Designation: D7300 – 18

Standard Test Method for Laboratory Determination of Strength Properties of Frozen Soil at a Constant Rate of Strain[1]

This standard is issued under the fixed designation D7300; 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.

INTRODUCTION

Knowledge of the stress-strain-strength behavior of frozen soil is of great importance for civil engineering construction in permafrost regions. The behavior of frozen soils under load is usually very different from that of unfrozen soils because of the presence of ice and unfrozen water films. In particular, frozen soils are much more subject to creep and relaxation effects, and their behavior is strongly affected by temperature change. In addition to creep, volumetric consolidation may also develop in frozen soils having large unfrozen water or gas contents.

As with unfrozen soil, the deformation and strength behavior of frozen soils depends on interparticle friction, particle interlocking, and cohesion. In frozen soil, however, bonding of particles by ice may be the dominant strength factor. The strength of ice in frozen soil is dependent on many factors, such as temperature, pressure, strain rate, grain size, crystal orientation, and density. In ice-rich soils (that is, soils where the ratio of the mass of ice contained in the pore spaces of frozen soil or rock material, to the mass of solid particles in that material is high), frozen soil behavior under load is similar to that of ice. In fact, for fine-grained soils, experimental data suggest that the ice matrix dominates when mineral volume fraction is less than about 50 %. At low ice contents, however, (ice-poor soils), when interparticle forces begin to contribute to strength, the unfrozen water films play an important role, especially in fine-grained soils. Finally, for frozen sand, maximum strength is attained at full ice saturation and maximum dry density (**1**).[2]

1. Scope

1.1 This test method covers the determination of the strength behavior of cylindrical specimens of frozen soil, subjected to uniaxial compression under controlled rates of strain. It specifies the apparatus, instrumentation, and procedures for determining the stress-strain-time, or strength versus strain rate relationships for frozen soils under deviatoric creep conditions.

1.2 Values stated in SI units are to be regarded as the standard.

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

1.3.1 For the purposes of comparing measured or calculated value(s) with specified limits, the measured or calculated value(s) shall be rounded to the nearest decimal or significant digits in the specified limits.

1.3.2 The procedures used to specify how data are collected/recorded or calculated, in this standard are regarded as the industry standard. In addition, they are representative of the significant digits that generally should 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 be commensurate with these considerations. It is beyond the scope of this standard to consider significant digits used in analytical methods for engineering design.

---

[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.19 on Frozen Soils and Rock.

Current edition approved Nov. 15, 2018. Published December 2018. Originally approved in 2006. Last previous edition approved in 2011 as D7300–11. DOI: 10.1520/D7300-18.

[2] The boldface numbers in parentheses refer to the list of references at the end of this 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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.5 *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:*[3]

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 Used in Engineering Design and Construction

D4083 Practice for Description of Frozen Soils (Visual-Manual Procedure)

D6026 Practice for Using Significant Digits in Geotechnical Data

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of common technical terms in this standard, refer to Terminology D653.

3.1.2 Definitions of the components of freezing and thawing soils shall be in accordance with the terminology in Practice D4083.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 The following terms are used in conjunction with the determination of the strength properties of frozen soils and supplement those in Practice D4083 and in the glossary on permafrost terms by Harris et al (**2**).

3.2.2 *creep, n—of frozen ground*, the irrecoverable time-dependent deviatoric deformation that results from long-term application of a deviatoric stress.

3.2.3 *failure, n*—the stress condition at failure for a test specimen. Failure is often taken to correspond to the maximum principal stress difference (maximum deviator stress) attained, or the principal stress difference (deviator stress) at 15 % axial strain, whichever is obtained first during the performance of a test. Depending on frozen soil behavior and field application, other suitable failure criteria may be defined, such as the principal stress difference (deviator stress) at a selected axial strain or strain rate.

3.2.4 *ice-rich permafrost, n*—permafrost containing excess ice.

3.2.5 *pore ice, n*—ice occurring in the pores of soil and rocks.

3.2.6 *total water content, n*—the ratio of the mass of water (unfrozen water + ice) contained in the pore spaces of frozen soil or rock material, to the mass of solid particles in that material, expressed as percentage.

3.2.7 *unfrozen water content, n*—the ratio of the mass of water (free and adsorbed) contained in the pore spaces of frozen soil or rock material, to the mass of solid particles in that material, expressed as percentage (**2**).

4. Summary of Test Method

4.1 A cylindrical frozen soil specimen is cut to length and the ends are machined flat. The specimen is placed in a loading chamber and allowed to stabilize at a desired test temperature. A strain rate in compression is applied to the specimen and held constant at the specified temperature for the duration of the test. Axial stress and deformation of the specimen are monitored continuously. Typical results of a set of uniaxial compression tests are shown in Fig. X1.1 (**3**).

5. Significance and Use

5.1 Understanding the mechanical properties of frozen soils is of primary importance to frozen ground engineering. Data from strain rate controlled compression tests are necessary for the design of most foundation elements embedded in, or bearing on frozen ground. They make it possible to predict the time-dependent settlements of piles and shallow foundations under service loads, and to estimate their short and long-term bearing capacity. Such tests also provide quantitative parameters for the stability analysis of underground structures that are created for permanent or semi-permanent use.

5.2 It must be recognized that the structure of frozen soil in situ and its behavior under load may differ significantly from that of an artificially prepared specimen in the laboratory. This is mainly due to the fact that natural permafrost ground may contain ice in many different forms and sizes, in addition to the pore ice contained in a small laboratory specimen. These large ground-ice inclusions (such as ice lenses, a dominant horizontal, lens-shaped body of ice of any dimensions) will considerably affect the time-dependent behavior of full-scale engineering structures.

5.3 In order to obtain reliable results, high-quality intact representative permafrost samples are required for compression strength tests. The quality of the sample depends on the type of frozen soil sampled, the in situ thermal condition at the time of sampling, the sampling method, and the transportation and storage procedures prior to testing. The best testing program can be ruined by poor-quality samples. In addition, one must always keep in mind that the application of laboratory results to practical problems requires much caution and engineering judgment.

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.

[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.

6. Apparatus

6.1 *Axial Loading Device*—The axial compression device shall be capable of maintaining a constant strain rate within one percent of the applied strain rate. The device may be a screw jack driven by an electric motor through a geared transmission, a platform weighing scale equipped with a screw-jack-activated load yoke, a deadweight load apparatus, a hydraulic or pneumatic loading device, or any other compression device with sufficient capacity and control to provide the loading conditions prescribed in Section 8. Vibrations due to the operation of the loading device should be kept at a minimum.

6.2 *Axial Load-Measuring Device*—The axial load-measuring device may be a load ring, electronic load cell, hydraulic load cell, or any other load measuring device capable of the accuracy prescribed in this paragraph and may be a part of the axial loading device. For frozen soil with a deviator stress at failure of less than 100 kPa, the axial load measuring device shall be capable of measuring the unit axial load to an accuracy equivalent to 1 kPa; for frozen soil with a deviator stress at failure of 100 kPa and greater, the axial load-measuring device shall be capable of measuring the axial load to an accuracy of 1 % of the axial load at failure.

6.3 *Measurement of Axial Deformation*—The interaction between the test specimen and the testing machine loading system can affect the test results. For this reason, in order to observe the true stress-strain-rate behavior of a frozen soil specimen, deformations should be measured directly on the specimen. This can be achieved by mounting deformation gages on special holders attached to the sides of the specimen (**4**). If deformations are measured between the loading platens, it should be recognized that some initial deformation (seating error) will occur between the specimen ends and the loading surface of the platens.

6.4 *Bearing Surfaces*—The specimen cap and base shall be constructed of a noncorrosive impermeable material, and each shall have a circular plane surface of contact with the specimen and a circular cross section. The weight of the specimen cap shall be less than 0.5 % of the applied axial load at failure. The diameter of the cap and base shall be greater than the diameter of the specimen. The stiffness of the end cap should normally be high enough to distribute the applied load uniformly over the loading surface of the specimen. The specimen base shall be coupled to the compression chamber so as to prevent lateral motion or tilting, and the specimen cap shall be designed to receive the piston, such that the piston-to-cap contact area is concentric with the cap.

NOTE 2—It is advisable not to use ball or spherical seats that would allow rotation of the platens, but rather special care should be taken in trimming or molding the ends of the specimen to parallel planes. The ends of the specimen shall be flat to 0.02 mm and shall not depart from perpendicularity to the axis of the specimen by more than 0.001 radian (about 3.5 min) or 0.05 mm in 50 mm. Effects of end friction on specimen deformation can be tolerated if the height to diameter ratio of the test specimen is two to three. However, it is recommended that lubricated platens be used whenever possible in the uniaxial compression and creep testing of frozen soils. The lubricated platen should consist of a circular sheet of 0.8-mm thick latex membrane, attached to the loading face of a steel platen with a 0.5-mm thick layer of high-vacuum silicone grease. The steel platens are polished stainless steel disks about 10 mm larger than the specimen diameter. As the latex sheets and grease layers compress under load, the axial strain of the specimen should be measured using extensometers located on the specimen (**5, 6**).

6.5 *Thermal Control*—The compressive strength of frozen soil is also affected greatly by temperature and its fluctuations. It is imperative, therefore, that specimens be stored and tested in a freezing chamber that has only a small temperature fluctuation to minimize thermal disturbance. Reduce the effect of fluctuations in temperature by enclosing the specimen in an insulating jacket during storage and testing. Reference (**7**) suggests the following permissible temperature variations when storing and testing frozen soils within the following different ranges:

Temperature, °C	0 to –2	–2 to –5	–5 to –10	below –10
Permissible deviation, °C	±0.1	±0.2	±0.5	±1.0

7. Test Specimen

7.1 *Thermal Disturbance Effects:*

7.1.1 The strength and deformation properties of frozen soil samples are known to be affected by sublimation, evaporation, and thermal disturbance. Their effect is in the redistribution and ultimate loss of moisture from the sample as the result of a temperature gradient or low-humidity environment, or both. Loss of moisture reduces the cohesion between soil particles and may reduce the strength (that is dependent on temperature). The effects of moisture redistribution in frozen soil are thought to change its strength and creep behavior.

7.1.2 Thermal disturbance of a frozen sample refers not only to thawing, but also to temperature fluctuations. Soil structure may be changed completely if the sample is thawed and then refrozen. Temperature fluctuations can set up thermal gradients, causing moisture redistribution and possible change in the unfrozen moisture content. Take care, therefore, to ensure that frozen soil specimens remain in their natural state, and that they are protected against the detrimental effects of sublimation and thermal disturbance until testing is completed.

7.1.3 In the event that the soil sample is not maintained at the in situ temperature prior to testing, bring the test specimen to the test temperature from a higher temperature to reduce the hysteresis effect on the unfrozen water content.

7.1.4 Before testing, maintain the test specimen at the test temperature for a sufficient period, to ensure that the temperature is uniform throughout the volume.

7.2 *Machining and Preparation of Specimens for Testing* (**7**):

7.2.1 The machining and preparation procedures used for frozen soils depend upon the size and shape of the specimen required, the type of soil, and the particular test being performed. Follow similar procedures for cutting and machining both naturally frozen and artificially frozen samples.

7.2.2 Handle frozen soil samples with gloves and all tools and equipment kept in the cold room to avoid sample damage by localized thawing. A temperature of –5 ± 1°C is the most suitable ambient temperature for machining with respect to material workability and personal comfort. At warmer temperatures, surface thawing is a problem, and cutting tools must be cleaned frequently, for they become coated and clogged with frozen soil, reducing their cutting efficiency.