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65-17

Calculation of the Saturated Hydraulic Conductivity of Fine-Grained Soils

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CONTENTS

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PREFACE

This is a standard guideline for calculating saturated hydraulic conductivity (K_{sat}), permeability (k), and porosity (n) of fine-grained soils using (1) strain-stress data from the incremental loading of a soil sample in a standardized consolidometer (step-load test), (2) one-dimensional vertical consolidation theory relating K_{sat} to the coefficient of consolidation (c_v), (3) the relation between K_{sat} and k, and (4) the relation between the porosity and the void ratio of a soil undergoing primary consolidation. An undisturbed soil specimen is inserted in a consolidometer and subjected to incremental vertical loads allowing axial (vertical) drainage. The vertical axial deformation of the soil specimen is measured as a function of elapsed testing time through various cycles of incremental loading until the end of the consolidation test. The measured deformation is graphed as a function of the $\log_{10}$ of time or the square root of time for each increment of vertical load. These graphs are used to calculate the coefficient of consolidation for each loading increment applied to the soil specimen. Terzaghi's (1925) one-dimensional (1D) vertical consolidation theory relating K_{sat} to c_v is then applied to calculate K_{sat} for each increment of vertical load applied to the soil specimen. The permeability and porosity of the soil sample decrease with increasing applied vertical load according to known laws. The permeability and porosity of the tested soil specimen are calculated for each load increment as well. The calculated K_{sat}, k, and porosity yield a series of pairs of values (K_{sat}, vertical effective stress; k, vertical effective stress; and porosity, vertical effective stress) that are graphed to produce relations between (1) K_{sat} and vertical effective stress, (2) permeability and vertical effective stress, and (3) porosity and vertical effective stress. This standard guideline demonstrates the relation between 1D consolidation and land subsidence driven by groundwater withdrawal, highlighting the relevance of strain-stress phenomena observed in consolidometer testing to the groundwater-induced phenomenon of land subsidence (consolidation of compressible strata by groundwater withdrawal). The increase in vertical effective stress caused by declining pore water pressure during sustained groundwater extraction; the changes effected by groundwater withdrawal on K_{sat}, k, and porosity; and the associated land subsidence are the primary foci of this standard guideline. This standard's methodology can be applied to refine or improve calculations of land subsidence, groundwater flow predictions, and transport of dissolved solutes moving in groundwater through fine-grained soils. The methods of this standard guideline are limited to fine-grained, compressible, inorganic soils. Highly organic soils (peat) exhibit anomalous primary and secondary consolidation not within the scope of this standard guideline.

This standard guideline represents the consensus of the Standards Committee on Fitting of Hydraulic Conductivity using Statistical Spatial Estimation (called KSTAT) of the Standards Development Council (SDC) of the Environmental and Water Resources Institute (EWRI) of ASCE. This standard guideline is the fourth in a series of standards that seeks to enhance the probabilistic and empirical characterization and understanding of the saturated hydraulic conductivity (K_{sat}), a key groundwater parameter. The KSTAT Standards Committee has published three companion standard guidelines: Standard ASCE/EWRI 50-08 (ASCE 2008a), Standard ASCE/EWRI 51-08 (ASCE 2008b), and Standard ASCE/EWRI 54-10 (ASCE 2010). Standard ASCE/EWRI 50-08 addresses the optimal fitting of saturated hydraulic conductivity (K_{sat}) with skewed probability density functions (pdfs). Standard ASCE/EWRI 51-08 deals with the estimation of the effective saturated hydraulic conductivity, a parameter that relates the average specific discharge to the average hydraulic gradient. Standard ASCE/EWRI 54-10 presents a methodology for the geostatistical interpolation and block averaging of K_{sat} in statistically homogeneous and isotropic aquifers.

The formulas in this standard guideline require that all their values be expressed in the same system of units, be it the International System of Units (SI) (meter, second, Newton, etc.) or the common system of units in the United States (feet, second, pound, etc.).

The provisions of this document are written in permissive language and, as such, offer to the user a series of options or instructions but do not prescribe a specific course of action. Significant judgment is left to the user of this document.

ASCE does not endorse commercial spreadsheets, numerical software, or testing methods produced by other organizations cited in this standard guideline. Any such products are cited in this standard guideline to illustrate possible ways of carrying out calculations and conducting experimental tests. It is left to the user's discretion to choose and verify the accuracy of whichever computational technique or testing method to apply to implement the methodology.

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CHAPTER 1
SCOPE

This is a standard guideline for calculating the saturated hydraulic conductivity (K_{sat}), permeability (k), and porosity (n) of fine-grained, isotropic, and homogeneous soils using (1) strain-stress data from the incremental loading of a soil sample in a standardized consolidometer (step-load test), (2) 1D vertical consolidation theory relating K_{sat} to the coefficient of consolidation (c_v), (3) the relation between K_{sat} and k, and (4) the relation between porosity and the void ratio of a soil undergoing primary consolidation. An undisturbed soil specimen is inserted in a consolidometer and subjected to incremental vertical loads allowing axial (vertical) drainage. The vertical axial deformation of the soil specimen is measured as a function of elapsed testing time through several cycles of incremental loading until the end of the consolidation test. The measured deformation is graphed as a function of the $\log_{10}$ of time or the square root of time for each increment of vertical load. These graphs are used to calculate the coefficient of consolidation for each load increment applied to the soil specimen. (Casagrande's unpublished work of 1938 and Taylor's 1948 graphical methods are commonly used.) Terzaghi's (1925) 1D vertical consolidation theory relating K_{sat} to c_v is then used to calculate K_{sat} for each increment of vertical load applied to the soil specimen. The permeability and porosity of the soil sample decrease with increasing applied vertical load according to known laws. The permeability and porosity of the tested soil specimen are calculated for each loading increment as well. The calculated K_{sat}, k, and porosity yield a series of pairs of values (K_{sat}, vertical effective stress; k, vertical effective stress; and porosity, vertical effective stress) that are graphed to produce relations between (1) K_{sat} and the vertical effective stress, (2) permeability and vertical effective stress, and (3) porosity and vertical effective stress.

The classical theory of 1D (vertical) consolidation (Terzaghi 1925) assumes that K_{sat}, k, and porosity remain constant as soils consolidate under increasing vertical effective stress caused by external loads or groundwater extraction. In fact, the poroelastic theory of 3D consolidation makes the same assumption concerning K_{sat} of a deforming soil (Loáiciga 2013). Yet, the experimental evidence from 1D consolidation tests indicates that K_{sat}, k, and porosity decrease when a soil consolidates under increasing vertical effective stress as discussed in this document. The increase in vertical effective stress caused by declining pore water pressure during sustained groundwater extraction; the changes effected by groundwater withdrawal on K_{sat}, k, and porosity; and the associated land subsidence are the primary foci of this standard guideline. This standard guideline demonstrates the relation between 1D consolidation and land subsidence driven by groundwater withdrawal, highlighting the relevance of strain-stress phenomena observed in consolidometer testing to the groundwater-induced phenomenon of land subsidence (consolidation of compressible strata by groundwater withdrawal). This standard's methodology can be applied to calculations of land subsidence, groundwater flow predictions, and transport of dissolved solutes moving in groundwater through fine-grained soils.