Designation: D5881 – 20

# Standard Practice for (Analytical Procedures) Determining Transmissivity of Confined Nonleaky Aquifers by Critically Damped Well Response to Instantaneous Change in Head (Slug)[1]

This standard is issued under the fixed designation D5881; 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.

## 1. Scope*

1.1 This practice covers determination of transmissivity from the measurement of water-level response to a sudden change of water level in a well-aquifer system characterized as being critically damped or in the transition range from underdamped to overdamped. Underdamped response is characterized by oscillatory changes in water level; overdamped response is characterized by return of the water level to the initial static level in an approximately exponential manner. Overdamped response is covered in Guide D4043; underdamped response is covered in Practice D5785/D5785M, Guide D4043.

1.2 The analytical procedure in this practice is used in conjunction with Guide D4043 and the field procedure in Test Method D4044/D4044M for collection of test data.

1.3 *Limitations*—Slug tests are considered to provide an estimate of the transmissivity of an aquifer near the well screen. The method is applicable for systems in which the damping parameter, ζ, is within the range from 0.2 through 5.0. The assumptions of the method prescribe a fully penetrating well (a well open through the full thickness of the aquifer) in a confined, nonleaky aquifer.

1.4 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D6026.

1.4.1 The procedures used to specify how data are collected/recorded and calculated in this standard are regarded as the industry standard. In addition, they are representative of the significant digits that should generally be retained. The procedures used do not consider material variation, purpose for obtaining the data, special purpose studies, or any considerations for the user's objectives; and it is common practice to increase or reduce significant digits of reported data to commensurate with these considerations. It is beyond the scope of this standard to consider significant digits used in analysis methods for engineering design.

1.5 *Units*—The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard. Reporting of results in units other than SI shall not be regarded as nonconformance with this standard.

1.6 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 the 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 the consideration of a project's many unique aspects. The word "Standard" in the title of this document means only that the document has been approved through he ASTM consensus process.

1.7 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.8 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

## 2. Referenced Documents

2.1 *ASTM Standards:*[2]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

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

[1] This test method 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] 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.

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

Used in Engineering Design and Construction
D4043 Guide for Selection of Aquifer Test Method in Determining Hydraulic Properties by Well Techniques
D4044/D4044M Test Method for (Field Procedure) for Instantaneous Change in Head (Slug) Tests for Determining Hydraulic Properties of Aquifers
D5717 Guide for Design of Ground-Water Monitoring Systems in Karst and Fractured-Rock Aquifers (Withdrawn 2005)[3]
D5785/D5785M Practice for (Analytical Procedure) for Determining Transmissivity of Confined Nonleaky Aquifers by Underdamped Well Response to Instantaneous Change in Head (Slug Test)
D6026 Practice for Using Significant Digits in Geotechnical Data

## 3. Terminology

3.1 *Definitions*—For definitions of common technical terms in this standard, refer to Terminology D653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *aquifer, confined, n—in ground water*, an aquifer bounded above and below by confining beds and in which the static head is above the top of the aquifer.

3.2.2 *critically damped well response, n—in ground water*, characterized by the water level responding in a transitional range between underdamped and overdamped following a sudden change in water level.

3.2.3 *observation well, n—in ground water*, a well open to all or part of an aquifer.

3.3 *Symbols and Dimensions:*

3.3.1 $T$—transmissivity [$L^2T^{-1}$].

3.3.2 $S$—storage coefficient [*nd*].

3.3.3 $L$—static water column length above top of aquifer [$L$].

3.3.4 $L_e$—effective length of water column in a well, equal to $L_c + (r_c^2/r_s^2)\,(b/2)$ [$L$].

3.3.5 $L_c$—length of water column within casing [$L$].

3.3.6 $L_s$—length of water column within well screen [$L$].

3.3.7 $g$—acceleration of gravity [$LT^{-2}$].

3.3.8 $h$—hydraulic head in the aquifer [$L$].

3.3.9 $h_o$—initial hydraulic head in the aquifer [$L$].

3.3.10 $h_s$—hydraulic head in the well screen [$L$].

3.3.11 $r_c$—radius of well casing [$L$].

3.3.12 $r_s$—radius of well screen [$L$].

3.3.13 $t$—time [$T$].

3.3.14 $t'$—dimensionless time [*nd*].

3.3.15 $\hat{t}$—dimensionless time [*nd*].

3.3.16 $w$—water level displacement from the initial static level [$L$].

3.3.17 $w_o$—initial water level displacement [$L$].

3.3.18 $\alpha$—dimensionless storage parameter [*nd*].

3.3.19 $\beta$—dimensionless inertial parameter [*nd*].

3.3.20 $\gamma$—damping constant [$T^{-1}$].

3.3.21 $\tau$—wavelength [$T$].

3.3.22 $\omega$—angular frequency [$T^{-1}$].

3.3.23 $\zeta$—dimensionless damping factor [*nd*].

## 4. Summary of Practice

4.1 This practice describes the analytical procedure for analyzing data collected during an instantaneous head (slug) test for well and aquifer response at and near critical damping. Procedures in conducting a slug test are given in Test Method D4044/D4044M. The analytical procedure consists of analyzing the response of water level in the well following the change in water level induced in the well.

4.2 *Theory*—The equations that govern the response of well to an instantaneous change in head are treated at length by Kipp (**1**).[4] The flow in the aquifer is governed by the following equation for cylindrical flow:

$$\frac{S}{T}\frac{dh}{dt} = \frac{1}{r}\frac{d}{dr}\left(r\frac{dh}{dr}\right) \tag{1}$$

where:

$h$ = hydraulic head,
$T$ = aquifer transmissivity, and
$S$ = storage coefficient.

4.2.1 The initial condition is at $t = 0$ and $h = h_o$, and the outer boundary condition is as $r -$ and $h - h_o$.

4.2.1.1 An equation is given by Kipp (**1**) for the skin factor, that is, the effect of aquifer damage during drilling of the well. However, this factor is not treated by Kipp (**1**) and is not considered in this procedure.

4.2.2 The flow rate balance on the well bore relates the displacement of the water level in the well riser to the flow into the well:

$$\pi r_c^2\frac{dw}{dt} = 2\pi r_s T\frac{dh}{dr}\Big|_{r=rs} \tag{2}$$

where:

$r_c$ = radius of the well casing, and
$w$ = displacement of the water level in the well from its initial position.

4.2.3 The fourth equation describing the system relating $h_s$ and $w$, comes from a momentum balance equation of Bird et al (**2**) as referenced in Kipp (**1**):

$$\frac{d}{dt}\int_{-b}^{0}\pi r_s^2\,\rho v dz = \left(-\rho v_2^2 + p_1 - p_2 - \rho g b\right)\pi r_s^2 \tag{3}$$

where:

$v$ = velocity in the well screen interval,
$b$ = aquifer thickness,
$p$ = pressure,

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

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