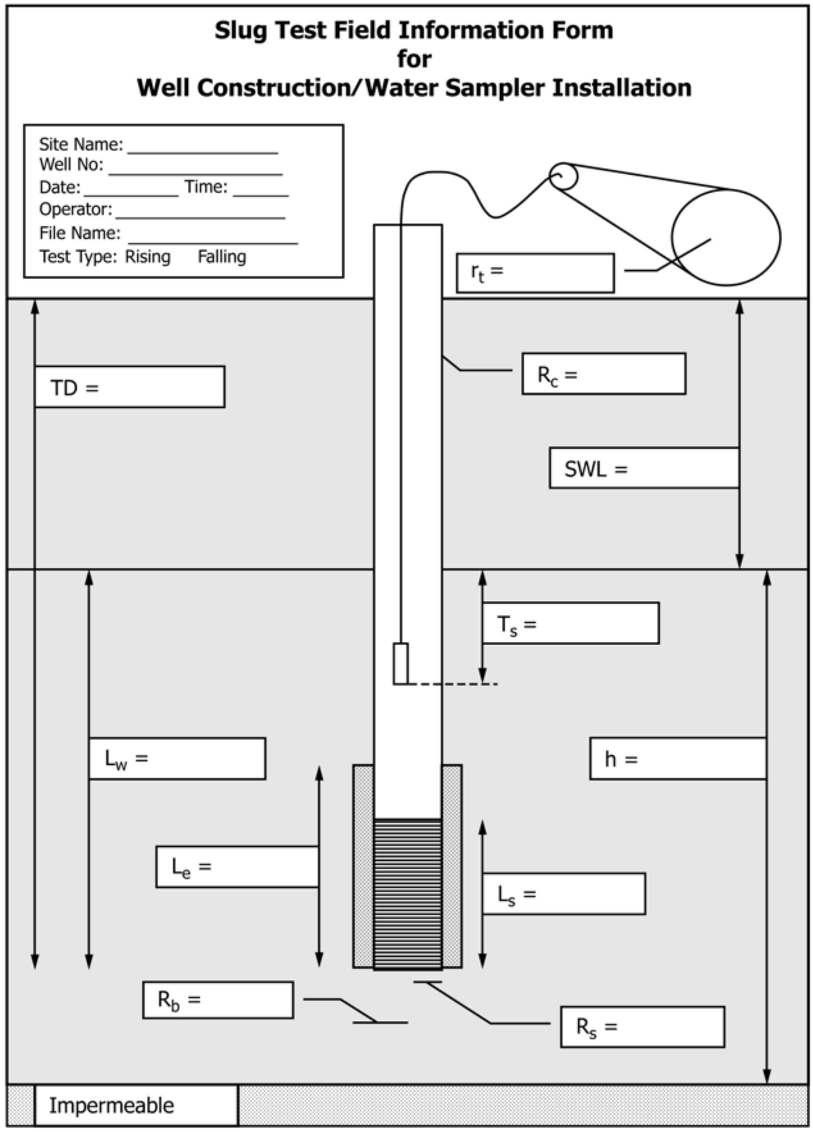
12.1 aquifer; direct push; hydraulic conductivity; pneumatic; slug test

APPENDIX

(Nonmandatory Information)

X1. SLUG TEST FIELD INFORMATION FORM FOR WELL CONSTRUCTION / WATER SAMPLER INSTALLATION

X1.1 See Fig. X1.1.



H_o = Initial change in head at instant the slug test is started. For pneumatic slug tests, this may be estimated from the stabilized pressure (or vacuum) gauge readout on the manifold just before the slug test is started.
h = Saturated thickness of aquifer.
L_e = Effective screen length: This will include length of any artificial sand pack extending above the well screen.
L_s = True screen length. The length of slotted or perforated screen exposed to the formation.
L_w = Length of water column in the well (L_w = TD – SWL).
R_b = Radius of filter pack or borehole over the screen interval.
R_c = Casing radius. True internal radius of casing where the water level occurs.
Note—Casing radius must be constant over the interval where water level change occurs during the slug test. If the casing radius is not constant over this interval, the rate of water level change observed by the transducer will be distorted causing errors in modeling and determination of aquifer parameters.
Rcc = $(R_c^2 - r_t^2)^{1/2}$ (Ref **(8)**). For wells or DP casing less than 25-mm [1-in.] radius the casing radius must be corrected for the radius of the transducer cable. In smaller wells, the transducer cable begins to displace a significant volume and will result in increased rate of water level recovery. If not accounted for this will cause a systematic error in calculation of aquifer parameters.
R_s = Screen radius. Radius of the slotted or perforated casing where water enters the well during the slug test.
r_t = Radius of the transducer cable. Specifically, the radius of the cable over which the water level change occurs during the slug test.
SWL = Static water level. Water level in the undisturbed well at ambient atmospheric pressure.
TD = Total depth. Depth of well screen as measured from reference point at the surface.
T_s = Depth the transducer is submerged below the static water level.
Aquifer Type—Review sample cores, well and boring logs, and/or geophysical logs to determine if the aquifer is confined or unconfined.
Formation Type—Provide a verbal description of the formation material being slug tested (for example, clay, silt, sand, gravel, silty-sand, etc.). Best if this description is based on a sample collected from the interval being tested.

NOTE 1—Not all parameters identified here are required for use with each model to calculate hydraulic conductivity.

FIG. X1.1 Slug Test Field Information Form for Well Construction / Water Sampler Installation

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SUMMARY OF CHANGES

Committee D18 has identified the location of selected changes to this standard since the last issue (D7242 – 06) that may impact the use of this standard. (Approved Dec. 1, 2013.)

(1) Revised the standard into a dual measurement system with the units of measurement now stated in either inch-pound units or SI units.

(2) Deleted reference to D4750, which has been withdrawn.