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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 Values stated in SI units are to be regarded as 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.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 653 Terminology Relating to Soil, Rock and Contained Fluids[3]
D 2850 Test Method for Unconsolidated Undrained Strength of Cohesive Soils in Triaxial Compression[3]
D 4083 Practice for Description of Frozen Soils (Visual Manual Procedure)[3]
D 4341 Test Method for Creep of Cylindrical Hard Rock Core Specimens in Uniaxial Compression[3]
D 4405 Test Method for Creep of Cylindrical Soft Rock Core Specimens in Uniaxial Compression[3]
D 4406 Test Method for Creep of Cylindrical Rock Core Specimens in Triaxial Compression[3]

3. Terminology

3.1 *Definitions:*

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

3.1.2 *excess ice*—the volume of ice in the ground which

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[1] This test method is under the jurisdiction of ASTM Committee D-18 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.

[3] *Annual Book of ASTM Standards*, Vol 04.08.

exceeds the total pore volume that the ground would have under unfrozen conditions.

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

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

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

3.1.6 *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.

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

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

3.1.9 *permafrost*—perennially frozen soil or rock.

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

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

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

3.1.13 *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.

3.1.14 *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 **(2)**.

3.2 For definitions of other terms used in this test method, refer to Terminology D 653.

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 undisturbed 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, 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.

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 loadmeasuring 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 **(3)**. 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 1—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 highvacuum 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 **(4, 5)**.

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 **(6)** 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*:

7.2.1 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.

7.2.3 Cylindrical specimens are either machined on a working lathe or cut carefully with a coring tube in the laboratory. They can also be cored from block samples, using a diamond set core barrel and a large industrial drill press. For machining on a working lathe, the best results are obtained when the specimen is turned at 690 r/min and the carriage feed set at 30 mm per 36 revolutions. Limit the maximum depth of cut to 0.38 mm. A tungsten carbide cutting tool, with a minimum back clearance of 45°, gives the best results. For clean cuts, sharpen the tool often, as the abrasive action of the soil dulls the edge quickly **(7)**. Shaping coarse sand or gravel specimens on a lathe is difficult, because the soil grains are pulled out leaving an uneven pitted surface, that should be made smooth by filling the pits with ice and fine sand mixture. It is important that the ends of the specimen are parallel and plane, so that intimate contact occurs with the loading platens.

7.3 *Test Specimen Shape and Size*:

7.3.1 Both the shape and size of frozen soil test specimens can influence the results of uniaxial compression tests. The sizes of specimens used in compression testing are generally a compromise between theoretical and practical considerations. Some of these considerations are:

7.3.1.1 The influence of boundary conditions of the test, that, among other things, include the lateral restraint imposed on the test specimen by the end platens,

7.3.1.2 The maximum size of particles in a soil specimen,

7.3.1.3 The loading capacity of the available loading equipment,

7.3.1.4 The maximum dimensions and weight of a test specimen that can be handled conveniently,

7.3.1.5 The size of soil samples that can be taken from a field site using common sampling methods, and

7.3.1.6 Equipment that is readily available to shape and protect specimens.

7.3.2 To reduce the influence of boundary conditions and that of maximum soil particle size, the test specimen should be as large as can be tested conveniently.

7.3.3 From the testing of unfrozen soils, the importance of the ratio of specimen height to diameter has long been recognized as an important factor where the type of loading platens influences the test results. Experience with compression testing of frozen soils **(6, 8, 9)** indicates that consistent creep and strength results can be obtained when the height to diameter ratio is 2:3, regardless of the type of end platens used in testing. Based on this information, it is recommended that: the shape of the test specimen be a right circular cylinder, the height-to-diameter ratio of the test specimen be two to three, the minimum diameter of the test specimen be at least ten times the maximum soil particle size, and either 50 or 100-mm diameter be used when the soil particle size does not control the diameter size **(10)**.

8. Procedure

8.1 *Requirements for Placing Specimen in Test Apparatus*—Place the lower platen on the base of the loading device. Wipe clean the bearing faces of the upper and lower platens and of the test specimen, and place the specimen on the lower platen. Place the upper platen on the specimen and align properly. A small axial load, approximately 20 to 50 kPa, may be applied to the specimen by means of the loading device to properly seat the bearing parts of the apparatus.

8.2 *Temperature-Control Requirements*—When appropriate, install temperature-controlled enclosure and deformation transducers for the apparatus and sensors used. During the test, keep the temperature variations in the specimen within the limits of tolerance indicated in 6.5.1.

8.3 *Determination of Test Loads*:

8.3.1 The stress level at which creep tests are conducted depends upon the type of frozen soil (clay, silt, sand, or gravel), the temperature, and stresses it is expected to experience during the life of the structure. Because resources and time available for performing creep tests are limited, choose the creep stress levels so that sufficient and appropriate data are obtained from the tests to evaluate the creep strength and deformation parameters in a timely manner.

8.3.2 To provide a common basis for comparing the results of creep tests, the following optional procedure is recommended **(10)**:

8.3.2.1 First, determine the short-term uniaxial compression strength, *q*, of the frozen soil under investigation, by performing uniaxial compression tests with a constant axial strain rate of 1 %/min (0.017 %/s), related to the initial height of the specimen.

8.3.2.2 The constant compression stress for each creep test should be a fraction of the short-term uniaxial compression strength, *q*, of the soil under investigation.

8.3.2.3 Perform four or more creep tests, each with a different constant compression stress σ_1, for example $\sigma_1 = 0.7$ *q*, 0.5 *q*, 0.4 *q*, and 0.3 *q*, respectively.

8.3.2.4 With respect to determination of creep parameters and for creep tests longer than 100 h, reduce the compressive stresses for the creep tests to become, for example, 0.5 *q*, 0.3 *q*,, 0.2 *q*, and 0.1 *q*, respectively.

8.4 *Loading Procedure*:

8.4.1 Apply the axial load continuously and without shock to the required test load within 20 s. Thereafter, hold the load constant for the remainder of the test for constant load testing, or increase with specimen deformation, for constant true-stress testing.

8.4.2 Record the strain or deformation immediately after the required test load has been applied. Thereafter, record the strain or deformation at suitable time intervals. During the early rapid transient straining, take readings every few minutes to few hours, until the deformation rate slows and becomes relatively constant. Take readings at least twice daily, until the test is terminated. If the strain rate accelerates as failure is approached, increase the frequency of readings appropriately.

8.4.3 Record the load and specimen temperature either continuously or each time the strain or deformation is read.

8.5 *Requirements for Test Duration*:

8.5.1 As stated in 8.3.1, and shown in Fig. X1.2 **(11)**, the length of time in a creep test, necessary to attain either the minimum strain rate of creep failure, ranges from several minutes at stresses close to the short-term strength, *q*, to several days and even months at very low stresses equal to a small fraction of *q*. In order to keep the creep testing procedure within reasonable time limits, it is recommended that the duration of each creep test be at least 24 h, unless creep failure occurs at an earlier time.

8.6 *Number of Tests*:

8.6.1 For satisfying the requirements under 8.3.2.1 and 8.3.2.3, and taking into account a possible scatter of experimental results, a minimum of 15 specimens for each selected temperature and moisture content combination is needed for determination of creep properties of a given frozen soil.

8.6.2 Alternatively, in order to reduce the required number of specimens, stage-loaded creep tests can be performed. A stage-loaded creep test, carried out on a single specimen, consists in increasing the load in several successive stages, and holding the load constant at each stage for a given length of time. The performance and interpretation of such tests is described in Refs **(12-14)**.

9. Calculation

9.1 Calculate the conventional axial strain, ϵ_1, for a given applied axial load, as follows:

$$\epsilon_1 = \Delta L / L_o \quad (1)$$

where:

ΔL = change in length of specimen as read from deformation indicator, and

L_o = initial length of test specimen when piston contacts specimen cap.

9.2 Calculate the average cross-sectional area, *A*, for a given applied compressive axial load as follows:

$$A = A_o/(1 - \epsilon_1) \quad (2)$$

where:

A_o = initial average cross-sectional area of the specimen, and

ϵ_1 = axial strain for the given axial load.

9.3 Calculate the deviator stress (principal stress difference), for a given applied axial load as follows:

$$(\sigma_1 - \sigma_3) = P/A \quad (3)$$

where:

P = given applied axial load (corrected for uplift and piston friction, if required),

A = corresponding average cross-sectional area, and

σ_1, σ_3 = principal normal stresses in axial and radial direction, respectively.

9.4 *Creep Curve*—Prepare a graph, as in Fig. X1.1(*a*), showing the relationship between axial strain ϵ_1 and time, *t*, for each applied constant axial stress, σ_1, and a given constant temperature. Prepare also a plot of log ϵ versus log *t*, as in Fig. X1.2, to establish the point of inflection of the creep curve.

9.5 *Stress Versus Strain Rate Curve*—Prepare a graph, as in Fig. X1.3, showing the relationship between axial stress and axial strain rate, by plotting, for each given temperature, the applied axial stress, σ_1, versus minimum strain rate, $\epsilon_{1,\ min}$.

9.6 *Strength-Temperature-Time Curves*—If creep tests are made at different temperature, prepare a graph, as in Fig. X1.4, showing the relationship between uniaxial strength and temperature, for any given time to failure (or minimum axial strain rate).

10. Report

10.1 Report the following information:

10.1.1 *Description of Soil*—Unified soil classification system for frozen soils **(16)**, grain size gradation curve, Atterberg limits (where applicable), physical properties, including total water content, dry unit weight of soil, specific gravity of soil grains, water/ice saturation in percent, and salinity.

10.1.2 *Sampling Conditions and Specimen Preparation*—Sampling method, ground temperature at the time of sampling, temperature fluctuation during transportation and storage, specimen machining method, and specimen dimensions.

10.1.3 *Testing Conditions*—Test temperature, end conditions of test specimen, loading conditions, including data on loading equipment, description of all tests, and graphs of test results as described in 9.4-9.6.

11. Precision and Bias

11.1 *Precision*—At present, adequate data for determining the precision of a uniaxial compression creep test on cylindrical frozen soil specimens are not available. Data are being sought to develop a precision statement.

11.2 *Bias*—Bias cannot be determined since there is no standard creep deformation that can be used to compare with values determined using this test method.

12. Keywords

12.1 creep; deformation; frozen soil; strain; stress; temperature; uniaxial compression

APPENDIXES

(Nonmandatory Information)

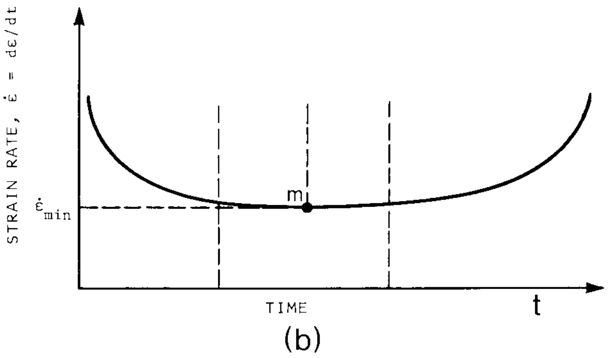
X1. GENERAL CONSIDERATIONS ON CREEP TESTING OF FROZEN SOILS

X1.1 *Creep in Uniaxial Compression:*

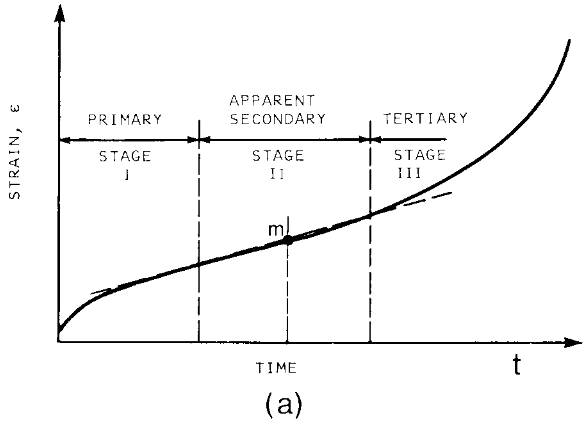
X1.1.1 To describe the effect of time on the behavior of frozen soils, uniaxial compression creep tests on cylindrical specimens, subjected to a constant uniaxial stress, are frequently run. When a step load is applied on the specimen, it responds by an instantaneous deformation, followed by creep. A typical creep curve resulting from such a step loading is shown in Fig. X1.1(*a*), and the related strain rate curve is shown in Fig. X1.1(*b*). The creep curve is usually thought to consist of three stages, in which the creep rate is, in order: decreasing ("primary creep"), essentially constant ("secondary" or "steady-state" creep, corresponding to the "minimum creep rate"), and increasing ("tertiary creep"), that eventually leads to ultimate failure of the specimen. However, the" secondary" or "steady-state" portion of the creep curve is usually reduced to an inflection point (shown as point "m" in Fig. X1.1 and Fig. X1.2). If, for some practical reasons, a straight line with a constant slope is drawn through the point "m," it represents an apparent secondary creep that includes, in fact, the final portion of the "primary creep" and the initial portion of the "tertiary creep" **(1)**.

X1.1.2 The proportion of the total curve each stage represents depends not only on the material, but also on the stress level used during the test, and, to a certain degree, on the specimen shape and the test conditions. At low-stress levels, primary creep appears to dominate under certain conditions **(1)**.

X1.1.3 At intermediate stress levels, as in many practical creep problems in ice-rich soils, the apparent steady-state creep is found to be dominant **(16)**, and steady-state creep approximation is often used for extrapolating laboratory creep data to long term creep problems **(13)**. At high-stress levels, the



(*a*) Creep Curve



(*b*) Strain Rate Versus Time Curve

FIG. X1.1 Typical Creep Test Results

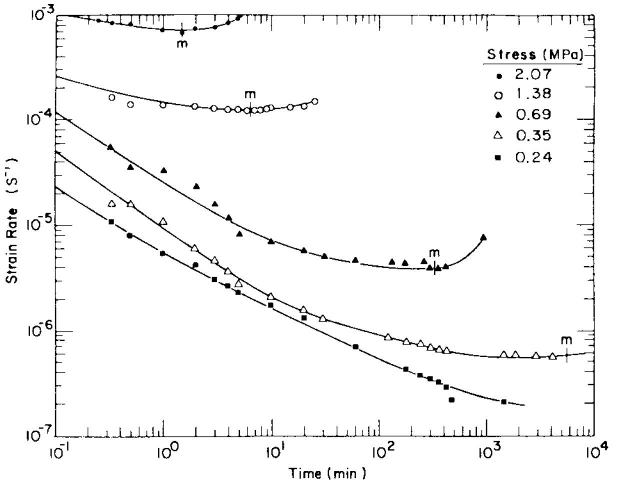


FIG. X1.2 Creep Curves Shown in a Log (Strain Rate) Versus Log (Time) Plot **(11)**

specimen may appear to go straight into accelerated creep, without well-defined primary and secondary stages, and fails after a short period of time. The stress producing such a short-term failure of the specimen is referred to as the "short-term strength" of the material **(12)**. On the other hand, it is generally considered, that a true "long-term strength," defined as a stress condition below which the creep rate will always tend to zero with time, can be found only in triaxial (confined) compression creep tests on frozen soils, characterized by internal friction or mineral cohesion, or both.

X1.1.4 Uniaxial compression creep tests can provide parameters needed to estimate time-dependent deformation and strength of a frozen soil. The stress level selected for creep tests depends on the frozen soil type (clay, silt, sand, or gravel) and the temperature and stresses expected during the life of the structure.

X1.2 *Creep Strength in Uniaxial Compression:*

X1.2.1 Creep strength is defined as the stress level at which, after a finite time interval, either rupture or instability leading to rupture occurs in the material. In tensile creep testing, the creep strength is usually taken as the stress at which actual specimen rupture occurs. In compression creep testing, however, especially in frozen soils in which much less clearly defined plastic type of failure is common, the creep strength is most often identified with the time at which the first sign of instability occurs. In constant-stress creep testing, this is the time at which accelerating creep starts at the point of inflection, shown as point "m" in Fig. X1.1 and Fig. X1.2.

X1.2.2 A creep testing program is usually designed so as to furnish a relationship between the creep strength and the magnitudes of such factors as time to failure, steady-state or minimum creep rate, strain at failure, and temperature. For a given frozen soil and a constant temperature, the relationship between the creep strength and the minimum creep rate can be obtained from a series of constant-stress creep tests at different stress levels, and can be represented in a log (stress) versus log (minimum creep rate) plot, as shown in Fig. X1.3 **(15)**.

X1.3 *Effect of Temperature and Salinity on Creep and Strength:*

X1.3.1 Creep and strength properties of frozen soils are strongly influenced by their temperature, mainly because of the temperature-dependent behavior of the pore ice and the variation with temperature of the unfrozen water content. Fig. X1.4 **(11)** shows a typical variation of uniaxial compression strength with temperature and time to failure for a frozen fine sand, covering the usual permafrost temperature range and a large span of loading rates.

X1.3.2 The effect of increasing salinity of pore water on creep and strength of a frozen soil is in many aspects similarto that of increasing temperature, because both of them affect the unfrozen water content, that is a governing factor in the frozen soil behavior.

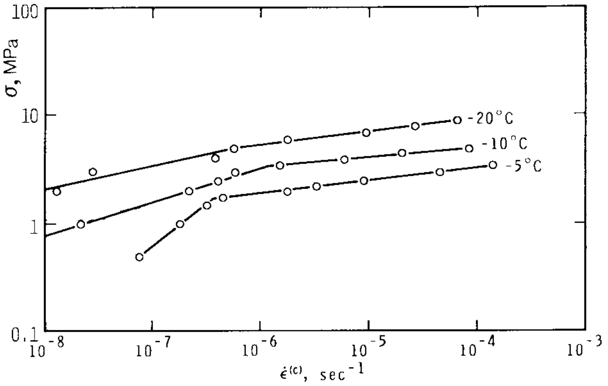


FIG. X1.3 Plot of Log (Stress) Versus Log (Minimum Strain Rate) Obtained in Uniaxial Compression Creep Tests With a Frozen Silty Sand **(4, 13, 16)**

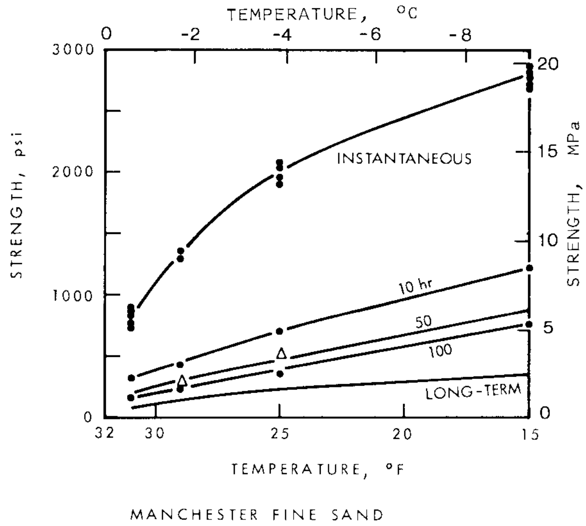


FIG. X1.4 Temperature and Time-to-Failure Dependence of Uniaxial Compressive Strength of a Frozen Sand **(1)**

X2. STORAGE AND PROTECTION OF SAMPLES

X2.1 *General*—Protect undisturbed block and core samples of frozen soil from thawing and loss of moisture, from the time they are taken from the ground and throughout the period of transportation, storage, machining, and testing. In most cases the sample must be maintained under the same thermal and moisture conditions existing at the time of sampling.

X2.2 *In the Field and During Transportation*—In the field, when the samples have been examined visually and logged at the site, wrap them in cellophane and place them in polyethylene bags. Evacuate air from the bag, and seal it to reduce sublimation. This can best be accomplished by using a vacuum pump, but can also be done by forcing most of the air out by hand before sealing. Maintain humidity by placing some snow or crushed ice inside and around the outside of the bag. After the sample has been packaged, to keep sublimation to a minimum, some facility is required at the site to prevent thermal disturbance. When frozen samples are obtained for strength and creep tests, maintain their temperature as close as possible to the in situ temperature. As ground temperatures vary with depth during the year, determine the temperature at the time of sampling. If adequate storage facilities are not available at the field site, and the samples are to remain frozen, transport them immediately to a humidity- and temperature-controlled storage area, and ship them to the laboratory in refrigerated containers or insulated boxes **(7)**.

X2.3 *Before and During Testing*—Careful control of temperature and humidity in storage areas is necessary to protect frozen specimens from sublimation and thermal disturbance, from the time they have been molded or machined, or both, until testing has been completed. Protection methods are similar to those used when transporting frozen samples from the field. Wrap specimens in an impermeable material and store them in a refrigerated room or freezer. Minimize their sublimation by controlling the humidity and reducing air flow around the specimens.

REFERENCES

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