DESCRIPTION AND CLASSIFICATION OF FROZEN SOILS

Based Upon a Joint Effort of the Division of Building Research, National Research Council of Canada, and the Arctic Construction and Frost Effects Laboratory, U. S. Army Corps of Engineers

DRAFT

TECHNICAL REPORT NO. 75

Arctic Construction and Frost Effects Laboratory
U. S. Army Engineer Division, New England
Waltham, Massachusetts

for

Office of the Chief of Engineers
Civil Engineering Branch
Engineering Division
Military Construction

January 1961
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Details of illustrations in
this document may be better
studied on microfiche
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PREFACE

The heart of the description and classification of frozen soils shown in columns (1) through (6) of Figure 2 of this report represents the joint efforts of representatives of the Building Research Division, National Research Council of Canada, and of the Arctic Construction and Frost Effects Laboratory, U. S. Army Engineer Division, New England. It is based on the experience of these organizations over several years with various forms of a system originally devised by the Arctic Construction and Frost Effects Laboratory in 1952. The remainder of Figure 2, and of the report, is a contribution of the Arctic Construction and Frost Effects Laboratory.

This presentation is the product of a program of studies being conducted for the Chief of Engineers, Department of the Army, under the administrative direction of the Civil Engineering Branch, Engineering Division, Military Construction. The program is aimed at developing engineering criteria for design and construction in arctic and subarctic regions and in areas of seasonal frost.

*Published as Appendix A of Vol. 1 of "Investigation of Description, Classification and Strength Properties of Frozen Soils," by Arctic Construction and Frost Effects Laboratory, issued as Report 8 of U. S. Army Snow, Ice and Permafrost Research Establishment, June 1952.
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SYNOPSIS

The description and classification of frozen soils presented herein is an extension of the Unified Soil Classification System adopted by the U. S. Army Corps of Engineers and the U. S. Bureau of Reclamation in 1952. Descriptions, based on physical appearance, are non-genetic and are applicable to both naturally and artificially frozen soils. Field identification data pertaining to frozen soils and those pertinent properties of frozen materials which can be measured by physical tests are indicated. Also, guides are presented for construction on soils subject to freezing and thawing. The report includes photographic illustrations of frozen soil types; a chart showing relationships between unit dry weight of soil, water content, and ice volume; and an illustrative example of graphical presentation of frozen soil data.
INTRODUCTION

1. When the Unified Soil Classification System is extended to classification of frozen soils, special expansion of the system is required in order to meet engineering and scientific needs for adequate and concise identification of the materials. Identification of seasonally frozen soil or permafrost according to structural divisions caused by freezing and thawing such as "suprapermafrost" or "annual frost zone," illustrated in Figure 1, provides no information on those factors of appearance and physical properties which are essential guides to the nature and behavior of the materials in the frozen state and to the changes which may occur upon thawing. Also, such identification is not applicable to specimens frozen in the laboratory. Therefore, a frozen soil description and classification system, which is independent of the geologic history or mode of origin of the material, is needed. This system should also be capable of easy expansion or contraction in order to provide any desired degree of detail. The system described herein affords these characteristics.

*Described in Technical Memorandum No. 3-357, U. S. Army Waterways Experiment Station, March 1953, with Appendixes A and B.
FEATURES OF THE FROZEN SOIL CLASSIFICATION SYSTEM

2. Parts of the System. The system for describing and classifying frozen soil is shown in Figure 2. As indicated in the first column of Figure 2, the frozen soil is identified in three steps, denoted as Parts I, II, and III. Under Part I the soil phase is identified independently of the frozen state; the Unified Soil Classification System is used, a summary of which is shown in Figure 3. Under Part II, the soil characteristics resulting from the frozen state of the material are added to the soil description. Under Part III, important ice strata found in the soil are described.

3. Classification of Frozen Soil - Major Groups. As shown in columns (2) and (3) of Figure 2, under Part I, frozen soils are divided into two major groups: soils in which segregated ice is not visible to the unaided eye (designation N), and soils in which segregated ice is visible (designation V). Since, as will be described below, ice layers exceeding 1 inch in thickness are identified separately, the latter major grouping is applied only to soil containing ice layers 1 inch or less in thickness.

4. Frozen soils in the N group will commonly, on inspection by the unaided eye, reveal the presence of ice within the soil voids by crystalline reflections or by a sheen on fractured or trimmed surfaces; however, the appearance is given that the water has frozen within the original voids in the soil, without segregation. Frozen soils in the V group give the opposite impression, and segregated ice is visible not merely as pin point crystalline reflections or a diffuse sheen but as separate ice inclusions of measurable dimensions.
5. **Frozen Soils in which Segregated Ice is not Visible.** As shown in columns (4) and (5) of Figure 2, materials in which segregated ice is not visible to the unaided eye (designation N) are divided into two types:

*NF (Ice non-visible; friable).* This is poorly bonded or friable material in which segregated ice is not visible to the unaided eye. This condition exists when the degree of saturation is low. This type of frozen soil is illustrated in photographs 1 and 2 of Figure 4.

*Nb (Ice non-visible; bonded).* This is well bonded frozen soil in which the ice cements the material into a hard solid mass, but segregated ice is not visible to the unaided eye. Soils showing this characteristic are generally at a moderate to high degree of saturation. When at high degree of saturation, they may or may not contain substantial quantities of microscopic segregated ice. On basis of detailed examinations and tests this sub-group may be further divided into the following sub-categories:

*Nbn (without excess ice).* No segregated ice is present, either visible to the unaided eye or microscopic. This type of frozen soil is illustrated in photographs 1 and 3, Figure 4.

*Nbe (contains excess ice, microscopic).* This condition may occur in very fine silty sands or coarse silts where excess ice is present but is so uniformly distributed that it is not readily apparent to the unaided eye. Appreciable settlement may occur in such soils upon thawing. This type of frozen soil is illustrated in photograph 4, Figure 4.
The soils in which significant segregated ice is visible to the unaided eye (designation V) are divided into the following two subgroups, arranged approximately in sequence of increasing ice content as commonly encountered:

- **Vx**: ice visible in (diagram) particles
- **Vt**: ice visible (irregularly oriented ice formations)
- **Vs**: ice visible (regularly oriented ice formations)

The Vx type of frozen soils are illustrated in photographs 5, Figure 4; Vt types of frozen soils are illustrated in photographs 6 and 7, Figure 5, and Vs types in photographs 8, 9, and 10, Figure 5.

7. **Description of Substantial Ice Strata.** Referring to columns (2) and (3) of Figure 2 under Part III, substantial ice strata greater than 1 inch in thickness are designated separately as ICE. As shown in columns (4) and (5) of Figure 2, the identification may fall into either of the following two broad categories:

- **Ice Plus Soil Type (ice with soil inclusions)**
- **Ice (ice without soil inclusions)**

8. **Identification and Description.** Field identification guidance is presented in column (6) of Figure 2. In addition to determination of major group and sub-group in accordance with columns (2) through (5) of Figure 2, additional descriptive terms and data may be used as indicated therein.
Some of the soil found in permafrost regions may also be described in exploration logs by special terms (such as "muskeg") for additional clarification.

9. When more than one sub-group characteristic is present in the same material, multiple sub-group designations may be used, as VS, R. Photograph 2, Figure 4, shows an example of frozen soil of the latter type.

10. When greater detail and more specific information is desired than is obtainable from visual inspection, physical tests and measurements may be performed on the frozen soil as indicated in column (7) of Figure 2. A camera, a small-power hand magnifying lens, and pint-size graduated jars should be standard items of field equipment for soil and survey crews. To obtain a rough estimate of the possible presence of excess ice, a simple field test can be made by placing a lump of frozen soil in a jar, allowing it to melt and visually observing the relative volume of supernatant or free water standing above the soil after the lump has melted. By initially performing this test with specimens of known ice content, a basis for field judgement can be established. Since proportions of ice and soil may vary widely, it may sometimes be difficult to decide without such a test whether a given material falls, for example, in the category of frozen soil or of ice with soil inclusions. Material containing as much as 80 percent of ice by volume and only 20 percent soil can sometimes give the appearance of being mostly soil. When more exact evaluation of presence of excess ice is required, specimens may be thawed in the laboratory in consolidometers or rubber membranes, or material may be thawed in place in the field.
11. Only needed portions of the detail and descriptive material outlined in columns (4) through (7) of Figure 2 should be used. In many of the simpler engineering applications, only a few of the most important elements need be recorded. For some investigations it may be satisfactory to use the Nb designation with a breakdown into Nbn or Nbe categories. In other applications it might even be sufficient to use only the N and V major group designations, to indicate whether or not segregated ice is visible. On the other hand, in many scientific studies very detailed records may be necessary.

12. Thaw Characteristics. For engineering purposes, it is of very great importance to known whether significant settlement will take place upon thawing of the frozen soil. If the amount of ice present will produce more water upon melting than can be held in the voids of the soil, then the material is thaw-unstable to a degree that is dependent upon the amount of the excess ice and the soil density. If all the melt water can be absorbed by the soil voids without significant settlement, then the soil can be considered thaw-stable. Columns (8) and (9) of Figure 2 present guides for construction on soils subject to freezing and thawing. The thaw characteristics shown in column (8) are particularly significant. Frozen soils designated as Nf and Nbn are usually thaw-stable, that is, no detectable settlement of structures would normally be anticipated if thawing occurred. Frozen soils in all other sub-groups are potentially thaw-unstable and significant settlement of structures founded thereon may occur.
13. Frozen open-work gravel is a special type of material which often proves difficult to evaluate as to its thaw-settlement potential. Although substantial amounts of pure ice are apparent in the voids of such material, sufficient point contacts between particles may exist to limit settlement on thaw to minor amounts. In critical cases, field thaw-settlement tests, using loaded plates and steam thawing, may be necessary.

14. Frozen bedrock does not always provide a thaw-safe foundation. Therefore, when bedrock is encountered in subfreezing temperatures, careful observations should be made to determine the quantity and mode of occurrence of all ice formations in bedding planes, fissures, or other spaces.

ICE OR WATER CONTENT OF FROZEN SATURATED SOILS

15. In considerations involving frozen soils, the generally prevailing conditions include complete saturation of the soil phase and all of the water frozen. For these conditions, and assuming a specific gravity of the soil particles of 2.70, the relationships between the unit dry weight of soil, water content, and ice volume are shown in Figure 6. This chart may be used by designers or field engineers for rapid estimation of the relationships between these variables. Use of the chart is indicated by the following example and illustrated by lines and arrows on Figure 6. Assume a specimen of frozen silt with excess ice estimated at approximately 60 percent. Based on the appearance of the silt layers in the core, it is estimated that the normal dry unit weight of the silt is fairly high, say 95 pcf. The chart is then entered at 95 pcf on the left and a horizontal line is extended to the
The intersection of the sloping 60 percent excess ice line. The total porosity, \( n \), which in this case equals the proportion of ice volume of the total specimen, is then observed on the scale at the bottom of the plot (77 percent). The intersection of the vertical line (77 percent porosity) with the 100 percent saturation line indicates on the left-side scale the equivalent overall dry unit weight of the frozen specimen, i.e., 38 psi. The curve in Figure 6 marked "Percent Volume of ice vs Water Content" shows the relationship between the water content of a frozen specimen and total volume of ice or porosity, \( n \). For a porosity of 77 percent in the above example, the water content indicated by the right-side scale would be approximately 114 percent.

**GRAPHICAL PRESENTATION OF SOILS DATA**

16. It is customary to present the results of soils explorations on drawings as schematic representations of the borings or test pits, with the various soils encountered shown by appropriate symbols. The recommended procedure for graphical presentation of frozen soil classification consists of showing the applicable letter symbols for the soil phase in accordance with the Unified Soil Classification System for unfrozen soils, followed by the frozen soil designation. An illustrative example of the use of the frozen soil classification system in a typical exploration log is shown in Figure 7. For the purpose of readily identifying the frozen soil zones, a wide line is drawn down the left side of the graphic log of the exploration within the range that the frozen material occurs.
ILLUSTRATIONS OF TERMINOLOGY USED TO IDENTIFY CHARACTERISTIC STRUCTURAL CLASSIFICATIONS OR SOIL FEATURES IN AREAS OF FROZEN GROUND

Definitions of Soil and Other Terms Relating to Frozen Ground Areas

Annual frost zone (active layer). The top layer of ground subject to annual freezing and thawing. In arctic and subarctic regions where annual freezing penetrates to the permafrost table, suprapermfrost and the annual frost zone are identical.

Excess ice. Ice in excess of the fraction which would be retained as water in the soil voids upon thawing.

Frost table. The surface, usually irregular, which represents the penetration, at any time in spring and summer, of thawing of the seasonal frozen ground.

Frozen zone. A zone of depth within which the soil is frozen. The frozen zone may be bounded both top and bottom by unfrozen soil, or at the top by the ground surface.

Ground ice. A body of more or less clear ice within frozen ground.

Ice wedge. A wedge-shaped ice mass in permafrost, usually associated with fissure polygon.

Icing. A surface ice mass formed by freezing of successive sheets of water.

Muskeg. Poorly drained organic terrain consisting of a mat of vegetation overlying peat of varying thickness, from a few inches to many feet.

Permafrost. Permanently frozen ground.

Permafrost table. The surface which represents the upper limit of permafrost.

Perletoch. A frozen layer at the base of the active layer which remains unthawed for one or two summers.

Residual thaw zone. A layer of unfrozen ground between the permafrost and the annual frost zone. This layer does not exist where annual frost extends to permafrost.

Suprapermfrost. The entire layer of ground above the permafrost table.

For more complete list of definitions, see Brandon, F., Frost and Permafrost Definitions, National Research Board Bulletin 111, 1954.

FIGURE 1
<table>
<thead>
<tr>
<th>Description and Classification of Frozen Soils</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Flow Identification</strong></td>
</tr>
<tr>
<td>Location</td>
</tr>
<tr>
<td>Groundwater</td>
</tr>
<tr>
<td><strong>Figure 2</strong></td>
</tr>
</tbody>
</table>
**TABLE 3**

**Group Identification (including classification and description)**

<table>
<thead>
<tr>
<th>Major Classes</th>
<th>Group Number</th>
<th>Typical Names</th>
<th>Field Identification Procedure</th>
<th>Information Required for Describing Data</th>
<th>Laboratory Classification Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet or dry</td>
<td>1</td>
<td>Wet-dense gravel, wet-dense sand, and wet-dense clay.</td>
<td>Visual appearance and physical characteristics, noting the presence or absence of wetness.</td>
<td>For each sample, size and shape of grains, color, density, and degree of compaction.</td>
<td>Greater than 3</td>
</tr>
<tr>
<td>Wet or dry</td>
<td>2</td>
<td>Wet-lens gravel, wet-lens sand, and wet-lens clay.</td>
<td>Visual appearance and physical characteristics, noting the presence or absence of wetness.</td>
<td>For each sample, size and shape of grains, color, density, and degree of compaction.</td>
<td>Greater than 3</td>
</tr>
<tr>
<td>Wet or dry</td>
<td>3</td>
<td>Wet-dense gravel, wet-dense sand, and wet-dense clay.</td>
<td>Visual appearance and physical characteristics, noting the presence or absence of wetness.</td>
<td>For each sample, size and shape of grains, color, density, and degree of compaction.</td>
<td>Greater than 3</td>
</tr>
</tbody>
</table>

**Figure 3**

**Graphs and Data**

- **Graph A**: Compressibility of soil samples under different conditions.
- **Graph B**: Engineering properties of cohesive soils.
- **Graph C**: Strength and stability of soil samples under varying conditions.

**Figure 3 Notes**

- **Graph A**: Indicates a significant increase in compressibility with increasing load.
- **Graph B**: Demonstrates the influence of different soil types on engineering properties.
- **Graph C**: Highlights the importance of soil strength in engineering applications.

**Graph Source**: Department of Environmental Science, January 2022
Photograph 1
Frozen fine SILT. Top portion well-bonded, saturated. Classification: ML, Nbe
Bottom portion friable. Classification: ML, Nf

Photograph 2
Frozen lean CLAY. Ice lenses in top portion formed from moisture drawn from below. Classification: CL, V, r
Bottom portion medium bonded and somewhat friable. Classification: CL, Nf

Photograph 3
Frozen well-graded silty SAND, Well-bonded. Classification: SM, Nbe

Photograph 4
Frozen fine SAND, Well-bonded, high degree of saturation. Classification: SK, Nbe

Photograph 5
Frozen, clayey sandy GRAVEL with ice coatings on numerous stones. Classification: GW-GC, Vc

FIGURE 4
PHOTOGRAPHS OF FROZEN SOIL TYPES
Photograph 6
Frozen, clayey, gravelly SAND with considerable irregular ice segregation.
Classification: SM, Vr

Photograph 7
Upper Portion: Frozen clayey SILT with occasional stones.
Classification: ML-CL, Vr
Lower Portion: ICE, irregular, up to 2-inches thick, and containing some silt inclusions.

Photograph 8
Frozen lean CLAY with stratified ice lenses.
Classification: CL-OL, Vr

Photograph 9
Frozen lean CLAY with stratified ice lenses.
Classification: CL, Vs

Photograph 10
Upper Portion: Frozen silty CLAY, with stratified ice lenses.
Classification: CL, Vs
Lower Portion: ICE with numerous clay inclusions. [Total ice volume approx. BTI.]

FIGURE 5
PHOTOGRAPHS OF FROZEN SOIL TYPES
SOIL DRY UNIT WEIGHT, ICE VOLUME, AND WATER CONTENT RELATIONSHIPS
ILLUSTRATIVE EXAMPLE OF THE USE OF THE FROZEN SOIL CLASSIFICATION SYSTEM IN TYPICAL EXPLORATION LOG

<table>
<thead>
<tr>
<th>Depth in Feet</th>
<th>Soil Type</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>OL</td>
<td>Organic SANDY SILT, not frozen.</td>
</tr>
<tr>
<td>0.5</td>
<td>GW</td>
<td>Brown, well-graded SANDY GRAVEL medium compact, moist, not frozen.</td>
</tr>
<tr>
<td>1.8</td>
<td>GW, Nf</td>
<td>Brown, well-graded SANDY GRAVEL, frozen, no visible segregation, negligible thin ice film on gravel sizes and within larger voids, poorly bonded.</td>
</tr>
<tr>
<td>3.7</td>
<td>GW, Nbh</td>
<td>Brown, well-graded SANDY GRAVEL, frozen, no visible segregation, well bonded.</td>
</tr>
<tr>
<td>5.4</td>
<td>ML, Vs</td>
<td>Black, micaceous SANDY SILT, frozen, stratified horizontal ice lenses averaging 4 inches in horizontal extent, hairline to 1/4 inch in thickness, 1/2 to 3/4 inch spacing. Visible ice = 20 ±% of total volume. Ice lenses hard, clear, colorless.</td>
</tr>
<tr>
<td>7.7</td>
<td>ICE</td>
<td>ICE, hard, slightly cloudy, colorless, few scattered inclusions of silty sand.</td>
</tr>
<tr>
<td>9.1</td>
<td>PT, Vr</td>
<td>Dark brown PEAT, frozen, well bonded, high degree of saturation. 5% visible ice.</td>
</tr>
<tr>
<td>10.5</td>
<td>MH, Vr</td>
<td>Light brown SILT, frozen, irregularly oriented ice lenses and layers 1/4 to 3/4 inch thick on random pattern grid approx. 3 to 4 inch spacing. Visible ice = 10 ±% of total volume. Ice moderately soft, porous, gray-white.</td>
</tr>
<tr>
<td>14.3</td>
<td>Bedrock</td>
<td>Laminated shale. Top few feet weathered. 1/16&quot; thick ice lenses in fissures to 16.0'. None below.</td>
</tr>
<tr>
<td>20.6</td>
<td>Bottom of exploration</td>
<td></td>
</tr>
</tbody>
</table>