Alaska Department of Transportation and Public Facilities

Alaska Geotechnical Procedures Manual

Effective May 2007

Introduction

This 2007 *Geotechnical Procedures Manual* replaces the 1993 *Engineering Geology and Geotechnical Exploration Procedures Manual* and the 2003 *Alaska Geotechnical Procedures Manual*.

The manual provides the basic policy, procedures, methods, and standards for geotechnical investigations and reports for the design and construction of highways, airports, bridges, marine facilities, buildings, retaining walls, and other Department facilities. The manual provides guidelines and procedures for developing a consistent baseline of engineering and geologic data for use by geotechnical engineers, design engineers, and contractors. The manual also presents guidance for the analysis of other geotechnical issues and problems, and recommendations for resolving such issues.

This new manual includes the following stand-alone guides published in October 2003:

- Field Soil Classification Guide
- Field Rock Classification and Structural Mapping Guide
- Geotechnical Report Preparation Guide

The following stand alone guides published in May 2007 complete the basic manual:

- Geological Field Investigation Guide
- Guide to Description and Classification of Peat and Organic Soil

Additional guides that may be developed in the future as part of this manual include
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- Foundation Investigation Guide
- Liquefaction Analysis Policy and Procedure Guide
- Material Site Investigation Guide
- Slope Stability Investigation Guide

The manual and its included guides constitute the procedures followed by Department staff and those consultants under contract who act as an extension of Department staff. The content of the manual is intended to be as flexible as possible so that each guide may be revised individually and other sections may be added as needed. The manual must be revised from time to time to keep pace with changes in geotechnical engineering, engineering geology, and civil engineering.
In situations where the manual does not provide adequate guidance, we expect geotechnical and geological practitioners to follow state-of-the-practice procedures and methods in their respective disciplines. Except where otherwise indicated, the Department will adhere to the appropriate and relevant American Association of State Highway and Transportation Officials (AASHTO) or American Society of Testing and Materials (ASTM) methods and tests.

Alaska Department of Transportation and Public Facilities

Alaska Geotechnical Report Preparation Guidelines

Effective October 1, 2003

Preface

This is one of a series of guides on geological/geotechnical investigations, procedures, and reports for the Alaska Department of Transportation & Public Facilities (DOT&PF). This is a guide for Department staff and consultants who prepare geotechnical data reports for use in the design and construction process.

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1. Guidelines for Preparation of Geotechnical Reports

1.1. Introduction

The geotechnical report is the tool the Department uses to describe project site conditions and to present formal design and construction recommendations to roadway design, bridge, and construction engineers. We cannot overstate the importance of the preparation of an adequate geotechnical report. The report is a critical reference during design, during construction, and following completion of the project if there are claims to resolve. The report must be as clear, concise, and accurate as possible.

To the extent possible, obtain the necessary geotechnical data early in the design phase so that the data and data interpretations are available throughout the design of the project. The various types of geotechnical information for a project are compiled into the formal geotechnical report as part of the project's materials report, which must be completed no later than the project contract advertising date for inclusion in the bid package.

1.2. What Does a Geotechnical Report Contain?

The report normally contains both factual data and data interpretation necessary to develop and present specific design and construction recommendations. You, the author, should exercise great care to differentiate factual data from interpretive data, and clearly identify the interpretive data as such.

The factual data can be presented in a wide variety of formats. Consistency of format is important to the extent that the minimum information necessary for the design and construction of a project is included in the geotechnical report. An annotated outline of a geotechnical report is presented in Chapter 2 of this guide. Department staff and consultants are expected to follow this guideline in preparing geotechnical reports.

1.2.1 Factual Information

The factual information included in a geotechnical report includes:

- Procedures and methods used in investigation
- Summary of or reference to all relevant existing data collected during the course of the investigation
- Geologic setting and relationship of geology to project
- New data developed during the investigation, including logs of test holes/test pits, laboratory test results, geophysical data, ground water information, etc.

1.2.2 Interpretive Information

This kind of information in the geotechnical report is derived from factual data. Engineering or geologic data are assessed, synthesized with pre-existing and new data and then translated into useable form to provide conclusions on conditions of soil, rock, groundwater, frozen soil, and other characteristics. It is often necessary to interpret geological data to clarify a geotechnical aspect of the project. Note that such data presentation tools as soil and rock profiles, geologic cross-sections, geological mapping, and rock structure mapping are interpretive in that they depict conditions at points between boring locations or other data collecting points. Indicated conditions at intermediate points are estimated, and should be presented in that light. Interpretive information includes:

- Interpretation of data and conditions on the project
- Analysis of data and conditions

1.2.3 Analysis and Recommendations

Design professionals use the factual information together with the interpreted information as the basis for analysis and design of facilities. This process includes the following products:

- Specific engineering recommendations for design

- Discussion of conditions that may be encountered during construction with recommendations for solutions to anticipated problems
- Recommendations for specific contractual provisions to address particular conditions or anticipated problems
- Recommendations for notes included with plan sets on various features, such as potential problems with drainage or erosion control, slope stability, slope design, location of support features, rockfall hazard mitigation methods and locations, etc.

1.3. What Is Excluded From the Report?

Some of the geotechnical information generated during the design phase is not ordinarily useful or pertinent during construction, so exclude it from the report. Such information may relate to superseded alignments or locations, technical or economic comparisons of design alternatives, details that are not adopted, or items deleted from the project scope. Make the decision as to what is pertinent and what is not on a project-by-project basis.

1.4. Setting a Geotechnical Baseline

One of the purposes of the geotechnical report is to set a baseline of geotechnical conditions. The baseline is a representation of the geotechnical conditions the parties to the construction contract may expect to encounter. The Department may prepare a formal geotechnical baseline report for use in complex projects or a geotechnical summary for inclusion in the special provisions. Absent an explicit, separate baseline report or summary, the baseline is established by the geotechnical report.

The conditions defined in the geotechnical report provide the basis for interpretation and analysis of claims under the differing site conditions (DSC) clause. Federal law requires that all federal-aid highway contracts include a differing site conditions clause. A contractor filing a DSC claim must contend either: (1) that ground conditions are materially different from those that would be expected from a reasonable interpretation of the contract documents, or (2) that an unusual, unknown physical condition exists that materially differs from those ordinarily encountered.

A significant portion of contractor claims and problems during construction involves subsurface conditions and soil/rock construction materials. This is due primarily to the complexity and variability of natural earth and rock formations and materials. Juries have awarded in the millions of dollars for contractor claims based on the DSC clause. The Army Corps of Engineers has documented that from 1980 to 1990, contract claims escalated by more than 200 percent, and by 1990 averaged more than $1 billion annually.

Because the geotechnical report is made available to bidders to use as an aid in preparing bids, it becomes a key document to both the Department and the contractor if a dispute regarding geotechnical conditions arises during construction of the project. Because of this, it is extremely important to prepare the report with the idea in mind that it may become the focal point of a geotechnical DSC claim. Errors, omissions, or misrepresentations in the report may lead to resolution in favor of the claimant. This could greatly increase the cost of the project. Conversely, a carefully prepared and accurate geotechnical report will do much to prevent DSC claims, or to provide the basis for an equitable resolution of a DSC claim in favor of the state.

1.5. Practices to Avoid

This section details some unwise practices by authors of geotechnical reports. Avoiding these common pitfalls will help avoid claims and contract disputes over geotechnical issues. The list of issues is not a comprehensive set of considerations or situations. The examples are used to illustrate some, but by no means all, of the issues that you should consider in a geotechnical report.

1.5.1 Incomplete, Ambiguous, or Subjective Statements

DSC claims have been awarded on the basis of, literally, one or two words in a report. The choice of words is so important that every author of a report should have reference to a glossary of geologic terms, a dictionary, and reliable reference texts in specialty fields such as engineering geology, groundwater, geophysics, and soil and rock mechanics. Check yourself whenever you have the slightest question as to the meaning a reader may assign a word. Reviewers of the report have an obligation to raise questions about such words or phrases. In a claim (or court) case, a tactic often used by the plaintiff or the plaintiff’s attorney is to examine the geotechnical report in detail to find statements that will help the claim by being inaccurate, very broad, or ambiguous.

Ambiguities can result in a misunderstanding of what the author intended to convey. Words such as "isolated, some, few, numerous, rapidly, occasional, scattered, useable, "etc. should be used only if the meanings of such words are quantified to a narrow range of meaning within the context of the report.

1.5.2 Unnecessary or Overly Optimistic Interpretations

Data interpretations and geologic interpretations are often necessary in a geotechnical report, but be careful to ensure that a given interpretation or conclusion contributes to the technical merit of the report. As an example of an interpretation that is unnecessary and does not contribute to the technical merit of the report, consider the following statement that appeared in a geotechnical report:

> *"The sandy gravel deposit has a shallow water table (4'-6' below the surface) but as it is an elevated terrace, it will drain rapidly."*

This statement is improper for at least two reasons. First, it has no technical merit – the statement is pointless, since it is an outright guess. Unfortunately, such a statement appearing in a technical report will almost certainly be given more credibility by the reader than it deserves. Second, the term "drain rapidly" is subjective unless it is defined (in the report) to be within a range of values used to define drainage rates.

Certainly, the author in the above example should have pointed out the shallow water table, and a prudent interpretation of the geologic conditions would have been that the shallow groundwater could have an adverse effect on excavation operations. An example of a better statement to alert the reader to this risk is:

> *"The water table was noted at a depth of 4' to 6' below the surface, and any excavation deeper than this will probably require bailing or dewatering. Dewatering characteristics of the soils were not measured."*

Experience has shown that one of the most defensible reasons for geologic interpretations in a geotechnical report is to warn the reader about some geological feature or aspect that may pose a risk of geotechnical surprise.

1.6. Geotechnical Risk Factors

Risk factors perceived by contractors bidding on projects increase the bid cost of the projects. When they realize the risk during construction, the price of the project goes up due to claims or less confrontational changes to the contract through change orders or force account work. The presence of boulders, for example, is a risk factor that can greatly influence excavation costs, and their presence in ground that is being excavated often leads to contract disputes or DSC claims on the basis that they were not anticipated in significant quantities. This is an area where presentation of geological interpretations may be justified if, for example, boulders were noted in the geotechnical explorations for a project, but not in quantities that could be anticipated from interpretation of the geologic setting of the project. The purpose of including such interpretations is to alert the reader to the risk of boulders being present in significantly greater quantities than might be indicated by the exploration data alone.

1.6.1 Example 1

The following example demonstrates a situation where presentation of a geologic interpretation contributed to the technical merit of the report by pointing out the risk of boulders in a proposed cut.

Exploratory borings for a proposed deep cut detected only a few boulders, but geologic interpretation and construction histories of excavations in nearby areas in geologically similar terrains suggested a strong possibility that many boulders could be encountered. The following statement was put into the report:

> *"The proposed cut from Station 970 to Station 2060 will be into what is interpreted as an ancient terrace of the Copper River. Exploratory borings indicate boulders are present, and other excavations into ancient Copper River terraces have encountered concentrations of nested large boulders ranging in size from one to ten or more feet in diameter."*

Boulderous gravel was, in fact, encountered during excavation of the cut. There is no way to know if the above statement gets credit, but there was no claim filed for boulders.

A list of other geotechnical risk factors that may be present on any given transportation project in Alaska includes seismic potential, permafrost, deep seasonal frost, wet soils, soft ground, extremely moisture-sensitive soils (such as soils derived from volcanic ash, soils with glacial silt fines, or ancient weathered sands and gravels), areas where wet construction seasons or unusually short construction seasons commonly occur, potential landslides, or floods, to name a few. Most risk factors can usually be discussed on a wholly factual basis, but if interpretation will contribute to the technical merit of the report, include it.

1.6.2 Example 2

For example, consider the following case history:

> *"For design of a highway in an area in the interior of Alaska where the construction season is quite short (and often wet), test borings were made in the fall and early winter of the year. Laboratory tests of soil samples taken along the proposed route indicated that glacial silt soils in the upper five feet or so were below optimum moisture. Good borrow sources in the project area were sparse, so the soils were designed for incorporation into the highway embankment. However, when construction began, it became apparent that the soils were too wet to compact, and attempts to dry them failed dismally in the cool, damp weather that was common to the area. This project, with all the claims and extra charges, ultimately cost more than double the original cost estimate."*

This could have been avoided if geotechnical interpretations of the risk involved in trying to use the silts were made and presented on any or all of the following bases:

1. A study of construction histories of projects in similar geologic and environmental settings would have revealed that glacial silts were almost always a "problem soil" when attempts were made to compact them to modern moisture/density specifications.
2. An application of the knowledge that moisture content test results from samples of frost-susceptible soils taken within the seasonal frost penetration zone can be misleading. If the samples are taken during the fall and early winter months, the silts have had weeks to thaw and drain, and moisture content test results will be drier (sometimes a lot drier) than the soil will be during the early and mid-part of the construction season.
3. The risk of a very wet construction season, not uncommon in the environmental setting of the project, could spell disaster to an attempt to use the silts, even if they were as dry during the construction season as the test results indicated.

Obviously, had the decision been made to design the silts as waste, the cost of the project would have increased. It would have been necessary to locate and obtain rights to additional borrow sources, and also obtain additional right-of-way to accommodate a large quantity of wasted silt. To accomplish this, unless the decision was made early in the design process, may have delayed advertising the project for a year. Even considering all this extra time and expense, it is highly likely that the final cost of the project would have been much less if geotechnical interpretation had resulted in the silts being designed as waste.

1.7. Editing Boring Logs

If the logs shown in the report, variously referred to as the "final," "formal," or "drafted" logs, are not exact copies of the original field logs (and they usually are not), take care when editing, rewording, condensing, or otherwise changing the original field logs. Make sure that notes regarding such risk elements as boulders, water table measurements, caving or squeezing ground, or drilling characteristics are not inadvertently edited out.

Editing of field soil textural descriptions requires careful judgment. For example, it may be easy to interpret that a soil described in the field log as "fine sand" is likely a "silt" when three samples of the stratum are tested and classified as silt. The interpretation is much less clear when, for example, the soil is described as "coarse gravel," and test results of samples (which were taken with a Standard Penetration Test (SPT) split-spoon sampler) classify as "sand." The difficulty and critical nature of such interpretations mandates that a senior engineering geologist should either do them or check them.

Note in red on the field logs any differences between the field logs and the final logs. If the rationale for the change is not clear, briefly explain it. Retain field logs until the project is completed and any disputes resolved.

1.8. Specific Report Guidelines

Each geotechnical report will be different and project-specific, so a “cookbook” report guide is neither possible nor desirable, as long as the minimum basic information set forth above is included. For the purposes of uniformity throughout the Department, the format guideline will be used by each region, and by consultants hired by the Department.

Do not assume that all aspects of a project will be automatically covered in one of the sections of the report outline. Look at the report outlines and refer to the guideline text to be sure that subjects important to the project are covered. If a subject does not seem to fit into any of the sections, do not ignore it; find a place where it seems to best fit, add a subsection, or make a note somewhere in the report to address the item.

2. Annotated Outline: Geotechnical Report

The geotechnical report may take many forms depending on the requirements of the project and the specific preferences in the regions. The outline below represents the contents that will cover virtually all the Department's geotechnical reports. The format of the report is not important – the content of the report is the issue. Consistency among the regions is desirable.

2.1. Title Page

Include the project name, federal and state project number, the DOT&PF region, the date of publication by month and year, and necessary signatures. The signatories on the title page should include the author and the responsible engineer, but may also include other approving officials including the chief geologist, the regional geotechnical engineer, the regional materials engineer or the state materials engineer. State law and Department policy require that a civil engineer registered in the State of Alaska stamp engineering geology/geotechnical reports unless they are merely reporting data.

For reports prepared by a consultant, the stamp of the consulting engineer in responsible charge will appear on the title page. The consultant company name, address of the office that prepared the report, its telephone number, and the consultant project number should also be included on the title page.

2.2. Table of Contents

Use a table of contents to show the starting page number for each section and subsection in the report, and list all the appendices. If necessary, include a list of figures. These include vicinity maps, location maps, photographs, charts, flow diagrams, graphs, etc. Include figures within the body of the text close to the point where they are referenced. If warranted, include a list of tables. In the list, include page numbers. Locate tables close to their point of reference in the text. A table of contents is not necessary for a short report or a memorandum-style report.

2.3. General Location Map

This should show the location of the project with respect to the state map and nearby communities.

2.4. Specific Location Maps

These maps will show the beginning and end of the project, stationing, centerline alignment, existing roads, major topographic and drainage features, a north arrow, map scale, materials site locations, and highway milepost locations. Material sites should be shown on this drawing. If material sites are not near the alignment, use separate sheets as needed.

2.5. Summary

The summary is a brief (one page or less) discussion of the project scope, the geotechnical field investigation, and the results of the investigation. Identify in the summary the problem areas or issues and discuss analysis of the problems and recommendations for resolution. Include a brief description of potential material sources, their availability, and any conclusions about the adequacy of the sources to meet project requirements.

2.6. Introduction

Include in the introduction a detailed scope of the proposed project (including type of facility, roadway length, width, paved or unpaved, important design features, etc.), the purpose of the report and the investigation, dates of field exploration, and identification of personnel who conducted the exploration. Include a list of previous explorations or reports for the project and whether they have been supplemented or superceded by the current investigation. Note the investigative techniques and exploration methods used (e.g., review of published data, site reconnaissance and mapping, equipment types, method of subsurface exploration, laboratory testing, analyses, etc.).

Include the following statements:

> *"This report documents subsurface geotechnical conditions and provides analyses and interpretation of anticipated site conditions at the project. This report recommends design and construction criteria for the project. This report also establishes a geotechnical baseline to be used in assessing the existence and scope of changed or differing site conditions. This report is intended for use by the project design engineering staff, construction personnel, bidders and contractors."*

2.7. Other Reports and Investigations

List any additional reports that pertain to this project. Include information describing authorship and dates of completion. Document the literature and references used in researching the geotechnical conditions for the project. The literature may be geologic maps, topographic maps, aerial photographs, previously completed reports for this or adjacent projects, regional geology reports, "as-built" plans, construction completion reports, or other documents. Include pertinent maps in the appendix if they are of particular value to understanding the project's geotechnical conditions.

2.8. Physical Setting

2.8.1 Climate

Describe climatic conditions that will have an effect on the project design, construction, or maintenance. Present the range of temperatures in the vicinity of the project. Note nighttime conditions, if available, if night construction is possible. Describe seasonal conditions such as temperature extremes, heavy rain, snow, or fog that could limit construction seasons, the ability to reduce the moisture content of construction materials, affect traffic control, etc. Briefly state the mean annual temperature, the temperature extremes, mean annual precipitation, heaviest rainfall months, snowfall amounts, the date of general onset of freezing temperatures, the freezing and thawing indices, and the design freezing and thawing indices if available. This data may be in presented in table form. Include references to the sources of the data, including Web site addresses.

2.8.2 Topography, Drainage and Vegetation

Describe the landforms and drainages through which the project will pass. Describe topographic highs such as hills and ridges that will require cuts for the project alignment and the approximate depths of the cuts. Also describe topographic lows such as valleys, swales, marshes, and minor creeks that the embankment will traverse. Discuss depth below or height above profile grade. Measure and describe steepness of slopes along and perpendicular to the alignment. Describe slopes that will receive side hill cuts or fills. Note drainage patterns including creeks, intermittent streams, and rivers; and vegetation types, sizes, and density. Include special note of vegetation that indicates something about subsurface conditions (such as small spruce trees that indicate possible frozen ground; heavy growth of alder indicating presence of shallow groundwater; or leaning, curved trees that may indicate ground movement).

2.8.3 Significant Man-Made and Natural Features

The project may cross, abut, or parallel certain features that may be adversely affected by the project or may impact the project. For example, existing retaining walls could be affected by embankment placed upslope of the wall, even though the toe of fill is located well back from the wall. As another example, rock cuts can remove support from bedding planes and reduce the lateral support of materials or facilities well outside the right of way. Identify such situations in this part of the report for later consideration.

Similarly, there may be features such as rivers, wetlands, utilities, railroads, or political boundaries that require added clearance through retained fills or overly steep cut slopes. Include information on the presence of any underground utilities (e.g., petroleum lines, natural gas pipelines, water supply lines, etc.) as features for geotechnical consideration.

2.8.4 Regional Geology and Seismicity

Describe the regional geologic setting of the project area. Include geomorphic province, major topographic features (such as mountain ranges and valleys), and major characteristics such as depth of alluvium over bedrock, bedrock formations, and included rock types. Include discussion of known or documented geologic hazards such as landslides, rockslides, flooding, etc.

Describe the regional seismic setting, including names of known active faults, distances and directions from the project site, and maximum credible earthquake magnitudes. If appropriate, provide a map at a suitable scale to show the regional faulting within 75 miles, with the appropriate annotation showing relative proximity of the project location. Where the project includes construction of structures such as bridges and retaining walls, include the expected peak ground acceleration (PGA) of the specific site, with careful reference to the parameters of the PGA and the source of the information, whether U.S. Geological Service, American Association of State Highway and Transportation Officials (AASHTO), or other publications.

2.8.5 Site Geology

Describe the geology of the project site and a sufficiently large area surrounding the project to include geologic features of potential significance to the project. Provide enough detail characterizing the geologic setting so that a reader can visualize the site geology. Preparation of a geologic map in hillside or mountainous terrain is helpful. Emphasize properties or conditions of the soil and rock materials that will impact design or construction of the project. Where a structure is planned for construction in alluvial sediments, include an estimate of the age of the sediments and an estimate of the depth to bedrock at the specific site. A separate foundation investigation will normally be conducted for all but the simplest and smallest structures.

2.9. Field Investigation

2.9.1 Exploration

In this section, describe the intent of the investigation, with reference to the exploration plan. Then describe what was accomplished during the field investigation and any deviations from the exploration plan with explanations for the deviation. Include a summary description of the type, scope, and purpose of the field investigations. Include a section on problems encountered during the exploration program that may have design or construction implications.

If some portion of the planned or desired fieldwork could not be done for some reason (right-of-entry refused by property owner, for example), state what work was desired, why it could not be done, and possible consequences. In Section 2.10. “Station to Station Descriptions,” discuss the assumptions that you had to make as a result of the omitted fieldwork.

2.9.2 Drilling and Sampling

Briefly describe the number, type, and depths of borings, trenches, and test pits made for the field study. Provide a general statement about the types and intervals of samples taken (bulk, undisturbed, SPT, etc.) and the reasons for each type. State the status of the samples: whether they were taken to the laboratory, were used in testing, are in storage, or were discarded. Also include a statement about how drill holes or pits were completed (filled with cuttings, grouted, converted to an observation well, backfilled and compacted, etc.).

2.9.3 Geophysical Studies

Describe the type, scope, general locations, and intended purpose of any geophysical studies performed. Indicate the locations of field data collection sites/lines on a plan view map or location drawing. Show the data in the profile sheets where appropriate, or other data sheets. Present the data, including all graphs and interpretations made from raw field data, in the appendix and reference the data in this section. Include a statement about the storage location of the raw data in case anyone wishes to look at it.

2.9.4 Instrumentation

Describe any instrumentation installed during the field exploration (e.g., slope inclinometers, extensometers, piezometers and observation wells). Indicate their locations on the plan view map or location drawing. State why each was installed and present summaries of the data in an appendix. If a monitoring program must continue beyond the time of the initial investigation, provide a schedule and duration. Present and discuss relevant data from instrumentation monitored during original construction or from previous exploration programs of relevance to the project.

2.9.5 Exploration Notes

Describe and briefly discuss any aspect of the exploration program that may affect design or construction. Include such items as caving or squeezing in the borings, extremely hard drilling or alternating hard and soft drilling, and problems with access to certain sites or gaps in the exploration program. The intent of this section is to disclose conditions that may not be addressed in the geotechnical analyses and recommendations sections, but which may be indicative of potential geotechnical behavior during construction.

2.9.6 *In Situ Geotechnical Testing*

Describe the in situ testing performed for the subsurface exploration program (e.g., vane shear tests, pressuremeter tests, electronic cone penetration tests, in situ permeability, etc.). Reference the test methods used, and include modifications of existing test methods or unpublished test methods in the appendix. Explain why you used that method instead of a published method. Where the in situ test results lend themselves to a concise summary (i.e. general data in the form of result ranges) include the summary here, otherwise summarize as appropriate in an appendix.

2.9.7 *Laboratory Testing*

Describe laboratory testing performed for this report. Include a listing of the testing performed such as classification tests, quality tests, and special tests such as consolidation tests or triaxial tests, etc. Refer to the controlling standards for the test methods used in the testing program. Include modifications of existing test methods or unpublished tests methods in the appendix. Explain why you used that method instead of a published method. Provide the laboratory test results on an approved soils testing report form approved in your region.

2.10. Station-to-Station Descriptions

The station-to-station descriptions are the heart of the geotechnical report. The geologist breaks down the alignment into logical intervals based on differences in soil/rock conditions, terrain differences, and other factors. The description of these intervals includes all factual items of importance noted from visual inspections of the terrain conditions and factual engineering geology/geotechnical information obtained during surface mapping or observations and from the test holes and/or test pits in each interval discussed.

The discussion of the intervals may also include carefully identified geologic interpretation of the data by a qualified geologist. The interpretation is made to increase the usability and reliability of information that must be inferred between points of factual data. Obviously, geologic interpolation cannot provide certainty regarding subsurface conditions, but it can provide a rational basis for assumptions made by a geotechnical engineer in performing stability or settlement analysis, or in developing geotechnical design recommendations. Make clear to the reader the distinctions between what is factual and what is interpretive.

Subjects to discuss include:

- Topography
- Types and density of vegetative cover
- Surface drainage and groundwater conditions
- Detailed description of the soil and rock present in the interval
- Frozen ground conditions, including permafrost if applicable
- Geologic hazards such as slope stability (slides, slumps), rockfall potential, likely settlement areas
- Boulders and cobbles, if present on the ground surface or encountered or suspected in the subsurface

Where groundwater is encountered or might be expected, discuss the observations from drilling or test trenching and the results of any observation wells or piezometers.

Follow the procedures set out in the *Alaska Field Soil Classification Guide* and the *Field Rock Classification and Structural Mapping Guide* to identify and describe soil and rock materials encountered during the investigation. DOT&PF uses the Unified Soil Classification System field and lab methods from ASTM D2487 and D2488 to describe and identify soils.

Where rock slopes are present along the alignment, provide an assessment of the existing slopes for rockfall hazards. Where rock cuts are planned, present the results of field mapping and analysis as to the structural characteristics of the rock. Include a discussion of the depth and nature of overburden above the rock slopes and the expected groundwater conditions.

Where frozen ground is encountered or expected, discuss the expected characteristics that may affect construction, such as temperature (give thermistor results), presence of excess ice, expected thaw instability, etc.

You must fully describe and document geologic hazards with mapping, photography and other means. Also discuss and recommend mitigation of the hazards.

Where boulders or cobbles are encountered or suspected, give the best possible estimate of the percentage of each present. Describe the occurrence– nested boulders, disseminated through a soil layer, etc. Where possible, use the methods outlined in the *Field Soil Classification Guide* to measure the percentage of boulders and cobbles.

For small, uncomplicated projects, it may be practical and effective to present the descriptions on plan and profile sheets rather than in the text of the report.

2.11. Graphical Representation of Geotechnical Information

Present in this section the geological and geotechnical information acquired along the project route. The data and interpretive information is typically shown on location drawings and plan and profile sheets, easily obtainable from the design section for modification for use in the materials report. However, in many cases the test hole/test trench logs may be shown on separate sheets referenced to a location drawing. Plan and profile sheets may be inadequate to fairly represent the logs, because of space requirements or a significant deviation between the existing ground and the planned profile.

The plan view should show features such as:

- Muskeg areas, ridges and benches, steep side-hill terrain, and any other terrain features that may affect the design of the facility
- Existing or potential slides or slumps, and any other features that may put geologic constraints on the design
- Man-made features such as houses, bridges, retaining structures, pipelines, railroad tracks, etc.
- The location of all test holes, test pits, or probes

A profile view should show the test hole logs, which will include at least:

- The test hole number and date
- The top of the test hole plotted at its actual elevation, where possible
- The depth and thickness of each soil layer
- The textural description of the soils
- Sample locations and numbers, blow counts, and sample recovery
- Selected sample test data
- Water table
- Frozen soil
- Cobbles and/or boulders

Note that factual engineering geology/geotechnical information or comments regarding the drilling or surface features recorded on or with the field logs should not be edited out of the published report.

In addition to the station-to-station descriptions, other geotechnical data may be obtained during the course of the investigation that is best presented in a graphical format. The report may incorporate charts, graphs, photos, and auxiliary software output (rockfall plots, slope indicator data, etc.). In many instances, the insertion of a single photograph into the text can make otherwise confusing paragraphs clear.

2.12. Geotechnical Analysis and Design Recommendations Analysis

The Materials section staff use the geotechnical data and information obtained from the various field investigations, the laboratory testing data, and geologic interpretations of site conditions to determine and characterize the relevant engineering properties of the rock and soil materials encountered at the project site. A geotechnical engineer will do the detailed geotechnical analyses necessary for the formulation of geotechnical design recommendations. He or she may ask the project geologist for assistance in such geological interpretations as needed to help develop geotechnical parameters for the analyses.

The analysis alerts designers, construction staff, and contractors to potential problems, and may provide the basis for choosing from various alternative design solutions. The analysis also may help in assessment of risks associated with the alternative design solutions. This analysis is not intended to provide detailed solutions to engineering problems. Rather, the analysis provides the basic information, some guidance on potential problems, and some possible solutions available to the design engineer.

The quality of the analysis depends on several factors, including staff knowledge of engineering principles and practical experience in application of these principles to projects involving similar facilities and materials. The analysis requires frequent communication and an unrestricted flow of information between the regional Materials section staff, the design engineering staff, and later, the construction staff.

2.12.1 Recommendations

The engineering geologist provides the regional geotechnical engineer with the necessary data and interpretations for the formulation of geotechnical recommendations as soon as practicable following completion of the field investigation. The geotechnical engineer prepares the recommendations with the assistance of the engineering geology staff and sends them to the design staff as soon as possible. The recommendations, which will ultimately be included in final form in the geotechnical report, may be considered preliminary during early development of the design, and may be presented in a preliminary report format to the designer.

2.13. General Material Site Information

List here the number and identity of sites investigated and selected for possible use. Specific material site reports will be in a separate section of the report or may be published as a separate report, depending on the project scope and other factors. (Material Site investigations and the material site report are discussed separately in another part of the Geotechnical Procedures Manual.) Identify the status of the individual sites as “designated,” “available,” or “other material sources,” pursuant to the Standard Specifications. Discuss the rejected sites and the reasons for rejecting them, as this could be helpful in future exploration. Discuss the sites selected for possible use and their characteristics, interpreted quantity available, quality of material, and limitations of the information used to make the interpretation. Recommend specific limitations or problems with the sources and details required for mining plans. Include photos of the site and the specific areas investigated to establish conditions at the time of the investigation.

Alaska
Department of
Transportation
and
Public Facilities

Alaska Field Rock Classification and Structural Mapping Guide

Effective October 1, 2003

Table of Contents

Preface

This *Field Rock Classification and Structural Mapping Guide* is one of a series of guides that comprise the Alaska Department of Transportation and Public Facilities' (DOT&PF) *Geotechnical Procedures Manual*. This guide is meant to assist Department staff and consultants in obtaining geotechnical data for use in the design and analysis of rock slopes, rock excavations for foundations, and rock anchorage features. The first part of this guide (Rock Classification) describes a process for naming rock. The second part of the guide (Structural Characteristics of Rock) is a discussion of the elements of rock mass description and structural rock mapping. Finally, the last part of the guide (Structural Rock Mapping Procedures) provides the methodology for field structural rock mapping.

Both geologic rock type identification (naming) and structural mapping (describing) are important in characterizing rock materials encountered in engineering works, because both provide basic data required for design of rock slopes, rock foundations, and rock anchorage. Rock identification is accomplished through observation of the mineral composition and texture of intact rock samples. Rock identification may be determined using any reasonable accepted system that provides a commonly recognized rock name, but variations on classification schemes are numerous. The Department recommends use of *Classification of Rocks* (Travis, 1955). The Department also recommends reference to publications and works in progress of the International Union of Geological Sciences and their work in standardizing nomenclature of rocks. The level of detail in the identification depends, in part, on the level of complexity of the project and the specific role the rock plays as a foundation or backslope material. The geologist should always describe the rock as completely as possible under the circumstances.

Structural rock mapping for engineering purposes consists of two assessments: one for intact rock and one for its *in situ* character.

- **Intact rock** is a block or fragment of rock free of defects, in which the mechanical properties are controlled by the characteristics of the material, rather than by discontinuities (Hunt, 1984).
- ***In situ* rock** is the rock mass that contains defects such as joints, fractures, cavities, etc., that separate the rock mass into blocks of intact rock and control the mechanical and hydraulic properties of the mass (Hunt, 1984).

The engineering characteristics of *in situ* rock masses are important where rock slopes or excavations are developed, where structures are founded on rock, or where anchors are set into rock, among other applications. These characteristics are identified by a combination of mapping, testing, and analysis. The geologist or engineer must address these characteristics where rock excavation is planned. At a minimum, the geologist must identify rock types and map the orientation of discontinuities in the rock mass, but the extent of the investigation depends on the nature of the project. Where the project involves no more than a simple low rock cut, a less intensive investigation may be sufficient to identify the important issues. However, for example, where a high rock cut is planned, or a bridge abutment is planned on rock, a detailed investigation is warranted.

The product of the geological field investigation is the data obtained during mapping. The final section of this guide presents the field procedures for acquiring the data.

Principal References

The four cornerstone references for field procedures for structural rock mapping for the Department are:

- "*Suggested Methods for the Quantitative Description of Discontinuities in Rock Masses,*" International Society for Rock Mechanics, (Int. J. Rock Mech. Min. Sci. & Geomech. Abstr. Vol. 15, 1978)
- *"Foundations on Rock,"* Wyllie, D.C. (E&FN Spon, 2nd Ed. 1999)

- "*Rock Slopes,*" Wyllie, D.C. and Mah, C.W. (Federal Highway Administration Report No. FHWA-HI-99-007, 1998)
- "*Rock Slope Engineering*," E. Hoek and J.W. Bray (Institution of Mining and Metallurgy, 1974).

The combination of a systematic methodology and pragmatic philosophy found in these publications provides a complete guide to rock mapping for the Department. Each DOT&PF geologist working with rock slopes and foundations must have access to these publications, and should learn the methods and philosophy in these documents.

The product of the analysis of the field data varies considerably from project to project. The result of the structural analysis may range from simple recommendations to complex design products including:

- Stereonet-based kinematic and/or total stress analysis of a rock mass
- Slope angle and limitations
- Typical rock slope sections
- Typical sections for rockfall catchment ditches
- Blasting specifications and recommendations
- Rockfall mitigation measures (rock bolts, draped wire mesh, cable fences, barriers)
- Rock strength data
- Analysis of suitability of rock for structural foundation

Some projects will require considerable effort to adequately analyze rock mass characteristics. Other projects with only minor rock cut slopes will not require detailed analysis.

Additional Selected References

- *Manual on Subsurface Investigation* (American Association of State Highway and Transportation Officials [AASHTO], 1988)
- Brawner, C.O., *Rockfall Hazard Mitigation Methods,* Brawner, C.O. (Participant Workbook – Federal Highway Administration Publication No. FHWA SA-93-085, 1994).
- Hunt, Roy E., *Geotechnical Engineering Investigation Manual,* (McGraw-Hill, 1984)
- *Basic Geotechnical Description of Rock Masses* (International Society for Rock Mechanics, Int. J. Rock Mech. Min. Sci. & Geomech. Abstr. Vol. 18, 1981)
- Maerz, N.H., *Highway Rock Cut Stability Assessment in Rock Masses Not Conducive to Stability Calculations,* (in Proceedings: 51st Annual Highway Geology Symposium, Seattle, WA, 2000).
- Pierson, L.A. and Van Vickle, R., *The Rockfall Hazard Rating System – Participant's Manual,* (Federal Highway Administration Report FHWA-SA-93-057, 1993)
- Travis, Russell B., *Classification of Rocks,* (Vol. 50, No. 1, Colorado School of Mines Quarterly 1955, [reprinted at CSM Quarterly, Vol. 99, No.2, 1999]).
- *Standard Guide for Using Rock-Mass Classification Systems for Engineering Purposes,* (Standard D 5878, American Society for Testing and Materials, 2000)

- Le Maitre, R. W. (Ed.), *Igneous Rocks: A Classification and Glossary of Terms: Recommendations of the International Union of Geological Sciences Subcommission on the Systematics of Igneous Rocks ("Igneous Rocks")*, (Cambridge University Press, 2nd Ed. 2002)
- Schmid R., Fettes D., Harte B., Davis E., Desmons J., and Siivoloa J., *Towards a Unified Nomenclature in Metamorphic Petrology: 1. How to Name a Metamorphic Rock*, International Union of Geological Sciences Subcommission on the Systematics of Metamorphic Rocks, (Provisional Version July 31, 2002 on website http://www.bgs.ac.uk/SCMR)

1. Rock Classification

1.1. Introduction

Classification is a preliminary step in analyzing the suitability of rock for use as a construction material. In some cases, the rock name is nearly irrelevant. For some projects, understanding the rock type may be critical to a stability analysis. The following quote from "Classification of Rocks," although nearly 50 years old, is a sound statement of good practice for determining rock classification:

> *"Rocks are classified chemically, petrographically, or genetically, depending on the purpose of the classification. Each basis has its own merits, but for general use in naming and describing rocks, the petrographic basis has certain obvious advantages that account for its nearly universal adoption. Even so, the petrographic basis applies only after a primary division based on genesis has been made.*
>
> *In support of this procedure, the principle followed herein, after the primary genetic division has been made is to name the rocks on the basis of visible features, not on the basis of inference. Rock classification should be independent of the method of examination. More precise identification can be accomplished with a microscope than with a hand lens, but this fact does not justify separate classification schemes. A rock is a rock and should have an identifying name irrespective of the method of study." (Travis, 1955)*

Travis's classification scheme includes comprehensive charts providing all the detail likely to be useful on Department projects. Use of the charts will reveal quickly whether a rock can be precisely named. If not, apply a purely descriptive name, such as "black fine-grained sedimentary rock," "tan schist," "coarse-grained granitic rock," or "altered volcanics," until you can make a more complete examination. For many purposes, simple descriptive names are sufficient.

In addition to Travis's comprehensive classification scheme, also refer to comprehensive and detailed classification systems developed under the aegis of the International Union of Geological Sciences. The IUGS publication on igneous rocks (Le Maitre, Ed., 2002) is a modern reference work. There are some new publications available online from the IUGS Subcommission on the Systematics of Metamorphic Rock in draft or proposed form for metamorphic rocks.

Geologists classify rock genetically as one of three types: igneous, metamorphic or sedimentary. Rock names should be as complete as circumstances permit. When more accurate and precise names are needed, use the Travis charts and classification system. However, keep in mind that rock-naming charts provide an artificial systematization. "The lines on the charts are not honored by nature and all gradations of composition and texture are possible" (Travis, 1955).

The effort made to arrive at the rock name should reflect the importance of the rock material to the project. If, for example, a project includes a fill over deep soil over bedrock, it is not necessary to provide a detailed description of the rock. Identifying the material as bedrock is most likely adequate. However, where an investigation is undertaken for a bridge abutment founded on rock, a detailed description may be critical. Fine-grained, uncommon, weathered, or altered rock may be difficult to identify in the field. Use inexpensive commercial thin section services wherever warranted to confirm the field or office identification of rock specimens.

1.2. Primary Division

The first step in identifying rock under the Travis system is to decide whether it is igneous, sedimentary, or metamorphic. Use the guidelines in Figure 1-1, below, a graphical representation of the "primary division" discussed in "*Classification of Rocks.*"

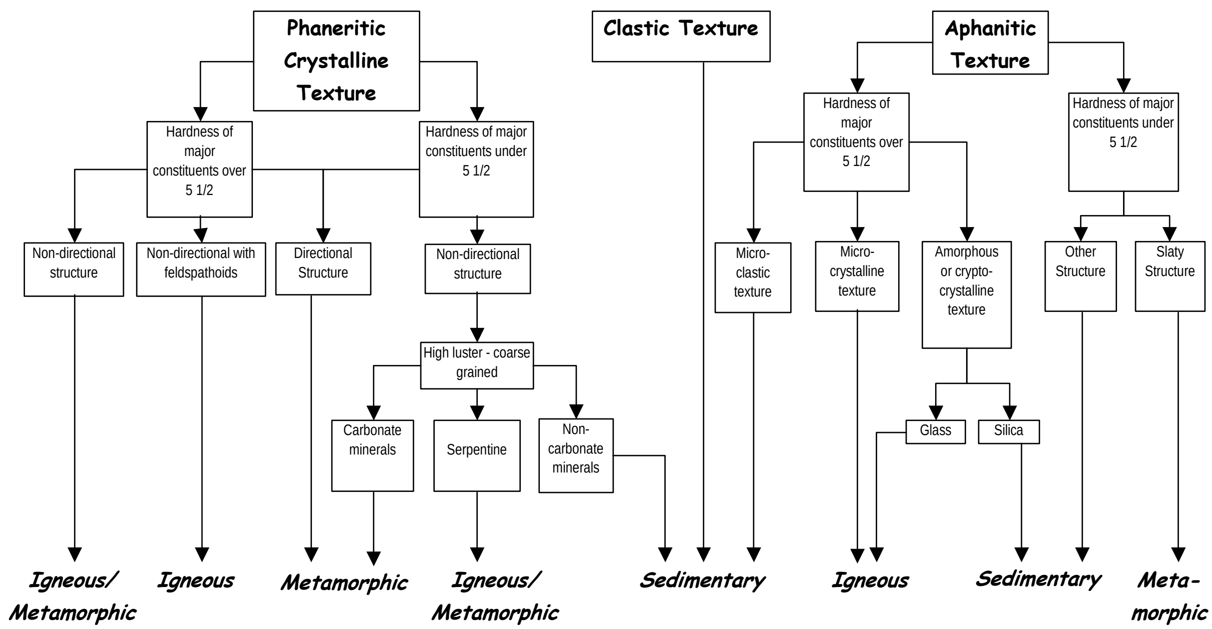


Figure 1-1
Primary Division of Rock Types (after Travis, 1955)

Once the preliminary genetic identification is made, make the rock classification, either descriptive, if appropriate, or a more detailed petrographic description, if necessary and if possible. Regional and local experience will often quickly lead you to the appropriate rock name. The tables below contain some typical rock types and characteristics.

1.3. Igneous Rocks

Igneous rocks are formed when molten rock cools and crystallizes. Igneous rocks are classified on the basis of mineralogy and occurrence (whether the rock is intrusive or extrusive) based on the rock's texture. To classify or describe igneous rocks, the geologist must have command of the most common textural terms. Refer to the listing in "*Classification of Rocks*" (Travis, 1955) Section I – Igneous Rocks and to the IUGS publication.

Nomenclature for igneous rocks should include color, texture, alteration (if any), accessory minerals and the root name. The complete name may not be necessary and as described above, abbreviated names are desirable for some uses. Color may include both the color index and the chromatic color name. The color index is the dark mineral percentage and applies only to phaneritic rocks. Texture includes degree of crystallinity, grain size, grain relationships, degree of crystal face development on grains and specialized textural terms relating for instance to volcanic rocks or pyroclastic rocks. Definitions are set out below. Igneous rocks may be all crystalline, all glassy, or both. The grain size division is between rock with grains visible to the unaided eye and those with grain sizes smaller than can be seen with the unaided eye. Refer to Travis for a complete discussion.

1.3.1 Textural Definitions

The igneous rocks can be described using a multitude of modifiers for texture. A partial listing includes:

General

- Vesicular: spherical, ovoid or tubular openings
- Amygdaloidal: vesicles are filled with secondary minerals

Grain size

- Aphanitic: grains not visible to the unaided eye (microcrystalline, cryptocrystalline or glassy)
- Phaneritic: grains visible to the unaided eye (coarse grained > 5mm, medium grained 1-5mm, or fine grained <1mm

Grain relationships

- Granular: nearly equidimensional grains
- Porphyritic: grains of one or more sizes in a finer-grained groundmass
- Pegmatitic: grains of a wide range of sizes conspicuously larger than those of the parent rock
- Aplitic: composed of anhedral (no crystal faces) grains, sugary

Pyroclastic Rocks

- Pumice: highly vesicular, finely cellular with tubular vesicles
- Scoria: highly vesicular, coarsely cellular, usually spherical vesicles
- Ash: includes glass shards, crystals and crystal fragments, stony or glassy rock fragments (sand to silt size - <2mm)
- Tuff: Rock name for rock with ash-sized cemented volcanic particles <2mm in size
- Lapilli: commonly pumice or scoria particles 2-64 mm in size (pebble size). The rock name is lapillistone.
- Tuff Breccia: ejected volcanic material >32 mm in size in an ash/tuff matrix
- Lapilli Tuff: ejected volcanic material 4-32 mm in size in ash/tuff matrix
- Blocks and Bombs: cobble and boulder size. Blocks are angular and rigid; bombs are plastic during eruption and are shaped to streamlined forms during flight. When indurated, the name is volcanic breccia or agglomerate.

Table 1-1
Pyroclastic Rock Names

Particle Name	Rock Names	Particle Size	Features
Ash, cinders	Lithic Tuff, Vitric Tuff, Crystal Tuff, Welded Tuff	<2 mm	Ash-sized particles may be flows from vent (poorly sorted) or falls from ejection into atmosphere (well sorted).
Lapilli	Lapillstone, Lapilli breccia, Lapilli Tuff	2-64 mm	Usually ejecta.
Blocks and Bombs	Pyroclastic breccia, agglomerate	>64 mm	Usually ejecta.

Table 1-2
Porphyritic Rock Texture

Groundmass Texture	Percent Phenocrysts			
	Under 12	12-50	50-75	Over 75
Phaneritic (grains visible)	Granite or Porphyritic Granite	Granite Porphyry	Granite Porphyry	Granite
Aphanitic (grains not visible)	Rhyolite or Porphyritic Rhyolite	Rhyolite Porphyry	Granite Porphyry	Granite

1.3.2 Color Index

The color index is the percentage of dark minerals in the rock. Figure 1-2 on the next page (Travis, 1955 - Figure 1, Page 8) is a useful reference for determining color index. The terms “trap” and “felsite” are color terms for aphanitic rocks, with trap referring to dark rocks and felsite to light-colored rocks.

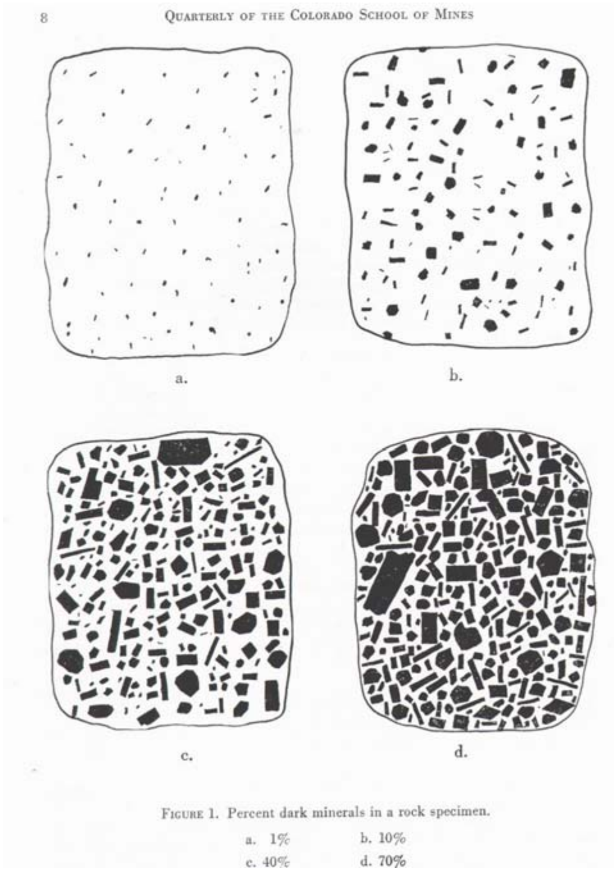


Figure 1-2
Color Index

1.3.3 Mineralogy

In addition to texture, the geologist must have an understanding of the essential minerals that make up the igneous rocks. These minerals determine the root name of the rock. In particular, it is essential for the geologist to be able to differentiate among the feldspars. A good working knowledge of accessory and secondary minerals will also assist you in naming rocks. Although naming rocks using Travis's nomenclature can be complex, the reference includes a simplified procedure that allows for abridgement of the full name to the root name prefixed by the most conspicuous feature of the rock; for example, "pink granite" or "vesicular olivine basalt." Travis also allows for the use of terms such as "felsite" and "trap."

Table 1-3
Common Igneous Rock Types and Descriptions

Name	Color or Color Index	Description
Pegmatite	Light	Coarse-grained, mostly quartz and feldspar as large grains.
Granite	10	Light colored, coarse-grained, usually approx. equal sized grains with quartz, feldspars, dark accessory minerals. Most common igneous rock.
Rhyolite	10	Light colored, fine-grained, same content as granite, but in microcrystalline form.
Pumice	Light	Light colored, vesicular (“frothy”), lightweight glassy rock with approximately the same composition as rhyolite.
Diorite	25	Generally light colored, coarse-grained, may be gray to dark gray. Composed mostly of plagioclase and dark accessory minerals.
Andesite	25	Fine-grained, usually dark gray or green rock.
Basalt	50 – gray to green-black	Generally dark and fine-grained, often with vesicles.
Peridotite/Pyroxenite/Hornblendite	95	Dark rocks composed of grains of dark minerals.
Obsidian	Black	Usually black natural glass with conchoidal fracture and brilliant luster.

1.4. Sedimentary Rocks

Sedimentary rocks form as a result of the decay of rock masses (detrital) or from chemical precipitates (nondetrital) or the special case of formation of coal. The particles resulting from these processes are deposited into sedimentary basins and eventually lithify to form rock. The classification of sedimentary rocks is based on grain size, mineralogy, and the relationship of the grains. As with the igneous rocks, a good knowledge of terminology is essential to a facility for naming sedimentary rock.

The sedimentary rock names depend first on texture based on grain size. Travis’s chart has three divisions of grain size, along with further divisions based on composition of the major and minor fractions.

1.4.1 Textural Terms

As with the igneous rocks, many textural terms may used to describe sedimentary rocks. Some of these common terms include:

- Clastic: fragmental, composed of discrete grains each having their own boundary
- Detrital: products of weathering, disintegration and mechanically deposited with a clastic texture
- Crystalline: composed of interlocking grains formed in place by chemical deposition
- Amorphous: non-crystalline material formed in place by chemical deposition
- Chemical: composed of products formed in place or chemically deposited or crystalline or amorphous texture
- Oolitic: composed of spheroids less than 2 mm in diameter.
- Pisolitic: composed of spheroids greater than 2 mm in diameter
- Bioclastic: composed of fragments of fossils

1.4.2 Descriptive Terms

Fissile: rock that may be readily split along closely spaced planes

Friable: rock or mineral that is easily broken, pulverized, or reduced to powder

Induration: the degree of hardening or consolidation or a rock (or soil) by heat, pressure, or cementing agents

1.4.3 Other Features

Sedimentary rocks are further differentiated or named by reference to such features as mineralogy, color, structure (mostly field observations of the outcrop), and shape of grains. Figure 1-3 below shows the relative sphericity and roundness of particles.

Most sediments are composed of a mixture of a detrital fraction and a chemical fraction. Extreme examples are uncemented sandstone and a pure evaporite; the sandstone is entirely detrital while the evaporite is purely chemical. The detrital fraction may be relatively easy to identify in coarse-grained rock, but becomes increasingly difficult as grain size decreases. Chemical and aphanitic detrital constituents may be distinguished using such simple field tests and observations as whether the rock effervesces in dilute hydrochloric acid, and observations of luster, fissility, and relative density. Nomenclature for sedimentary rock is more highly descriptive than for igneous rocks because there are fewer root names. The convention for rock names is as follows: color, structure, grain size, minor constituents, root name.

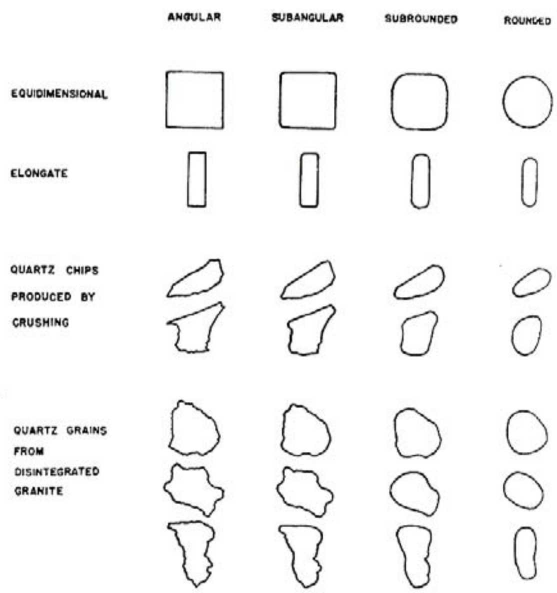


FIGURE 2. Two-dimensional sphericity and roundness of grains.

Figure 1-3
Grain Shape

Refer to *Classification of Rocks* for additional detail and guidance in naming sedimentary rock and the exceptions and special cases highlighted in the reference. Naming of sedimentary rocks is controversial; the IUGS subcommission on sedimentary rock is inactive at the time of this writing in 2003 because the subcommission was unable to resolve serious disagreements on nomenclature.

Table 1-4
Common Sedimentary Rock Types and Descriptions

Conglomerate	Rounded fragments of any rock type.
Sandstone	Predominantly quartz grains cemented by silica, iron oxide, clay or carbonate. Varying colors depending on cementing agent. Thick beds common.
Graywacke	Strongly indurated impure sandstone with a clayey matrix.
Siltstone	Composition similar to sandstone, but finer-grained. Usually thin beds.
Argillite	Hard, indurated shales, similar to slates, but without fissility.
Claystone/mudstone	Clay-sized particles compacted into rock without fissility.
Shale	Particle size predominantly less than 0.002 mm with a well-developed fissile fabric.
Limestone	Contains more than 50% calcium carbonate with the remaining percentage consisting of impurities. Many varieties that may be precipitated or of detrital origin.
Dolomite	Harder and heavier than limestone. May be chemical precipitate or altered limestone.
Coal	Highly altered plant remains. Lignite (brown coal), bituminous (soft coal), anthracite (hard coal).
Chert	Silica deposited from solution in water. May be small nodules or thick beds.

1.5. Metamorphic Rocks

Metamorphic rocks are formed when a parent rock is subjected to geologic processes that alter the original rock's structure and/or mineralogy. We characterize metamorphic rocks by their structure, texture, and mineralogy. Naming metamorphic rocks essentially consists of prefixing the names of the most abundant minerals to a structural term that defines the rock. The structure is categorized as either directional (e.g., schistose, slaty) or nondirectional (e.g., marble, hornfels).

1.5.1 Structural Terms

While the igneous rocks and sedimentary rocks are described with reference to texture, the metamorphic rocks descriptions rely primarily on structural terms. Common structural terms include:

- Blasto: a prefix indicating relic fabric in a metamorphic rock
- Lineation: a parallel directional structure expressed in one direction only
- Foliation (schistosity): parallel directional structure expressed in two directions and imparting a tendency to split into layers
- Granulose texture: granular with non-directional structure
- Hornfelsic structure: nondirectional structure
- Cataclastic structure: structure developed by crushing and granulation
- Mylonitic structure: foliated fine-grained cataclastic structure
- Slaty structure: foliation in aphanitic metamorphic rocks that permits splitting into thin sheets
- Schistose structure: foliation due to parallel orientation of phaneritic flaky, lamellar, or occasionally rod-shaped minerals
- Phyllitic structure: foliation intermediate between slaty and schistose, aphanitic, but exhibiting a sheen on the foliation surface due to oriented micaceous minerals

- Gneissose structure: foliation due to alternation of granulose and schistose bands
- Migmatitic: a genetic term denoting mixed igneous and metamorphic origin; bands, veins, and pods of granitic rock in a metamorphic host rock

See *Classification of Rocks* (Travis, 1955) for a more complete discussion. Metamorphic rock-forming minerals are conveniently divided into two categories: essential minerals and characterizing accessory minerals. Travis provides a listing.

1.5.2 Complications

Complications arise in a few areas. First, metamorphic and igneous processes merge in two cases: low-grade and high-grade metamorphism. The gradation across the boundary between igneous and metamorphic rocks is not agreed upon and rocks in this zone are sometimes included in both igneous and metamorphic groupings. Examples include serpentine, talc, and migmatite. Another example of complications occurs in rocks that retain their original structure but may have new minerals (metagabbro, metasandstone). In addition, rocks that have become somewhat foliated, but have not undergone recrystallization, retain their original name. Other rocks may have the structural term “schistose” added as a prefix (e.g., “gray schistose sandstone,” “schistose biotite rhyolite”).

Table 1-5
Common Metamorphic Rock Types and Descriptions

Gneiss	Coarse-grained. Imperfect foliation resulting from bands of different minerals. Main minerals are quartz and feldspar, but includes accessory minerals such as micas and dark minerals.
Schist	Fine-grained with well developed foliations from parallel arrangement of platy minerals such as mica, chlorite and talc. Garnet also common accessory mineral. Schist and Gneiss may grade into each other and a clear distinction not always possible.
Phyllite	Thinly foliated into platy fragments. Generally soft satiny or silky luster on cleavage surfaces due to minute crystals of chlorite or sericite.
Slate	Thinly foliated and very fine-grained with well-defined planar cleavage into hard, brittle plates.
Quartzite	Metamorphosed recrystalized sandstone. Very hard.
Marble	Metamorphosed recrystallized calcite, limestone or dolomite. Hard.
Mylonite	Produced by intense mechanical metamorphism that crushes and pulverizes the original rock. May be strongly laminated with a flow structure expressed as streaks and bands. Beds may be very thin to hundreds of feet thick. May cause unstable conditions in slopes or other rock excavations. Mylonitic structure may be recognizable only under microscope.

2. Structural Characteristics of Rock

2.1. Introduction

Rock mapping is of critical importance in projects where, for example, there is a high rock cut slope or where structural foundations are founded on rock, or where structures are anchored into rock. The minimum information includes rock type and the orientation of discontinuities. Rock type is important, among other reasons, as an indicator of strength characteristics, of the potential orientation of discontinuities, and of the potential for weathering. Along with rock type, the geologist maps the orientation and characteristics of the discontinuities in the rock mass, and determines the shape and size of blocks bounded by discontinuities following the techniques developed by the International Society of Rock Mechanics (ISRM, 1978) and discussed and summarized in "*Rock Slopes"* (Wyllie and Mah, 1998) and "*Foundations on Rock*" (Wyllie, 1999).

Mapping furnishes the fundamental information on site conditions. The data gathered during mapping are the basis for many subsequent engineering decisions including the location and type of structures and rock anchors, and the need for reinforcement of rock. The mapping is a vital part of the investigation, but is an inexact process because geological and engineering judgment is necessary to extrapolate from limited data from outcrops and cores that may represent only a small fraction of the affected rock mass.

The geologist uses the field data to identify the types of failures (planar, wedge, toppling, circular) that are kinematically possible in the rock by analysis of the discontinuity orientations with respect to the rock slope or structure using stereographic projections. Plot the discontinuity orientations along with the existing/proposed rock slope and analyze them to determine the potential direction of movement. Also obtain indication of the possible stability condition. If you identify one or more of the four potential failure modes, further analyze the likelihood of such failures. In addition to the geometric conditions established by stereographic projection analysis, analyze other factors to determine the stability of a rock slope. These other forces may include foundation loads, water conditions, and proposed reinforcement. Rigorous geological and engineering analysis supported by laboratory testing may be required to assess the stability of potentially unstable slopes.

2.2. Stability Analysis of Rock Masses

Rock slope stability analysis is beyond the scope of this guide. However, a brief discussion is included here as an introduction. Department staff and consultants should follow state-of-the-practice procedures as represented by the references cited in this guide and other authoritative publications. We cannot overstate the importance of properly describing and analyzing the stability of a rock mass. In rock excavations, the rock slopes typically adjoin traveled ways. Failing rock slopes have caused disastrous losses of life and property. For bridge or retaining wall foundations on rock, the importance of understanding the structure and characteristics of the rock is equally obvious. The analysis of rock for foundation purposes must be a cooperative venture involving qualified engineers and geologists working together to reach an understanding of the nature of the rock material and how the rock mass will react to the forces imposed on it during and after construction.

The geologist or engineer who performs the structural analysis may use hand calculations using stereonets and stereographic projections, approved structural analysis software (e.g., RockPack, Dips, Swedge), and more sophisticated methods. For significant excavations, they should undertake a more rigorous study to determine whether the character of the discontinuities, strength of rock, presence of water in the slope, etc., indicate the potential for failures. If so, the geologist and engineer should consider the available means to mitigate the possibility of failure. Refer to FHWA's "*Rock Slopes*" and *Rockfall Hazards Mitigation Methods* manual for guidance.

2.3. Rock Mass Classification and Description

There are numerous rock mass classification systems that have been developed for special purposes, such as tunneling, mining, and rock slope stability. ASTM Standard D 5878 contains a brief discussion of the some of these systems. The International Society of Rock Mechanics has developed a system discussed in *Basic Geotechnical Description of Rock Masses* (ISRM 1981). A discussion of several systems related to highway slopes is set out in "*Rock Slopes*" (Wyllie and Mah, 1998) and in *Highway Rock Cut Stability Assessment in Rock Masses Not Conducive to Stability Calculations* (Maerz, 2000).

Rock mass classification includes a description of *in situ* rock mass characteristics:

- Rock strength
- Weathering or alteration
- Hardness
- Discontinuity orientation and description

The procedures for a quantitative description of discontinuities in rock masses developed by the International Society of Rock Mechanics is published (ISRM 1977) and has been summarized and discussed in detail in *Foundations on Rock* (Wyllie, 1999). The procedures provide a language that enables geologists to transmit their observations of the rock mass and its anticipated behavior. The procedures provide quantitative data rather than subjective observations alone. The data obtained using the procedures are derived from simple measurements and provide a complete description of the rock mass for engineering purposes.

Thirteen rock mass properties may be examined and described quantitatively using the procedures. The characteristics that have importance for engineering design can be described in five categories (Wyllie, 1999), including:

- Rock material description (rock type, wall strength, weathering)
- Discontinuity description (type, orientation, roughness, aperture)
- Infilling (type, width)
- Rock mass description (spacing, persistence, number of sets, block size, and shape)
- Groundwater

The benefits of examining these characteristics and using these procedures are twofold: first, you discuss and quantitatively describe the parameters so the results can be used directly in design; second, the use of standardized procedures allows different personnel to use the procedures and interpret the results comparably. Figure 2-1, on the following page, provides an overview of the rock mapping criteria and their relationship to the rock mass.

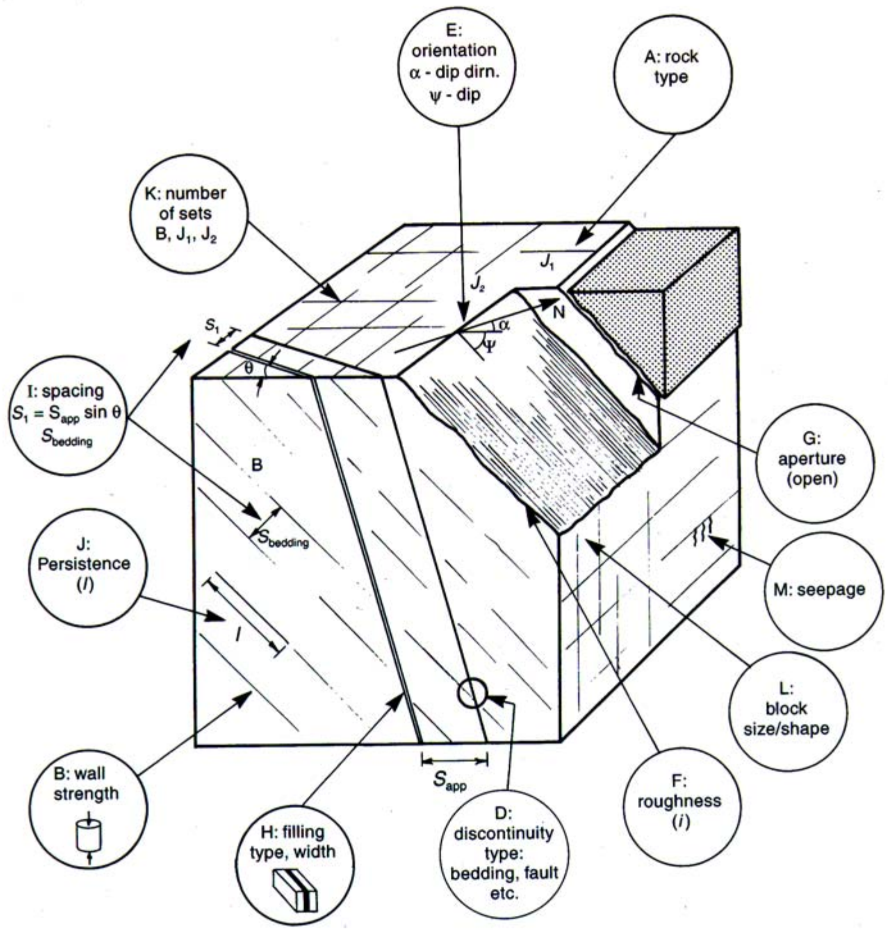


Figure 2-1
Illustration of Geologic/Structural Mapping Terms (After Wyllie, 1999)

Use of these standardized terms will provide a sound basis for mapping and describing characteristics of rock masses. An explanation of each of the terms is set out in Table 2-1 on the next page. See "*Foundations on Rock*," Sec 4.2.1, pp 99-104. (Wyllie, 1999) for further discussion of these characteristics.

Table 2-1
Description of Geologic Structural Mapping Terms (ISRM, 1977)

ID	Term	Description
A	Rock Type	The rock types are defined by the origin of the rock (i.e., sedimentary, metamorphic, igneous), color (including whether light or dark minerals predominate), texture or fabric (ranging from crystalline, granular, or glassy) and grain size (ranging from boulders to silt/clay size particles)
B	Wall Strength	The compressive strength of the rock forming the walls of discontinuities will influence shear strength and deformability. Rock compressive strength categories and grade vary from extremely strong (>36,000 psi, grade R6) to extremely weak (35-150 psi, grade R0) (See Table 2-2)
C	Weathering	Reduction of rock strength due to weathering will reduce the shear strength of discontinuities as well as reduce the shear strength of the rock mass due to reduced strength of the intact rock. Weathering categories and grades are summarized in Table 2-3.
D	Discontinuity Type	The discontinuity type ranges from smooth tension joints of limited length to faults containing several inches or feet of clay gouge and lengths of many miles. Discontinuity types include faults, bedding, foliation, joints, cleavage, and schistosity.
E	Discontinuity Orientation	The orientation of discontinuities is expressed as the dip and dip direction of the surface. The dip of the discontinuity is the maximum angle of the plane to the horizontal (angle ψ in Fig. 1) and the dip direction is the direction of the horizontal trace of the line of the dip measured clockwise from north (angle α in Fig. 1).
F	Roughness	Roughness should be measured in the field on exposed surfaces with lengths of at least 2 m. The degree of roughness can be quantified in terms of Joint Roughness Coefficient (JRC). Wall roughness is an important component of shear strength, especially in the case of undisplaced and interlocked features (e.g., unfilled joints).
G	Aperture	Aperture is the perpendicular distance separating the adjacent rock walls of an open discontinuity (thereby distinguishing it from the width of a filled discontinuity), in which the space is air or water filled. Categories of aperture range from cavernous (> 1m) to very tight (< 0.1mm).
H	Infilling Type and Width	Infilling is the term for material separating the adjacent walls of of discontinuities such as fault gouge; the perpendicular distance between adjacent rock walls is termed the width of the filled discontinuity. Filled discontinuities can demonstrate a wide range of behavior and thus their affect on shear strength and deformability can vary widely.
I	Spacing	Discontinuity spacing can be mapped in rock faces and in drill core; spacing categories range from extremely wide (> 6000mm) to very narrow (< 6mm). The spacing of individual discontinuities has a strong influence on the mass permeability and seepage characteristics of the rock mass.
J	Persistence	Persistence is the measure of the continuous length or area of the discontinuity; persistence categories range from very high (> 20m) to very low (< 1m). This parameter is used to define the size of blocks and the length of potential sliding surfaces. Persistence is important in the evaluation of tension crack development behind the crest of a slope.
K	Number of Sets	The number of sets of discontinuities that intersect one another will influence the extent to which the rock mass can deform without failure of the intact rock. As the number of sets increases and the block sizes decrease, the greater the likelihood for blocks to rotate, translate, and crush under applied loads.
L	Block Size and shape	The block size and shape are determined from the discontinuity spacing, persistence, and number of sets. Block shapes include blocky, tabular, shattered and columnar, while block sizes range from very large (> 8 m^3) to very small (< 0.0002 m^3).
M	Seepage	Observations of the seepage from discontinuities should be provided. Seepage quantities in unfilled discontinuities range from very tight and dry to continuous flow. Seepage quantities in filled discontinuities range from dry in heavily consolidated infillings to filling materials that that are washed out completely and very high water pressures are experienced.

2.3.1 *Rock Type ("A")*

This feature was discussed above in the rock classification section. Such characteristics of rock as strength and presence of discontinuities may be controlled to some degree by the rock type.

2.3.2 *Wall Rock Strength ("B")*

Strength can be characterized in several ways. Obtain rock strengths by testing intact specimens using either direct or indirect methods (compressive strength testing devices, impact hammers, point load testing devices, etc.). Simple field tests can also be related to rock strength. Table 2-2 sets out a widely accepted rock strength classification system.

Table 2-2
Classification of Rock Materials Strengths (ISRM, 1977)

Grade	Description	Field Identification	Approximate Range of compressive strength Mpa	p.s.i.
R6	Extremely Strong Rock	Specimen can only be chipped with geological hammer	>250	>36,000
R5	Very Strong Rock	Specimen requires many blows of geological hammer to fracture it.	100-250	15,000-36,000
R4	Strong Rock	Specimen requires more than one blow with a geological hammer to fracture it.	50-100	7,000-15,000
R3	Medium Weak Rock	Cannot be scraped with a pocketknife; specimen can be fractured with a single firm blow of geological hammer.	25-50	3,500-7,000
R2	Weak Rock	Can be peeled with a pocketknife; shallow indentations made by firm blow with point of geological hammer.	5-25	725-3,500
R1	Very Weak Rock	Crumbles under firm blows with point of geological hammer; can be peeled with pocketknife.	1-5	150-725
R0	Extremely Weak Rock	Indented by thumbnail.	0.25-1	35-150
S6*	Hard Clay	Indented with difficulty with thumbnail.	>0.5	>70
S5	Very Stiff Clay	Readily indented by thumbnail.	0.25-0.5	35-70
S4	Stiff Clay	Readily indented by thumb, but penetrated only with great difficulty.	0.1-0.25	15-35
S3	Firm Clay	Can be penetrated several inches by thumb with moderate effort.	0.05-0.1	7-15
S2	Soft Clay	Easily penetrated several inches by thumb.	0.025-0.05	4-7
S1	Very Soft Clay	Easily penetrated several inches by fist.	<0.025	<4

*The soil material strengths may refer to infillings in discontinuities.

2.3.3 *Weathering ("C")*

Chemical and mechanical weathering and alteration of rocks affects the edges and walls of rock blocks more than their interiors. The wall strength is therefore usually less (sometimes much less) than the strength of the rock in the interior of the block. Weathering results in opening of discontinuities, conversion of rock to clay minerals in discontinuities, opening of grain boundaries, fracture of individual mineral grains, and other effects. The combined effect is a weakening of the rock mass, even though the weathering may only affect a thin skin of rock along discontinuities in the mass. Simple field tests can be used to classify weathering characteristics as summarized in Table 2-3 below.

Table 2-3
Weathering and Alteration Grades (ISRM 1977)

Grade	Term	Description
I	Fresh	No visible sign of rock material weathering; perhaps slight discoloration on major discontinuity surfaces.
II	Slightly weathered	Discoloration indicates weathering of rock material and discontinuity surfaces. All the rock material may be discolored by weathering and may be somewhat weaker externally than in its fresh condition.
III	Moderately weathered	Less than half the rock material is decomposed and/or disintegrated to a soil. Fresh or discolored rock is present either as a continuous framework or as corestones.
IV	Highly weathered	More than half the rock material is decomposed and/or disintegrated to a soil. Fresh or discolored rock is present as a discontinuous framework or as corestones.
V	Completely weathered	All rock material is decomposed and/or disintegrated to soil. The original mass structure is still largely intact.
VI	Residual Soil	All rock material is converted to soil. The mass structure and material fabric are destroyed. There is a large change in volume, but the soil has not been significantly transported.

2.3.4 Discontinuity Type ("D")

This characteristics is important because each type of discontinuity has properties that influence behavior of the rock mass. The discontinuity types include: faults, bedding planes, foliations, joints, cleavage, and schistosity. Each type of feature has a set of characteristics that may lead the investigator to conclusions about its contribution to rock mass strength. For example, faults are major structures possibly miles in length that likely contain weak infillings of gouge or crushed rock, while joints are relatively short and may have little or no infilling.

2.3.5 Discontinuity Orientation ("E")

Orientation of discontinuities is described by the dip and dip direction of the plane representing the discontinuity. The dip is the maximum down angle on the plane measured from the horizontal. The dip direction is the azimuth (measured from north) of the line of maximum dip. See Figure 2-1. The orientations of the discontinuities in a rock mass with respect to nearby engineering works largely control whether there is a possibility of unstable conditions. The orientation is combined with other features, such as shear strength of the rock materials, in making a stability assessment.

2.3.6 Roughness ("F")

Roughness is an important feature of the shear strength of discontinuities, particularly for undisplaced and interlocked features. The asperities (small scale roughness) affect the strength of the discontinuity because they tend to be broken or damaged by block movement. The undulations (large scale) are too big to be broken by the movement, so the rock blocks must move normal to the discontinuity (dilation). As the separation between adjacent rock blocks increases, the effects of roughness decrease in importance. In describing roughness, for small-scale features of up to a few inches, use the terms rough, smooth, and slickensided. For larger scale features of up to many feet, use the terms stepped, undulating and planar. These terms, when combined as in Figure 2-2, provide a systematic terminology. You may also describe roughness by the numeric Joint Roughness Coefficient (Figure 2-3) with scaled values related to roughness profiles. In field practice, you may be unable to resolve the

JRC distinctions to the finest detail of two units out of 20. Use of divisions with an interval of five units out of 20 may be adequate.

Figure 2-2
Roughness Profiles and Nomenclature

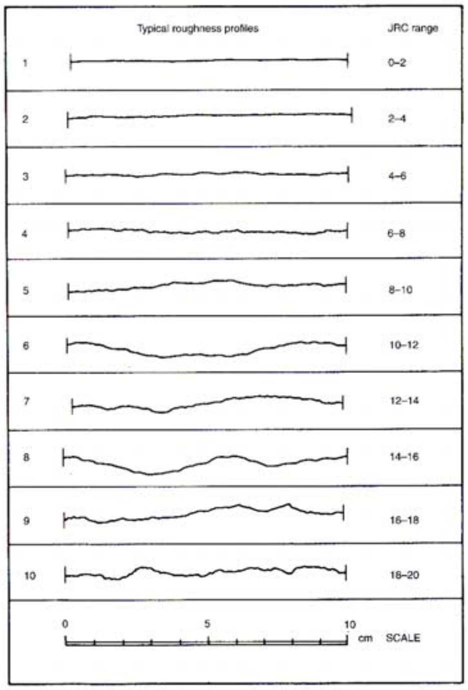
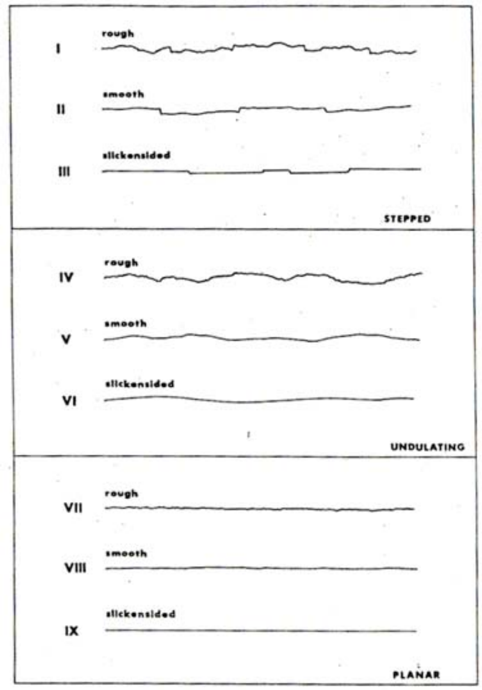


Figure 2-3
Roughness Profiles for Joint Roughness Coefficient



2.3.7 Aperture ("G")

This feature describes the air or water-filled openings between adjacent rock walls. Soil or mineral-filled discontinuities are not apertures. Apertures in subsurface masses are usually quite small, less than half a millimeter. Apertures in surface rock may be much larger, to greater than a meter. The size of the apertures may be important in how the rock may be loosened and more importantly, in reductions to rock mass strength by reduction of normal stress where water is present in the apertures. In addition, the conductivity and storage capacity of the apertures may be of importance for some structural stability analysis.

Table 2-3
Aperture Description

Aperture (inches/feet)	Description	Category
<0.004 in	Very tight	Closed
0.004 – 0.01 in	Tight	Closed
0.01 – 0.02 in	Partly open	Closed
0.02 – 0.1 in	Open	Gapped
0.1 – 0.4 in	Moderately wide	Gapped
0.4 – 2.5 in	Wide	Gapped
2.5 – 4.0 in	Very wide	Open
4.0 in – 3 ft	Extremely wide	Open
> 3 ft	Cavernous	Open

2.3.8 Infilling Type and Width (“H”)

Infilling is the type of material separating the adjacent walls of discontinuities in rock. The infilling may be minerals such as calcite or chlorite, clay, silt, fault gouge, breccia, etc. The perpendicular distance between the rock walls is the width of the filled discontinuity, as opposed to the aperture of an open discontinuity. The wide variety of conditions and types of fillings that may occur can influence the strength of the discontinuity and the stability of the rock mass. Several features of the infilling can be observed and measured, including:

- Type or mineralogy of the infilling
- Grading or particle size
- Over-consolidation ratio
- Water content and permeability
- Previous displacement
- Wall roughness
- Width
- Fracturing or crushing of wall rock

Observe, measure, and record as many of these features as possible under the circumstances. For structurally important discontinuities, the observations may be critical to the stability analysis. For important engineering features such as dams, tunnels or high slopes, considerable effort may be necessary to characterize and understand the importance of the role of infilling materials in the stability of the rock mass. The effort may include physical testing of the infilling material and in situ strength tests. Refer to the ISRM suggested methods for rock description (ISRM 1977) for a thorough discussion of characterization of infilling.

2.3.9 Spacing (“I”)

The spacing between adjacent discontinuities largely controls the size of individual blocks. Many closely spaced sets of discontinuities results in a rock mass with lower cohesion than widely spaced sets. In some cases closely spaced discontinuities may result in a circular failure mode instead of a translational failure. The spacing will have a significant influence on permeability and seepage characteristics of the rock mass. Generally, hydraulic conductivity will be inversely proportional to the spacing, assuming comparable apertures of individual joints. Represent spacing by reference to Table 2-4.

Table 2-4
Discontinuity Spacing

Description	Spacing
Extremely close	< 0.8 in
Very close	0.8 – 2.5 in
Close	2.5 – 8 in
Moderate	8 – 24 in
Wide	24 – 79 in
Very wide	79 in – 20 ft
Extremely wide	>20 ft

2.3.10 Persistence (“J”)

Persistence, the areal extent of a discontinuity within a plane, is an important but hard-to-determine feature. Frequently, the only clue to the persistence of the discontinuity is the trace of the discontinuity on the surface of a rock exposure. Understanding the persistence of discontinuities may be critical in assessing whether a tension crack is present behind a rock mass or whether unfavorably oriented discontinuities extend beneath a rock mass. Use Table 2-5 below to characterize the dimension of persistence.

Table 2-5
Persistence

Description	Dimension, ft
Very low	<3
Low	3-10
Medium	10 – 30
High	30 – 60
Very high	>60

2.3.11 Number of Sets (“K”)

The number of sets of discontinuities will control the appearance and more importantly, the mechanical behavior of a rock mass. The number of sets determines appearance in rock blasting since the number of sets determines the extent of possible overbreak. The number of sets determines whether the rock mass can deform without failure of intact rock. Large numbers of sets can change the mode of failure from translational to rotational/circular. The number of sets may not be readily recognizable during the field mapping, but can be determined during stereographic projection analysis.

2.3.12 Block Size and Shape (“L”)

Block size in a rock mass is determined by the discontinuity spacing, the number of sets, and the persistence of discontinuities. Rock masses composed of large blocks tend to be less deformable. Block size is also important in a determination of usability of excavated rock for structural fill, riprap, and other purposes. Block size can be described by average block size dimensions, by block size distribution, and by descriptive terms as shown below:

- Massive: few joints or wide spacing
- Blocky: approximately equidimensional
- Tabular: one dimension considerably smaller than the other two
- Columnar: one dimension considerably larger than the other two
- Irregular: wide variations of block size and shape

- Crushed: heavily jointed

2.3.13 Seepage ("M")

Seepage generally occurs through flow of water in discontinuities. In some sedimentary rock, the greatest volume of flow may be through rock pores, rather than discontinuities. Provide the information necessary to characterize groundwater levels, seepage paths, and approximate water pressures. Carefully note presence of water in the rock exposure, sources of surface water above the exposure, and the presence of tension cracks behind a rock slope. Also note the presence of flow barriers from clay filled discontinuities, impermeable rock layers, or dikes. The observations of water in discontinuities can be given as a seepage rating following Table 2-6 below.

Table 2-6
Seepage Rating

Seepage Rating	Description of Discontinuity
1	Very tight and dry. Water flow along it does not seem possible
2	Dry with no evidence of water flow
3	Dry, but shows evidence of water flow, e.g., iron staining, etc.
4	Damp, but no free water present
5	Seepage evident as occasional drops of water, but no continuous flow
6	Continuous flow of water. Estimate gals/min and describe pressure as high, medium or low.

Assess the likely effectiveness of surface drainage features, drilled drain holes in rock cuts, and the potential for icing and ice-blocked drainage paths.

2.4. Rock Quality

Percent of core recovery for drilled rock cores provides a measure of rock quality. The percent recovery is the amount of core recovered expressed as a percentage of the total length drilled in a core run. A high percentage of rock recovered in the core barrel may be an indicator of relatively good quality rock.

The Rock Quality Designation ("RQD" – ASTM D6032) is a modified core recovery indicator for drilled cores. RQD measures the total length of intact core segments over 4 inches long as a percentage of the core run length. RQD and core recovery percentage taken together provide a subjective, but numerical evaluation of the rock quality. The RQD number may also be expressed as a descriptive term as in the table below.

Table 2-7
Rock Quality Description

RQD Value	Description of Rock Quality
0% - 25%	Very poor
26% - 50%	Poor
51% - 75%	Fair
76% - 90%	Good
91% - 100%	Excellent

Where warranted for specific projects (e.g., a bridge abutment founded on rock) considerable additional effort may be expended to characterize the rock quality. In some cases, high quality rock cores obtained using double or triple tube core barrels are sufficient. In other cases, it may be necessary to obtain oriented cores using one of several methods for obtaining such cores (Hunt, 1984). Down-hole camera techniques may be used in conjunction with computer software to obtain high-resolution photographs of borehole walls and a discontinuity analysis.

2.5. Rockfall Hazard and Slope Management

In addition to rock mass classification systems, there are classification and hazard rating systems tailored to rock slope stability. Although slope management is not within the scope of this guide, it is worth mentioning here for reference. Several existing systems could be applied to state facilities construction projects. Of these rock slope classification systems, the most applicable to Alaska conditions is the Rockfall Hazard Rating System (RHR) (Pierson and Van Vickle, 1993). The RHR system incorporates a rating methodology that helps determine which slopes should have priority for limited rockfall hazard mitigation.

DOT&PF is developing an Unstable Slope Management System. The USMS will likely be modeled after an existing hazard rating system. The essential features of the USMS will include:

- Inventory of unstable slopes
- Initial assessment of unstable slopes into high risk, low risk and eliminated slopes
- Preparation of relational database with inventory of slopes
- Detailed evaluation of high risk slopes
- Design of repair or rehabilitation projects
- Identification of funding source
- Construction of repair or rehabilitation projects
- Periodic reevaluation

Relevant data obtained from mapping and analysis of rock slopes and other rock exposures for project purposes should be incorporated into the database for the Unstable Slope Management System.

3. Structural Rock Mapping Procedures

3.1. Introduction

There are many ways to map rock. The most suitable method for one rock exposure and one type of facility will be inappropriate for another exposure or a different project. The objective is to use procedures that define, and then successively refine, information on those features that will be critical to stability (Wyllie, 1998). The Department follows guidance from the ISRM source materials, the FHWA manual *Rock Slopes*, and *Foundations on Rock* as discussed above. Other useful references are listed at the beginning of this guide.

The best quality mapping is produced by a team of professionals using the right tools and open minds. Before detailed mapping, first study the regional geology and topography and how the local geology fits the regional scheme. Next, examine the rock exposure from a distance, if possible, and place it in the context of the local geology. Finally, examine the exposure from close up and perform the detailed mapping as laid out below.

Follow a flexible procedure in mapping and describing rock exposures. The nature of the project and field conditions will dictate, to some extent, the field procedure, and you must remain flexible enough to modify the mapping plan to suit the conditions and findings as they are developed. It is important to integrate and synthesize data into preliminary conclusions as the mapping progresses. By the time you leave the field, you should have a thorough understanding of the key elements of the rock exposure. The office analysis will usually confirm what you have concluded about the rock, but as the data are plotted and the analysis is developed, there will occasionally be surprises. With this in mind, it is a good idea to plan for one or more re-visits for additional mapping, especially on projects where the consequences of error are significant.

Rock mapping can be subdivided into two different types and several different levels of detail. Rock mapping can be either subjective (biased) or objective (random). The subjective survey describes only the discontinuities that appear important. The objective survey describes all discontinuities that intersect a fixed line or area of rock exposure (ISRM, 1978). Differing levels of detail are represented in critical features mapping, window mapping, and line mapping (Wyllie and Mah, Appendix I, 1998). The distinctions between these levels of detail in mapping are not sharp and you should carefully select the best methodology for obtaining the necessary information.

Choose the methodology of mapping to meet the project requirements, the conditions at the site, and limitations on time and money for investigations. Choose among three specific mapping types: critical features mapping, window mapping, and line mapping. Often, the best choice for the Department's structural mapping will be subjective (biased) joint set and critical features mapping. There will be circumstances where window mapping or line mapping may be useful. However, critical features mapping gives you the most flexibility in observation and preliminary analysis during the field mapping process. This in turn produces a focused mapping effort and relies on your analytical skills, rather than on statistical analysis of random data. Objective (random) surveys are time consuming, inflexible, and often fail to produce a statistically significant volume of data.

Where time or budget constraints preclude a complete detailed mapping effort, the mapping should be prioritized in the following order:

- Orientation and location of major faults and weak zones
- Orientation and location of contacts between major rock types
- Orientation of persistent discontinuities

- Spacing of persistent discontinuities
- Infilling of persistent discontinuities
- Surface properties of discontinuities

Generalized feature mapping consists of locating and describing features such as faults, rock type contacts (including weathering and alteration), fold axes, prominent bedding planes, foliations, and joint sets. The orientation of the features is measured using a structural compass and recorded. If there is adequate time the mapping can include brief notes on infillings, displacement, presence of water, etc. Once you have the larger picture in mind, the next step is a more detailed look. Detailed mapping includes critical features mapping, window mapping, and line mapping. Each method has its place. After the major features have been mapped and considered, determine what features or areas warrant detailed mapping. It is not desirable to map every feature in an exposure. Such detailed mapping can be wasteful and misleading and may produce data points for minor features that have no effect on stability. Such irrelevant data points can skew the data, if not carefully filtered out in the analysis. Features that are persistent or have unfavorable orientations should always be included.

Record the important features on a plan set to show the location with respect to the project features. Representative oriented data should also be plotted by hand in the field on stereonets so you can see the stereonet and the rock exposure at the same time. In the office, you can process the bulk of the data through versatile and time-saving structural analysis software such as Dips, Swedge, or RockPack.

3.2. Critical Features Mapping

Here, detailed mapping is undertaken for specific features that are critical to stability. For instance, analysis of preliminary data from a rock slope may reveal the necessity of determining characteristics of an unfavorably oriented joint set that is critical for understanding stability. Following the mapping plan developed under the section on “Mapping Procedures” below, make careful measurements or estimates of spacing, strength of the joint infilling along with roughness and other characteristics that may be required to determine the stability of the rock mass.

Mapping joint sets produces data about a set of joints including location, discontinuity type, orientation, spacing, persistence, infillings, and surface properties. Identify and locate by reference to centerline or other surveyed points the structural zones or domains in the exposed rock. In each identifiable structural zone or domain, map discontinuity sets for location, type, orientation, spacing, persistence, infilling, and surface properties. Take enough measurement to establish a consistent range of values for each data set.

3.3. Line Mapping

In this method, a surveyed or accurately located line is established along all or part of the exposure, and every feature that intersects the line is mapped and described following the mapping plan and procedures set out under “Mapping Procedures” in the following section. This method is tedious and leaves little room for flexibility or analysis as the data collection is under way. Take enough measurements for each discontinuity set to achieve a statistically valid basis for analysis. This may not be feasible where the exposure is small. If it is not possible to delineate clear joint sets, map only features that are persistent or are adversely orientated.

3.4. Window Mapping

In this method, detailed mapping is performed in selected representative windows at intervals along an exposure. Intervening areas are reviewed for similarity; significant variations or features in these areas may also be mapped. In each window, record the mean orientation and characteristics for each discontinuity set. Choose the size and interval of the windows to suit the project; for rock slopes, a typical layout is 5 feet by 30 feet windows centered every 150 feet. Select the location for mapping and mark the boundaries. Locate the window by station and offset or state plane coordinates, using survey methods or GPS. Observe and describe the material and structural features within the window, following the mapping procedures in the following section.

3.5. Mapping Procedure

3.5.1 Review Available Information

- Obtain and familiarize yourself with the plan sheets, cross sections and other available information before going into the field.
- Obtain and review geological reports and maps, air photos, previous geotechnical reports, etc., before going to the field.
- Identify potential problem areas such as high cuts, retaining wall sites, thick overburden, poor quality rock, fault zones, etc.
- Consider impact to nearby structures and topography inside and outside the right-of-way.
- At a minimum, take plan sheets and cross sections to the field.
- If possible, take topographic maps, proposed cut and fill slope limits, geologic maps, soil maps, etc.

3.5.2 Prepare Rock Mapping Plan

Following is an idealized plan for conducting mapping. Each project will require modification to this generalized plan, so don't rely on this as an all-inclusive checklist.

- The first step is to identify the area of interest in a project. Conduct such office reconnaissance as is possible to identify the scope of work necessary to obtain geotechnical data needed for design. Obtain and examine air photos, geologic maps, hazard maps, project drawings, geologic survey reports, previous Department reports, etc.
- If necessary and feasible, conduct a brief field reconnaissance to establish the methods of mapping and fieldwork.
- Select a mapping technique suitable for the project and the field conditions. This decision may be made in the field.
- Begin field exploration. Examine the exposures starting with gross features and the "big picture" and work toward more detailed looks at smaller areas.
- Identify and mark, if necessary, the area or areas for mapping.
- Locate the area(s) in relation to geographic reference points, whether stationing, temporary reference stations, or GPS coordinates.
- Establish a baseline for locating measurements within the mapping box. Describe the orientation of the baseline and its relationship with prominent features, with centerline and the trend of the cut or with the planned structure footprint, if available. Make sure the "north" used for field mapping is the same "north" used in developing project plans. Set compasses at "0" declination for field mapping and normalize the data to the proper declination as a step in the office analysis procedure (This may complicate the preparation of field stereonets).
- At the appropriate level of effort, measure the orientation of discontinuities and their location with respect to the baseline.
- Describe the discontinuities and the rock mass using the ISRM guidelines to describe the various characteristics.
- Photograph the rock cut or exposure from a distance, if possible, and in as many close-ups or intermediate shots as necessary to record the necessary details. A digital camera with a preview screen is an invaluable tool for this purpose. Make sketches if helpful.

3.5.3 Conduct Mapping According to Plan

- Record general views and details of the rock exposure for the existing exposure and the proposed cut. For photographs, use an appropriate scale in the photo, such as a stake or lathe painted contrasting colors at one-foot increments. The photos and sketch of the exposure will be a valuable aid for refreshing your memory during the analysis phase, after completion of the field work.
- Starting from the regional level and working toward more localized detail, summarize the geologic setting of the exposure in the context of regional and local geology and topography.
- Locate the exposure with respect to the project stationing or survey grid.
- Measure and record the shape of the existing cut or exposure. At a minimum, record length of exposure or cut, height at several locations, and existing slope angle.
- Observe and record details about existing rockfall, surface drainage, springs in rock exposures, effectiveness of existing ditch, apparent extent of weathering of exposed rock surfaces, existing slope angles, blast damage from original construction, evidence of previous blasting methods, presence of nearby facilities, structures, streams, or other features that might be affected by construction.
- Describe zones of similar conditions in the rock exposure by rock type and other obvious characteristics.
- Observe and record major discontinuity sets.
- Identify windows or scan lines for detailed mapping.
- Using the ISRM-based mapping forms, characterize the rock, identify, measure, and describe the discontinuities.
- Conduct detailed supplemental mapping in localized areas.

3.5.4 Field Book/Mapping Form Entries

For each data collection point enter the following information:

- Station or location
- Distance right or left of proposed or existing centerline
- Distance to top of cut
- Distance to toe of cut
- Distance to bottom of ditch (may be same as toe of cut)
- Distance to edge of ditch (top of foreslope)
- Distance to edge of existing or proposed pavement
- Azimuth of tape or line
- Azimuth of road moving along the tape or line (may need several)
- Discontinuity orientations
- Discontinuity characteristics

- Notes (water, terrain features, existing retaining structures, previous failures, unstable rock masses, significant joint sets, debris in ditch, old rock bolts, culverts, distance to buildings, wells and other significant features)

Appendix A. Forms

The following forms are adapted from several sources, (principally Golder & Assoc.) and are based on the ISRM procedures. These forms provide a useful means of recording the mapping data outlined above and in the ISRM publications. The **Rock Mass Description Data Sheet** describes the rock in terms of its color, grain size and strength. The form provides for description of the rock mass in terms of its block shape and size, the state of weathering, and the number and spacing of discontinuity sets. The **Rock Discontinuity Data Sheet** is a form for describing the characteristics of discontinuities: type, orientation, persistence, aperture and width, fillings, surface roughness, and water conditions.

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Design & Engineering Services
Statewide Materials

ROCK MASS DESCRIPTION DATA SHEET

Date: ____________

Project Name: ____________

Field Party: ____________

Project No: ____________

Weather: ____________

GENERAL INFORMATION

Location [ ] Station/Hole No. [ ]

Locality Type [ ] Slope Length [ ] No. of Sheets of Discontinuity Data [ ]

1. Natural Exposure
2. Construction Excavation
3. Trial Pit
4. Trench
5. Adit
6. Tunnel
7. Drill Hole

Slope Height [ ] Sketch [ ]

Core Size [ ] Photograph [ ]

REMARKS (exposure type/age, stability condition, design issues etc.)

ROCK MATERIAL INFORMATION

Color [ ] [ ] [ ]

1. Light	1. Pinkish	1. Pink
2. Dark	2. Reddish	2. Red
	3. Yellowish	3. Yellow
	4. Brownish	4. Brown
	5. Olive	5. Olive
	6. Greenish	6. Green
	7. Bluish	7. Blue
	8. Greyish	8. White
		9. Grey
		10. Black

Grain Size [ ]

1. Very coarse - boulders (>12 in)
2. Coarse - cobbles (3-12 in)
3. Medium - gravel (0.2-3 in)
4. Fine - sand (0.003-0.2 in)
5. Very fine - silt/clay (<0.003 in)

Compressive Strength [ ]

	PSI	
S1 Very soft clay	<4	
S2 Soft clay	4-7	
S3 Firm clay	7-15	
S4 Stiff clay	15-35	
S5 Very stiff clay	35-70	
S6 Hard clay	>70	
R0 Extremely weak rock	35-150	
R1 Very weak rock	150-725	(Moldable by fingers, but retains fabric)
R2 Weak rock	725-3,500	(Hammer craters surface, sides pushed up)
R3 Medium strong rock	3,500-7,000	(Hammer creates smooth dent)
R4 Strong rock	7,000-15,000	(Hammer creates rough pit)
R5 Very strong rock	15,000-36,000	(Hammer rebounds)
R6 Extremely strong rock	>36,000	

Method to Determine Compressive Strength [ ]

1. Measured
2. Assessed

Rock Type [ ]

Qualifying terms to describe rock:

ROCK MASS INFORMATION

Fabric [ ]

1. Blocky
2. Tabular
3. Columnar
4. Shattered

Block Size [ ]

1. Very large (>216ft^3 or 6ft cube)
2. Large (8-216ft^3 or 2-6ft cube)
3. Medium (0.3-7ft^3 or 0.67-2ft cube)
4. Small (12in^3-0.3ft^3 or 2.3in to 0.67ft cube)
5. Very small (<12 in^3 or 2.3in cube)

State of Weathering [ ]

1. Fresh
2. Slight
3. Moderate
4. High
5. Complete
6. Residual Soil

Failure Mode e.g. Toppling, Wedges [ ]

No. of Major Discontinuity Sets [ ]

LINE SURVEYS TO DETERMINE DISCONTINUITY SPACING (OR DRILL HOLE ORIENTATION)

	Plunge of line / hole	Trend of line / hole	Length of line (m)	No. of Fractures	Spacing	Remarks / True Spacing
Line 1						
Line 2						
Line 3						

Discontinuity spacing

1. Extremely close (<1 in)
2. Very close (1-2.5 in)
3. Close (2.5 - 8 in)
4. Moderate (8 in - 2 ft)
5. Wide (2-6 ft)
6. Very wide (6-20 ft)
7. Extremely wide (>20 ft)

State of Alaska DOT & PF
Design & Engineering Services
Statewide Materials

DISCONTINUITY SURVEY DATA SHEET

Project Name: ______________________

Project No: ______________________

Date: ______________________

Field Party: ______________________

Weather: ______________________

GENERAL INFORMATION

Location: [ ] Station/Hole No.: [ ] Disontinuity Data Sheet No.: [ ] of [ ]

NATURE AND ORIENTATION OF DISCONTINUITY

Station or Depth	Type	Dip	Dip Direction	Persistence	Termination	Aperture/ Width	Nature of Filling	Strength of Filling	Surface Roughness	Surface Shape	Waviness Wavelength	Waviness Amplitude	JRC	Water Flow	Remarks

TYPE
0. Fault Zone
1. Fault
2. Joint
3. Cleavage
4. Schistosity
5. Shear
6. Fissure
7. Tension Crack
8. Foliation
9. Bedding

PERSISTENCE
1. Very Low (<3 ft)
2. Low (3-10 ft)
3. Medium (10-30 ft)
4. High (30-60 ft)
5. Very High (>60 ft)

APERTURE/WIDTH
1. Very tight (<.004 in)
2. Tight (.004-.01 in)
3. Partly Open (.01-.02 in)
4. Open (.02-.1 in)
5. Moderately Wide (.1-.4 in)
6. Wide (>.4in)
7. Very wide (.4 - 4 in)
8. Extremely wide (4 in - 3 ft)
9. Cavernous (> 3 ft)

NATURE OF FILLING
1. Clean
2. Surface staining
3. Non-cohesive
4. Inactive clay or clay matrix
5. Swelling clay or clay matrix
6. Cemented
7. Chlorite, talc or gypsum
8. Other - specify

COMPRESSIVE STRENGTH OF INFILLING

	PSI
S1 Very soft clay	<4
S2 Soft clay	4-7
S3 Firm clay	7-15
S4 Stiff clay	15-35
S5 Very stiff clay	35-70
S6 Hard clay	>70
R0 Extremely weak rock	35-150
R1 Very weak rock	150-725
R2 Weak rock	725-3,500
R3 Medium strong rock	3,500-7,000
R4 Strong rock	7,000-15,000
R5 Very strong rock	15,000-36,000
R6 Extremely strong rock	>36,000

WATER FLOW (Open)
0. Discontinuity very tight and dry, water flow doesn't appear possible
1. Discontinuity dry, no evidence of water flow
2. Discontinuity dry, shows evidence of water flow e.g. rust staining
3. Discontinutiy is damp, but no free water present
4. Discontinuity shows seepage, occasional drops of water, no continuous flow.
5. Continuous flow of water (Estimate l/min and describe pressure i.e. low medium high)

WATER FLOW (Filled)
6. Filling materials heavily consolidated and dry; significant flow unlikely due to very low permeability
7. Filling materials damp, no free water present
8. Filling material wet, occasional drops of water
9. Filling materials show signs of outwash, continuous flow of water (Estimate l/min)
10. Filling materials locally washed out; considerable water flow along outwash channels (Estimate l/min and describe pressure)

TERMINATION
0. Neither end visible
1. One end visible
2. Both ends visible

SURFACE ROUGHNESS
1. Slickenslided
2. Smooth
3. Rough

SURFACE SHAPE
1. Planar
2. Undulating
3. Stepped

JRC (Joint Roughness)
0 Slickenslided, planar
5
10 Smooth, undulating
15
20 Rough, stepped

Alaska
Department of
Transportation
and
Public Facilities

Alaska Field Guide for Soil Classification

Effective October 1, 2003

Table of Contents

Preface

This *Field Guide for Soil Classification* is one of a series of guidelines that comprise the Alaska Department of Transportation and Public Facilities' (DOT&PF) *Geotechnical Procedures Manual*. This publication is intended to guide Department staff and consultants whose task is to obtain geotechnical data for use on Department projects.

Accurate classification and a detailed, complete field description of earth materials are essential to support design and construction of state facilities. The description and classification includes more than naming the soil – it includes consideration and reporting of the physical characteristics and engineering properties of the material, and ancillary information such as drilling action or presence of contaminants. The depth of detail of this process depends, in part, on the level of complexity of the project and the nature of the facility. However, the field geologist should always describe the soil as completely as possible.

Consistent adherence to standard terminology and procedures is important so that the geologists, engineers, designers, construction staff, and contractors throughout the design and construction process all have the same understanding of the earth materials used or affected by our projects. Note that interpretive information about materials should be reported separately from the factual classification and descriptive information. The factual data are reported on logs of test holes/test pits, in summary sheets, and in tables or other summary formats in the text of a geotechnical report. Interpretive commentary about the factual data should be clearly identified as such.

This guide contains numerous references to manuals and test methods. The guide refers to both "authoritative" and "advisory" references. Authoritative references may include American Society for Testing and Materials (ASTM) or American Association of State Highway Transportation Officials (AASHTO) standards or test methods or the Department's publications. Advisory references may include text books, FHWA guidance manuals and guides or manuals from other state DOTs. The reference list below is divided into authoritative and advisory references.

In some cases, we have excerpted, summarized, or copied text, charts, and tables into this guide. Unless otherwise noted, the original reference defines the appropriate action. The excerpts, summaries, and modified charts and graphs are presented for illustrative purposes.

Authoritative References

- AASHTO (1988), *Manual on Subsurface Investigation*
- AASHTO (1978), *Manual on Foundation Investigations*
- Alaska Department of Transportation and Public Facilities (1993), *Engineering Geology & Geotechnical Exploration Procedures Manual*
- ASTM Standard Practice D 2487-00 (2000), *Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)*

Advisory References

- California Department of Transportation (1996), *Soil & Rock Logging Classification Manual (Field Guide)*
- Federal Highway Administration (2002), *Evaluation of Soil and Rock Properties*, Geotechnical Engineering Circular No. 5, FHWA-IF-02-034
- Hunt, Roy E. (1984) *Geotechnical Engineering Investigation Manual*
- Oregon Department of Transportation (1987), *Soil and Rock Classification Manual*

1. Field Classification and Description of Soil Laboratory Classification

1.1. Introduction

The Unified Soil Classification System (USCS; ASTM D2487 and D2488) is used to name and describe soils. The ASTM classification method "Classification of Soils for Engineering Purposes (Unified Soil Classification System)" (ASTM Method D2487) is a laboratory test-based classification system. Use the Standard D2487 procedure to confirm field soil classifications and clarify borderline or difficult-to-determine classifications. After the field work is completed, the geologist prepares a sample testing protocol tailored to the project for testing selected samples. The laboratory determines the soil classifications under ASTM D2487. The geologist summarizes the sample test results and classifications and integrates the results of the laboratory testing, the soil descriptions in the field logs, drilling notes, geologic mapping observations, and other pertinent information to arrive at a final soil group name, soil group symbol, and any additional description.

1.2. Field Classification

Field classification of soil follows the ASTM "Standard Practice for Description and Identification of Soils (Visual-Manual Procedure)" (ASTM Method D2488). The field procedure for classification is based on the size and distribution of soil particles and the properties of the fine-grained portion of the soil. ASTM D 2488 is used principally in the field, or where there is an absence of laboratory data. This procedure uses visual observations of the soil with simple manual tests to estimate the size and distribution of the coarse-grained fraction of the soil and to indicate the plasticity of the fine-grained fraction of the soil. The resulting soil group names (such as "sandy silt with gravel" or "poorly graded gravel with silt") and group symbols (such as "ML," "GP-GM") are entered into the field logs.

The best way to learn how to describe and classify soil is to carefully study the description and classification procedures, and then spend time in the field learning from a more experienced geologist. The inexperienced field geologist should repeatedly and systematically compare field classifications of various soil types to laboratory results until becoming familiar with the visual and manual characteristics that denote the common soil types, and achieve an acceptable level of competence.

The field description and classification of soil is based on the size and distribution of coarse-grained particles and on the behavior of fine-grained particles. Definitions of the various soil constituents follow in Table 1-1.

Table 1-1
Definition of Soil Constituents

Boulders	Particles of rock that are retained on a 12-inch square opening.
Cobbles	Particles of rock that pass a 12-inch square opening, but are retained on a 3-inch square opening.
Gravel	Particles of rock that pass a 3-inch square opening and are retained on a No. 4 sieve. USCS Class GP or GW.
Sand	Particles of rock that pass a No. 4 sieve and are retained on a No. 200 sieve. USCS Class SM or SP.
Silt	Soil passing a No. 200 sieve that exhibits little or no plasticity and has little or no strength when air dry. USCS Class ML or MH.
Clay	Soil passing a No. 200 sieve that exhibits plasticity within a range of water contents and that has considerable strength when air dry. USCS Class CL or CH.
Organic Soil	A soil containing sufficient organic material to influence the soil properties. ASTM Class OL or OH.
Peat	A soil composed primarily of vegetable matter in various stages of decomposition that usually has a pronounced organic odor, a dark brown or black color, a spongy consistency, and a texture ranging from fibrous to amorphous. ASTM Class PT.

2. Field Procedures

2.1. Introduction

Use the field procedures below to describe the soil characteristics in Table 2-1. A geologist who is experienced with identification and familiar with the visual-manual process and laboratory testing procedures can often make accurate field classifications with a minimum of field tests, based on experience. It is not necessary for an experienced field geologist to use each visual-manual test with each soil description. Generalized experience with soil types in the vicinity and specific project experience as the field program progresses may allow rapid identification of similar soil types without thorough field-testing.

Soils that appear similar may be grouped together by testing one sample and applying the results to several similar samples. The visual-manual procedure allows description of a large number of soil samples without running expensive laboratory tests on each. However, it is important for the field geologist to take abundant samples, even if the samples are not tested. The field geologist reexamines the samples after the laboratory test data are available, and other geologists, the geotechnical engineer, or the foundation engineer may also examine them.

Confirmation of the field classifications may require only a few laboratory tests where the soil horizons are relatively uniform and simple. In more difficult situations with numerous soil types and complex soil conditions, much more laboratory testing may be required. Less experienced geologists should request ample laboratory tests until they become experienced enough to make accurate field classifications.

Table 2-1
Descriptive Soil Characteristics

Characteristic	Test Method or Reference
Soil name/group name	ASTM D2488
Group symbol	ASTM D2488
Coarse-grained soils: Particle	ASTM D2488
Size/shape/angularity/gradation	DOT&PF cobble/boulder procedure (See page 15)
Fine-grained soils: consistency, dry strength, dilatancy, toughness, plasticity	ASTM D2488 - Tables 5, 9, 10, 11 & 12.
Organic soil/peat name	FHWA Geotechnical Engineering Circular No. 5, Section 7.4, ASTM D2974
Color	Use simple color scheme. Use of color charts such as Munsell Color System is optional.
Odor	If organic or other condition is noticeable or unusual
Moisture condition	Table 3: ASTM D2488
Reaction to hydrochloric acid	If calcium carbonate soil suspected (Table 4 - ASTM D2488)
Cementation	Table 6: ASTM D2488
Structure of intact soil specimen	Table 7: ASTM D2488
Density/consistency	Based on Standard Penetration Test blow counts
Description of frozen soil	ASTM D4083, Department Chart: Description and Classification of Frozen Soils
Other characteristics or information	Unit weight, sensitivity, hardness of particles, presence of contaminants, formation names, staining, etc.
Drilling characteristics	Heaving, sloughing or caving, bouncing, grinding, drilling speed, etc.

2.2. Applying Group Names/Group Symbols

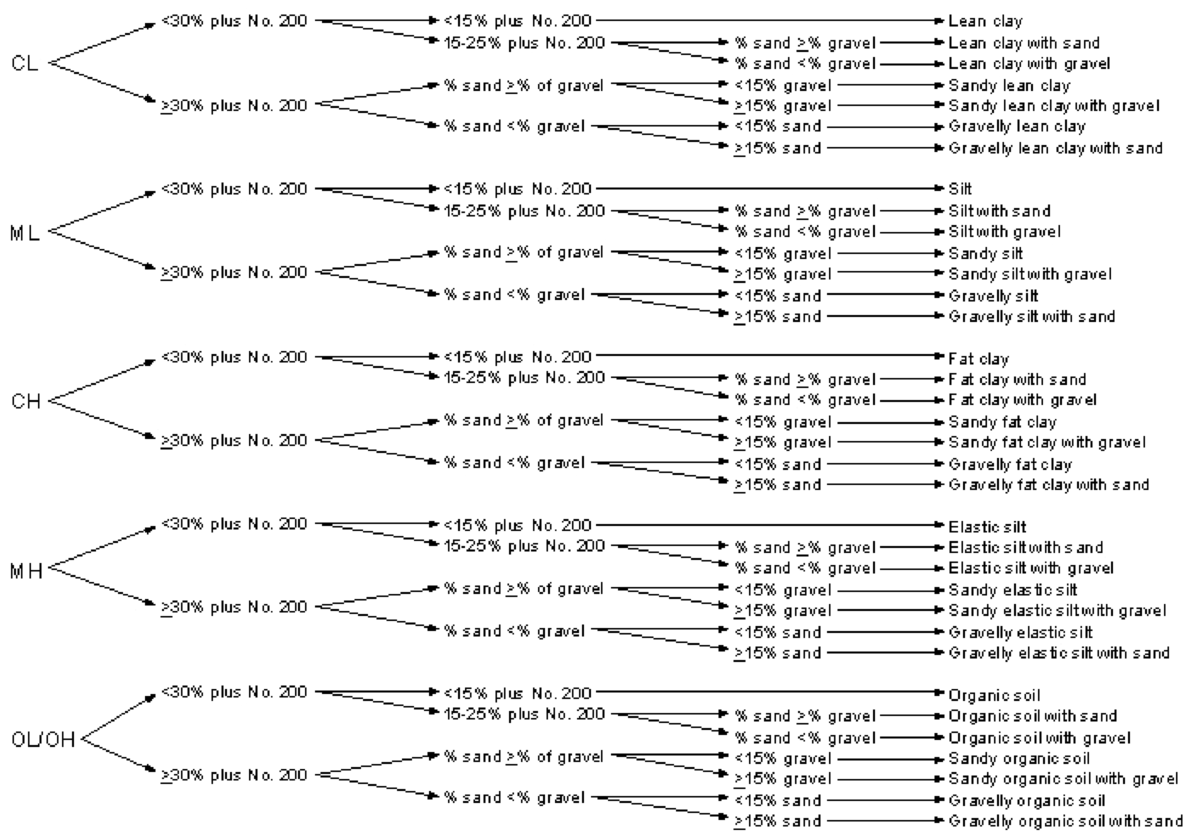
The first step in describing soil under the visual-manual method is to determine whether the soil is fine-grained, coarse-grained, or organic by visually estimating the percentage of gravel, sand, fines, and organic matter. Soils with more than 50 percent gravel or sand are coarse-grained. Soils with more than 50 percent fines are fine-grained. Soil with a notable presence of organic matter should be identified and described under separate procedures set out below. Laboratory tests for soils containing organic material may yield misleading results, particularly if the organic fraction is not recognized in the initial description.

3. Field Description of Fine-Grained Soils

3.1. Introduction

For fine-grained soils, perform the visual manual field procedures described in ASTM D2488 for consistency, dry strength, dilatancy, toughness, and plasticity, and assess the presence or absence of organics, as outlined below. Use Figure 3-1 (ASTM D2488 - Figure 1a and 1b) to assist in assigning group names and symbols for fine-grained soils.

Figure 3-1
Flow Chart for Identifying Fine-Grained Soil
(after ASTM D2488: Figure 1a and 1b)



3.2. Consistency

Use this test for intact samples of fine-grained, cohesive soil. For soil with significant amounts of gravel, this test is inappropriate. Consistency is an indicator of shear strength. Field tests using a Torvane or Pocket Penetrometer may also be done to aid in this description. When run on SPT samples, these tests produce approximations of strength criteria. Where shear strength is important, the field geologist should collect undisturbed samples using thin wall tube sampling methods. The geotechnical engineer can then schedule a testing program.

Table 3-1
Criteria for Describing Consistency
(ASTM D 2488 Table 5)

Description	Criteria
Very soft	Thumb will penetrate soil more than 1 inch.
Soft	Thumb will penetrate soil about 1 inch.
Firm	Thumb will indent soil about ¼ inch.
Hard	Thumb will not indent soil. Thumbnail readily indents soil.
Very hard	Thumbnail will not indent soil.

3.3. Dry Strength

Dry strength of fine-grained soil can be related to soil type. It may be necessary to dry a sample of the soil on a heat source, such as an engine exhaust manifold.

Table 3-2
Criteria for Describing Dry Strength
((ASTM D 2488 Table 8)

Description	Criteria
None	The dry specimen crumbles into powder with mere pressure of handling.
Low	The dry specimen crumbles into powder with some finger pressure.
Medium	The dry specimen breaks into pieces or crumbles with considerable finger pressure.
High	The dry specimen cannot be broken with finger pressure. Specimen will break into pieces between thumb and a hard surface.
Very high	The dry specimen cannot be broken between the thumb and a hard surface.

3.4. Dilatancy

Dilatancy is a soil's reaction to shaking and indicates the characteristics of the movement of water in the soil voids. Form a small moist sample in the palm of the hand and strike the hand sharply against the other hand several times. Note the reaction of water appearing on the surface. Then, squeeze the sample and observe the characteristics of the water disappearing from the surface of the sample.

Table 3-3
Criteria for Describing Dilatancy
(ASTM D 2488 Table 9)

Description	Criteria
None	There is no visible change in the specimen.
Slow	Water appears slowly on the surface of the specimen during shaking and does not disappear or disappears slowly upon squeezing.
Rapid	Water appears quickly on the surface of the specimen during shaking and disappears quickly upon squeezing.

3.5. Toughness

Toughness is a measure of the soil's plasticity in its plastic state. After completing the dilatancy test, shape the specimen into an elongated pat or lump and roll out to a thread of about 1/8" diameter. Remold the soil and roll it out to 1/8" repeatedly until the thread crumbles at about 1/8" in diameter. At this point, note the pressure required to roll out the thread, the strength of the thread, and the toughness of the soil as it is kneaded together to form a pat or lump.

Table 3-4
Criteria for Describing Toughness
(ASTM D 2488 Table 10)

Description	Criteria
Low	Only slight pressure is required to roll the thread near the plastic limit (the moisture content at which a rolled-out thread crumbles at 1/8" diameter). The thread and lump are weak and soft.
Medium	Medium pressure is required to roll the thread to knead the plastic limit. The thread and lump have medium stiffness.
High	Considerable pressure is required to roll the thread to knead the plastic limit. The thread and the lump have very high stiffness.

Table 3-5 provides a summary of soil types versus characteristics to assist the geologist in describing and identifying fine-grained soil types.

3.6. Plasticity

The plasticity of a soil is an important indicator of characteristics of cohesive soils.

Table 3-5
Criteria for Describing Plasticity
(ASTM D 2488 Table 11)

Description	Criteria
Nonplastic	A 1/8" thread cannot be rolled at any water content.
Low	The thread can barely be rolled and the lump cannot be formed when drier than the plastic limit (the moisture content at which a rolled-out thread crumbles at 1/8" diameter).
Medium	The thread is easy to roll and not much time is required to reach the plastic limit. The thread cannot be re-rolled after reaching the plastic limit. The lump crumbles when drier than the plastic limit.
High	It takes considerable time rolling and kneading to reach the plastic limit. The thread can be re-rolled several times after reaching the plastic limit. The lump can be formed without crumbling when drier than the plastic limit.

3.7. Fine-Grained Soil Name

Once you have assessed the characteristics described above, use Table 3-6 below and Chart 3-1 above to determine the soil name. Add descriptors for consistency (Table 3-1 above), color, moisture content, etc., to the root soil name.

Table 3-6
Identification of Inorganic Fine-Grained Soils From Manual Tests
(ASTM D 2488: Table 12)

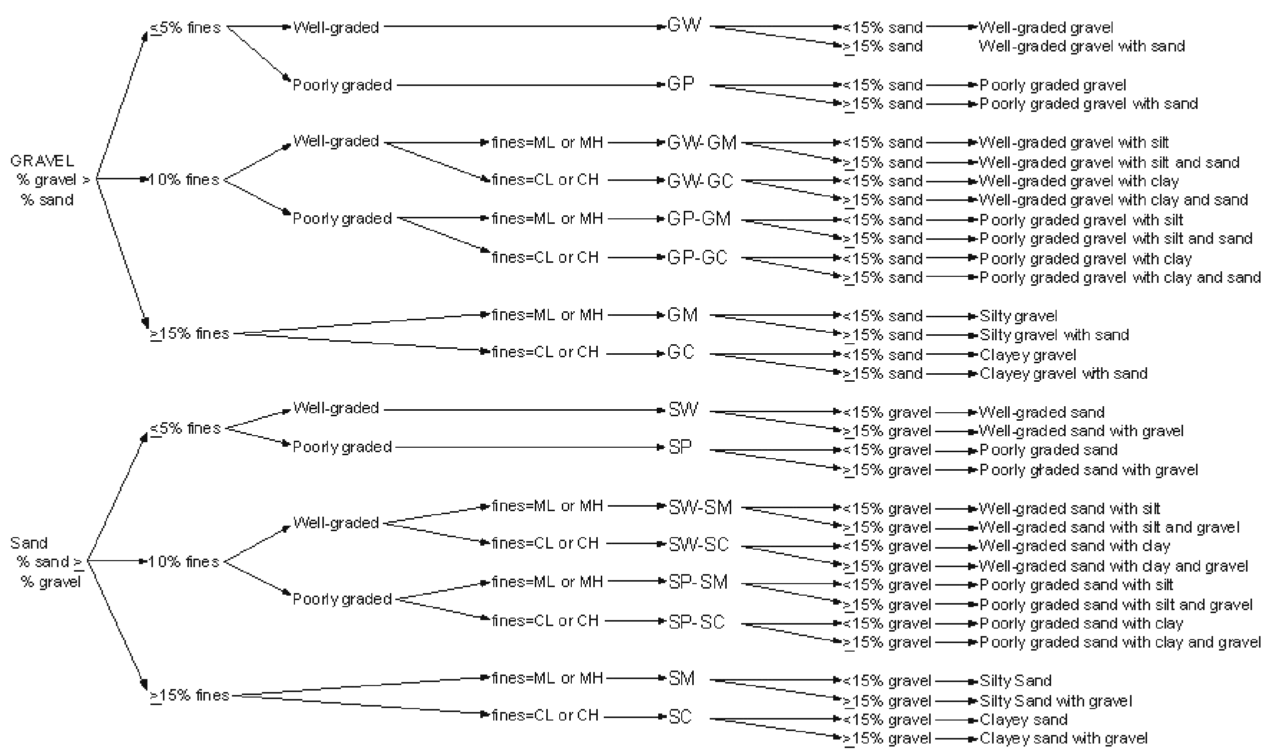
Soil Symbol	Dry Strength	Dilatancy	Toughness	Plasticity
ML	None to low	Slow to rapid	Low or thread cannot be formed	Low or non-plastic
CL	Medium to high	None to slow	Medium	Medium
MH	Low to medium	None to slow	Low to medium	Low to medium
CH	High to very high	None	High	High

4. Field Description of Coarse-Grained Soils

4.1. Introduction

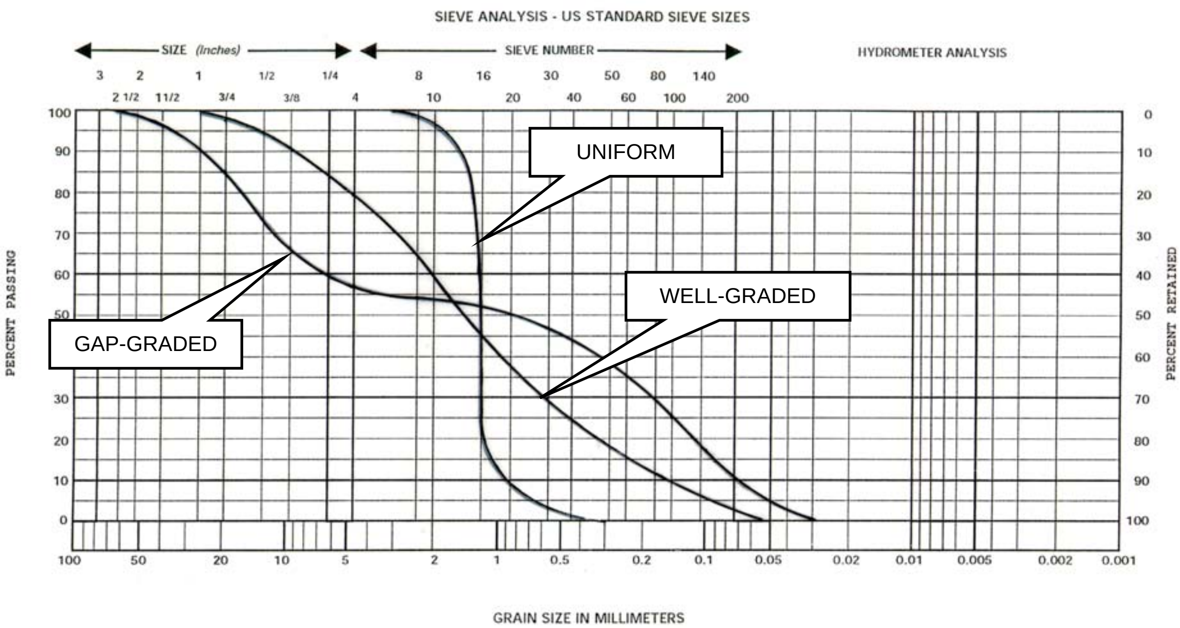
Field identification of soil that contains less than 50 percent fines (silt and clay) is made on the basis of the estimated percentage of soil constituents. If there is more sand than gravel, the soil is classified as sand. The percentage and characteristics of fines contained in coarse-grained soil also plays a role in the soil name. If there is more than 15 percent passing the No. 200 screen (P200), the soil is sand or gravel "with fines." Assess the characteristics of the fines to determine whether the soil should include a modifier "clayey" or "silty." Dual identifications are also included depending on the particular soil characteristics. Use Chart 4-1 below to determine the soil group name and group symbol.

Chart 4-1
Identifying Coarse-Grained Soil
(after ASTM D2488: Figure 2)



If the soil has less than 5 percent fines, the soil is called "clean" sand or gravel. The field geologist makes a field evaluation of grading characteristics, then later confirms the grading assessments based on laboratory test results. If the soil contains a wide range of particle sizes, it is called "well-graded." Soil that has a narrow range of grain sizes is "poorly-graded." Soil consisting predominantly of one size particle is "uniformly-graded." Soil missing some intermediates particle sizes is "gap-graded." The soil laboratory determines grading characteristics by computing coefficients of uniformity and curvature to determine under ASTM Method D 2487. See Figure 4-1 below. The laboratory results are used to confirm the field geologist's assessment of grading.

Figure 4-1
(after ODOT Soil and Rock Classification Manual)



4.2. Particle Characteristics of Coarse Fraction

The coarse fraction of the soil (greater than No. 200 sieve size) is described by observing the size, shape, and distribution of the particles. Table 4-1 (ASTM D 2488 Table 1) provides criteria for describing the angularity of particles. Figure 4-2 (Angularity) gives a visual means of identifying the various categories. Table 4-2 (ASTM D 2488 Table 2) and Figure 4-3 (Flat and Elongated Criteria), provide particle shape descriptions and criteria. A Department method for determining the percentage of cobbles and boulders is also described. Finally, the geologist must make observations of the grading characteristics of the soil to determine whether it is well graded or poorly graded.

Table 4-1
Criteria for Describing Angularity of Coarse-Grained Particles
(ASTM D2488: Table 1)

Description	Criteria
Angular	Particles have sharp edges and relatively plane sides with unpolished surfaces.
Subangular	Particles are similar to angular description but have rounded edges and unpolished surfaces.
Subrounded	Particles have nearly plane sides but have well-rounded corners and edges.
Rounded	Particles have smooth curved sides and edges.

The photo in Figure 4-2 shows a variety of gravel size particles, demonstrating the sometimes subtle distinctions between angularity classifications.

Figure 4-2
Angularity
(See ASTM D2488: Figure 3)

Table 4-2
Criteria for Describing Particle Shape
(ASTM D2488: Table 2)

Description	Criteria
Describe the particle shape as follows where length, width, and thickness refer to the greatest, intermediate, and least dimensions of a particle, respectively.	
Flat	Particles with width/thickness > 3
Elongated	Particles with length/width > 3
Flat and Elongated	Particles meet criteria for both flat and elongated

Figure 4-3
Flat and Elongated Criteria
(ASTM D2488: Figure 4)

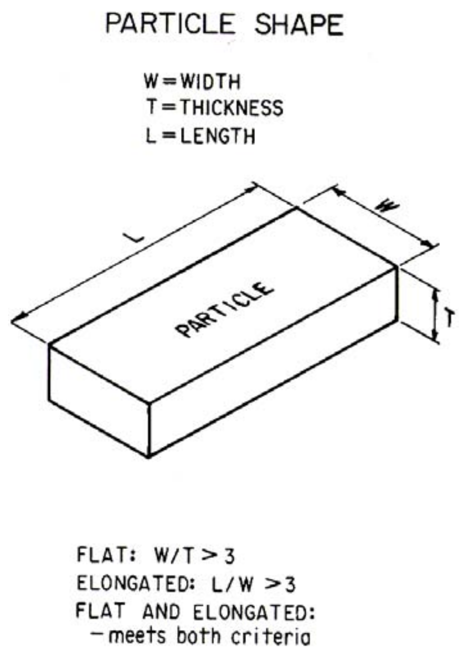


FIG. 4 Criteria for Particle Shape

4.3. Cobbles and Boulders

Cobbles and boulders are often present in soils in glacial terrain, and much of our highway system has been subject to glacial activity in the past. The presence of cobbles and boulders is often a source of claims in earthwork projects, so it is incumbent on geotechnical staff to carefully characterize the cobble and boulder content of soil layers. At a minimum, test hole logs must indicate where cobbles and boulders are suspected. In drilled test holes, it is not possible to accurately determine the percentage of cobbles and boulders, but the logs must indicate where drilling action suggests the presence of large rock. In test pits and other surface excavations, the percentage of cobbles and boulders by volume can be visually estimated and so indicated on the logs. Where warranted (as in materials site investigations, for example), the geologist should conduct a field test to more accurately determine the percentage of cobbles and boulders. The procedure is described below.

4.4. DOT&PF Cobble and Boulder Percentage Determination Procedure

Determine the percentage of cobbles and boulders in the field by collecting a large volume sample with a backhoe or other equipment and weighing the sample using a large capacity container (a cut-off 55-gallon drum is well suited) fitted with cable or chains for lifting, and a 500-pound capacity spring scale with suitable hooks. The field procedure is as follows:

- Record the tare weight of the container.
- Collect the sample using the backhoe bucket.
- Place the sample in the weighing container, connect the backhoe bucket to the scale, and lift the container with the backhoe bucket. Record the total weight of the sample.

- Empty the sample onto a tarp or other suitable surface. Separate the cobbles and boulders from the sample using a 3-inch square opening screen and tape measure.
- Count the number of boulders.
- Weigh the cobbles and boulders.
- Record the size of the largest cobble and boulder.
- Make note of any other pertinent information such as shape and composition of the cobbles and boulders, clay coatings, and other characteristics.
- Compute and record the cobble and boulder proportion as a weight percentage of the total. It might also be useful to submit the coarse particles for durability analyses and a sample representing the minus-3-inch aggregate for gradation analysis.

5. Supplementary Soil Descriptive Terms

5.1. Color

While soil color is not an engineering property, it may be indicative of other useful characteristics and properties. For example, iron staining or mottling may indicate repeated wet and dry cycles and the presence of groundwater. Yellow or red indicate iron oxides and significant weathering processes. Dark colors may indicate the presence of organic material. Color may also be useful in making correlations of strata between test holes. When applying color names, use simple colors and modifiers, such as brown, tan, light orange, and medium gray. Avoid using exotic, unusual, or invented color names or modifiers such as "coral," "turquoise," or "beige-ish." Soil and rock color charts such as the Munsell Color System may be used.

5.2. Odor

If the presence of organic material or some other condition, such as chemical contaminants, results in a noticeable odor of organic matter, petroleum products, organic solvents, sewage, or other odors, record a description of the perceived odor.

5.3. Moisture

Describe the moisture content in the field using Table 5-1 below as a guide. Return samples to the soil laboratory for testing to confirm estimates. Moisture contents in soils containing organic material can be deceptive and require special care. If no organic content is noted in the field, but the laboratory moisture content is high, consider testing for organic content. Even a small percentage of organic material can affect the soil properties. Permeable (granular) soils from below the water table are not normally tested for moisture content. Moisture samples may be obtained from low permeability (fine-grained) soil from below the water table from undisturbed samples (thin-wall tube samples).

Table 5-1
Criteria for Describing Moisture Condition
(ASTM D 2488: Table 3)

Description	Criteria
Dry	Absence of moisture, dusty, dry to the touch
Moist	Damp, but no visible water
Wet	Visible free water, usually soil is below the water table

5.4. Reaction to Hydrochloric Acid (HCl)

This test is rarely used for soil, but is applicable if calcium carbonate or cemented soil is suspected. (See Table 4, ASTM D 2488.)

5.5. Cementation

Cementation is the bonding of grains by secondary minerals or degradation products. Cementation may be suspected if exposures of the soil stand at steeper angles than expected, if the soil is iron-stained, or if the soil appears to hold together more than expected for the soil type. Cementation by calcium carbonate may be detected by the soil's reaction to HCl. (See Table 4, ASTM D 2488). Cementation may play an important role in determining susceptibility to liquefaction under seismic loading.

Table 5-2
Criteria for Describing Cementation at Field Moisture
(ASTM D 2488: Table 6)

Description	Criteria
Weak	Crumbles or breaks with handling or little finger pressure
Moderate	Crumbles or breaks with considerable finger pressure
Strong	Will not crumble or break with finger pressure

5.6. Soil Structure

The field geologist should make every effort to fully describe the structure of the soil deposit, including its mode of occurrence (alluvial, glacial deposits, rock weathered in place). Describe the soil's structural features in terms of stratification, relict rock structure, lenses, voids, inclination of the layers, presence of varves, and other features. Structure may indicate differing strength for soil that has the same gradation. For example, water-deposited alluvial silt may have a significantly weaker structure than wind-deposited silt (loess) with a similar gradation. The design of a back slope for a cut in these two materials may be significantly different. Similarly, layering of sand deposits at a bridge site may have a significant impact on the liquefaction characteristics and the design of the bridge foundation.

Table 5-3
Criteria for Describing Soil Structure
(ASTM D 2488: Table 7)

Description	Criteria
Varved	Thin repeating layers or laminae grading upward from coarse to fine within each layer. Normally includes a coarser summer layer and a finer winter layer deposited from still water.
Stratified	Alternating layers of varying material or color with layers at least ¼" thick
Laminated	Alternating layers of varying material or color with the layers less than ¼" thick
Fissured	Breaks along definite planes of fracture with little resistance to fracturing
Slickensided	Fracture planes appear polished or glossy, sometimes striated
Blocky	Cohesive soil that can be broken down into small angular lumps that resist further breakdown
Lensed	Inclusion of small pockets of different soils, such as small lenses of sand scattered through a mass of clay
Homogeneous	Same color and appearance throughout

5.7. Density/Consistency

Density and consistency descriptors are primarily based on sampler blow counts from the Standard Penetration Test (AASHTO T-206, ASTM D1586). Consistency of fine-grained soils may also be based on visual manual tests described in ASTM D2488. Record blow counts, and hammer and sampler details on the test hole logs along with notations about unusual conditions or events during sampling. Record blow counts for frozen and unfrozen soil. Do not use blow counts in frozen soil to determine density descriptors. Similarly, do not use blow counts to determine density descriptors where the sampling interval crosses a soil horizon.

Add additional detail by using the Pocket Penetrometer or the Torvane to arrive at rough strengths.

Table 5-4
Density Based on Blow Count for Non-Cohesive Soils
(Adapted from several sources)

Number of blows per foot	Density
0-4	Very loose
5-10	Loose
11-30	Medium dense
31-50	Dense
>50	Very dense

Table 5-5
Consistency Based on Blow Count for Cohesive Soils
(Adapted from several sources)

Number of blows per foot	Consistency
<2	Very soft
2-4	Soft
5-8	Firm
9-15	Stiff
16-30	Very stiff
>30	Hard

6. Special Soil Conditions

6.1. Organic Soil

Peat soils are relatively easy to identify. However, soils that are predominately mineral matter but contain organic matter are more difficult to recognize. Where field relationships indicate the possibility of organics in the soil, the geologist should pay close attention to color and odor of the soil. Test dark-colored soils and soil with fine woody particles for organic content (ASTM D 2974) and for moisture content. Some gravel deposits contain small amounts of organic material (<2-3%), which render the gravel difficult or impossible to handle in the presence of water. For suspect fine-grained soils, specify both wet and dry preparation methods for testing for Atterberg Limits and maximum density/optimum moisture. Soils containing organic material may be classified as shown below.

Table 6-1
Classification of Organic Soils
(After FHWA Geotechnical Engineering Circular No. 5, April 2002)

Material	Percent Organics (by weight)	Moisture Content	Specific Gravity	Fiber Content (by volume)
Peat (Pt)	>80%	>500%	<1.7	>50%
Peaty Organic Soil (PtO)	60-80%	150 – 800%	1.6 – 1.9	<50%
Organic Soil (O)	5-60%	100 – 500%	>1.7	Insignificant
Organic Silt (MO) Organic Clay (CO)	1-5%	<100%	>2.4	None

Strength and consolidation testing may be critical for the design of roadways and embankments in peat and organic soil. Where organic soils are expected, the geotechnical engineer will provide an exploration plan for sampling and testing the organic materials. The sampling and testing may include in situ field testing with vane shear apparatus (ASTM D 2573), sampling with thin-walled tube sampler for consolidation and strength, and other testing in the laboratory. Geologists should be prepared to run field strength tests and take undisturbed samples when unexpectedly encountering thick (greater than 4') organic soil deposits. When organic soils are encountered, increase the frequency of test holes and sampling after consultation with the geotechnical engineer to provide ample data for analysis and design.

6.2. Frozen Soil

The principal reference for describing frozen soil is the ASTM D 4083-89 "Standard Practice for Description of Frozen Soils (Visual Manual Procedure)." This procedure, when used in conjunction with the Department's Figure 6-1: "Description and Classification of Frozen Soils," provides the geologist guidance in how to identify and describe frozen soils when encountered in the field. The chart is a modified and combined version of three charts that appear in the ASTM procedure. Use of the combined chart or the ASTM procedure is approved for use on Department projects.

Figure 6-1
Description and Classification of Frozen Soils
(After ASTM D4083)

DESCRIPTION AND CLASSIFICATION OF FROZEN SOILS

Part I Description of Soil Phase **(a)** (Independent of Frozen State)	Major Group: Description (2)	Major Group: Designation (3)	Sub-Group: Description (4)	Sub-Group: Designation (5)	Field Identification (6)	Pertinent Properties of Frozen Materials which may be measured by physical tests to supplement field identification. (7)	Guide for Construction on Soils Subject to Freezing and Thawing: Thaw Characteristics (8)	Guide for Construction on Soils Subject to Freezing and Thawing: Criteria (9)
Part II Description of Frozen Soil	Segregated ice is not visible by eye **(b)**	**N**	Poorly Bonded or Friable	**Nf**	Identify by visual examination. To determine presence of excess ice, use procedure under note **(c)** below and hand magnifying lens as necessary. For soils not fully saturated, estimate degree of ice saturation: Medium, Low. Note presence of crystals, or of ice coatings around larger particles.	In-Place Temperature Density and Void Ratio a) In Frozen State b) After Thawing in Place Water Content (Total H_2O, including ice) a) Average b) Distribution Strength a) Compressive b) Tensile c) Shear d) Adfreeze Elastic Properties Plastic Properties Thermal Properties Ice Crystal Structure (using optional instruments.) a) Orientation of Axes b) Crystal size c) Crystal shape d) Pattern of Arrangement	Usually Thaw-Stable	The potential intensity of ice segregation in a soil is dependent to a large degree on its void sizes and may be expressed as an empirical function of grain size as follows: Most inorganic soils containing 3 percent or more of grains finer than 0.02 mm in diameter by weight are frost-susceptible. Gravels, well-graded sands and silty sands, especially those approaching the theoretical maximum density curve, which contain 1.5 to 3 percent finer than 0.02 mm by weight without being frost-susceptible. However, their tendency to occur interbedded with other soils usually makes it impractical to consider them separately. Soils classed as frost-susceptible under the above criteria are likely to develop significant ice segregation and frost heave if frozen at normal rates with free water readily available. Soils so frozen will fall into the thaw-unstable category. However, they may also be classed as thaw-stable if frozen with insufficient water to permit ice segregation. Soils classed as non-frost-susceptible (*NFS) under the above criteria usually occur without significant ice segregation and are not exact and may be inadequate for some structure applications: exceptions may also result from minor soil variations. In permafrost areas, ice wedges, pockets, veins, or other ice bodies may be found whose mode of origin is different from that described above. Such ice may be the result of long-time surface expansion and contraction phenomena or may be glacial or other ice which has been buried under a protective earth cover.
			No excess ice Well Bonded	**Nb** / **n**				
			Excess ice	**Nb** / **e**				
	Segregated ice is visible by eye. (Ice 1 inch or less in thickness) **(b)**	**V**	Individual ice crystals or inclusions	**Vx**	For ice phase, record the following as applicable: Location / Size Orientation / Shape Thickness Spacing / Pattern of arrangement Length Hardness } Structure } per part III Below Color } Estimate volume of visible segregated ice present as percent of total sample volume		Usually Thaw-Unstable	
			Ice coatings on particles	**Vc**				
			Random or irregularly oriented ice formations	**Vr**				
			Stratified or distinctly oriented ice formations	**Vs**				
Part III Description of Substantial Ice Strata	Ice (Greater than 1 inch in thickness)	**Ice**	Ice with soil inclusions	**Ice + Soil Type**	Designate material as ICE **(d)** and use descriptive terms as follows, usually one item from each group, as applicable: Hardness: Hard, Soft (mass, not indi-crystals) Structure: Clear, Cloudy, Porous, Candled, Granular, Stratified Color: e.g.: Color-less, Gray, Blue Admixtures: e.g.: Contains Thin Silt Inclus-ions	Same as Part II above, as applicable, with special emphasis on Ice Crystal Structure.		
			Ice without soil inclusions	**Ice**				

DEFINITIONS:

Ice Coatings on Particles are discernible layers of ice found on or below the larger soil particles in a frozen soil mass. They are sometimes associated with hoarfrost crystals, which have grown into voids produced by the freezing action.

Ice Crystal is a very small individual ice particle visible in the face of a soil mass. Crystals may be present alone or in a combination with other ice formations.

Clear ice is transparent and contains only a moderate number of air bubbles. **(e)**

Cloudy Ice is translucent, but essentially sound and non-pervious

Porous Ice contains numerous voids, usually interconnected and usually resulting from melting at air bubbles or along crystal interfaces from presence of salt or other materials in the water, or from the freezing of saturated snow. Though porous, the mass retains its structural unity.

Candled ice is ice which has rotted or otherwise formed into long columnar crystals, very loosely bonded together.

Granular Ice is composed of coarse, more or less equidimensional, ice crystals weakly bonded together.

Ice Lenses are lenticular ice formations in soil occurring essentially parallel to each other, generally normal to the direction of heat loss and commonly in repeated layers.

Ice Segregation is the growth of ice as distinct lenses, layers, veins and masses in soils, commonly but not always oriented normal to direction of heat loss.

Well-bonded signifies that the soil particles are strongly held together by the ice and that the frozen soil possesses relatively high resistance to chipping or breaking.

Poorly-bonded signifies that the soil particles are weakly held together by the ice and that the frozen soil consequently has poor resistance to chipping or breaking.

Friable denotes a condition in which material is easily broken up under light to moderate pressure.

Thaw-Stable frozen soils do not, on thawing, show loss of strength below normal, long-time thawed values nor produce detrimental settlement.

Thaw-Unstable frozen soils show on thawing, significant loss of strength below normal, long-time thawed values and/or significant settlement, as a direct result of the melting of the excess ice in the soil.

Modified from: Linell, K. A. and Kaplar, C. W., 1966, *Description and Classification of Frozen Soils,* Proc. International Conference on Permafrost (1963), Lafayette, IN, U.S. National Academy of Sciences, Publ. 1287, pp 481-487.

NOTES:

(a) When rock is encountered, standard rock classification terminology should be used.

(b) Frozen soils in the N group may on close examination indicate presence of ice within the voids of the material by crystalline reflections or by a sheen on fractured or trimmed surfaces. However, the impression to the unaided eye is that none of the frozen water occupies space in excess of the original voids in the soil. The opposite is true of frozen soils in the V group.

(c) When visual methods may be inadequate, a simple field test to aid evaluation of volume of excess ice can be made by placing some frozen soil in a small jar, allowing it to melt and observing the quantity of supernatant water as a percent of total volume.

(d) Where special forms of ice, such as hoarfrost, can be distinguished, more explicit description should be given.

(e) Observer should be careful to avoid being misled by surface scratches or frost coating on the ice.

Alaska
Department of
Transportation
and
Public Facilities

Alaska Guide to Description and Classification of Peat and Organic Soil

(March 2007)

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1. Classification of Peat and Organic Soil

1.1. Introduction

The classification of peat and organic soils requires special attention beyond that needed to classify other soils. There are several existing classification schemes for peat and organic soils, but no single system that allows classification of any soil that contains any amount of organic material.

The many peat classification schemes often rely on overly descriptive means to categorize these soils for engineering purposes. Some of the peat classification systems rely on biologic descriptions of plant constituents. Geologists and engineers are usually not well versed in botany and are unlikely to make much use of classification schemes that require biological knowledge. Instead, engineers and geologists tend to rely on methods that use numerical values as part of the system for nomenclature.

A classification system for peat and organic soils should include a means to readily distinguish organic soil from peat. The system described in this paper (Appendix A) provides a unified classification scheme that covers the whole spectrum of organic soils and peat. The system is based primarily on current ASTM test methods, including a recently developed test method based on an 83-year-old Swedish classification system (See Von Post, L. 1921) that uses a simple field test for classifying peat.

The systems developed thus far generally only cover part of the spectrum of organic soil and do not focus on the soil characteristics engineers need to consider in order to design a project. A classification system that directs its users to critical characteristics of a soil type will help geologists and engineers focus their investigation and design efforts.

There has been research to establish correlations between classifiable characteristics of organic soil and critical soil properties. More such research will be useful in further establishing the correlations. During preparation of this guide, little information was found about classification of coarse-grained soil containing organic material. Additional information and research is needed to address behavior of coarse-grained soil with small, but significant, amounts of organic material that affects handling characteristics.

1.2. Description and Classification of Peat

All operations involving the use of nuclear gauges must be carried out under the direction of a Regional Radiation Safety Officer (RRSO). The Regional Construction Engineer designates RRSOs.

The RRSO is authorized to initiate remedial action or to temporarily halt or immediately terminate the use of a nuclear gauge or licensed activities that are found to be a threat to health, safety, or property or otherwise in violation of federal, state, or local regulations or the requirements of this manual.

Peat (PT) is a naturally occurring, highly organic substance composed primarily of vegetable matter in various stages of decomposition. It is fibrous to amorphous in texture, is usually dark brown to black, and has an organic odor. Ash content will be less than 25 percent when tested under ASTM D2974. Peat does not include the surface organic mat. The organic mat is not peat; it is the living matter that dominates the upper layer of a soil column, consisting primarily of live plants and roots, but may include dead vegetative matter and windblown soil.

The procedure for classifying peat is outlined in Standard Classification of Peat Samples by Laboratory Testing (ASTM D 4427). This method includes use of the following test methods:

Field Tests

- Fiber content by field testing for degree of humification (ASTM D 5715)

The humification test was developed in the early 1920s in Sweden, and is related to the fiber content of the peat. This simple field test consists of taking a sample of peat and squeezing it in the hand. The material that is extruded between the fingers is examined and the soil is identified as one of 10 categories. The categories have been divided between three types of peat as shown in Table 1-1, below.

Laboratory Tests

- Ash content by the ignition test (ASTM D 2974),
- Fiber content determination by wet sieving (ASTM D 1997),
- Acidity (ASTM D 2976),
- Absorbency (ASTM D 2980)

The specific situation will guide whether and which laboratory tests should be used. Use of the laboratory tests methods may be inappropriate in many situations.

Botanical descriptions are included as part of the ASTM D 4427 test method, but as noted above, engineering geologists and engineers are generally not expected to be adept at botany. Classification schemes that rely on biological type or species recognition are not likely to be widely accepted or used.

Further classification of peat may be made by dividing the peat into one of three type categories based on the degree of humification (ASTM D 5715) or the fiber content of the soil (ASTM D 1997):

Name	Fiber Content	Degree of Humification
Fibric Peat	>67%	H_1-H_3
Hemic Peat	33%-67%	H_4-H_6
Sapric Peat	<33%	H_7-H_{10}

Table 1-1
Peat Naming Conventions

Where the classification of the peat is not critical, peat soil may simply be identified as "Peat," with moisture content and ignition test results to provide data for the geotechnical engineer and designer.

Fiber content has been related to numerous soil properties such as permeability, shear strength, compression index, water content, void ratio, density, etc. (See references). These established relationships can be quite useful to geotechnical engineers and designers in determining the behavior and characteristics of peat and highly organic soils. Discussion of the utility of these relationships and how they may be used is beyond the scope of this paper, which focuses on identifying and classifying organic soil and peat.

1.3. Description and Classification of Organic Soil

Organic soil has enough organic content to significantly affect the soil characteristics. For fine-grained organic soil, the question of how much organic soil is "significant" is addressed in ASTM methods, as discussed below. For coarse-grained organic soils, the answer is not readily apparent. In both cases, this paper presents a method to classify the soil.

For laboratory classification of organic soil, the most common current practice is to use the ignition test for determination of organic content (ASTM D 2974). When used in conjunction with Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System) (ASTM D 2487), the ignition test provides a quick and inexpensive means of determining organic content of soils and is, in many cases, the only laboratory test needed for classification of organic soil.

A classification system for organic soil must include few enough classes to be useful, but enough classes to separate differing types of organic soil and peat along important boundaries. The key to differentiating between organic and non-organic soils is the influence that the organic constituents have on the soil properties. This is true for both visual-manual methods and laboratory test methods. (See ASTM D2488 § 14.8 and ASTM D2487 § 11.3.2.)

1.3.1. Fine-Grained Organic Soils

In the field, the engineering geologist can determine whether soil is organic by observation of the soil characteristics and field relationships of the soil horizons, and the use of a few simple visual-manual tests outlined in Standard Practice for Description and Identification of Soils (Visual-Manual Procedure) (ASTM D 2488). The tests are:

- *color* (soil color lightens upon drying);
- *toughness* (soil thread for toughness test feels spongy); and
- *plasticity* (soil will have low or no plasticity).

In addition, the engineering geologist in the field will note the soil conditions and relationships that may suggest the presence of organics. For example, silt layers below a peat deposit would be expected to have organics; an alluvial sand and gravel deposit downstream from a marsh might be expected to have some organic component; and a silt deposit in the Yukon-Kuskokwim Delta area would be expected to have organic layers or finely disseminated organic particles. The engineering geologist will also describe soil samples and the presence and nature of visible organic particles.

In the laboratory, fine-grained soils are tested following ASTM D2487 classification methods. The Atterberg Limits test determines whether a soil is organic enough to "influence soil properties." Where the liquid limit as determined after oven drying is less than 75 percent of the liquid limit determined before oven drying, the soil is an organic silt or organic clay.

1.3.2. Coarse Grained Organic Soils

As mentioned in the introductory comments, the classification of coarse-grained soils with organics is problematic. Little information is presently available to provide a sound basis for determining whether the presence of organic matter affects the soil characteristics in significant and measurable ways. This is the case both for learning the important engineering characteristics of the soils and for determining what characteristics must be examined in order to develop a sound classification system.

At present, this classification system includes somewhat arbitrary boundaries for coarse-grained organic soil classification, with reference to the 1993 Engineering Geology and Geotechnical Exploration Procedures Manual guidelines that say in part:

"Mineral soils containing less than 50% organics should be described as follows:

1. <u>Highly Organic</u> – A soil, which contains large amounts (15 to 50%) of visible organic material such as sticks, roots, tree trunks, and peaty layers. This organic material may preclude the use of the soil as embankment material.

2. <u>Organic</u> – A soil which contains small (5 to 15%) amounts of organic material, which may significantly affect its handling and compaction characteristics. Usability as embankment material will generally depend on its natural moisture and/or prevailing weather conditions at the project location. The organic material may or may not be visible.

3. <u>Slightly Organic</u> – A soil, which has minor (less than 5%) or traces of organic material that are not visible but may have an effect on handling or compacting characteristics. Laboratory testing is necessary to determine the percent organics."

This classification system modifies the boundaries for two reasons: First, for the boundary between peat and highly organic soil to reflect a value representing the range of values appearing in the literature; second, to establish a lower limit for slightly organic soil of 2 percent to address test method inconsistencies that may result in reporting low levels of organic material in non-organic mineral soil and rock.

1. Highly Organic – 15 to 75 percent

2. Organic – 5 to 15 percent

3. Slightly Organic – 2 to 5 percent

As research and new data are developed concerning the behavior and characteristics of coarse-grained soils with organics, this new classification scheme may be revised to reflect new understanding of the role organic material plays in affecting important characteristics of organic soil and peat.

1.4. References

Burwash and Wiesner, 1984, "*Classification of Peats for Geotechnical Engineering Purposes,*" Proceedings: Cold Regions Engineering Specialty Conference, April 4-6, 1984, Canadian Society for Civil Engineering, Montreal, Quebec, Canada.

Federal Highway Administration, 2002, "*Geotechnical Engineering Circular No. 5 – Evaluation of Soil and Rock Properties,*" FHWA Publication No. FHWA-IF-02-034.

Flaate, K., "*The Classification of Peat and Peat Deposits for Engineering Purposes*," 1965, 11th Annual Conference on Muskeg Research, May 6-7, 1965, Sudbury, Ontario, Canada.

Korpijaakko, E.O. and Woolnough, D.F., "*Peatland Survey and Inventory,*" (in Muskeg and the Northern Environment in Canada, 1977, Radforth, N.W., and Brawner, C.O., Ed.s).

McFarlane, I.C., "*Guide to a Field Description of Muskeg*," 1958, National Research Council of Canada, Associate Committee on Soil and Snow Mechanics, Technical Memorandum 44 (revised edition).

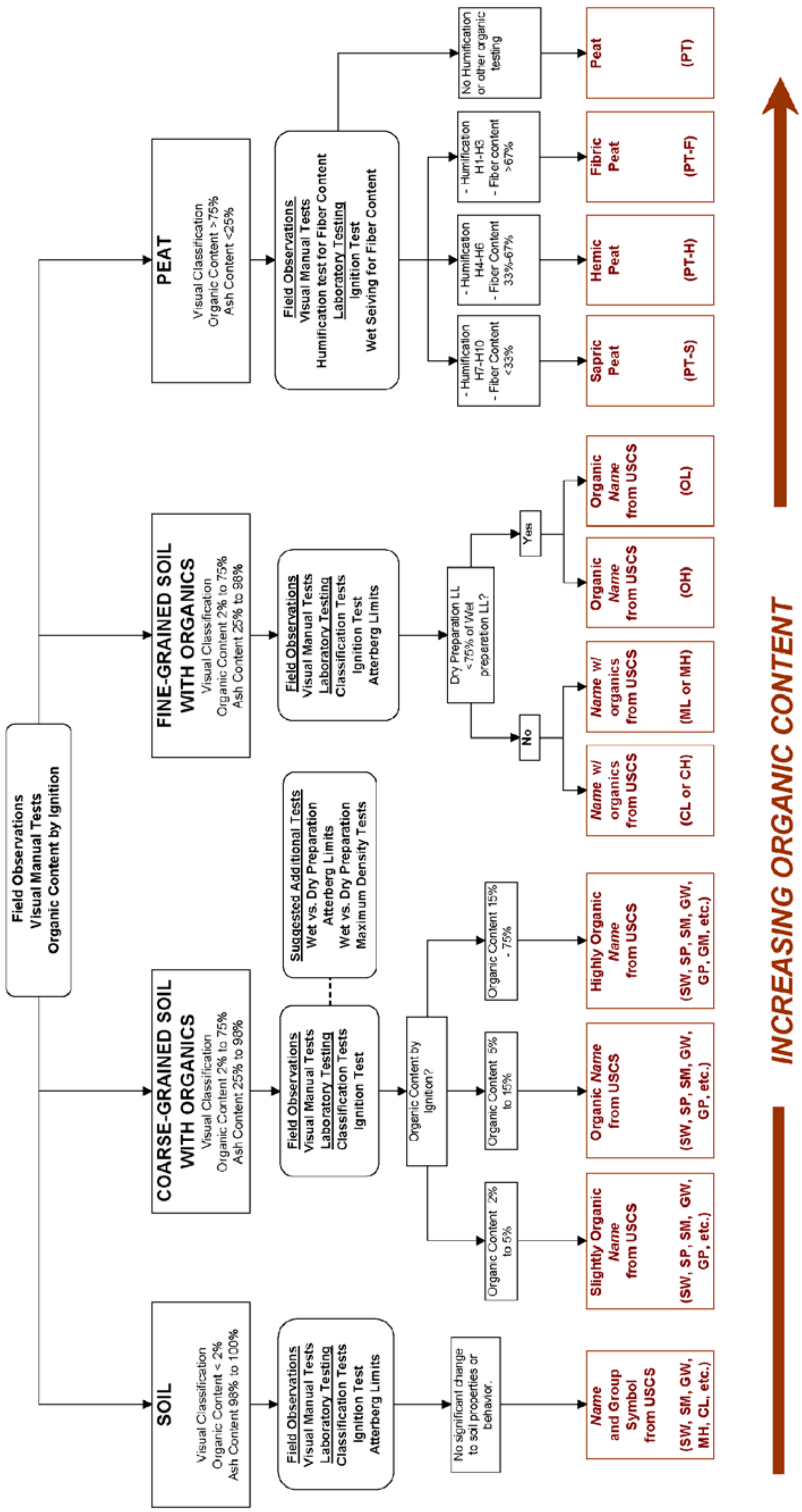
McFarlane, I.C., "*Muskeg Engineering Handbook,*" 1969, University of Toronto Press.

Radforth, N.W., "*Classification of Muskeg*", (in Muskeg Engineering Handbook, MacFarlane, I.C., Ed., 1969, National Research Council of Canada, Associate Committee on Geotechnical Research, Muskeg Subcommittee).

Von Post, Lennart, "*Sveriges Geologiska Undersöknings Torvinventering Ocj Några Av dess Hittills Vunna Resultat*," Svenska Mosskulturfor. Tidskrift, vol. 36, 1921

Walmsley, M.E., "*Physical and Chemical Properties of Peats,*" (in Muskeg and the Northern Environment in Canada, 1977, Radforth, N.W., and Brawner, C.O., Ed.s)

Appendix A. Peat and Organic Soil Classification System



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Alaska Geological Field Investigations Guide

(March 2007)

INTRODUCTION

The Alaska Geotechnical Procedures Manual consists of a series of guidelines for geological/geotechnical investigations, procedures, and reports for the Department. The Alaska Geotechnical Procedures Manual guidelines are intended to aid Department staff and consultants whose task is to obtain geological/geotechnical data for use in the design process and for other Departmental purposes.

Throughout this guide, the term "geotechnical" is used broadly to denote a general terminology for geotechnical engineering and support functions such as geological investigation and data interpretation and analysis, geotechnical design engineering, materials lab testing, GIS mapping in support of geological investigations, pavement management and design, etc. This broad use is contrasted with the use of the term geotechnical engineering, a specialty branch of civil engineering. The "geotechnical" staff may be thought of as a subset of the "materials" staff.

This Geological Field Investigation Guide is about the collection of geological and geotechnical engineering data, but is not intended as an exhaustive directive as to all the possible procedures and methods used to obtain the data. The individuals or teams who are tasked with collecting the data will, of necessity, adjust their methods and procedures to meet the specific project needs and requirements.

This guide is based on and borrows from numerous references that are listed in Section 20. Below is a listing of authoritative references that are used in conjunction with the guide. Each of the Department's materials sections and the consultants who perform geotechnical investigations under contract to the Department should have copies of these references to use along side this guide.

AASHTO, "*Manual on Foundation Investigations*," Washington, D.C., 1978

AASHTO, "*Manual on Subsurface Investigations*," Washington, D.C., 1988

FHWA, *"Evaluation of Soil and Rock Properties,"* Geotechnical Engineering Circular No. 5, FHWA-IF-02-034, DOT, FHWA, 2002.

FHWA, "*Soils and Foundations Workshop Manual, 2nd Edition*," FHWA-HI-88-009, 1993.

FHWA, "*Subsurface Investigations*," NHI Course Manual No. 13231 (Module 1), FHWA-HI-97-021, 1997

Topics Not Covered in this Guide

The three topics of interest listed below are not specifically addressed in this guide.

Material site investigations will be addressed in a separate guide that is in progress at the time of this writing in 2006.

Slope stability investigations are also not covered in this guide. A guideline for this topic is under consideration. The Transportation Research Board (TRB) has a publication (listed below) that has thorough and authoritative coverage of landslide investigations. There is also a 2005 publication (also listed below) on landslide investigation, analysis and mitigation by Derek Cornforth. Together, these two references will provide excellent guidance for landslide investigations. Department Geotechnical staff working on slope stability issues should have ready access to both Special Report 247 and to the Cornforth book.

TRB, "*Landslides: Investigation and Mitigation*," Transportation Research Board Special Report 247, ISBN 0-309-06151-2, 1996.

Cornforth, Derek H., "*Landslides in Practice*," John Wiley & Sons, Inc., ISBN 0-471-67816-3, 2005.

Foundation investigations for bridges, retaining walls, buildings, marine facilities, etc., are not given in-depth coverage in this guide. The drilling methods discussed are applicable to foundation investigations. The AASHTO "Manual on Foundation Investigations" listed above is nearly thirty years old and a Department guide is under consideration. The requirement for a foundation investigation is addressed in the AASHTO Load and Resistance Factor Design (LRFD) Bridge Design Specifications, 2004. Our drilling methods are subject to modification to meet requirements of LRFD as applied to bridges and foundations. There may also be modifications to drilling methodology to accommodate LRFD methods for earthwork in the future

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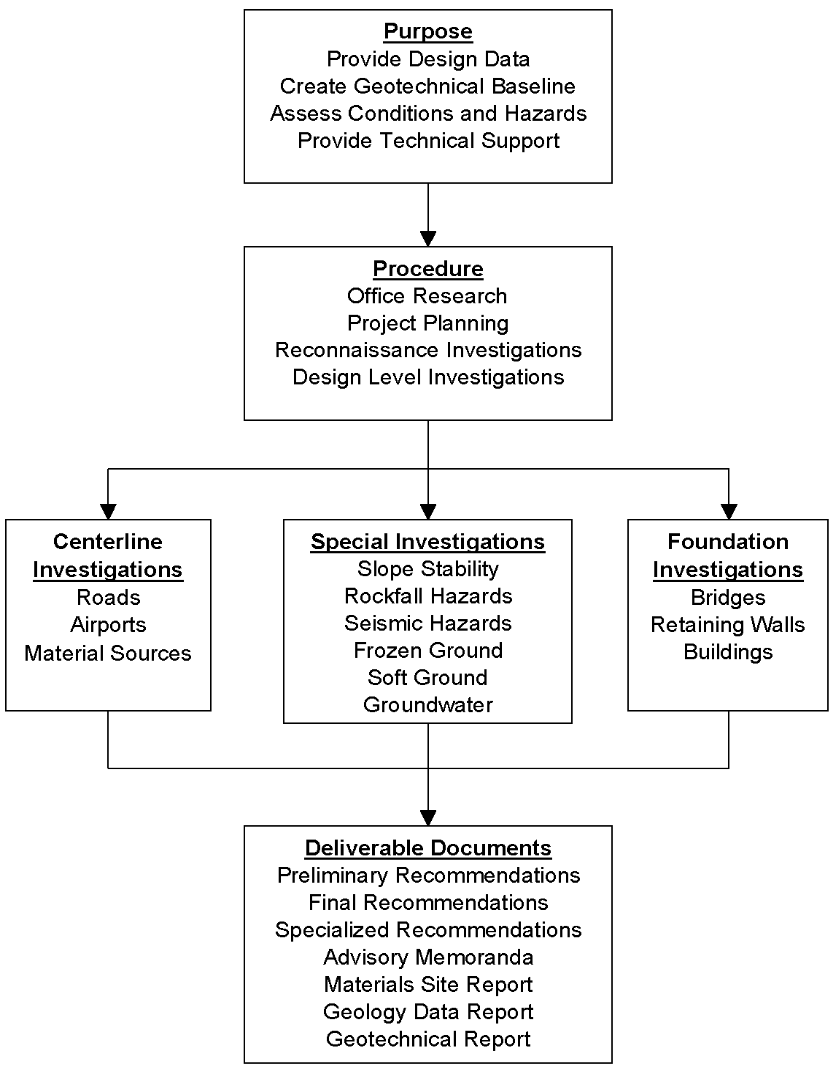
1.0 PURPOSE OF GEOLOGICAL/GEOTECHNICAL INVESTIGATIONS

1.1. Purpose

The Department is responsible for understanding the characteristics of soil and rock materials that support or are adjacent to transportation facilities to ensure that the facility, when designed and constructed, will adequately and safely perform its intended function. The purpose of geotechnical investigations is to support transportation engineers by providing design data and a geotechnical baseline, assessing hazards, assessing conditions of existing structures and other transportation facilities.

This geotechnical work provides technical support for projects from the development stage and project conception, design, and construction and throughout the maintenance and operations phase. See Figure 1-1 below.

Figure 1-1
Purposes, Procedures, and Deliverables for Geological Investigations



1.2. Requirement for Geotechnical Investigation

Geotechnical investigation and design is needed for all Department projects, and particularly for those that include significant soil or rock cuts or fills, involve unstable ground (landslides or rockfall, e.g.), soft ground (peat or soft sediments, e.g.), frozen ground, or other hazardous conditions, or include structures such as buildings, retaining walls or bridges.

> "Both an adequate site investigation and a comprehensive geotechnical report are necessary to construct a safe, cost-effective project." (*Checklist and Guidelines for Review of Geotechnical Reports and Preliminary Plans and Specifications, FHWA Publication No. ED-88-053, Federal Highway Administration, 2003.*

> "The initial step in any highway project must include consideration of the soil or rock on which the highway embankment and structures are to be supported. The extent of the site investigation will depend on many factors. . . ." (*Soils and Foundations Workshop Manual, 2nd Ed.*, FHWA Publication No. HI-88-009, National Highway Institute, 1993).

> "Subsurface explorations shall be performed for each substructure element to provide the necessary information for the design and construction of foundations." (*AASHTO LRFD Bridge Design Specifications*, 3rd Ed., American Association of State Highway and Transportation Officials, 2004.)

In some cases, there will be sufficient data and information already compiled and no additional investigation is necessary. In most cases, however, an investigation will be needed to provide adequate data to support a design. A geological investigation must be conducted by engineering geologists who possess adequate training and experience and in accordance with Department standards and policies and regionally or nationally accepted state of the practice standards and methods.

1.3. Requirement for Geotechnical Report

A geotechnical report should be prepared for each Department project. The interaction between Department road and airport embankments, bridges, buildings and other facilities and the soil and rock materials that support or are adjacent to the facilities requires careful consideration in the design process. The geotechnical investigation is the means by which the interaction between our facilities and the earth is analyzed. The geotechnical report is the tool used to communicate the site conditions and design and construction recommendations to the design and construction staff. The geotechnical report may be in a variety of formats depending on the stage of the project and requirements of the user. Draft reports and memoranda may be used to transmit data and recommendations, but a final report suitable for inclusion in project bid documents should be prepared for each project. Refer to Alaska Geotechnical Report Preparation Guidelines.

The geologists and other staff assigned to the project are responsible for the development of exploration plans for geotechnical investigations that meet project requirements and local conditions while adhering to minimum requirements for geotechnical investigations. No standard approach is possible for all geotechnical investigations because of the diverse variety of conditions from project to project, differences in project scope, budget and time constraints, availability of equipment, experience of assigned staff, etc. This guide is intended to aid geotechnical staff in conducting investigations, but does not provide a step-by-step process.

The collected field data, assessments and interpretations are the basis for all subsequent engineering decisions and, as such, are of paramount importance to the design and success of a project. The data collected and collated during the course of an investigation and published as the project's geotechnical report, together with previous (still valid) geotechnical data and reports, establish the geotechnical baseline from which potential differing site conditions are judged. By outlining and describing these requirements and steps, it will be possible to standardize procedures and considerably reduce time and expense that would be required to return to the project site and obtain important information not obtained during the initial investigation.

The complexity and detail of the geotechnical investigation and of the geotechnical report should reflect the complexity of the project. Simple overlay projects do not require the same detail and level of effort as a project involving hundreds of feet of rock cuts. The following are fundamental data requirements, most of which should be obtained for most projects during a geotechnical investigation and published in the geotechnical report:

- Condition and performance of existing transportation facilities including embankments, slopes, structures such as bridges and retaining walls.
- Identification, delineation and characterization of soil and rock strata.
- Qualitative and quantitative information (field and laboratory testing) on the character and engineering properties of the soil and rock designated on the specific project as borrow, unclassified or classified excavation materials, select material or processed aggregates.
- Groundwater levels and environmental issues, if any
- Geologic hazards or constraints such as unstable soil or rock slopes, seismic hazards, permafrost soil, drainage issues, etc.

The basic steps for a geological investigation are summarized in this and other guides contained in the Geotechnical Procedures Manual. Here we consider the commonly used methods for performing field explorations. This guide addresses procedures for investigations for various types of projects including roadway and airport centerline investigations, foundation investigations and special investigations for slope stability. Guides for description and classification of soil and rock, and preparation of geotechnical reports, and other topics are located elsewhere in the Manual.

2.0 ROLE OF MATERIALS SECTIONS

The four materials sections (three Regional materials sections and Statewide Materials) all have responsibilities for conducting the Department's geotechnical program. The role of the materials sections in the project development process is outlined in the *Alaska Preconstruction Manual*. Additional detail is provided in the *Alaska Geotechnical Procedures Manual*, of which this *Geological Field Investigation Guide* is a part. The materials sections conduct geological/geotechnical investigations or supervise consultants who conduct the work. The investigations result in the collection and publication of the geotechnical data needed to supply the design staff with information to support project designs. The information may include raw or processed data and interpretations of conditions, along with geological recommendations and geotechnical design recommendations.

In addition to the design process for project development, the material sections and geotechnical staff perform numerous services and functions throughout all phases of the Department's operations. The services and function include such diverse topics as:

- providing technical advice and recommendations for mitigation of geological hazards,
- conducting slope stability investigations,
- research into geotechnical issues such as use of hard aggregate in pavement, use of wire mesh to control rockfall, use of geophysical methods in geotechnical investigations, etc.,
- development of standards and procedures for geotechnical work.

A substantial part of the Department's design work is performed by contractors (about half the design work at the time of this writing). One of the materials sections' primary functions should be to monitor the geotechnical work undertaken by our contractors. The materials sections should have a role from the initial development of the scope of the investigation and exploration plan, through field work and including review of the final geotechnical report and the plans and specifications for the project.

3.0 PROJECT DEVELOPMENT

Geotechnical work is part of all phases of project development from initial conception and scoping, through the environmental, design and construction phases of the project, and continuing through the life of the project during maintenance activities. The Alaska Preconstruction Manual outlines the involvement of the geotechnical sections through the design process. During the initial phases of the project, staff may rely on existing geotechnical data to support scoping and pre-design or preliminary engineering work. Preliminary geotechnical site visits or reconnaissance investigations are conducted to assist staff in siting facilities and selecting alignments. During this reconnaissance phase for larger or more complex projects, the geotechnical section may conduct mapping, sampling and drilling test holes or excavating test pits.

Geological field investigations should not be conducted until certain project-specific information has been obtained. Table 3-1 identifies typical project requirements and suggests where the necessary information on specific subjects may be obtained. Table 3-1 may be used as a guide for determining the sources of documentation for this preliminary information.

While considering the project development phase, remember the importance of site visits and on-the-ground inspections of the project area. For every project, numerous questions will be answered and numerous others raised by a simple walking tour of the project area. Other sources of site specific information should be considered. Table 3-1 provides a listing of potential sources.

Table 3-1
Sources for Site Specific Information

Project Specifics	Information Sources
Type of proposed project. Proposed project termini. Scope of Project. Design Study Report. Funds available. Schedule requirements. Items requiring investigation. Local contacts. Location and type of utilities present.	Design Project Manager
Scope of investigation required. Timing of investigation. Availability of exploration equipment. Exploration Plan.	Regional Materials Engineer, Foundation Engineer, Geotechnical Engineer, Regional Geologist, Chief Geologist
Location of structures.	Bridge Section, Design Project Manager
Site maps Air Photos Field reference systems	GIS Unit, Location/Survey Unit, Statewide Planning, Right of Way, private vendors
Permits and specific site restrictions such as water quality, environmental considerations, or other agency considerations.	Regional preliminary design and/or environmental staff, through Design Project Manager

3.1. Use of Consultants

Ordinarily, the materials section having subject or area responsibility conducts the geotechnical work for a project. For example, regional materials sections are responsible for centerline investigations and Statewide

Materials is responsible for foundation investigations. However, a significant percentage of Department projects are designed under contracts with engineering design consultants. For most of these projects, geotechnical investigations are part of the contracted services. Whenever feasible, the design project managers responsible for these projects should solicit the appropriate materials section to review the scope of work. The materials section should review and comment on the exploration plan and the work products produced under the contract, particularly the final geotechnical report. The materials sections also should review and comment on the plans and specifications produced under the design contract.

3.2. Preliminary Engineering through Environmental Document (Preconstruction Manual §430)

In the earliest phases of projects, the development process includes route studies and selection of alternatives. During this phase, support groups such as the materials sections begin assessment of the preliminary alternatives in conjunction with the environmental process. Once alternative routes for highways or airports have been selected, the geotechnical staff provides information to refine locations, to assess potential hazards, to assess material sites, and to consider options for construction methods. This preliminary engineering to develop and support the environmental document should include geotechnical field reconnaissance. During this phase, the geotechnical staff may produce memoranda or preliminary reports to assist designers. In some cases the material section may produce a formal reconnaissance investigation report. Depending on the project, most of the geotechnical work to support the final design may be conducted during the preliminary phases of development.

3.3. Preliminary Engineering through Final PS&E (Preconstruction Manual §450)

Once the project enters the final design stage, the appropriate materials section conducts design-level geotechnical investigations to characterize the topography, drainage, soil and rock characteristics, geological hazards, and other geotechnical aspects of the project. This final geotechnical work culminates in the production of preliminary and final geotechnical recommendations and the final geotechnical report for the project. The geotechnical report is the tool used to communicate the site conditions and design and construction recommendations to the design and construction staff. The geotechnical report also establishes the baseline of geotechnical data for the project, against which potential differing site conditions are compared during construction.

Each project has its own specific attributes and requirements. When planning geotechnical investigations and considering the needs and requirements for geotechnical data, refer to the FHWA Geotechnical Engineering Circular No. 5 – Evaluation of Soil and Rock Properties, Table 1, pages 12 to14 for a comprehensive summarization of requirements for various highway applications.

3.4. Work Flow for Geotechnical Investigations

Multiple project tasks are undertaken as the project development progresses. In keeping with accepted organizational principles, the responsibility and decision-making for these tasks should be assigned as far down the chain of command as is feasible. Table 3-2, below shows common principal tasks associated with geotechnical investigations.

Table 3-2
Geotechnical Tasks

GEOTECHNICAL TASK OR INFORMATION	PERFORMED OR PROVIDED BY
Scope, Schedule & Budget Request Design Study Report Air Photos Location Drawings Preliminary Plan Set X-Sections	**Provided by** Design Project Manager
Scope, Schedule & Budget	**Drafted by** Field Geologist **Concurred by** Regional Materials Engineer, Geotechnical Engineer, Regional Geologist, Chief Geologist **Approved by** Design Project Manager
Exploration Plan	**Drafted by** Field Geologist **Concurred by** Regional Geologist, Regional Materials Engineer **Reviewed by** Chief Geologist **Approved by** Design Project Manager
Environmental Permits for Drilling or Access	**Applied for by** Field Geologist through Design Project Manager
Access Permits Rights of Entry	**Requested by** Field Geologist from Right - of – Way section through Design Project Manager
Traffic Control Plan	**Prepared by** Field Geologist **Approved by** Traffic Engineer
Traffic Control Contract	**Requested by** Field Geologist **Work Scope Drafted by** Regional Geologist or Chief Geologist **Issued by** Contracts Section
Conduct Investigation	**Conducted by** Field Geologist
Preliminary Memoranda and Recommendations	**Prepared by** Field Geologist **Approved by** Regional Geologist **Concurred by** Regional Materials Engineer **Reviewed by** Chief Geologist **Submitted to** Design Project Manager
Final Geology Data or Geotechnical Report	**Prepared by** Field Geologist **Concurred by** Regional Geologist **Approved by** Regional Materials Engineer **Reviewed by** Chief Geologist **Submitted to** Design Project Manager

4.0 PRELIMINARY GEOTECHNICAL ACTIVITIES

4.1. Review of Project Requirements

The first step in performing a geological investigation is a thorough review of the project requirements. It is important that geological investigations be carefully planned, and coordinated between those who will obtain the field data and the end users of the information. The geologist and geotechnical engineer should thoroughly understand the following project details and limitations before planning and performing the geological investigation:

- Project location and size
- Project type and features (airport, highway, realignment, rehabilitation, bridge, retaining wall, rock cut, embankment, etc.)
- Project criteria (alignment, approximate structure locations, approximate structure loads, approximate bridge span lengths and pier locations, soil and rock cut and fill area locations, required quantities of borrow materials, structural fills, etc.)
- Project constraints (ROW, environmental and cultural assessments, permitting, etc.)
- Project design and construction schedules and budgets
- Field exploration constraints such as environmental permitting, rights of entry, utility conflicts, climate or weather-related time constraints, etc.

Depending on the stage of project development, the materials staff should have access to typical section, plan and profile sheets, and cross sections with a template for the proposed roadway showing cuts and fills. This project specific data aids the staff in planning the investigation to meet the project requirements. One goal of properly planning a geotechnical investigation is to minimize exploration costs and the number of site visits needed to obtain vital design information.

Prior to performing any fieldwork, the geologist assigned to the project must have obtained Right of Entry permits to the site and any necessary environmental permits through the design project manager. Copies of the environmental permits should be taken to the field. Following the identification of proposed exploration sites, the field geologist will obtain utility locations and clearances before proceeding with the investigation.

4.2. Use of Geographical Information Systems

Geographical Information Systems (GIS) have become an integral part of the materials sections' methodology. Each region has to some degree incorporated GIS in its set of geotechnical tools. GIS can be used to develop an integrated model of geotechnical information about a project. GIS can be used to digitally store, retrieve, and integrate geotechnical data into a digital or paper format for analysis and display. Geo-referenced data can be located on displays with layers for survey boundaries, topographic maps, air photos. Layers can be added for geologic mapping, test hole data, soils and rock characteristics, drainage patterns, etc. A GIS project can be used by interested parties such as environmental staff, design staff, geotechnical staff, construction staff and maintenance and operations forces for a variety of purposes. The Department has invested considerable resources into development of this useful tool and the geotechnical staff is a primary user in planning, conductin8yand reporting on geotechnical investigations. Little mention of this useful tool will be made in this manual, but keep in mind the uses for GIS in all phases of geotechnical investigations.

4.3. Office Review of File Materials and Other Available Data

After gaining a thorough understanding of the project requirements, the geologist will collect and review all relevant available information on the project site. Data may be available from previous projects in the same area or on nearby projects from the Department, other state or federal agencies, local government, Native corporations, or other private sources. Available data may consist of reports, maps, aerial photographs, previous as-built plans, personal communications with individuals with local knowledge and other sources. The Department may have soils data on file from State projects and as-built drawings as well as pile driving records for existing structures. Existing boring information or well drilling logs can contain relevant and useful information. This data can be quite useful in setting preliminary boring locations and depths and in predicting problem areas. Maintenance records for nearby roadways and structures may also provide insight into the subsurface conditions. For example, indications of differential settlement or slope stability problems may provide the geologist or geotechnical engineer with valuable information on the long-term characteristics of the site.

Project drawings and cross sections may be obtained from the design team. Considerable information may be gathered about the project history by review of the design files and materials section files. At this stage the geotechnical staff should gather together all of the available file information into a project file, including Design Study Reports, if available, relevant environmental documents, previous project geotechnical reports, air photos, drawings, test hole logs, etc., as discussed below. Review of this information provides a basis for understanding the geology, topography, and geomorphology of the area. An initial understanding of the engineering properties of subsurface materials and groundwater characteristics can often be obtained from this available data, which can help in developing the exploration plan.

4.4. Topographic Maps

These maps portray physical features, configuration and elevation of the ground surface, and surface water features. Interpretations of these maps can aid the geotechnical staff in determining changes in relief and slope angles, landform and drainage characteristics, identification of potential landslide terrain, accessibility for field equipment, and possible problem areas. (A complete set of digital topographic maps of the entire state is available through the computer program TOPO!) Additional topographic maps are sometimes prepared on a larger scale by the Department during early planning phases of a project. Department plan sets often include detailed topography of the project within the right of way.

4.5. Aerial Photographs

Aerial photographs and ortho photgraphs are available from the Department, other agencies and private aerial photogrammetry firms. These photos are valuable tools in planning the site reconnaissance and, depending on the age of the photographs, show manmade structures, excavations, or fills that affect accessibility and the planned depth of exploration. Historical photographs can also provide a better understanding of how the project site has been modified throughout the years. It may be useful to obtain new air photo coverage of the project alignment.

4.6. Geological Maps and Reports

Considerable information on the geological conditions of an area can be obtained from geological maps and reports. These reports and maps show the location and relative position of the different geological strata and present information on the characteristics of these materials. This data can be used directly to evaluate the rock conditions to be expected and indirectly to estimate possible soil conditions, since the parent material is one of the factors controlling soil types. Geological maps and reports can be obtained from the USGS, DNR's Division of Geological and Geophysical Surveys, university or other resource libraries, the Geotechnical or Materials Sections of DOT&PF, and other sources.

4.7. Soils Conservation Service Surveys

These surveys are compiled by the U.S. Department of Agriculture (Soil Conservation Service) usually in the form of soils maps. These surveys can provide valuable data on surface soils including areal extent, mineralogical composition, grain size distribution, and depth to rock, water table information, drainage characteristics, geologic origin, and presence of organic deposits

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4.8. Hydrogeological Surveys and Well Logs

Hydrogeological surveys generally focus on the presence, depth, amount, and condition of groundwater. These resources can aid the geologist by giving some indication about the presence and depth of groundwater in terms of its effect on construction conditions and its control over shear strength of soil and rock masses. Water well logs produced by private drilling contractors may be recorded by other State agencies such as DNR. In addition to groundwater information, such logs can serve as useful tools in supplying general subsurface information, including depth to bedrock near bridge locations.

5.0 EXPLORATION PLANNING

During the planning for exploration, several steps may be underway at once. The geotechnical staff will usually be working on schedule and budget at the same time they are developing the exploration plan and obtaining access and environmental permits.

5.1. Preparation of Scope, Schedule and Budget

At an early stage of the work, the geotechnical staff assigned to the project prepares a scope, schedule and budget memorandum for the design project manager. This document represents the understanding between the materials section and the design team as to the nature of the work, the estimated cost and timing of the geotechnical work and the deliverable documents that will arise from the work. The geotechnical staff must review enough of the work already done on the project to understand the project requirements, as described above, and the work needed to provide design data. The Regional Geologist and the Regional Materials Engineer should prepare the scope, schedule and budget for the design project manager's approval. For regional work or structure foundation investigations involving Statewide Materials staff, the Chief Geologist should also review and participate in preparation of the scope, schedule and budget.

5.2. The Exploration Plan

The exploration plan is the principal guide for the geotechnical staff in the conduct of the investigation. Thus, preparation of the exploration plan is one of the most important steps in the geotechnical investigation. Keep in mind that the exploration plan is a flexible guideline for the exploration. Unexpected conditions and findings as the field work is underway, scheduling problems due to equipment efficiency, weather, and many other factors can lead to changes to the ongoing program.

The geotechnical engineer and the assigned field geologist and other supporting materials staff cooperatively prepare the exploration plan for conducting the geological investigation. Once the preliminary research and record review has been done, the plan is prepared and submitted to the design project manager for approval.

The preparation of the exploration plan requires a site visit, if possible, by the geotechnical engineer and geologist assigned to the project and representatives of the design staff. For remote sites with difficult access, it may be necessary to rely on file information and interviews with staff members who have visited the site during the pre-design phase. File materials, air photos, topographic maps, and other data, as described above, can be used to prepare a base document of mapping and images. The proposed exploration elements can then be plotted on the base document.

At a minimum, the exploration plan should consist of:

- Proposed scope of the investigation, including reconnaissance and design investigations as required.
- Schedule of work and deadlines for deliverable documents.
- Proposed staff.
- Enumeration of project requirements for borrow materials, quantity of cut and fill materials, etc.
- Maps, drawings or images of the project site, showing existing and proposed alignments, site access, proposed structures, drainage features, etc.
- Outline of sampling and testing program.

- Proposed drilling or other exploration equipment.
- Proposed test hole/test pit locations and depths.
- Spacing and depth of test holes. The Department typically spaces exploratory holes at 500 foot intervals in fill sections and at 200 foot intervals in cut sections. However, this only a rule of thumb and the project requirements and expected soil conditions may dictate smaller or larger intervals between hole locations. In addition, the plan may require modification once the field work begins. Alteration of exploration plans is not unusual, but should be undertaken with concurrence of the regional geologist, regional geotechnical engineer, and regional materials engineer. For reference, see Appendix D – *Guidelines for Minimum Number of Investigation Points and Minimum Depth of Investigation*, from *Geotechnical Engineering Circular No. 5 - Evaluation of Soil and Rock Properties*, FHWA Publication FHWA IF-02-034 (April 2002). Also refer to guidelines in "*Checklist and Guidelines for Review of Geotechnical Reports and Preliminary Plans and Specifications,*" FHWA Publication FHWA ED-88-053 (Revised February 2003). The suggested spacing for test hole or test pit locations should be modified as necessary for project specific requirements.
- Discussion of required environmental permits and constraints that may affect the geotechnical work schedule
- Discussion of rights or entry or access permits necessary for the field program
- Utilities that may conflict with exploration sites.
- Proposed material site locations and access routes.
- Known or expected geologic hazards.
- Right of Way and property boundaries.

Any significant changes to the exploration plan once field work is underway should be made in consultation with the geotechnical engineer. The principal reason the plan is a flexible guideline is that as each new piece of data is acquired by the field geologist and synthesized with the information already known, a better picture of the conditions and features of the overall project is developed. As each test hole or test pit is advanced, the geologist assesses the new information and decides where the next piece of information should come from and how it should be obtained. Where uniform conditions occur as expected during planning, few changes are likely to be made to the investigation. However, where conditions are variable and not as expected, major changes to the field exploration may be necessary to accomplish the goals of the investigation.

5.3. Permits and Access for Geotechnical Investigations

Once the exploration plan has been drafted and test hole or test pit locations have been selected, send the plan to the design project manager for forwarding to the appropriate staff with a request for access and environmental permits for field operations. The field geologist or Regional Geologist should make a written request to the project manager well in advance of the expected commencement of the field work to avoid scheduling problems. Once permits and rights of entry have been issued, the field geologist should review the documents for conformance with the exploration plan. Copies of permits and rights of entry should be kept with the field crew during the course of the investigation.

6.0 RECONNAISSANCE INVESTIGATIONS

6.1. Objective and Purpose

The objective of reconnaissance is to identify the key issues that will influence project design and to provide geotechnical and engineering geology data to the reconnaissance or design engineer to assist in selecting the best location for project elements. Conclusions by the geotechnical staff should be drawn from background information and field studies to assist the engineer in avoiding areas that may present design, construction, and/or maintenance problems. Although other considerations may, in some cases, force a choice of alternatives other than the "best" alternative from a geotechnical perspective, the reconnaissance report should alert the design engineer to the additional costs and problems associated with alternate choices.

Some projects may require an extensive geotechnical reconnaissance while others may require only a limited study. For example, rebuilding of existing airfields or roads may require only an examination of the performance of the existing facility and a review of "as-built" plans and construction records. For a new alignment, extensive geotechnical reconnaissance (including test holes and sampling) may be required for cuts in unknown soil types and large fills with questionable foundations, retaining walls, bridges, or possible subsurface drainage problems.

6.2. Site Visit

The geotechnical staff assigned to the project must visit the site to develop an appreciation of the topographic, geologic and geotechnical concerns of the project and become knowledgeable of access and working conditions. Pertinent project information (project development documents) and other conceptual information should be obtained from the project design team before the site visit. If at all possible the staff should have a set of plans (Plans-in-Hand or Pre-PS&E) and cross sections for the reconnaissance. A reconnaissance visit should be performed only after the geotechnical staff has an understanding of the project requirements and has a good understanding of the apparent geological conditions at the project.

The appropriate geotechnical staff should perform the field reconnaissance, preferably on foot. The value of ground reconnaissance cannot be overstated. For new alignments, it may be advisable to conduct aerial reconnaissance before or after the ground reconnaissance. The reconnaissance will almost always include air photos, but with an understanding of the limitations on amount and detail of the information from air photos. As part of the reconnaissance, key site locations and conditions, and exploration equipment access routes should be photographed.

6.3. Checklists

The geology/geotechnical staff is encouraged to make use of checklists in preparing for field investigations. Each field employee should develop and use his or her own checklists using as guides published checklists such as those included in:

Checklists and Guidelines for Review of Geotechnical Reports and Preliminary Plans and Specifications, FHWA ED-88-053 (rev. February 2003),

Subsurface *Investigations,* FHWA-HI-97-021 (1997)

Evaluation of Soil and Rock Properties, Geotechnical Engineering Circular No. 5, FHWA-IF-02-034 (2002)

Manual on Subsurface Investigations, American Association of Highway and Transportation Officials (1988)

6.4. Important Reconnaissance Issues

The following are some of the important issues that should be addressed during the field reconnaissance and should be resolved during the design level investigation:

- Geology and Topography – study and summarize the regional and site geology and topography and how they may affect the geotechnical investigation and project design. For example, if the area geology indicates the bedrock is highly weathered and fractured shale, any required rip rap would likely come from outside the project limits. Similarly, if the area is known to have considerable fine-grained surface soil and shallow groundwater, slope stability and settlement problems may occur and the geotechnical investigation should focus attention on those issues.
- Existing Transportation Facilities – Assess present alignment, existing embankments, soil and rock slopes, drainage features, effectiveness of culverts, conditions of existing bridges and approaches and retaining walls, etc.
- Planned New Alignment or Site – Assess the planned preferred alignment or sites and other possible alternates for feasibility and potential geotechnical problems with the alignment.
- Make "station-to-station" descriptions of the proposed alignment or site identifying the soil and rock strata. It may be advisable to take small numbers of representative samples of soil and rock for testing to generally delineate the soil and rock conditions. Identify problems areas of deep organic soils, suspected frozen ground, unstable slopes, water problems and other conditions.
- Existing Slopes – Assess the stability factors of major slope-forming geologic units. Natural slopes and any existing soil or rock slope failures should be measured and observed. Cut slope angles and orientations should be measured and their relative performance evaluated. Refer to the Erodibility Chart in Appendix C.
- Rock exposures – compare stratigraphy to information obtained from available data. Mapping and subsurface explorations and laboratory testing will ultimately define the rock units. Delineate outcrops or exposures that warrant further investigation in terms of structural mapping for stability analysis or that may be quarry sites.
- Groundwater and Surface Water – Estimate the general nature of surface water and groundwater regimes at the project site. Develop concepts for future investigations.
- Geologic Hazards – Identify geologic conditions that may tend to adversely affect project development plans (landslides, rockfall, frozen ground, soft ground, faults, flooding, erosion, etc.). Devise methods of investigating the degree of potential impact.
- Material Sites - Identify and preliminarily assess known and potential borrow sites and quarry sites in the project area. This includes assessment of large cut areas that may provide significant quantities of material for the project. Take limited numbers of soil and rock samples to confirm that material quality is adequate for the project requirements. Survey for adequate quantity and detailed quality testing should be conducted during the design investigation.
- Preliminary Assessment of Structure Sites – Identify general site characteristics and potential problems with exploration and construction such as adverse bedding in rock formations,

soft or weak rock formations, potential fault locations, possible liquefaction hazard, presence of boulders and cobbles, soft ground, frozen ground, etc.

- Scope of Future Explorations – Determine the scope of design investigation to best accomplish the project needs given the conditions at the site. Identify geotechnical problem areas requiring special attention during the design investigation.
- Design Investigation Logistics – Define the type, approximate locations and depths of geotechnical borings. Determine approximate routes of access to each drilling location and impact of vegetation. Look for any indications of overhead and underground utilities. Evaluate potential water sources for use during drill operations. Evaluate potential concerns that may need to be addressed while planning an exploration program (permits, overhead utilities, heavy or difficult vegetation, water crossings, equipment security, private property, etc.). If possible, exploration locations should be located with a Driller/Operator. It is desirable to review the proposed boring locations following utility locations to determine if any borings need to be relocated to avoid buried utilities. The presence of utilities may need to be rechecked for the adjusted boring locations.
- Environmental – Identify potential impacts the exploration program may have on: vegetation, lakes and streams, swamps or marshes, subsurface materials, landforms, and the surrounding area. Gather information needed to address best management practices for field exploration. See Appendix E.
- Historical or Cultural - Report any unidentified historical or cultural sites if there are conflicts with the investigation plan.

The deliverable result of the reconnaissance study is a reconnaissance report addressing the issues outlined above and any other issues unique to the project. The report may be focused on geological issues or may have a broader coverage of geotechnical or materials issues. Refer to the *Alaska Geotechnical Report Preparation Guide* for details on the preparation of geotechnical reports.

7.0 DESIGN INVESTIGATIONS

7.1. Objectives and Purpose

The objective of design level geological/geotechnical investigations is to provide all the geotechnical information necessary to complete the design of the project or facility. The ultimate product of a design level investigation is the formal geotechnical report with engineering recommendations. The geotechnical report provides the geotechnical data the designers use to make design decisions. The geotechnical report also provides the baseline of geotechnical data against which differing site conditions claims during construction will be compared. It is obviously very important for the materials staff to give as much attention to detail as possible to provide the highest possible quality data to the design team and well written and complete documentation for the project records and contract documents.

Often, the design investigation is performed in two or more phases. The preliminary or reconnaissance work, as discussed above, is usually done early in the design process before the final alignment is set and before structure locations are fixed. The early work typically includes a limited number of test holes, widely spaced and sited to capture general information about stratigraphy, soil and rock characteristics, groundwater, rock slopes, extent of soft ground, etc. For the design phase work, test holes will be located at close intervals to fully characterize and map surface and subsurface conditions along the alignment and at structure locations. This work may be done in several phases as an iterative process as problem areas are assessed and solutions identified and when design changes are made.

As discussed above in the Reconnaissance section, the use of checklists is strongly encouraged. While checklists are not intended to replace a thorough process of thinking through the appropriate steps of the investigation, such lists provide a useful aid in the process.

7.2. Mapping the Alignment - Surface Soils, Rock, Topography, Drainage, Vegetation

The field geologist should make use of geologic maps, topographic maps, aerial photography and make a foot reconnaissance of the project site or alignment. The value of ground reconnaissance cannot be overstressed and should be employed at every feasible opportunity. The geologist should make station by station notes, maps or sketches of the entire project area to identify the following features:

- Landforms
- Soil types and distribution
- Rock types and distribution
- Presence of rock exposures
- Usability of cut materials
- Amount of waste in cuts
- Amount of waste from surface organics and peat deposits
- Drainage issues and recommendations for subcuts, underdrains, etc.
- Erodibility of soil (see Erodibility Chart at Appendix C)
- Vegetation
- Groundwater conditions in cut and fill zones
- Presence of geologic hazards such as:
    - Soft ground and settlement issues
    - Frozen ground
    - Rockfall hazards
    - Rock or soil slope stability problems
- Material sites locations, accessmaterial types, and volumes

The list is not all-inclusive and many other issues may be involved on any particular project. Contact the local Maintenance & Operations staff to obtain details about particular problems noted along the alignment such as seasonal problems like springtime rockfall and seasonal springs and icing problems.

The geologist should conduct probing along the alignment to make a station-by-station determination of depth of organic material and waste soils within the footprint of the work. Seasonal reconnaissance may be necessary to identify areas of icing, seasonal frost depth, presence of springs, snow drifting, rockfall and other conditions that may occur only during particular times of the year. Locations and elevations should be determined using compass, level and tape or GPS. The alignment should be divided into logically separated sections based on the field mapping. Divisions may be based on landforms, soil or rock profiles, presence of cuts and fills, or other factors.

7.3. Rock Slope Mapping and Measurements

A detailed discussion on rock structural mapping is given in the Department's *Alaska Field Rock Classification and Structural Mapping Guide*. Field mapping should begin by observing road cuts, drainage courses, and bank exposures. A site plan and large-scale topographic map of the project area is essential for field mapping. The main objective of these initial observations is to confirm the general types of soil and rock present. Note any features that may assist in the engineering analysis, such as the angle and performance of existing slopes, or the stability of open excavations or trenches. The type and condition of vegetation may give an indication of ground and surface water regimes, as well as an indication of landslide or slope stability concerns.

Make note of any feature that may affect the boring program, such as accessibility, structures, overhead utilities, signs of buried utilities, or property restrictions. In addition, structures should be inspected to ascertain their foundation performance and their susceptibility to damage from construction-related ground vibrations or settlement due to embankment placement.

For rock slopes, performance of slopes and the rockfall history are important indicators of how a new slope in the same material will perform. More detailed rock structural mapping entails observing and measuring lithologic contacts and the engineering characteristics and orientation of rock discontinuities that make up the rock mass. The measurements are typically made with a geological or structural compass and consist of determining the dip and dip direction of rock discontinuities such as faults, joints, foliation, shear and bedding planes, and contacts with other rock units. These measurements can be presented graphically on a spherical projection such as an equal area stereonet. For more detail, see the Participant's Manual for the NHI course "Rock Slopes" (Module 5: No. 13235, 1998).

The AASHTO Manual on Subsurface Investigations (1988) describes the procedures for engineering geological mapping. It also provides suggestions for preparing geologic maps for different applications, such as Project Area Geologic Maps, ROW Geologic Maps, File Geologic Maps, Site Geologic Maps, and other special mapping (see Reference Chapter 4)

7.4. Field-Developed Cross-Sections

Field-developed cross-sections are applicable to nearly all types of site-specific geotechnical investigations. Their use can be applied to excavation and placement of materials; foundations and slopes; specific development of groundwater and aggregate resources; and for the graphic portrayal and analysis of significant features related to slope stability, seismicity, drainage, or other characteristics. Although these cross-sections lack the precision of high order engineering surveys, preparing them provides an excellent opportunity to observe the project area and apply the scientific method in resolving surface and subsurface relationships and other field observations.

Standard cross-sections prepared by survey crews or taken from digital terrain models do not depict the interpreted geotechnical relationships and other features that may prove very important during the design process. Another advantage to field-developed cross sections is that the sections are developed and plotted during the reconnaissance, so discrepancies can be identified and resolved immediately. This provides a high level of confidence when used later in the office.

The cross-section field gear typically includes a field notebook, cloth tape, hand clinometer, calculator, and Brunton compass. Measurements include all slope breaks and other identifiable, geotechnical features such as landslide cracks and groundwater features. The significance of each feature is described in the field notebook. Since slope breaks commonly occur as the strength characteristics of the subsurface material changes, many times the slope breaks represent contacts between different soil and/or rock units. Measurements of the contact orientation (strike, dip and surface trace) are normally denoted where appropriate in the field notebook.

The points comprising the cross-section should be plotted on graph paper as “x” and “y” coordinates while in the field. The coordinates can be readily calculated from the slope distance and angle between each point with the aid of a calculator. Include the interpretations of the surface and subsurface materials and relationships on the section along with relevant estimates of engineering parameters. The section should show the distribution of soil and rock units, estimated location/elevation(s) of surface and subsurface water, and original ground lines prior to any previous excavation, filling or slope movements. As these interpretations are developed, plan any explorations that may be needed to confirm the subsurface model that will be used in the analysis and design phase.

7.5. Logging Test Holes

The original field-prepared test hole or test pit log is the single most important document containing field data associated with geological investigations. A clear and complete record of field exploration activities and findings is essential. The field logs and final drafted drill logs should contain all the relevant information obtained during the field work. Field geologists normally record information from test holes and test pits directly onto the field logs. Additional information is recorded in field books and may be included as part of the final test hole logs.

The information contained within the test hole log, test pit log or penetrometer log (collectively referred to hereafter as “test hole logs”) is transferred to a final drafted form for publication. See Appendix A & B for examples. The original logs are retained and remain in the official record. One of the reasons the test hole logs are important is they are often the only contemporaneous record of what happened during the investigation and the observations made by the field geologist. If there is a claim on a project involving geotechnical issues, the test hole logs will be among the first documents requested. If there is a differing site conditions claim, the test hole log and the geotechnical report set the baseline from which any change in conditions is compared. It follows that preparation of the test hole log in the field must be given a great deal of attention to assure that a proper record is maintained and that the critical data is recorded and preserved.

The other and more obvious importance of the test hole log is to collect geological field data in one place for later transfer to the design team who need the data in their design process. Collecting, listing, preserving and reporting this data accurately and completely is of primary importance in the design process.

Due to the importance of the information, test holes and test pits should be logged at the time they are drilled or excavated by an experienced engineering geologist who has demonstrated knowledge, skills and abilities in performing this work. Logging test holes and performing geological investigations requires a specialized set of skills and abilities. Engineering geology is a part of a continuum of practice between engineering and geology that encompasses the application of geological principles, methods, and techniques to the study, investigations and interpretation of earth materials. Those who are not trained in the principles and techniques may make critical errors in classifying earth materials and understanding the geological relationships that are important to understanding the characteristics of the materials and the geologic setting in which they exist. The failure to correctly identify, interpret, log and report on the types of earth materials encountered on our projects can lead to improper design of Department facilities and expensive construction claims.

7.5.1. Supervision of Subsurface Explorations

The following guidelines for field geologists are summarized from the FHWA Subsurface Investigation Manual and the AASHTO Manual on Subsurface Investigations (Section 7.11):

- Thoroughly comprehend the purpose of the fieldwork in order to properly characterize the site for the intended engineering applications.
- Be thoroughly familiar with the scope of the exploration program. Maintain a copy of the exploration plan.
- Be familiar with site, access conditions, and any restrictions.
- Review existing subsurface and geologic information before leaving the office.
- Constantly review the totality of field data as it is obtained to synthesize the knowledge as it relates to the purpose of the investigation.
- The field staff should maintain frequent contact with the geotechnical engineer or foundation engineer regarding work progress, conditions encountered, problems, etc.
- Fill out forms regularly. Obtain a sufficient supply of boring and test pit logs and any other necessary forms to cover the expected explorations.
- Closely observe the driller's work at all times, paying particular attention to:
    - Current depth (measure length of rods and samplers)
    - Drilling and sampling procedures
    - Any irregularities, loss of water, drop of rods, etc.
    - SPT blow counts
    - Depth to groundwater and degree of sample moisture
    - Do not hesitate to question the driller, or to provide direction to ensure proper procedures are followed.
- Classify soil and rock samples. Put soil samples in jars and label them. Make sure rock cores are properly boxed, photographed, stored, and protected.
- Verify that undisturbed samples are properly taken, handled, sealed, labeled, and transported.
- Bring necessary tools to job.
- Do not hesitate to stop work and call a supervisor or manager if in doubt, or if problems are encountered.
- Always remember that the field data are the bases of all subsequent engineering decisions, and as such are of paramount importance.
- Make certain the site of exploratory test pits and test holes is maintained free from excessive damage by

equipment operations and discharge of cuttings and drilling fluids. Refer to Appendix E – "Best Management Practices for Spill Prevention and Erosion Control During Geological/Geotechnical Field Investigations" for guidance.

7.5.2. Format of Test Hole Logs

The Department has numerous forms for logging test holes, test pits and penetrometer soundings. See Appendices A and B. There are differences in the formats used among the regions and between Statewide Materials and the regions. The Department nearly uniformly uses a graphical/database software package (gINT) to produce test hole logs, but there are some test hole logs produced in AutoCAD. Test hole logs may be published as single pages or as part of plan and profile sheets or in one of many other formats. There is no common statewide agreement as to conventions for soil names combined with graphical representations, so it is important to include a legend that includes an explanation of the test hole logs with each geotechnical report. Soil names are assigned with reference to the *Alaska Field Guide for Soil Classification* and the Unified Soil Classification System (ASTM D2487, D2488).

The content of test hole logs varies to some extent depending on the purpose of the test hole. Shallow test pits to evaluate soils under an embankment require a different set of data than deep test holes to evaluate suitability of a site for deep foundations for a bridge.

However, certain basic information is needed:

- Project identification
- Start and finish date
- Weather conditions
- Test hole number
- Test hole location (station and offset, grid coordinates, latitude and longitude) to appropriate level of accuracy. (Accuracy level will vary between regions and with project and location. For example a bridge foundation may require accuracy of +/- 1 foot, but for a road centerline investigation on the NHS road system +/- 3 feet may be adequate. For a remote airport, +/- 10 feet may be accurate enough)
- Test hole collar elevation to appropriate level of accuracy and notes as to datum used
- Names of geologist and crew
- Description of exploration equipment (drill, excavator, etc.)
- Drilling method (solid flight auger, hollow stem auger, driven or drilled casing, rotary wash, casing advancer, rock coring methods, etc., including diameter of casing, auger, tools, etc.)
- Notes on method of advancing casing, including pre-drilling, blow counts, and use of casing advancer
- Notes on use of penetrometer, including blow count and pullout force from draw works or casing jack
- Sampler types and sizes and hammer type (auto hammer vs. rope and cathead)
- Sample data (depth, recovery, type of sample, SPT blow count)
- Groundwater information (depths, dates, description: artesian, perched, flow rates, etc.)
- Depth, description and results of any in situ field testing such as vane shears
- Description of materials encountered (soil, rock, obstacles, boulders, etc.) and depths to top and bottom of identified layers
- Description of moisture condition, color, odor, texture, temperature (noting frozen soil and description of ice), presence of boulders and cobbles, presence of organics and peat
- Field classification of materials
- Graphic log of materials
- Drilling notes (use of drilling muds, rate of advance, problems such as

heaving sand or loss of circulation, times for core runs, abandoned holes due to boulders or cave-in, etc.)

Any additional notes on terrain, apparent geology, drainage features, vegetation, sketches or cross sections of the area may be made on the drill logs or in field books as appropriate.

Field logs must be neat, legible and complete so that the logs may be easily read by supervisors and by the drafting personnel and translated to gINT logs. Vague, illegible, and incomplete descriptions are unacceptable.

7.6. Soil Profiles

Geological/geotechnical reports are often accompanied by soil profile sheets developed from test hole logs and laboratory test data. The soil profile can be a useful visual display of subsurface conditions. Profiles may be prepared longitudinally along an entire alignment or at specific sites where such information may be useful. More typically, profiles may be prepared for bridges, retaining walls or other structures where a limited area is targeted. When the geologist or engineer can prepare a profile with confidence, there is an indication that an adequate investigation has been conducted. Where there are many questions about the profile, it is likely that additional test holes are needed.

Use of profiles presents some risk. A soil or rock profile is a geologist's or engineer's best interpretation of the subsurface conditions, involving considerable judgment in extending the interpretation away from test hole locations or other data points. Projection of the information even for short distances may result in misleading representations and eventual claims. Keep in mind that the geotechnical report is the baseline for geotechnical conditions on a construction project. In any differing site conditions claim, the question is: "differing from what?" The answer is: differing from the conditions presented in the geological/geotechnical report.

Designers tend to desire a continuous profile of the subsurface conditions along the entire project alignment. Where conditions differ between test hole locations, the value of the profile is questionable and the geotechnical staff must exercise caution in producing, using and publishing profiles that are based on incomplete information or in variable subsurface conditions. In cases where there is a legitimate need for an accurate profile, the test hole spacing should be reduced and the geotechnical staff should consider various methods to increase confidence in the data, including probing, and geophysical methods.

7.7. Subsurface Exploration Methods

The information obtained from the steps discussed above is used to develop a subsurface exploration program. Guidelines concerning the number and depth of explorations and sampling and in situ testing requirements are discussed in:

- *Alaska Geotechnical Procedures Manual Checklist,* Geotechnical Procedures Manual (2005)
- *Checklists and Guidelines for Review of Geotechnical Reports and Preliminary Plans and Specifications,* FHWA ED-88-053 (rev. February 2003),
- *Subsurface Investigations,* FHWA-HI-97-021 (1997)
- *Evaluation of Soil and Rock Properties,* Geotechnical Engineering Circular No. 5, FHWA-IF-02-034 (2002)

Discussions of the various types of in situ tests to be performed during a subsurface exploration program may be found in several standard references below. Frequently used AASHTO and ASTM standards for subsurface explorations are listed in below in Section 19 - Specifications and Standards.

Once environmental permits, rights of entry and utility clearances have been obtained, field explorations can begin. Many methods of field explorations exist. The subsections below contain brief descriptions of the most common methods. Further detail is also available in standard reference works, including those references cited above.

7.7.1. Test Pits and Trenches

Pits and trenches are the simplest methods of observing subsurface soils. They consist of excavations performed by hand, backhoe, or dozer. Hand excavations are often performed with posthole diggers or shovels and offer the advantages of speed and ready access for sampling. In addition, bulk samples obtained from test pits are likely to be more representative of the actual gradation than sample obtained by drilling methods. Hand excavations are severely hampered by limitations of depth; and they cannot be used in very loose soils, boulders, below the water table or during the winter months.

7.7.2. Hand/Auger Probes

These are manually operated, solid stem or hollow bucket augers that can be used to quickly and cheaply observe shallow (less than 15 feet) subsurface conditions. They do minor disturbance to the ground surface, but are difficult to advance in rocky or dense material. Probes with steel rods are also useful in quickly delineating depth of organic soil or peat deposits, and soft soils.

7.7.3. Exploration Drilling Techniques

Borings are the most common method of exploration. They can be advanced using a number of methods. Excellent discussions of drilling methods are described in the following manuals: 1) U.S. Army Corps of Engineers, Soil Sampling Engineering Manual, 2) AASHTO Manual on Subsurface Explorations, and 3) NHI Manual on Subsurface Investigations, No. 13321 (Module 1). The most common methods are discussed below:

7.7.4. Solid Flight Auger Borings

Auger borings are advanced into the ground by rotating the auger while simultaneously applying a downward force using either hydraulic or mechanical pressure. The auger is advanced to the desired depth and then withdrawn. Samples of cuttings can be removed from the auger; however, the depth of the sample can only be approximated. These samples are disturbed and should be used only for material identification. This method is generally used to establish shallow soil strata and water table elevations, or to advance to the desired stratum before Standard Penetration Testing (SPT) or undisturbed sampling is performed. However, it cannot be used effectively in soft or loose soils below the water table. In addition, this method has limited capabilities in dense, rocky material where it may encounter refusal. See Section 19 - Specifications and Standards - ASTM D 1452 (AASHTO T 203).

7.7.5. Hollow-Stem Auger Borings

A hollow-stem auger consists of a continuous flight auger surrounding a hollow drill stem. A central “plug” bit, at the end of a drill rod is used to prevent soil from entering the hollow stem as the hole is advanced between samples. The hollow-stem auger is advanced in a manner similar to other augers; however, removal of the hollow stem auger is not necessary for sampling. The “plug” bit is removed and SPT and undisturbed samples are obtained through the hollow drill stem, which acts as a casing to hold the hole open. This increases usage of hollow-stem augers in soft and loose soil. Usually no drilling mud is required, which could otherwise interfere with accurate groundwater level readings. In addition, this method of drilling is extremely fast, cost effective, and requires little to no water. In some sandy and silty soils below the water table, removal of the center “plug” bit, allows sand to "heave" into the hollow stem, interfering with and affecting the validity of the SPT. One option when these conditions are encountered is to add water or drilling mud to the inside of the hollow stem to create a head of water and prevent heaving. Another disadvantage of hollow stem auger is that refusal may occur in boulders or dense rocky soils. See Section 19 - Specifications and Standards - ASTM D 6151 (AASHTO T 251).

7.7.6. Rotary Drilling

This method consists of using a rotary drill with rotating thick-walled, hollow, drill rods usually attached to a tri-cone bit. Water or drilling mud is circulated from a mud tub, and then through the drilling rods as the drill rod is advanced. The drilling mud lifts the drilling cuttings out of the borehole while maintaining hole stability. The drill cuttings are screened and separated from the drilling mud, which is then re-circulated. To collect a sample, the drill rods and bit are pulled out of the hole and are replaced with drill rods and the required sampling device. This method is fast, and provides excellent sampling and in situ testing data due to minimal disturbance to the soils at the bottom of the borehole prior to sampling. It is effective in all soil types except for very gravelly material with cobbles and boulders. No information can be reliably obtained about groundwater levels during the drilling operation, and the soil material between sampling intervals is difficult to observe from the drilling mud return.

7.7.7. Air Drilling/Downhole Hammer

This type of drilling uses a compressed air actuated downhole hammer drill to breakup and remove cuttings from the borehole as the drill bit is advanced. Both rotary or percussion techniques can be utilized and either open hole (rotary reverse circulation) or under-reamed casing advancement (ODEX) can be used in the drilling process. SPT samples can be obtained; however, the materials between samples are highly disturbed. This type of drilling is generally fast, but expensive, and is most useful when drilling deep holes in dense gravels and boulders where traditional Hollow Stem Auger and Mud Rotary techniques cannot reasonably drill or sample.

7.8. Penetrometer Soundings

A sounding is a method of exploration in which either static or dynamic force is used to cause a rod tipped with a solid tip or a testing device to penetrate soils. This method can be useful to determine the depth to harder strata or rock from the resistance to penetration.

7.8.1. Alaska Penetrometer Test

The Alaska Penetrometer Test (APT) dynamic penetrometer method uses a 2.5" O.D. heavy wall steel drill rod with a blunt tip, driven by a 340 pound drive hammer. Blows per foot are recorded and the blow counts are used to assess relative differences between test locations. The Department typically uses the APT dynamic method alternating with drilled test holes at bridge and other structure sites. While this test method does not correlate directly with soil properties it may be used to find bearing layers and as a quick, inexpensive means of filling gaps between conventional test holes.

7.8.2. Cone Penetrometer Test

Full-sized static and dynamic cone penetrometers (CPT) are a common sounding method, although not used often in Alaska. In this test, a cone tipped rod is driven with hammer blows or pushed into the soil using a reaction weight. Instrumentation in the cone tip and rods provides measures of tip resistance, sidewall friction, pore water pressure and other characteristics that can be correlated to soil properties. The CPT is generally used for fine-grained cohesionless and cohesive soils. One disadvantage of this investigation method is that no samples are obtained.

7.8.3. Dynamic Cone Penetrometer

A small-scale cone penetrometer test (Dynamic Cone Penetrometer or DCP) is in use in Alaska for shallow investigations, primarily in support of pavement design and management programs. The ASTM test method (ASTM D6951) describes the procedures for the test which provides strength values for in situ soils. The DCP is a portable field test that requires a relatively minimal amount of equipment. The DCP provides a direct correlation with the more expensive and time-consuming California Bearing Ratio for use in pavement design methods.

8.0 GEOPHYSICAL METHODS

Geophysical methods can sometimes provide general subsurface profile information, such as the depth to bedrock, depth to groundwater, and the extent of granular/rock borrow areas, peat deposits, or subsurface anomalies. Geophysical methods of exploration can provide a rapid and economical means of supplementing subsurface borings and test pits. These exploration techniques are most useful for extending the interpretation of subsurface conditions beyond what is determined from small diameter borings. A limitation of these techniques is that no samples are recovered. It must be emphasized that geophysical methods might not be capable or successful in all situations and should be carefully evaluated to determine whether any methods are appropriate for the specific project requirements and site conditions. A 2002 study for the Department using seismic refraction, ground penetrating radar and electrical resistivity, performed for materials sites in the Northern Region indicated that success of geophysical methods was very dependent on the operator and on the surface and subsurface conditions at the specific site under investigation.

"*Geophysical Technology for Identification of Geology/Geophysical Characteristics", AKSAS Project No. 74736* (*Task 2 Report – Evaluation of Geophysical Methods – Field Program, Golder Associates, September 23, 2002.)*

The reliability of geophysical results can be limited by several factors, including the presence of groundwater or frozen soil, presence of organic soil layers at the surface, non-homogeneity of soil stratum thickness, gradation or density, and the range of wave velocities within a particular stratum. Subsurface strata that have similar physical properties can be difficult to distinguish with geophysical methods. Because of these limitations, for most design applications, geophysics should be considered a secondary exploration method to drilling, and should generally be accompanied by conventional borings. A professional experienced in the particular method should conduct the investigation and interpret the field data. In many cases, it may be best to provide only the field data along with a discussion of the limitations of the methodology and the data and leave interpretation of the data to the reader. For additional information, see ASTM D 6429, FHWA, "*Application of Geophysical Methods to Highway Related Problems," FHWA-IF-04-021 (2004), "Geophysical Exploration for Engineering and Environmental Investigations,"* U.S. Army Corps of Engineers, Engineering Manual EM-1110-1-1802 (1995).

Geophysical techniques can be grouped into two categories: 1) methods conducted from the ground surface, and 2) methods conducted in or between boreholes. Passive methods include the use of gravimetric, electric, magnetic, thermometric, and nuclear techniques. Active methods include the use of seismic, acoustic, electric, electromagnetic, and nuclear techniques. The geophysical methods most commonly used for transportation engineering purposes in Alaska include:

8.1. Seismic Refraction and Reflection

These methods rely on the fact that seismic waves typically travel at different velocities through different materials. The times required for an induced seismic wave to travel from the energy source to vibration detectors (geophones) after being refracted or reflected by the various subsurface materials are measured. The measured seismic velocities are used to interpret certain material properties and the thickness of the units that comprise the subsurface profile. Seismic refraction is limited to profiles in which velocities increase with depth. Seismic investigations can be performed from the surface or from various depths within borings. For cross-hole seismic techniques, see ASTM D 4428. For the seismic refraction method, refer to ASTM D 5777. See Section 19 - Specifications and Standards

8.2. Electrical Resistivity

This method is based on the differences in electrical conductivity between subsurface strata. An electric current is passed through the ground between electrodes and the resistivity of the subsurface materials is measured and correlated to material types. Several electrode arrangements have been developed, with the Wenner (four equally spaced electrodes) being the most commonly used in the United States. See Section 19 - Specifications and Standards - ASTM D 6431.

8.3. Ground Penetrating Radar (GPR)

The velocity of electromagnetic radiation is dependent upon the material through which it is traveling. GPR uses this principle to analyze the reflections of radar signals transmitted into the ground by a low frequency antenna. Signals are continuously transmitted and received as the antenna is towed across the area of interest. The interpreted results yield a profile of the subsurface material interfaces. The depth of signal penetration is limited in finer grained soils. See Section 19 - Specifications and Standards - ASTM D 6432.

9.0 SOIL SAMPLING

Using existing soil sampling techniques, there is no way to obtain a truly "undisturbed" sample. The selection of the correct sampling tool, drilling technique, and borehole stabilization method should be based on the soil type being sampled and the subsurface conditions. The incorrect preservation and shipment of samples may further disturb the specimens to the point where they are no longer usable.

Laboratory tests on samples recovered during field investigations are the means by which field identification of samples is confirmed. Lab tests also are critical for "proving up" the quality of borrow materials used during construction. "Undisturbed" samples are taken for determination of critical soil characteristics. Great care should be taken to assure that samples are delivered safely to the testing laboratory in as close as possible to their natural condition. Samples should be carefully and completely identified with a waterproof means of identification. Samples used for natural moisture content must be sealed to prevent moisture loss. Samples that may contain organics should also be sealed to allow for wet preparation methods.

Common methods of soil sampling during field explorations include those listed below. All samples should be properly preserved and carefully transported to the laboratory to maintain sample integrity. See Section 19 - Specifications and Standards - ASTM D 4220. Obtain samples that represent each geologic material encountered. In test holes, take samples at five-foot intervals, or where the stratigraphy changes.

Exercise caution in sampling below the groundwater surface. Sampling below water level may result in washing out fines and non-representative samples. In sandy soils below water table the soil may readily "heave" into the casing or hollow auger stem. It may be necessary to keep a head of water inside the casing or auger stem to prevent heave. It may be difficult to distinguish between disturbed material below the auger or casing tip and undisturbed in-situ soil. Note any apparent difficulty in obtaining samples and note any concerns about whether the samples and blow counts from standard penetration tests are representative.

For materials that are significant to project design and construction, take as many samples as needed to fully characterize the material. The size and type of samples required is dependent on the testing needed, the relative sizes of the soil particles (larger particle sizes require larger samples) and the confidence in the understanding and interpretation of the subsurface conditions. The field geologist should err on the side of taking more samples than are necessary. Some samples may be left untested.

9.1. Disturbed Sampling Methods

9.1.1. Bag (Bulk) Samples

Bag samples are obtained from auger cuttings or test pits. The quantity of the sample depends on the type of testing to be performed, but can range up to 50 pounds or more. Testing performed on these samples could include classification, gradation, moisture content, organic content, maximum density, quality tests including LA Abrasion, degradation, Nordic ball abrasion, etc.
R Value, pH and resistivity (corrosivity) may also be tested from bulk samples. A portion of each sample to be tested for moisture content should be placed in a sealed container such as a plastic bag, tin or jar in order to accurately determine the natural moisture content. Refer to AASHTO, ASTM and Alaska Test Methods for sample sizes. See Section 19 - Specifications and Standards.

9.1.2. Cuttings Samples

These are highly disturbed and sometimes altered (in particle size) samples obtained from drilling operations. Samples from solid stem auger test holes are recovered from drill cuttings spun to the surface from the annulus between the auger and the test hole wall. These are highly disturbed samples that may have had particles crushed and broken down, may have increased fines content and may be mixed with several stratigraphic layers. These problems are exacerbated in frozen ground conditions when advancing the augers takes much longer and the augers grind on the soil cuttings for long periods of time. Hollow stem augers are used to allow less disturbed samples to be recovered from below the auger tip. Cuttings samples should only be used to try to identify major changes in lithology. The depths from which cutting samples are obtained can only be roughly estimated, but can be aided by changes in drilling action.

9.1.3. Standard Split Spoon Sampler

Also known as a split barrel sampler or split tube sampler, this method is used in conjunction with the Standard Penetration Test (SPT). See Section 19 - Specifications and Standards – ASTM D1586 or AASHTO T 206. The standard SPT sampler is an 18 inch long 2-inch (O.D.) split tube, threaded on each end to accommodate adapters and a driving shoe. The sampler is driven into the soil with a 140-pound hammer free-falling 30 inches. After the sampler has been driven 18 inches, it is withdrawn and the sample removed. The Department routinely uses longer samplers (24 inch) to obtain larger samples.

The sum of the number of hammer blows required to drive the sampler the second and third six-inch increments is the standard penetration value referred to as the uncorrected “N” value (blows per foot). N values can be correlated to a number of different design parameters including relative density, angle of withdrawal, friction and shear strength. The Department periodically calibrates the hammers and samplers with a pile driving analyzer. Consultants providing services to the Department must also conduct this calibration. A suggested calibration interval is every two years.

The sample should be immediately examined, logged and placed in sample jar for storage. These are disturbed samples, and are not suitable for strength or consolidation testing. They are adequate for moisture content, gradation, and Atterberg limits tests, and valuable for visual identification. See Section 19 - Specifications and Standards - ASTM D 1586 or AASHTO T-206.

9.1.4. Larger Diameter Split Tube Samplers

California Modified Sampler (CMS) or Dames & Moore Sampler are two names for the same sampler - split barrel samplers that are similar to the split spoon samplers used with the SPT test. The CMS is a 3-inch (O.D.) split barrel, which is driven into the soil normally with a 300-pound hammer, free-falling 30 inches. It is threaded at both ends for accepting inner rings that are 2.36-inches I.D. by .98-inches high. These ring samples can be used for various soil property tests; however, they are considered disturbed samples. Generally, this sample is used to facilitate sample recovery in coarser-grained material due to its larger diameter as compared to the standard split spoon (SPT) sampler. Blow counts obtained from the penetration of this sampler are sometimes correlated to SPT values. However, these correlations are not standardized, and engineering judgment should be applied when they are used.

9.2. Partially Disturbed Sampling

The Denison sampler is a large diameter, double tube core barrel, which is effective in obtaining 5-7/8-inch diameter samples of hard cohesive soils, soft rock, cemented soils, and soils containing gravel that cannot be obtained with push-type samplers. This sampler consists of a rotating outer barrel with cutting teeth on the bottom and an inner barrel with a smooth cutting shoe. The sample is captured in a very thin inner liner, which facilitates retrieval and handling. Core catchers should not be used unless absolutely necessary to retain the soil sample. Care should be taken not to overdrive the sample to avoid disturbance.

The Pitcher sampler is also a double tube core barrel and is effective for the same soils as the Denison sampler. The primary advantage the Pitcher sampler has over the Denison sampler is that the Pitcher sampler automatically adjusts the amount by which the inner barrels lead the cutting bit as the hardness of the soil varies. The Pitcher sampler can also accept a standard thin wall sample tube in lieu of the inner barrel/liner.

The Sprague & Henwood sampler is a triple tube sampler designed for sampling overburden materials, and is an improvement over the Denison and Pitcher samplers.

9.3. Undisturbed Samples Using Thin Wall Samplers

9.3.1. Shelby Tube Sampler

This thin wall sampler is suitable for sampling all cohesive soils. Difficulty may be encountered in sampling very soft and wet soils that tend to drop out of the sampler. Damage to the sampling tube (resulting in a poor sample) sometimes occurs when sampling hard, cemented, or gravelly soils. Other tools are available for these difficult conditions. Good samples must have sufficient cohesion to remain in the tube during withdrawal. Cohesionless soils will likely need improved sampling methods, as described below.

A Shelby Tube is a thin walled steel tube, usually 3 inches (O.D.) by 30 inches long. The beveled cutting edge of the Shelby tube is slightly smaller in diameter than the inside of the tube, which allows the sample to slide easily in the tube with little disturbance. The tube is pushed into the soil with a fairly rapid, smooth stroke a distance of 24 inches and then retracted. If sample recovery becomes difficult, i.e., the sample stays in the ground, the tube should be left in place for roughly 10 to 15 minutes. During this waiting period, the sample will swell slightly to fill the sampler, increasing the likelihood of retaining the sample when the tube is retracted. This method produces a relatively undisturbed sample. Care should be taken to not over push the sample to avoid disturbance. The ends of the Shelby Tube should be properly sealed immediately upon withdrawal. See Section 19 - Specifications and Standards - ASTM D 1587 or AASHTO T 207. The sample is suitable for unit weight, strength and consolidation tests.

9.3.2. Piston Samplers

There are several varieties of piston samplers. These are not often used in Alaska practice. In this method, a piston is positioned at the bottom of the thin wall tube while the sampler is lowered to the bottom of the hole, thus preventing disturbed materials from entering the tube. The piston may be locked in place on top of the soil to be sampled. A sample is obtained by pressing the tube into the soil with a continuous, steady thrust. Sampler types include the stationary piston, the floating piston sampler, the retractable sampler, and the hydraulic (Osterberg) piston sampler fixed-sampler. Samples generally have a better recovery ratio than those from the Shelby Tube method.

9.4. Undisturbed Block Samples

Block sampling is a reliable method for minimizing sample disturbance. However, because gaining access to the zone to be sampled can be limited by the depth of overlying material and because the sampling process is fairly rigorous and time consuming, most samples are obtained via drilling. Samples can be carefully carved from test pits for special testing in the laboratory. The advantage of block samples is that the test pit offers a broad area to detect critical materials and ability to obtain the exact amount of the desired material. The size of the sample should be large enough to perform planned laboratory testing.

For block samples, the dimensions of the sample are controlled by the thickness of specimen of interest and by the size of the box used to hold the sample. A column of the soil is carefully exposed so that, when the sample box is centered over the column, a one-inch open space is left on all sides of the sample and a half-inch space is left at the top. The empty areas are then filed with microcrystalline wax. After the wax congeals, the top of the box is attached and the sample is carefully detached from the underlying ground with a spade. The sample is inverted and a half-inch of material is removed. This area is filled with wax. After it congeals, the bottom of the box is attached and the sample is ready for transport to the laboratory. The block samples should be carefully handled and should be protected with a moisture-proof barrier (i.e., plastic wrap and wax) and placed within a sturdy and stable container so the sample is fully supported/constrained.

10.0 ROCK SAMPLING AND CORING

Rock samples can be obtained from outcrops, test pits, or rock cores through drilling operations. Samples obtained from outcrops or test pits are termed “grab samples”. Typically, the sample sizes for classification and identification should be small enough to carry, but large enough to be tested in a point load device or utilized as hand specimens. For bulk samples for quality testing, sample sizes may be 200-300 pounds. Refer to AASHTO, ASTM and Alaska Test Methods for sampling methods and test methods for required sample weights. See Section 19 - Specifications and Standards. These samples should be labeled, and the location where they were obtained should be identified on a site map.

For rock coring, a sampling barrel is advanced through rock by the application of downward pressure during rotation. Rock cores are obtained using core barrels equipped with diamond or tungsten carbide tipped bits. There are three basic types of core barrels: single tube, double tube, and triple tube. Because single tube core barrels generally provide poor recovery rates, their use is not recommended. Double and triple tube core barrel systems, which are described below, are preferred. To protect the integrity of the core from damage (minimize extraneous core breaks), split inner tube swivel-type core barrels are preferred.

Circulating water removes ground-up material from the hole, while also cooling the bit. The rate of advance is controlled to obtain the maximum possible core recovery. A continuous rock core sample may be obtained with this drilling method. Core drilling is the most widely used method to explore subsurface rock formations. It is preferable to perform rock coring with as large a core barrel as possible in order to optimize core recovery and minimize core damage due to drilling action. An HQ-Size System is recommended where possible. The Department routinely uses both HQ and NQ sizes. See Section 19 - Specifications and Standards - ASTM D 2113 or AASHTO T 225.

It is essential to make every possible effort to obtain high quality core and to ensure that the maximum amount of data is obtained from the core and the drilling program. Core drilling is expensive and usually constitutes a major expenditure of effort in a geotechnical investigation. The field geologist should work closely with the drilling crew so that everyone understands the goals of the drilling program and the expectations for the work. The purposes for coring may be as simple as confirming that the test hole has intercepted bedrock and as complex as determining the structure and orientation of discontinuities of the rock mass and determining the characteristics of the groundwater regime. The quality of the core is a function of the skill of the driller and the type and condition of the drill rig and tooling used. The equipment must be selected carefully to maximize the return on the investment in recovered high quality core and other geotechnical information. When using a solid inner barrel, a hydraulic ram or pumped drilling fluid should be used to expel the core from the core barrel into an appropriate “V” shaped holding tray. Under no circumstances should the core barrel or inner tubes be subjected to hammer blows or other abuse to remove the core. See Section 19 - Specifications and Standards - ASTM D 2113 or AASHTO T 225.

10.1. Double Tube Core Barrel

The double tube core barrel consists of an inner core barrel tube and an outer tube that serves as the drill rod. The cutting end of the core barrel is equipped with a diamond or tungsten carbide drill bit. As coring progresses, fluid is introduced downward between the inner and outer tubes to cool the bit and to wash ground-up material to the surface in the annulus between the core barrel and the wall of the drilled hole. The inner tube protects the core from the highly erosive action of the drilling fluid. In a rigid type core barrel, both the inner and outer tubes rotate. In a swivel type, the inner tube remains stationary while the outer tube rotates. Several series of swivel type core barrels are available. The size of core that can be recovered is governed by the size of the drill bit. For standard applications, these will vary from 1.062-inch up to 3.270-inch O.D. Larger diameters generally obtain better core recovery in softer, highly erodible or highly fractured materials. The minimum diameter core obtained should be no less than A-size (1.062- to 1.185-inch O.D.). As a rule, it is recommended that a core size of H (2.406- to 3.000-inch O.D) be routinely used.

10.2. Triple Tube Core Barrel

Triple tube core barrel systems are similar to the double tube system described above, but include an additional inner liner. Two types of inner liners are used to retain the core, a clear plastic solid tube or a thin metal split tube. This barrel best preserves recovered fractured and poor quality rock cores in their in situ state.

10.3. Core Logging

A maximum amount of useful data will be collected during the drilling program if the field geologist uses a systematic method for logging, photographing and handling the core. Photographs should include a card describing the details of the core – project, test hole number, depth, date, etc. When logging core, use standard terminology from Department guides and standard references such as those produced by the International Society of Rock Mechanics and referenced in the Department's *Alaska Field Rock Classification and Structural Mapping Guide*. The use of ambiguous, vague and undefined terms is not helpful. Note that this guide does not provide step-by-step detailed instructions for logging core. Use the appropriate references for guidance in describing rock. (e.g., Travis, *Classification of Rocks)* Each geologist must develop and follow a routine that includes standard methods and results in standardized test hole logs and useable data.

Use current Department log forms for recording data in the field. Logging notes must include the basic data for all rock descriptions and such other information as may be required on a project-specific basis. The logs must include information about the test hole number, test hole location, collar elevation, water table, drilling methods, drill rig, tooling, core barrel type and size, weather, field crew, description of the soil and rock encountered including notes on percent recovery, RQD, fractures per foot, weathering, structure, presence of discontinuities and their characteristics, orientation of discontinuities with respect to the axis of the core, strength, color, grain size or crystal size, and rock type.

When the cores are delivered to the office or laboratory, the field geologist and others may make further examination of the cores and take additional photographs. As a result of these further examinations, the field geologist (and no one else) may make additional notes on the test hole logs. Test results for quality tests and petrographic analysis may also be added to the field logs for inclusion in the final drafted logs produced using gINT.

Rock cores, and certain types of drive samples, are usually the only physical sample evidence of the subsurface profile that remain available for a given site. In order to maintain the integrity of this record, it is beneficial to photograph the samples before parts are removed for testing purposes, or drying, or other disturbance occurs. Photographs provide for the preservation of the sampling record in the event that vandalism, negligence, or accident cause loss or destruction of the physical sample. It also may be desirable to photograph specific sampling techniques and equipment for future reference.

Although it is much more preferable to photograph samples under controlled conditions, including supplementary lighting and camera support devices, this may not be available under field conditions. Care should be given to optimize the size of the core within the photograph in order to show as much detail as possible. Digital color photographs are recommended. For more details, refer to the AASHTO Manual on Subsurface Investigations, Section 7.10.

10.4. Core Handling

Rock cores from geotechnical explorations should be handled with great care. Obviously, the cores are expensive to obtain and mishandling can result in loss of important data. The cores should be stored in structurally sound boxes made for the purpose. Wooden or metal boxes with hinged or fitted lids, waxed cardboard and plastic boxes are all acceptable. Once the core has been logged and photographed inside a split liner or immediately after extruding into a tray, the core can be carefully transferred to the core boxes. It may be necessary to break intact core to fit the boxes, but this should be avoided, if possible. Breaks in the core that occur during or after the core is transferred to the boxes should be refitted and marked to so indicate. Lay out core in the box in the same orientation as text in a document – left to right, top to bottom. Use wooden spacer blocks with depth markings to denote top and bottom of core and core loss. Use enough blocks to make up the entire length of the run. Mark the core boxes with permanent marker on the lid and both ends to show project name and number, structure name and number, test hole number, date, depths, and box number. Refer to "Subsurface Investigations" §3.2 and ASTM D 5079 for practices of preserving and transporting rock core samples. See Section 19 - Specifications and Standards.

10.5. Oriented Cores

In some rock slope or rock foundation applications, it is important to understand the precise orientation of rock discontinuities for the design. Orienting recovered rock core so it can be properly mapped and evaluated, as though it were still in place, requires special core barrels. In the past, core barrels were weighted on one side and used in an inclined boring. The heavier side of the barrel generally stayed on the down side of the hole allowing the core to be properly oriented when removed. Other techniques, such as using clay to make an impression of core run ends, have also been used for this purpose. Currently, specialized core barrels that scribe a reference mark (line) on the side of the core as it is drilled are more routinely used. Special recording devices within the core barrel relate known azimuth orientations to the reference mark so that when the core is subsequently removed from the core barrel, it can be oriented to the exact position it occupied in situ. These specialized core barrels are relatively expensive, and require additional training to use them properly and interpret the results.

10.6. Downhole Imaging

Test holes can be accessed with digital or film cameras to visually inspect the condition of the sidewalls and distinguish changes in lithology. Recently, digital down-hole cameras have been used in conjunction with computer programs that analyze digital images to identify fracture zones, shear zones, joint patterns, and other discontinuities and their orientations in rock core holes. Refer to AASHTO Manual on Subsurface Investigations, Section 6.12.

11.0 FIELD TESTING OF SOIL AND ROCK

The Department routinely conducts only a few soils and rock tests in the field. See "*Alaska Field Guide for Soil Classification and Alaska*" and "*Alaska Field Rock Classification and Structural Mapping Guide.*" For cohesive soil, we may conduct pocket penetrometer or Torvane tests on disturbed or undisturbed samples. Field geologists should be familiar with the pocket penetrometer and the Torvane and should routinely carry these instruments on investigations where cohesive soil strength may be an issue. We also test peat, organic soil and soft cohesive soil using full size vane shear test apparatus and methods. Our drill rigs routinely carry torque wrenches suitable for use in full size vane shear testing. The field geologist is responsible for making sure the vane shear apparatus is present when needed.

Occasionally, there may be reason to perform point load tests on rock samples in the field. Statewide Materials has a point load testing device suitable for either field or laboratory testing. Only those geologists who have been trained in the test method and the use of the testing equipment should attempt to run point load tests. Installation of in situ testing devices and equipment is discussed below.

12.0 EXPLORATION DIFFICULTIES

As discussed in the AASHTO Manual on Subsurface Investigations Section 7.8, limitations and difficulties may be encountered during explorations, which are common to all exploratory techniques. They are usually a result of site-specific geologic conditions and/or a function of the wrong equipment or technique being utilized. Several of these limitations and difficulties are described below.

12.1. Improper Drilling Techniques

The Department stresses the importance of the quality of geotechnical data and samples recovered during field investigations. Geotechnical staff must be aware of potential drilling problems and how to avoid them in order to properly obtain field information and samples. See AASHTO Manual on Subsurface Investigations, Section 7.12 and NHI 13321, Section 3.5. The following is a partial listing of common errors:

- **Failure to clean slough and cuttings from the bottom of the borehole.** The driller should not be allowed to sample through slough. Preferably the driller should reenter the boring and remove the slough before proceeding.
- **Jetting to advance a split barrel sampler to the bottom of the boring.** This method should not be used at any time as it produces unnecessary disturbance of soil in the sampling zone.
- **Poor sample recovery.** This may be due to improper use of sampling equipment or procedures and many other factors. When poor recovery is affecting a sampling program the field geologist should cease operations and confer with the drilling crew and supervisor to assess whether the sampling methods should be changed.
- **Forcing recovery of thin-walled tube samples by overdriving the sampling barrel to obtain a sample.** When sampling soft or noncohesive soils with thin wall samplers (i.e., Shelby Tube), it may be very difficult to recover an undisturbed sample because the sample will not stay in the barrel. The driller should be clearly instructed not to force recovery of thin wall tube samples.
- **Improper sample types or insufficient quantity of samples.** The field geologist and driller should be given clear instructions regarding the sample frequency and types of samples required. The field geologist and driller must keep track of the depth of the borings and the materials being recovered at all stages of the boring to confirm the sampling interval and obtain appropriate samples of changing soil and/or rock formations.
- **Improper hole stabilization.** Rotary wash borings and hollow-stem auger borings below the groundwater level require a head of fluid to be maintained within the drill stem at all times to prevent materials from surging up (“heaving”) into the casing/augers. When the drill rods are withdrawn, or as the hollow stem auger is advanced, this fluid level will tend to drop, and must be maintained by the addition of more drilling fluid. In some formations and particularly in alluvial soil in active flood plains, the heaving problem can be severe. For this reason the Department’s foundation investigations are not drilled with hollow stem auger because it is more often subject to the heave problem. Instead, foundation investigations are normally drilled with casing and rotary methods to minimize heave and improve the quality of samples. Use of drilling mud such as bentonite is recommended in heaving conditions, particularly for foundation investigations where sample quality is critical.
- **Sampler rods lowered into the boring with pipe wrenches, rather than hoisting plug.** The rods may be inclined

and the sampler can hit the boring walls, filling the sampler with debris.

- **Improper procedures for performing Standard Penetration Tests.** The field geologist and driller must assure that the proper weight and hammer drop are being used and that automatic hammers are maintained and adjusted frequently. The Department uses automatic hammer systems on all foundation projects and as the first choice for centerline projects. In remote areas with difficult access where small drills without auto hammers must be used or where portable equipment must be used, safety hammers are acceptable, so long as AASHTO/ASTM methods are followed. See Section 19 - Specifications and Standards – ASTM D 1586 or AASHTO T-206.

12.2. Sample Recovery

Occasionally, sampling is attempted and little or no material is recovered. In cases where a split barrel or some other type of sampler is used to recover a disturbed sample, it is appropriate to make a second attempt to recover the material immediately following the first failed attempt. In such instances, the sampling device may be modified to include a retainer basket, a hinged trap valve, or other measures to help retain the sample.

In cases where an undisturbed sample is desired, the field supervisor should direct the driller to drill to the bottom of the attempted (disturbed) sampling interval and repeat the sampling attempt. The sampling method should be reviewed, and the sampling equipment should be checked to understand why no sample was recovered (such as a plugged ball valve). It may be appropriate to change the sampling method and/or the sampling equipment, such as waiting a longer period of time before extracting the sampler, or extracting the sampler more slowly and with greater care, etc. If recovering a sample at a specific depth is necessary, a second boring may be advanced to obtain a sample at the prescribed depth using the improved technique.

Generally, sample recovery less than 10% is considered inadequate for representative sampling. However, the criteria may be waived for the specific situation (i.e., in thick, uniform deposits, recovery considerably less than 10% may be acceptable).

Various sampling devices equipped with check and pressure release valves, sample retaining springs, baskets and lifters should be used or determined to be operational. Occasionally, drillers will modify equipment to meet their specific drilling technique, which may have major effects on sample recovery.

12.3. Sample Disturbance

As discussed above in §9.0 sampling disturbance is a critical issue. Sample disturbance is dependent principally on sampling methods. Sampling methods may be dictated by drilling methods that are in turn dictated by cost constraints, accessibility to sites and numerous other factors. In addition operator error may result in undue disturbance of the samples. The field crew should be made aware of the importance of the samples and trained in sampling techniques designed to maximize sample recovery and limit disturbance. Although the Department does not often take “undisturbed” samples, the situations that require them warrant the expenditure of considerable time and effort to obtain and keep them as undisturbed as possible.

12.4. Obstructions

The termination of an exploration above the required design depth due to boulders, fill material, excessively dense materials, and other obstructions may occur during any investigation. When this occurs, it usually implies that the correct exploration method might not have been selected for the anticipated subsurface conditions. Specialized tools and equipment are available to increase the capacity of conventional drilling equipment. In some cases, obstacles are anticipated and a solution is to redrill the boring a few feet away.

12.5. Problematic Geologic Conditions

Special consideration and care must be taken when selecting the proper sampling equipment, obtaining the sample, and evaluating the performance of problematic geologic conditions. A list of these problems includes, but is not limited to the following:

- Organic Soils and deep peat deposits
- Frozen soil/permafrost and interpretation of gradation of soils
- Metastable soils (loess, alluvial deposits & mud flows)
- Variably or highly weathered or broken rock
- Faults and joints
- Asbestos-containing rock
- Sensitive or quick clays
- Unstable ground (landslides)
- Unstable rock exposures
- Meander loops & cutoffs
- Very dense glacial soils
- Boulders and cobbles
- Loose, granular soils
- Noxious or explosive formation gases
- Fill Material
- High groundwater and saturated soils
- Sampling below water table
- In coarse gravelly deposits, recovery of representative sample

12.6. Groundwater Conditions

Groundwater can affect the stability of the borehole, especially in cohesionless soils (gravel, sands, and some silts). Water flowing into the hole could cause caving and quick (liquefying) conditions, which would artificially reduce the SPT blow counts being measured, as well as make drilling and sampling progress difficult. Casing or drilling muds such as bentonite or polymers are typically used to stabilize the borehole in such situations. Use of hollow stem auger in these situations is discouraged because formation water often flows freely into the augers both through joints and through the auger tip, causing sampling problems and disturbance of the soil below the auger tip.

Where precise water level data is important, the affects of drilling water additives (bentonite and other materials) on the permeability of certain soils should be evaluated. In soils with lower permeability and flow rates, such as in silt or silty sand, the use of bentonite mud can dramatically limit the movement of water by coating the walls of the boring. A bentonite coating can reduce the likelihood that piezometer readings will represent true ground water levels or that the water levels in the boring will respond accurately to natural groundwater changes. In these situations, alternative drilling techniques, such as using casing, should be considered to help produce a stable borehole without relying on additives that can affect permeability. Following drilling, especially whenever low permeability conditions exist, staff should wait for an adequate period of time for the water level to reach equilibrium within the borehole before initiating groundwater measurements.

It is preferred that a groundwater reading should be made 24 hours after completing the boring to allow the water level to reach equilibrium. In fine-grained soils, depending on the permeability, even this period may not be adequate. The installation of permanent or temporary observation wells, which provide access for measuring the groundwater table over a longer period, can eliminate this difficulty. Observation wells are generally an inexpensive safeguard against erroneous assumptions regarding the presence and behavior of the groundwater conditions. Proper installation procedures for instrumentation are discussed in Section 12.0 below.

12.7. Contaminated Sites

The Department does not conduct hazardous materials explorations, testing, or evaluations. If contaminants are expected in the exploration area, the Department will hire a Consultant with expertise in this field to conduct the exploration. When contamination is observed or encountered during drilling operations, drill crews will suspend operations and without delay contact management and, if required by regulations, the Department of Environmental Conservation or other agencies for instructions on the appropriate response. Initial actions may require sealing the boring and demobilization from the site.

There are many problems and issues inherent in sampling and handling contaminated soils. The U.S. Environmental Protection Agency (EPA) document number 625/12-91/002 titled "Description and Sampling of Contaminated Soils – A field Pocket Guide" contains guidelines, background information, and a list of useful references on the topic.

Some signs of possible contamination are:

- Prior land use (e.g., old fill, landfills, gas stations, military installations, etc.)
- Stained soil or rock
- The apparent unnatural lack of vegetation or presence of dead vegetation and trees must be considered in the local site context. While in some places this could indicate contamination, in others it is just normal frozen ground conditions.
- Odors. It should be noted that highly organic soil may have a rotten egg odor that should not necessarily be construed as evidence of contamination. However, this odor may also be indicative of highly toxic hydrogen sulfide. Drilling crews should be instructed about this concern.
- Presence of liquids other than groundwater or pore water
- Signs of prior ground fires (e.g., at landfill or building sites). Established landfills will emit methane gas, which is colorless and odorless, and in high concentrations in the presence of sparks or fire will explode.
- Presence of visible elemental metals (e.g., mercury)
- pH is Low (<2.5) or High (>12.5).

Field crews who observe these signs should note them and report them as required. If an immediate safety hazard is apparent, the field crew should take whatever steps are appropriate to avoid injury to themselves or the public.

13.0 INSTRUMENTATION INSTALLATION

Geotechnical instrumentation may be required, depending on the scope of the project, the design elements, and the site conditions. Many geotechnical investigations include the installation of in situ testing devices including standpipes for groundwater measurements, piezometers, standpipes for installation of thermistor temperature monitoring, and slope indicator tubing. The geologist or geotechnical engineer in charge of such installations should work closely with the drilling crew to discuss the procedures in advance so that these installations are constructed properly.

Selecting the proper instrumentation and installing it correctly are important to insure that high quality geotechnical data is obtained at a reasonable cost. A discussion of the types of instruments and the proper techniques to use during installation may be found in various standard references. Some of the equipment and methods may be found in manufacturers' literature. A discussion of selected instrumentation installation procedures is given in Appendix A of the AASHTO Manual on Subsurface Investigation. An in-depth discussion on the installation of Inclinometer Casings is given in Section 4.1.5 of Chapter 11 of the TRB Special Report 247, Landslides: Investigation and Mitigation. Such summaries are not intended to be a strict guideline, nor are they all inclusive of the variety of methods and procedures that may be used for instrumentation installation. Since, as specific operational details and subsurface conditions vary, the installation techniques may need to be customized. Experience with standard applications and procedures are important before significant modifications are attempted.

14.0 BOREHOLE BACKFILLING/SEALING

Once boreholes or test holes have been completed they shall be backfilled or sealed, depending on circumstances. Where groundwater is present and there is the possibility of damage to an aquifer, the test hole should be sealed to prevent entry of surface water into the test hole and to prevent mixing of multiple groundwater layers or aquifers. Two references offer guidance regarding completion of test holes: AASHTO R-22-97, "*Decommissioning Geotechnical Exploratory Boreholes*" and National Cooperative Highway Research Program Report No. 378, "*Recommended Guidelines for Sealing Geotechnical Holes"* (1995).

14.1. Backfilling Exploratory Test Holes

All test holes should be properly backfilled at the completion of the field exploration. This is typically required for safety considerations and to meet the requirements of environmental permits. Generally, exploration test holes are re-filled with cuttings brought to the surface in the drilling operation. Backfill may also include bentonite chips, pellets or powder that may be placed directly in the borehole or mixed with soil cuttings and placed in the borehole.

Holes in pavements and slabs should be filled with quick setting concrete, or with asphalt concrete, as appropriate. Backfill for holes in soil surfaces should be mounded accommodate settlement and to drain surface water away from the borehole.

Generally, exploration pits can be backfilled with the spoils generated during the excavation. The backfilled material should be compacted to avoid excessive future settlements. Tampers or rolling equipment may be used to facilitate compaction of the backfill. If possible, vegetation removed from the test pit are should be saved and replaced at the surface of the test pit site. Excavations within existing roadways should be backfilled with granular material and compacted in lifts to restore subgrade support.

14.2. Sealing Exploratory Test Holes

Sealing test holes may be necessary to prevent contamination/commingling of groundwater by infiltration from the surface and mixing of groundwater aquifers penetrated by the boring. Sealing boreholes may be accomplished using grout mixtures, and various combinations of cement and bentonite as chips, pellets or powder. The seal may be limited to near the surface to prevent surface contamination from entering the borehole and may extend the full depth of the hole to create a permanent hydraulic barrier in the hole. In boreholes filled with water or other drilling fluids, tremied grout pumped through drill rods or other pipes inserted into the borehole will displace the water or drilling fluid. Provisions should be made to collect and dispose of all displaced drill fluid and waste grout appropriately. Extensive information on sealing and grouting is provided in the NCHRP report referenced above. The grout mixture may be cement, sand and water and may be bentonite mixed with water or water and cement. As noted above, bentonite may also be placed directly in the borehole or mixed with soil cuttings and placed in the borehole.

14.3. Seal Verification Report

Upon completion of sealed test holes, the field geologist should make a record for the project files of the details of the sealing process. A form similar to that shown in Appendix F should be used to record the methodology.

15.0 SAMPLE PRESERVATION AND SHIPPING

Samples of soil and rock are obtained for classification and subsequent testing to determine their various engineering properties. Rock and soil samples represent essential physical information concerning the subject site. These samples are obtained at a considerable cost to the Department and the project. Samples must be preserved, stored, and shipped under conditions that will minimize chances of disturbance or loss. More details are provided in AASHTO Manual on Subsurface Investigations, Section 7.9.

All soil samples and rock cores must be clearly, accurately, and permanently labeled to show all pertinent information which may be necessary in identifying the sample or core, and in determining the character of the subsurface condition.

The preserving, protecting and transporting of samples may be accomplished using the methods described below; but, in practice, any method that satisfactorily protects the sample from such things as shock, detrimental temperature changes (such as freezing or thawing), and moisture loss may be used.

- All samples should be collected from the borehole sampling sites on a daily basis and transported to the field project office or a suitable alternate location. Samples should not be left on a drill rig or in the back of a truck longer than necessary to get to a secure location.
- Rock core and thin wall tube soil samples should never be transported away from the field site in other than specially constructed wood, metal, plastic, or fiberglass shipping containers specially designed to protect them from shock and vibration.
- Samples intended for laboratory testing should not be held at the site in excess of one week.
- All sample containers should be identified as to borehole, depth interval, box number of total sequence, and project number.

16.0 SAMPLE TESTING PROGRAMS

Sample testing programs are tailored to individual projects, each of which will have unique testing requirements depending on the project. Field classifications of rock and soil samples are accomplished following the Department's *Field Soil Classification Guide* and *Field Rock Classification and Structural Mapping Guide*. Laboratory testing is performed to confirm field classifications. Minimum testing requirements will include index and classification testing of representative samples to confirm field classifications. In addition to classifying the soils and rock encountered, other tests may be conducted to evaluate the quality and usability of the soil and rock. Additional tests routinely run include proctor analysis for maximum density and optimum moisture and L.A. Abrasion, Nordic Ball Abrasion, Sodium Sulfate Soundness and Washington Degradation tests for assessment of durability.

When requested by the geotechnical engineer, "special" tests are run to determine organic and organic fiber content, consolidation characteristics, permeability, and strength. For projects where embankments are planned to overlay soft soil or peat deposits, the field geologist will provide thin-wall tube undisturbed samples for testing as requested. The regional geotechnical engineers will develop plans for sampling and testing of these soils and design of surcharges where needed. Permeability testing may be required to assess feasibility of drainage features such as wick drains. In some situations, soil strength testing may be an issue and the geologist will work with the geotechnical engineer to plan sampling and testing protocols tailored to the situation. Rock strength may be an issue where structure foundations rest on rock. We can conduct point load tests in the field or the laboratory and the laboratory is also equipped to run uniaxial unconfined compressive strength tests on rock samples.

17.0 SAFETY GUIDELINES

All field personnel, including geologists, engineers, technicians, and drill crews, and visitors to drilling sites should be familiar with the general health and safety procedures of the Department, specific procedures for drilling and field work, as well as any additional requirements of the particular project. All field crews and visitors to drilling sites and other field work locations should have the proper training in the use of any Personal Protective Equipment required for the work. This may include hard hats, safety boots, hearing protection, eye protection, reflective clothing, and other PPE.

A safety meeting should be held before commencement of field work to discuss any safety issues. Employees should also be aware of and have appropriate training in agency regulations from OSHA or the Alaska Department of Labor and other regulatory agencies in subjects such as first aid, traffic control and flagging.

Typical general safety guidelines for drilling into soil and rock are presented in the NHI Course Manual #13321 "*Subsurface Investigations*," Appendix A. Minimum protective gear for all personnel should include hardhat, safety boots, eye protection, hearing protection, gloves, and reflective clothing for working in or near traffic. The Department will provide necessary safety clothing or protective devices as required and provided for under union contracts.

18.0 GEOTECHNICAL PERSONNEL BEHAVIOR

When planning and conducting geotechnical investigations, Department staff should keep in mind that the field geotechnical crews are highly visible representatives of the Department. The public perception of the agency may be determined by the appearance and behavior of the field personnel and equipment. Each member of the field crew is responsible for maintaining a positive image of the exploration activities, including personal appearance and the appearance of the equipment. Safety is, of course, a principal concern. Operations must be conducted in a manner to maintain safety of the crew members and the public. Extra care must be taken when working close to traffic.

Field crews are often in contact with members of the public for a variety of reasons. All Department employees should maintain a respectful and polite attitude in dealing with the public. When questioned about the field activities, Department employees should generally not provide detailed explanation of our activities, since the project plans are usually not finalized when the exploration activities are underway and misunderstandings can cause significant problems. A general explanation of the field activities may be given to answer an inquiry - further inquiries should be referred to supervisory personnel.

19.0 SPECIFICATIONS AND STANDARDS

Table 19-1, Specifications and Standards provides a partial listing of some standards and test methods used in the conduct of geotechnical field investigations. The list is not exhaustive:

Table 19-1
Specifications and Standards

SUBJECT	ASTM	AASHTO
Conducting Geotechnical Subsurface Investigations		R13
Decommissioning Geotechnical Exploratory Boreholes	-	R22-97
Descriptive Nomenclature for Constituents of Natural Mineral Aggregates	C 294	M146
Soil Investigation and Sampling by Auger Borings	D 1452	T 203
Penetration Test and Split Barrel Sampling of Soils	D 1586	T 206
Thin Walled Tube Geotechnical Sampling of Soils	D 1587	T 207
Diamond Core Drilling for Site Investigation	D 2113	T 225
Test Method for Classification of Soils for Engineering Purposes	D 2487	M145
Standard Practice for Description and Identification of Soils (Visual-Manual Procedure)	D 2488	-
Standard Test Method for Field Vane Shear in Cohesive Soil	D 2573	-
Practice for Ring-Lined Barred Sampling of Soils	D 3550	-
Standard Practice for Description of Frozen Soils (Visual-Manual Procedure)	D 4083	
Standard Guide to Site Characterization for Engineering, Design, and Construction Purposes	D 420	T 86
Preserving and Transporting Soil Samples	D 4220	-
Cross-hole Seismic Testing	D 4428	-
Subsurface Liquid Levels in a Borehole or Monitoring Well (Observation Well)	D 4750	-
Standard Guide for Core Sampling Submerged, Unconsolidated Sediments	D 4823	-
Preserving and Transporting Rock Core Samples	D 5079	-
Standard Practice for Design and Installation of Ground Water Monitoring Wells in Aquifers	D 5092	
Standard Guide for Field Logging of Subsurface Explorations of Soil and Rock	D 5434	-
Seismic Refraction Method for Subsurface Investigation	D 5777	-
Standard Test Method for Performing Electronic Friction Cone and Piezocone Penetration Testing	D 5778	
Hollow-Stem Augers for Geotechnical Exploration and Soil Sampling	D 6151	T 251

SUBJECT	ASTM	AASHTO
Selecting Surface Geophysical Methods	D 6429	-
Direct Current Resistivity Method for Subsurface Investigation	D 6431	-
Surface Ground Penetrating Radar Method for Subsurface Investigation	D 6432	-
Field Measurement of Soil Resistivity Using the Wenner Four-Electrode Method	G 57	T 288
Provisional Guide for Selecting Surface Geophysical Methods	PS 78	-

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20.2. Computer Programs

Colorado Rockfall Simulation Program (CRSP v. 4.0)

gINT

RockPack II

RocScience Rockfall

RocScience Slide

RocScience Dips

RocScience Swedge

APPENDIX A

EXAMPLE FORMATS FOR TEST HOLE LOGS AND PENETROMETER LOGS

LOG OF TEST HOLE

HOLE # TH04-04

STATE OF ALASKA DOT&PF

Geology Section

***PROJECT NUMBER**: 56434*
***PROJECT**: King Cove Airport Lighting and Paving*
***NORTHING**: 249387 **EASTING**: 348312 (Local)*

Station / Location: *6+73*
Offset: *295 Rt*
Elevation: 136'

Equipment Type: *Mobile B-24*
Drilling Method:
Field Crew: *O. Saena and P. Mitchell*

Total Depth: *20.0 feet*
Date: *2/2/2004 - 2/2/2004*
Geologist: *C. BOECKMAN*

Ground Water Data

Depth in (ft.)	8	
Time		
Date	2/2/04	
Symbol	▼	

Sample Data

Depth (Feet)	Sample Type	Number	Blow Count	N-Value
0–1	GS	FS-4		
4–6	SPT	FS-5	100, 250, 90, 200	340
10–12	SPT		16, 20, 22, 16	42
15–17	SPT	FS-7	1, 3, 2, 2	5
18–20	SPT		4, 9, 6, 6	15

SUBSURFACE MATERIAL

Depth (ft)	USCS Classification	Description
0.0	GW-GM	**GRAVEL with Silt and Sand** (GW-GM) Contains cobbles., Brown, moist, very dense FS-4 p200=6.8%, Sa=24%, Gr=69%, Moisture=14.2%
2.0		
3.0	SM	**SILTY SAND with Gravel** (SM) Contains cobbles., Brown, moist, very dense FS-5 p200=20.4%, Sa=46%, Gr=34%, Moisture=6.7%
5.5		
8.0	ML	**SANDY SILT** (ML) Some organics (root systems)., Brown, wet, soft
10.0	GW-GM	**GRAVEL with Silt and Sand** (GW-GM) Contains cobbles., Brown, wet, dense
14.0	SM/OL	**SANDY Organic Soil** (SM/OL) Brown, wet, soft FS-7 Moisture=96.1%
17.0	SM	**SILTY SAND** (SM) Sandy silt (ML) layers., Brown, wet, stiff
20.0	BOH 20	Notes: Had to offset hole two times to get beyond cobbles in the fill for the apron pad.

☐ CME Auto Hammer ☒ Cathead Rope Method ☒ 140 lb. hammer with 30 in. drop ☐ 340 lb. hammer with 30 in. drop

Sheet Number 1 of 1

A USCS LOG OF TEST HOLE 2004 LOGS.GPJ 2004TEMPLATE.GDT 3/7/05

STATE OF ALASKA DOT&PF
Statewide Materials
Geology Section

PENETROMETER LOG

HOLE # Pen 1

***PROJECT NUMBER**: ACSTP-0075(1) / 56932*
***PROJECT**: Sterling Highway, Stariski Creek, Bridge No. 667*
***NORTHING**: 1542084, **EASTING**: 931239*

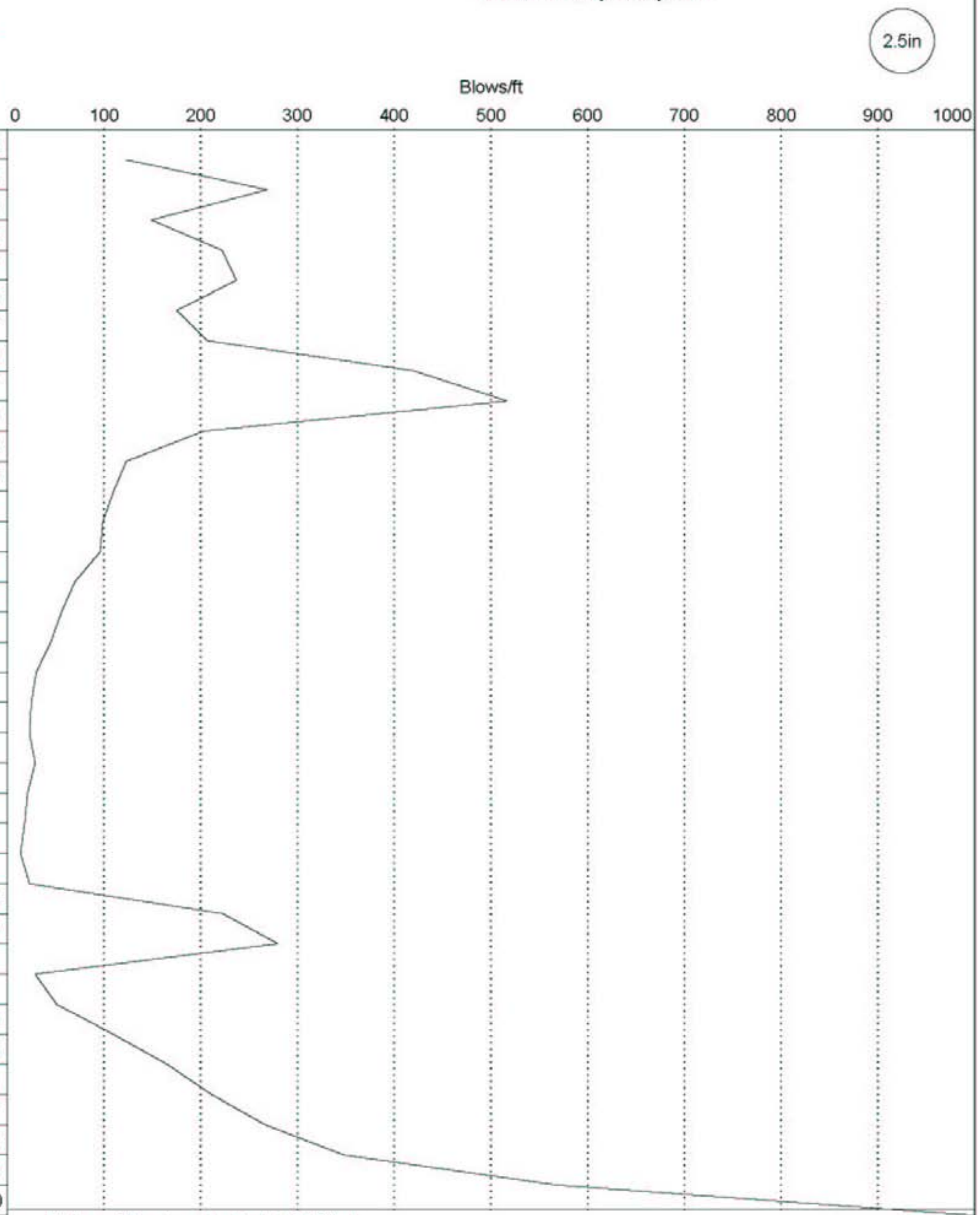
Station / Location: *4985+85.3*
Offset: *Lt. 9.3*
Elevation: *111.4 feet*

Equipment Type: *CME 75 Truck*
Drilling Method: *Penetrometer*
Field Crew: *Hamrick, Ruth*

Total Depth: *35.8 feet*
Date: *10/6/2004 - 10/9/2004*
Geologist: *P. Ondra*

Weather: Partly cloudy, 45°F

Elevation	Depth	Blow Count
111	0	123
110	1	269
109	2	149
108	3	222
107	4	237
106	5	175
105	6	207
104	7	420
103	8	517
102	9	203
101	10	123
100	11	110
99	12	99
98	13	96
97	14	70
96	15	56
95	16	45
94	17	30
93	18	25
92	19	23
91	20	29
90	21	21
89	22	18
88	23	14
87	24	23
86	25	223
85	26	280
84	27	29
83	28	51
82	29	109
81	30	165
80	31	211
79	32	267
78	33	348
77	34	569
76	35	1000



Bottom of Penetrometer Test at: 35.8 feet
Notes: 1. 1000 blows for 10 inches below 35 ft.
2. Penetrometer pullout break force was 66,740 lbs resistance.

C USCS PEN LOG STARISKI CREEK.GPJ 2004 TEMPLATE.GDT 3/7/05

Sheet Number 1 of 1

APPENDIX B

Example Test Hole Log and Location Presentations

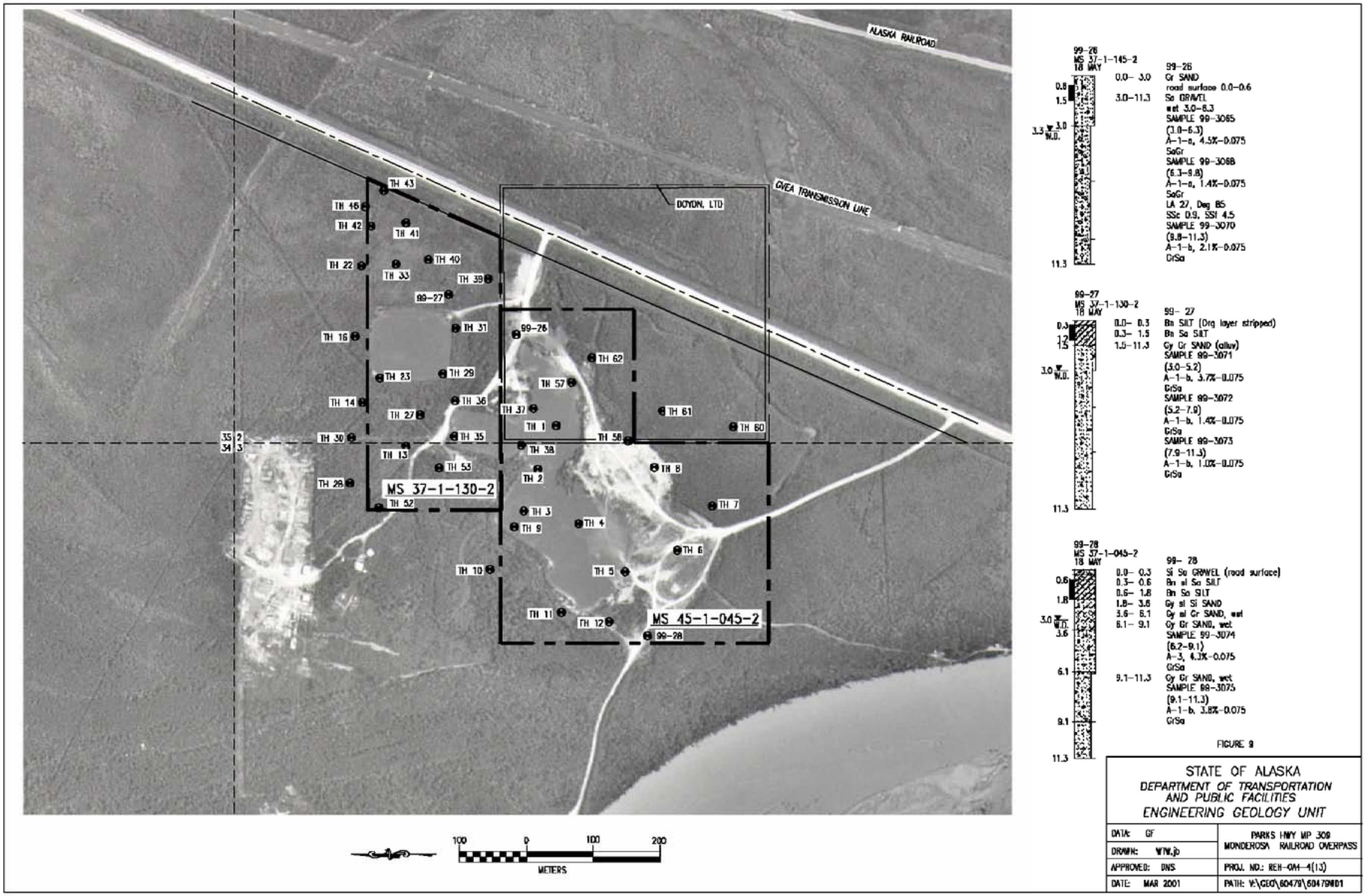
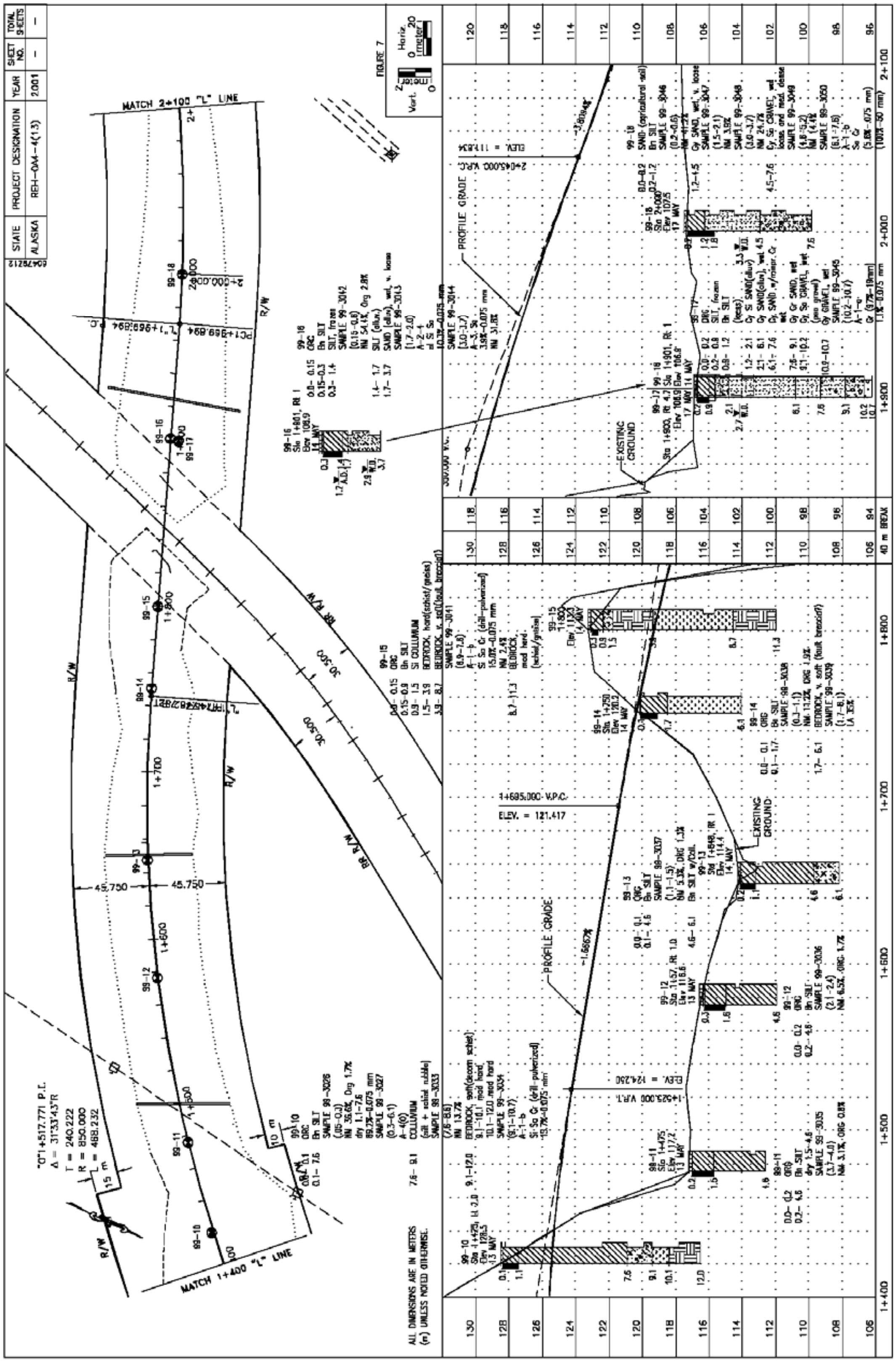
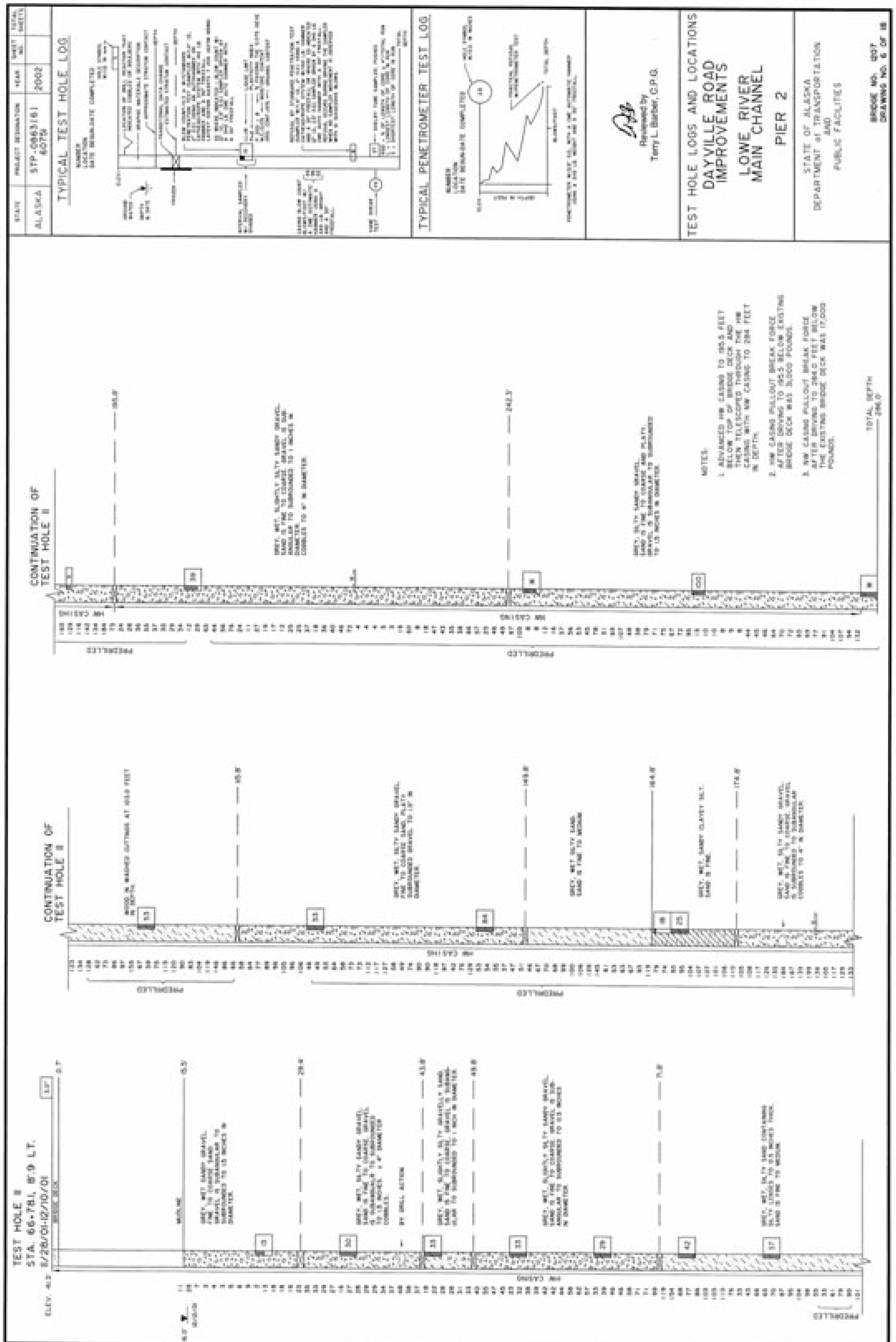
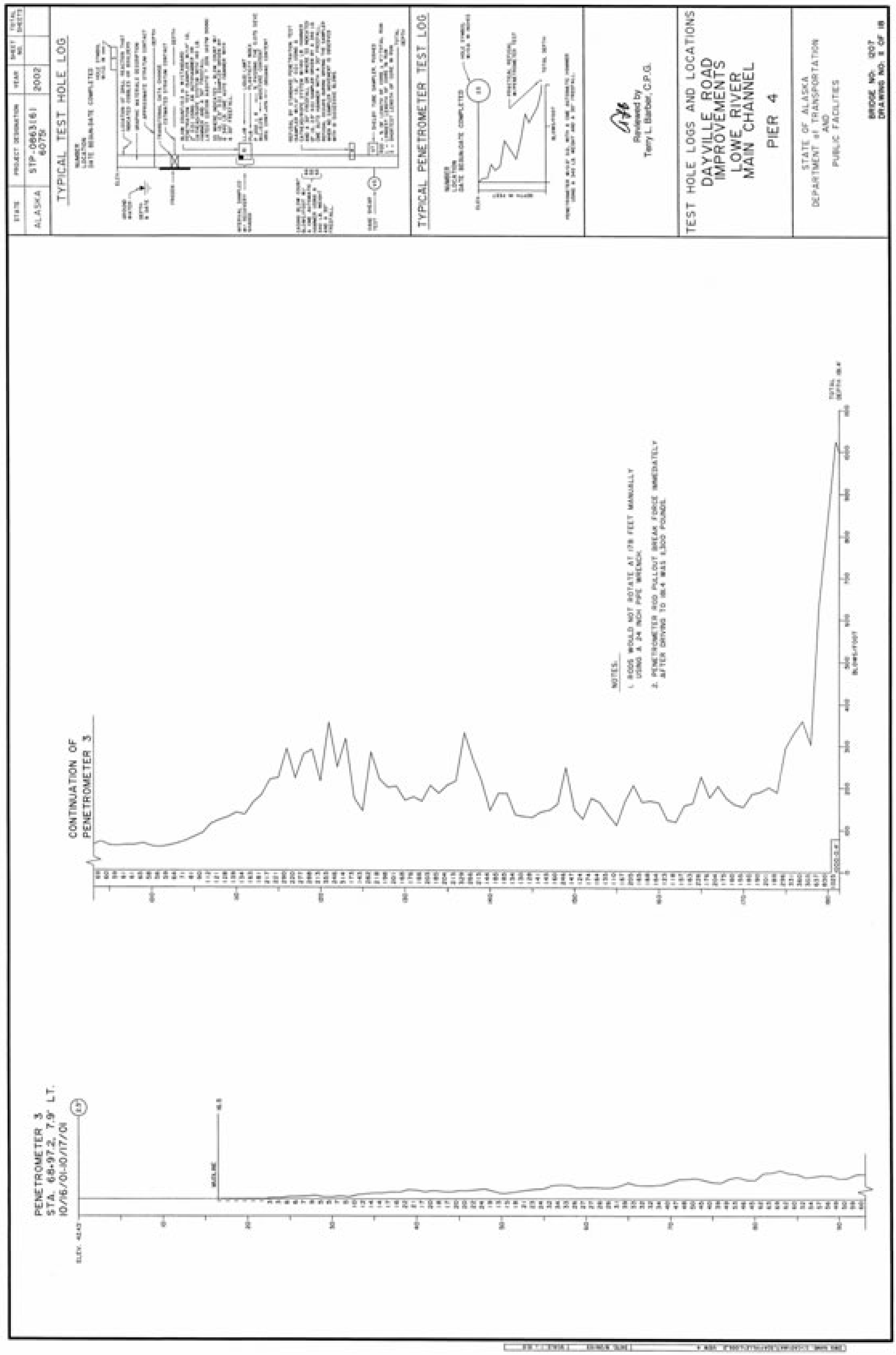

ALASKA RAILROAD
GVEA TRANSMISSION LINE
DOYON, LTD
MS 37-1-130-2
MS 45-1-045-2
TH 43
TH 45
TH 42
TH 41
TH 40
TH 22
TH 33
TH 39
99-27
TH 31
99-26
TH 16
TH 62
TH 23
TH 29
TH 57
TH 14
TH 36
TH 37
TH 61
TH 27
TH 1
TH 60
TH 30
TH 35
TH 58
TH 13
TH 38
TH 53
TH 8
TH 2
TH 28
TH 52
TH 7
TH 3
TH 4
TH 9
TH 6
TH 10
TH 5
TH 11
TH 12
99-28
35 2
34 3
100 0 100 200
METERS
99-26
MS 37-1-145-2
18 MAY
0.8
1.5
3.3 3.0 W.D.
11.3
0.0- 3.0 Gr SAND
road surface 0.0-0.6
3.0-11.3 Sa GRAVEL
wet 3.0-8.3
SAMPLE 99-3065
(3.0-6.3)
A-1-a, 4.5%-0.075
SaGr
SAMPLE 99-3068
(6.3-9.8)
A-1-a, 1.4%-0.075
SaGr
LA 27, Deg 85
SSc 0.9, SSf 4.5
SAMPLE 99-3070
(9.8-11.3)
A-1-b, 2.1%-0.075
GrSa
99-27
MS 37-1-130-2
18 MAY
0.3
1.2
1.5
3.0 W.D.
11.3
0.0- 0.3 Bn SILT (Org layer stripped)
0.3- 1.5 Bn Sa SILT
1.5-11.3 Gy Gr SAND (alluv)
SAMPLE 99-3071
(3.0-5.2)
A-1-b, 3.7%-0.075
GrSa
SAMPLE 99-3072
(5.2-7.9)
A-1-b, 1.4%-0.075
GrSa
SAMPLE 99-3073
(7.9-11.3)
A-1-b, 1.0%-0.075
GrSa
99-28
MS 37-1-045-2
18 MAY
0.6
1.8
3.0 W.D.
3.6
6.1
9.1
11.3
0.0- 0.3 Si Sa GRAVEL (road surface)
0.3- 0.6 Bn sl Sa SILT
0.6- 1.8 Bn Sa SILT
1.8- 3.6 Gy sl Si SAND
3.6- 6.1 Gy sl Gr SAND, wet
6.1- 9.1 Gy Gr SAND, wet
SAMPLE 99-3074
(6.2-9.1)
A-3, 4.3%-0.075
GrSa
9.1-11.3 Gy Gr SAND, wet
SAMPLE 99-3075
(9.1-11.3)
A-1-b, 3.8%-0.075
GrSa
STATE OF ALASKA
DEPARTMENT OF TRANSPORTATION
AND PUBLIC FACILITIES
ENGINEERING GEOLOGY UNIT
DATA: GF
DRAWN: WTW.jb
APPROVED: DNS
DATE: MAR 2001
PARKS HWY MP 309
MONDEROSA RAILROAD OVERPASS
PROJ. NO.: REH-OM-4(13)
PATH: V:\GEO\60479\60479I01

FIGURE 9


STATE
ALASKA
PROJECT DESIGNATION
REH-OA4-4(13)
YEAR
2001
FIGURE 7
MATCH 2+100 "L" LINE
MATCH 1+400 "L" LINE
PROFILE GRADE
EXISTING GROUND
ALL DIMENSIONS ARE IN METERS (m) UNLESS NOTED OTHERWISE.


TYPICAL TEST HOLE LOG
TYPICAL PENETROMETER TEST LOG
Reviewed by Terry L. Barber, C.P.G.
TEST HOLE LOGS AND LOCATIONS
DAYVILLE ROAD IMPROVEMENTS
LOWE RIVER MAIN CHANNEL
PIER 2
STATE OF ALASKA
DEPARTMENT of TRANSPORTATION AND PUBLIC FACILITIES
CONTINUATION OF TEST HOLE II
TEST HOLE II


TYPICAL TEST HOLE LOG
TYPICAL PENETROMETER TEST LOG
CONTINUATION OF PENETROMETER 3
PENETROMETER 3
ALASKA
2002
Reviewed by Terry L. Barber, C.P.G.
TEST HOLE LOGS AND LOCATIONS
DAYVILLE ROAD IMPROVEMENTS
LOWE RIVER MAIN CHANNEL
PIER 4
STATE OF ALASKA
DEPARTMENT of TRANSPORTATION AND PUBLIC FACILITIES

APPENDIX C

SOIL ERODIBILITY CHART

*SOIL ERODIBILITY CHART**

CLASSIFICATION		ERODIBILITY[1,2]				
GEOLOGIC DESCRIPTION	***USCS CLASSIFICATION*** [3]	*GENERAL*	*SLOPE ANGLE < 45 degrees*	*SLOPE ANGLE > 45 degrees*	*SLOPE LENGTH < 10 meters*	*SLOPE LENGTH > 10 meters*
ALLUVIAL						
High Energy	GW, GP, GM	Low	Low-Med	Med	Low-Med	Med
Low Energy	SM, SP, SW, ML, CL	Med-High	Med-High	High	Med-High	High
COLLUVIAL[4] **(Slope wash)**	Various	Low - High	Low - High	Low - High	Low - High	Low - High
EOLIAN (wind deposited)						
Dune Sand	SP	High	High	Very High	High	Very High
Loess	ML, SM	High - Very High	High-Very High	Very High	High-Very High	Very High
GLACIAL[5]						
Till	GM, SM, ML	Low-Med	Low-Med	Low-Med	Low-Med	Med
Outwash	GW, GP, GM, SW, SP, SM	Low-Med	Low-Med	Med	Low-Med	Med
Glaciolacustrine	ML, SM, SP	Med-High	Med	High	Med	High
LACUSTRINE (Lake deposits)	ML, SM, MH, OL, CL, CH, OH, PT	High	High	High-Very High	High	High to Very High
MARINE						
High Energy	GW, GP, SW, SF	Med	Med	Med-High	Med	Med-High
Low Energy	SM, ML, MH, CL, CH, OL, OH	High	High	High-Very High	High	High-Very High
RESIDUAL - SEDENTARY[6]	Various	Low - High	Low - High	Low - High	Low - High	Low - High

Notes

1 - Erodibility is the relative, qualitative erosion potential of a particular soil type as related to the indicated slope geometry. "Low" erodibility means little or no significant erosion is likely to occur during construction and the life of the project. "Medium" erodibility means that significant erosion is likely to occur during construction and the life of the project. "High" erodibility means significant erosion will occur during construction and during the life of the project, even with intensive soil conservation methods. Water conditions are assumed to be "worst case", with significant sheet flow and underground water daylighting on the slope. Climate, rainfall, and vegetative cover factors also dictate erodibility but are not addressed here.

2 - Select appropriate BMP after reference to DOT&PF "Standard Specifications for Highway Construction", DOT&PF "Erosion Prevention and Sediment Control Plan – Policy and Procedures; Guide to Preparing Erosion Prevention and Sediment Control Plans", DOT&PF "Best Management Practices for Construction Erosion and Sediment Control," DOT&PF Regional Best Management Practices, AASHTO "Guidelines for Erosion and Sediment Control in Highway Construction, Volume III", and Geotechnical Recommendations and Reports.

3 - Unified Soil Classification System - ASTM D-2487

4 - Mass of loose soil and/or rock fragments that has moved downslope - classification and erosion characteristics vary, depending on parent material, which can include any soil component from clay to boulders and organics.

5 - Till soils are directly deposited by glaciers and may contain any combination of inorganic soil components from clay to boulders.

6 - Weathered in place soil derived from parent rock material; characteristics vary depending on soil type

*Adapted, in part, from Koloski, J.W., Schwarz, S.D., and Tubbs, D.W., "Geotechnical Properties of Geologic Materials," Washington Division of Geology and Earth Resources Bulletin 78, 1989.

APPENDIX D

FHWA GUIDELINES FOR MINIMUM NUMBER OF INVESTIGATION POINTS AND MINIMUM DEPTH OF INVESTIGATION

Source: Evaluation of Soil and Rock Properties – Geotechnical Engineering Circular No. 5, Publication FHWA-IF-02-034, FHWA, April 2002.

Table 3. Guidelines for minimum number of investigation points and depth of investigation.

Application	Minimum Number of Investigation Points and Location of Investigation Points	Minimum Depth of Investigation
Retaining walls	A minimum of one investigation point for each retaining wall. For retaining walls more than 30 m in length, investigation points spaced every 30 to 60 m with locations alternating from in front of the wall to behind the wall. For anchored walls, additional investigation points in the anchorage zone spaced at 30 to 60 m. For soil-nailed walls, additional investigation points at a distance of 1.0 to 1.5 times the height of the wall behind the wall spaced at 30 to 60 m.	Investigate to a depth below bottom of wall between 1 and 2 times the wall height or a minimum of 3 m into bedrock. Investigation depth should be great enough to fully penetrate soft highly compressible soils (e.g. peat, organic silt, soft fine grained soils) into competent material of suitable bearing capacity (e.g., stiff to hard cohesive soil, compact dense cohesionless soil, or bedrock).
Embankment Foundations	A minimum of one investigation point every 60 m (erratic conditions) to 120 m (uniform conditions) of embankment length along the centerline of the embankment. At critical locations, (e.g., maximum embankment heights, maximum depths of soft strata) a minimum of three investigation points in the transverse direction to define the existing subsurface conditions for stability analyses. For bridge approach embankments, at least one investigation point at abutment locations.	Investigation depth should be, at a minimum, equal to twice the embankment height unless a hard stratum is encountered above this depth. If soft strata is encountered extending to a depth greater than twice the embankment height, investigation depth should be great enough to fully penetrate the soft strata into competent material (e.g., stiff to hard cohesive soil, compact to dense cohesionless soil, or bedrock).
Cut Slopes	A minimum of one investigation point every 60 m (erratic conditions) to 120 m (uniform conditions) of slope length. At critical locations (e.g., maximum cut depths, maximum depths of soft strata) a minimum of three investigation points in the transverse direction to define the existing subsurface conditions for stability analyses. For cut slopes in rock, perform geologic mapping along the length of the cut slope.	Investigation depth should be, at a minimum, 5 m below the minimum elevation of the cut unless a hard stratum is encountered below the minimum elevation of the cut. Investigation depth should be great enough to fully penetrate through soft strata into competent material (e.g., stiff to hard cohesive soil, compact to dense cohesionless soil, or bedrock). In locations where the base of cut is below ground-water level, increase depth of investigation as needed to determine the depth of underlying pervious strata.

Table 3. Guidelines for minimum number of investigation points and depth of investigation (continued).

Application	Minimum Number of Investigation Points and Location of Investigation Points	Minimum Depth of Investigation
Shallow Foundations	For substructure (e.g., piers or abutments) widths less than or equal to 30 m, a minimum of one investigation point per substructure. For substructure widths greater than 30 m, a minimum of two investigation points per substructure. Additional investigation points should be provided if erratic subsurface conditions are encountered.	Depth of investigation should be: (1) great enough to fully penetrate unsuitable foundation soils (e.g., peat, organic silt, soft fine grained soils) into competent material of suitable bearing capacity (e.g. stiff to hard cohesive soil, compact to dense cohesionless soil or bedrock) and; (2) at least to a depth where stress increase due to estimated footing load is less than 10% of the existing effective overburden stress and; (3) if bedrock is encountered before the depth required by item (2) above is achieved, investigation depth should be great enough to penetrate a minimum of 3 m into the bedrock, but rock investigation should be sufficient to characterize compressibility of infill material of near-horizontal to horizontal discontinuities.
Deep Foundations	For substructure (e.g., bridge piers or abutments) widths less than or equal to 30 m, a minimum of one investigation point per substructure. For substructure widths greater than 30 m, a minimum of two investigation points per substructure. Additional investigation points should be provided if erratic subsurface conditions are encountered. Due to large expense associated with construction of rock-socketed shafts, conditions should be confirmed at each shaft location.	In soil, depth of investigation should extend below the anticipated pile or shaft tip elevation a minimum of 6 m, or a minimum of two times the maximum pile group dimension, whichever is deeper. All borings should extend through unsuitable strata such as unconsolidated fill, peat, highly organic materials, soft fine-grained soils, and loose coarse-grained soils to reach hard or dense materials. For piles bearing on rock, a minimum of 3 m of rock core shall be obtained at each investigation point location to verify that the boring has not terminated on a boulder. For shafts supported on or extending into rock, a minimum of 3 m of rock core, or a length of rock core equal to at least three times the shaft diameter for isolated shafts or two times the maximum shaft group dimension, whichever is greater, shall be extended below the anticipated shaft tip elevation to determine the physical characteristics of rock within the zone of foundation influence.

APPENDIX E

BEST MANAGEMENT PRACTICES FOR SPILL PREVENTION AND EROSION CONTROL DURING GEOLOGICAL/GEOTECHNICAL FIELD INVESTIGATIONS

Best Management Practices
for
Spill Prevention and Erosion Control
During
Geological/Geotechnical Field Investigations

The Alaska Department of Transportation and Public Facilities (DOT&PF) is committed to protecting the environment while conducting field investigation activities for geotechnical and geological investigations in support of our road, airport and structure projects. This appendix outlines our best management practices (BMPs) for such field activities.

During the course of field investigations, DOT&PF crews and consultants often use backhoes, excavators, and drill rigs to advance test borings and test pits. Some of our test holes are drilled through existing embankments through asphalt with little risk of consequences from spills and no risk of erosion. Most of our test holes are drilled on vegetated or bare ground - some ground disturbance is inevitable. In some cases, drilling operations utilize water and/or drilling additives (drilling muds such as bentonite or polymers) to circulate in the test holes. When using water, the circulated water is normally released on the ground surface where it is absorbed into the soil. Some risk of erosion exists during these operations. Some of our exploration operations take place in or near active stream and river channels. In these cases, there is some potential for releases of drilling sediment from circulated drilling water and petroleum products that could enter waters of the state. Following are the BMPs implemented for drilling and exploration operations:

Disturbance minimizing BMPs

- Select the smallest drill rig capable of performing the required drilling.
- Conduct operations in marsh, peat and other soft ground areas during winter months when operating machinery will cause least damage to vegetations.
- Operate drilling and excavating machinery on un-vegetated ground where possible.

Waste Reduction BMPs

- Where possible, re-circulate drilling water and drilling muds in a mud tank or pit
- Minimize the amount of water used for circulation

Sediment Trapping BMPs for Drilling Fluids

- Use mud tanks to prevent fluid loss
- Where appropriate and necessary, use silt fences, straw bales or other barriers to prevent uncontrolled sediment flow
- When drilling through bridge decks, block scuppers and direct flow onto upland locations instead of into stream or river

Site Stabilization BMPs

- For excavated test pits, reshape surface to original contours and re-position vegetative clumps at test pit site.

Risk Minimization BMPs

- Visually inspect drill rigs and excavation equipment for leaks, worn hoses, etc. before commencing operations and on a daily basis
- Fix leaks before continuing with operations
- Use proper equipment to transfer hazardous materials
- Reduce the volume of hazardous materials on site
- Remove sources from the site while not actively working
- Secure any sources left unattended on site
- Use environmentally friendly materials
- Make sure sufficient spill response materials are available before commencing field work.

Maximization of Response BMPs

- Each field operation shall have a spill response kit or materials within easy access at the drilling excavation site
- Every member of the exploration crew shall have had training in spill response techniques
- Maintain phone numbers of supervisor, Department of Environmental Conservation, and spill response hotline numbers.
- Maintain communications in remote sites through use of satellite phones.

Procedure

All necessary and appropriate permits will be in place before the geologist and drill crew commence field activities. All provisions of the permits will be followed until completion of the project.

The approach to protecting the environment is focused on prevention. Prior to commencement of field activities the field geologist shall make a thorough inspection of the exploration areas for sensitive areas – wetlands, streams, drainage channels, porous ground conditions, etc. When sensitive areas are identified activities will be modified as necessary to avoid depositing or releasing drill cuttings or drilling fluids into the areas. If no sensitive areas are identified, drilling circulating water and fluids will be discharged and slowly infiltrated into the ground surface. Cuttings may be removed, if appropriate for the situation and stored in drums for off-site disposal.

APPENDIX F

GEOTECHNICAL EXPLORATORY HOLE SEAL VERIFICATION REPORT

Geotechnical Exploratory Hole Seal Verification Report
State of Alaska – DOT&PF – Geology Section

Project Name	**Project #s (AKSAS, Ledger Code, Collocode)**
Test Hole Number (attach test hole field log)	**Date Finished**
Test Hole Location Sketch	**Hole Location (Latitude/Longitude, Station and Offset, reference to survey monument, etc.)**
	River/Creek/Structure Name
	Bridge Number
Field Geologist	**Driller/Helper(s)**
Drilling Rig	**Drilling Contractor**
Drilling Methods (auger, casing, etc.)	
Hole Diameter	**Hole Total Depth**
Groundwater level(s)	**Artesian Conditions**
Reason for Sealing	
Method of Sealing (seal bottom to top, seal zone depths, seal surface, pour pellets, tremie grout, etc.)	
Quantity/Type of Sealing Materials (Grout, Grout/Bentonite mix, Bentonite chips, pellets, etc.)	
Sealing Difficulties	
Instrumentation Installed (standpipe, piezometer, thermistor, slope indicator, etc.)	
Field Geologist **Date**	**Supervising Geologist** **Date**