Designation: D5520 – 11

Standard Test Method for Laboratory Determination of Creep Properties of Frozen Soil Samples by Uniaxial Compression[1]

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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. At very high ice contents (ice-rich soils), 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 creep behavior of cylindrical specimens of frozen soil, subjected to uniaxial compression. 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 Although this test method is one that is most commonly used, it is recognized that creep properties of frozen soil related to certain specific applications, can also be obtained by some alternative procedures, such as stress-relaxation tests, simple shear tests, and beam flexure tests. Creep testing under triaxial test conditions will be covered in another standard.

1.3 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

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

1.4.1 For the purposes of comparing, a 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.

1.4.2 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 analysis 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.

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

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

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1.5 *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.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D2850 Test Method for Unconsolidated-Undrained Triaxial Compression Test on Cohesive Soils

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)

D4341 Test Method for Creep of Hard Rock Core Specimens in Uniaxial Compression at Ambient or Elevated Temperature (Withdrawn 2005)[4]

D4405 Test Method for Creep of Soft Rock Core Specimens in Uniaxial Compression at Ambient or Elevated Temperature (Withdrawn 2005)[4]

D4406 Test Method for Creep of Rock Core Specimens in Triaxial Compression at Ambient or Elevated Temperatures (Withdrawn 2005)[4]

D6026 Practice for Using Significant Digits in Geotechnical Data

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of 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 supplement those in Practice D4083 and in the glossary on permafrost terms by Harris et al (**2**).

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

3.2.3 *excess ice*—the volume of ice in the ground which exceeds the total pore volume that the ground would have under unfrozen conditions.

3.2.4 *ground ice*—a general term referring to all types of ice formed in freezing or frozen ground.

3.2.5 *ice-bearing permafrost*—permafrost that contains ice.

3.2.6 *ice-bonded permafrost*—ice-bearing permafrost in which the soil particles are cemented together by ice.

3.2.7 *ice content*—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, expressed as percentage.

3.2.8 *ice lens*—a dominant horizontal, lens-shaped body of ice of any dimension.

3.2.9 *ice-rich permafrost*—permafrost containing excess ice.

3.2.10 *permafrost*—perennially frozen soil or rock.

3.2.11 *pore ice*—ice occurring in the pores of soil and rocks.

3.2.12 *sample*—a portion of a material intended to be representative of the whole.

3.2.13 *specimen*—a piece or portion of a sample used to make a test.

3.2.14 *total water content*—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.

3.2.15 *unfrozen water content*—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 (**3**).

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. An axial compression stress is applied to the specimen and held constant at the specified temperature for the duration of the test. Specimen deformation is monitored continuously. Typical results of a uniaxial compression creep test are shown in Fig. X1.1.

5. Significance and Use

5.1 Understanding the mechanical properties of frozen soils is of primary importance to permafrost engineering. Data from creep 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. Creep tests also provide quantitative parameters for the stability analysis of underground structures that are created for 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) 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 creep tests. The quality of the sample depends on the type of frozen soil sampled, the in situ thermal condition at the time of sampling,

[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.

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.

6. Apparatus

6.1 *Axial Loading Device*—The axial compression device shall be capable of maintaining a constant load or stress within one percent of the applied load or stress. 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 creep test results. For this reason, in order to observe the true strain-time behavior of a frozen soil specimens, 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:*