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Chapter 9

LABORATORY TESTING

9.1 GENERAL

9.1.1 Overview

The Geotechnical Section operates a soil-testing laboratory in its Helena office. This laboratory in conjunction with the Physical Test Section laboratory are equipped to conduct both classification tests and engineering property tests in support of field exploration and foundation design studies for MDT's projects. Classification tests are conducted in support of engineering property testing and include the basic tests (e.g., moisture content determinations, Atterberg limits, grain-size analyses). The engineering property test capabilities include:

- triaxial and direct shear strength determination for soil samples,
- consolidation tests for soil compressibility evaluations,
- permeability tests on soil samples, and
- unconfined compression and point-load tests on rock samples.

Equipment used by the Geotechnical Section for engineering property testing includes electronic instrumentation for load and deformation monitoring, and computer control and recording of test results. These capabilities allow the Geotechnical Laboratory to conduct a variety of standard and special tests.

The project geotechnical specialist initiates the request for laboratory testing following the conclusion of the field investigation (see Chapter 8). In most cases, it will be desirable to consult with the Geotechnical Operations Manager or other Geotechnical Section personnel regarding the scope of the testing program and any special requirements related to sample handling, testing or data analysis. Also, consult the Geotechnical Operations Manager if schedule conflicts appear to be developing.

Where testing is required that is not within either the schedule or equipment capabilities of the Geotechnical Section's Geotechnical Laboratory, outside contractors/consultants can be used to conduct the laboratory tests. For example, the Geotechnical Laboratory currently does not conduct dynamic tests for earthquake studies. If these tests are required, an independent testing laboratory can be contracted to conduct these tests. Before contacting the independent laboratory, discuss the need for and objectives of the testing with the Geotechnical Operations Manager. When a decision is made to use an independent testing laboratory, factor the schedule into the selection of the contractor. It is not unusual for an independent laboratory to have significant schedule constraints, particularly during the busy summer months.

9.1.2 Responsibilities

9.1.2.1 Geotechnical Section Laboratory

Except for routine soil classification tests (e.g., grain-size analyses, Atterberg limits), which are performed by the Physical Test Section, the Geotechnical Laboratory is responsible for conducting the necessary laboratory tests to measure soil and rock engineering properties. Information from the Geotechnical Laboratory is used in support of soil and rock characterizations, foundation design studies and construction evaluations on MDT projects.

The Geotechnical Laboratory's responsibilities include the following:

- ensure the proper handling and storage of field samples in the lab;
- coordinate with the project geotechnical specialist in the development and scheduling of laboratory test programs;
- perform soil tests (e.g., unit weight, moisture content, hydrometer, specific gravity) in support of the engineering property tests;
- conduct engineering property tests (e.g., triaxial shear, direct shear, unconfined compression, consolidation, permeability) to determine strength, compressibility and permeability of soil and rock samples obtained during the field exploration program; and
- report laboratory test results to the District Geotechnical Managers or project geotechnical specialists.

9.1.2.2 MDT Physical Test Section

The primary responsibility of the Physical Test Section is to perform laboratory testing of materials required for construction to determine the engineering properties, either by providing guidance to the District Labs or by performing the testing. The Section also performs many of the basic classification tests for field samples collected by the Geotechnical Section. The Physical Test Section is also responsible for maintaining the *Materials Manual* and conducting lab inspections.

The Physical Test Section typically conducts the following (not all inclusive) tests:

- sieve analyses;
- Atterberg limits;
- soil classification;
- Proctor moisture-density;
- asphalt mix design;
- LA Abrasion;
- chemical:
    + corrosion properties for culverts (pH, resistivity),
    + organic content,
    + pH, and
    + soluble sulfate;
- Micro-Deval aggregate abrasion/degradation;
- geosynthetics:
    + grab elongation/strength (ASTM D 4632),
    + tear strength (ASTM D 4533),
    + puncture strength (ASTM D 4833), and

  - permittivity (ASTM D 4491);
- R-value;
- partial gradation results;
- quality control;
- asphalt content; and
- concrete/aggregates properties.

All testing conducted by the Physical Test Section is based on the *AASHTO Standard Specifications for Transportation Materials and Methods of Sampling and Testing*, adapted for application in Montana.

9.1.2.3 District Labs

The primary responsibility of the District Labs is to conduct tests as part of the Soil Survey used for pavement design and to test soils during construction. District field technicians collect samples for testing and send the samples to the District Labs. The following types of tests are conducted by the District Labs:

- soil classification (based on the AASHTO system),
- specific gravity,
- Atterberg limits, and
- Proctor compaction (e.g., optimum moisture content, maximum dry density).

Under some conditions, the District Lab may not have the experience or equipment to test the soil sample (e.g., testing soils for R-Values). In these conditions, the District Lab will provide the Geotechnical Section or Physical Test Section with the soil sample for testing.

9.1.2.4 Outside Geotechnical Laboratories

MDT rarely uses outside geotechnical laboratories on in-house projects. However, there are special occasions when outside laboratories may be used:

- when specialty tests are required; for example, dynamic testing (e.g., resonant column, cyclic triaxial, torsional shear, direct cyclic simple shear); or

- when the geotechnical component of the project has been contracted to an outside design firm.

When outside geotechnical laboratories conduct laboratory tests for MDT projects, procedures used by the outside laboratory should generally conform with those described within this Chapter, unless alternative methods are submitted for review and agreed in writing by the District Geotechnical Manager or project geotechnical specialist. Outside laboratories must be accredited by the AASHTO Materials Reference Laboratory (AMRL).

9.1.3 Sample Storage, Selection and Handling

9.1.3.1 Handling and Storage

Undisturbed soil samples should be transported and stored in accordance with AASHTO T207, ASTM D 4220 and ASTM D 5079 to ensure the structure and moisture content of the sample is maintained close to its natural conditions. Do not place specimens, even temporarily, in direct sunlight or sub-freezing temperatures. Store undisturbed soil samples in an upright position. Guidance for storage of rock cores can be found in ASTM D 5079. The temperature control requirements may vary and should match the environment of the parent formation to the extent practical. Maintain the relative humidity for soil storage at 90% or higher.

Long-term storage of soil samples in sampling tubes is not recommended for engineering property testing for two primary reasons:

- During long-term storage, sample tubes usually corrode, resulting in compression of the sample or even internal failures from the forces required to extrude the sample.

- Long-term storage of samples, even under the best conditions, may cause changes in the moisture content of the samples.

Research has shown that soil samples can be stored up to 90 days without changes in moisture content, which affects engineering properties (e.g., strength, compressibility) as long as samples are properly sealed and stored in a temperature and moisture controlled environment. Samples stored longer can be used for some types of classification testing and for visual inspections, but are generally not of appropriate quality for engineering property testing or moisture content measurements.

The Geotechnical Section’s policy is to retain soil and rock samples after testing until construction is completed and construction claims, if any, have been settled. These samples can provide valuable information regarding soil or rock type and general characteristics, even though they may be too old for classification or engineering property testing. After construction is complete and claims settled, the samples should be discarded unless specifically requested otherwise by the project geotechnical specialist.

9.1.3.2 Sample Selection for Laboratory Testing

The project geotechnical specialist should decide on the requirements for laboratory testing (e.g., when, how much, what type). At a minimum, the project geotechnical specialist should consider the following information when determining the scope of the laboratory testing:

- project type (e.g., bridge, embankment, rehabilitation);

- size of project;

- loads imposed on foundation soils;

- types of loads (i.e., static, dynamic);

- critical tolerance for the project (e.g., settlement limitations);
- vertical and horizontal variations in the soil profile as determined from boring logs, in-situ test results (e.g., cone penetrometer testing or seismic refraction) and visual identification of soil types in the laboratory;
- known or suspected characteristics of soils at the project location that could lead to problems during foundation design or operation (e.g., swelling soils, collapsible soils, organics); and
- presence of visually observed intrusions, slickensides, fissures, concretions, etc.

Selected specimens for laboratory testing must be representative of the formation or deposit being investigated. The project geotechnical specialist should study the boring logs, understand the geology of the site and visually examine the samples before selecting the test specimens. Sample color, physical appearance and structural features should be used as part of the selection process. Ensure the sample is representative of all types of materials present at the site, not just the worst or best.

9.1.3.3 Request for Laboratory Testing

After the requirements for laboratory testing have been identified and the sample selected, prepare the Geotechnical Analysis Request Form. This form should identify the samples for testing and all relevant information required to conduct the test, including:

- effective consolidation pressures for each strength test, porewater pressure monitoring requirements, rate of shear strain and any other non-standard test requirements;
- load increments for consolidation testing, including the need for rebound measurements, special load increments to establish preconsolidation pressures and any long-term secondary compression evaluations; and
- method for permeability testing and, if appropriate, confining pressures.

If there are questions on the preferred approach or test parameters, discuss the testing with the Geotechnical Operations Manager or other experienced Geotechnical Section personnel. The project geotechnical specialist should inspect the samples when they are extruded from Shelby tubes and are prepared and loaded in the test equipment to confirm that the sample quality and characteristics are consistent with anticipated soil type and proposed testing.

9.1.4 References

For further guidance on laboratory testing, review the following documents.

- *MDT Materials Manual*;
- MDT “Geotechnical Analysis Request Form” (in-house projects);

- *AASHTO Standard Specifications for Transportation Materials and Methods of Sampling and Testing*;
- Geotechnical Engineering Circular No. 5, *Evaluation of Soil and Rock Properties*, IF-02-034, FHWA;
- *Subsurface Investigations – Geotechnical Site Characterization*, NHI-01-031, FHWA;
- *Checklist and Guidelines for Review of Geotechnical Reports and Preliminary Plans and Specifications*, ED-88-053, FHWA; and
- *Annual Book of ASTM Standards*.

9.2 SOIL CLASSIFICATION TESTS

9.2.1 Overview

Soil classification tests are conducted on samples to define the physical characteristics of the soil. These characteristics include the moisture content, grain-size distribution and plasticity of the soil. Soil samples used for classification testing can be either from disturbed or undisturbed sampling; however, the sample must be representative of the in-place moisture content and physical-chemical characteristics of the soil.

The disturbed samples most often are obtained from Standard Penetration Test (SPT) sampling methods, but also can be obtained from hand sampling methods (e.g., backhoe test pits, flights on drill augers). For undisturbed samples, the classification tests can be conducted on portions of Shelby tube samples or on trimmings obtained during preparation of undisturbed samples for laboratory testing.

9.2.2 Classification Test Methods

The following tests are routinely performed during classification testing:

- visual description;
- moisture content;
- Atterberg limits (typically conducted by the Physical Test Section);
- gradation (typically conducted by the Physical Test Section) (full gradation typically performed, however; on a case-by-case basis No. 200 sieve test may be used);
- hydrometer (occasionally performed);
- percent organic (occasionally performed);
- electrochemical; and
- in-situ density.

The type of classification test depends on the type of soil sample being tested. Figure 9.2-A indicates the types of tests that are commonly performed on disturbed samples based on the soil type.

Figure 9.2-B presents a summary list of AASHTO and ASTM test designation used by MDT for testing soils in the laboratory.

Soil Type	Standard Classification Test
Cohesionless Soil	Visual Description, Moisture Content, Gradation (Sieve, P200, and sometimes Hydrometer)
Cohesive Soil	Visual Description, Moisture Content, Atterberg Limits, Gradation, Hydrometer
Organic Soil	Visual Description; Moisture Content; Atterberg Limits; Gradation; Organic Content

Figure 9.2-A — SOIL TYPE AND STRUCTURE TESTS

Test Category	Name of Test	Test Designation	
		AASHTO	ASTM
Classification	Practice for Description and Identification of Soils (Visual-Manual Procedure)	-	D 2488
	Practice for Description of Frozen Soils (Visual-Manual Procedure)	-	D 4083
	Test Method for Classification of Soils for Engineering Purposes	M145	D 2487 D 3282
Index Properties	Test Method for Determination of Water (Moisture) Content of Soil by Direct Heating Method	T265	D 4959 D 2216
	Test Method for Specific Gravity of Soils	T100	D 854
	Method for Particle-Size Analysis of Soils	T88	D 422
	Test Method for Amount of Material in Soils Finer than the No. 200 Sieve	-	D 1140
	Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils	T89 T 90	D 4318
	Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort (600 kN-m/m3)	T99	D 698
	Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort (2,700 kN-m/m3)	T180	D 1557
Corrosivity	Test Method for pH of Peat Materials	-	D 2976
	Test Method for pH of Soils	-	D 4972
	Test Method for pH of Soil for Use in Corrosion Testing	T289	G 51
	Test Method for Sulfate Content	T290	D 4230
	Test Method for Resistivity	T288	D 1125 G 57
	Test Method for Chloride Content	T291	D 512
	Test Methods for Moisture, Ash, and Organic Matter of Peat and Other Organic Soils	T194	D 2974

Figure 9.2-B — TYPICAL AASHTO AND ASTM CLASSIFICATION TESTS

9.3 ENGINEERING PROPERTY TESTS ON SOIL

9.3.1 Overview

Conduct engineering property tests on soil samples to quantify the strength, compressibility and permeability of the soil sample. In contrast to most classification tests, engineering property tests are usually more costly and time consuming. The results; however, provide specific data required for engineering analyses. These tests are conducted on undisturbed or reconstituted soil samples obtained during the field exploration program. Undisturbed samples are representative of not only the physical-chemical characteristics of the soil, but also retain the structure resulting from the geologic formation of the soil (e.g., the undisturbed sample retains any overconsolidation resulting from glacial loading that may have occurred thousands of years ago). Reconstituted soils retain the mechanical properties of the soil, but the moisture content and soil structure is changed during the preparation process. Typically, the preparation process for reconstituted samples involves compaction to a density and moisture content that will be representative of field construction conditions.

Various methods can be used to obtain undisturbed soil samples, including Shelby tube, piston or block sampling methods. SPT sampling does not provide an undisturbed sample. Undisturbed samples of soil must be handled with care to avoid disturbance through vibrations and temperature changes during transport or during setup in the laboratory.

Figure 9.3-A presents a summary of typical AASHTO and ASTM tests that are used or may be used by MDT for strength, compressibility and permeability testing in the laboratory.

9.3.2 Selection of Engineering Property Tests

The selection of representative specimens for testing is one of the most important considerations associated with engineering property tests. There is no comprehensive set of rules that can be applied to specimen selection. A summary of information needs and testing considerations for a range of applications is provided in FHWA *Subsurface Investigations — Geotechnical Site Characterization*. The project geotechnical specialist should also consult with other Geotechnical Section personnel.

Prior to conducting engineering property tests, the project geotechnical specialist may want to perform a laboratory visual identification of candidate soil samples obtained from the field investigation. If classification tests have been conducted, the project geotechnical specialist should use the classification information to determine the appropriate tests required for design or for validating engineering soil properties obtained from field tests.

9.3.3 Strength Tests

Soil shear strength is influenced by many factors including the effective stress state, mineralogy, packing arrangement of the soil particles, soil hydraulic conductivity, stress history, sensitivity and other variables. As a result, shear strength of soil is not a unique property. Laboratory-measured shear strength values will also vary because of boundary conditions during the test,

Test Category	Name of Test	Test Designation	
		AASHTO	**ASTM**
Strength Properties	Unconfined Compressive Strength of Cohesive Soil	T208	D 2166
	Unconsolidated, Undrained Compressive Strength of Clay and Silt Soils in Triaxial Compression	T296	D 2850
	Consolidated-Undrained Triaxial Compression Test on Cohesive Soils	T297	D 4767
	Direct Shear Test of Soils For Consolidated Drained Conditions	T236	D 3080
	Modulus and Damping of Soils by the Resonant-Column Method (Small-Strain Properties)	-	D 4015
	Test Method for Laboratory Miniature Vane Shear Test for Saturated Fine-Grained Clayey Soil	-	D 4648
	Test Method for Bearing Ratio of Soils in Place	-	D 4429
	Test Method For Resilient Modulus of Soils	T294	-
	Method for Resistance R-Value and Expansion Pressure of Compacted Soils	T190	D 2844
	Test Method for Permeability of Granular Soils (Constant Head)	T215	D 2434
Permeability	Test Method for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter	-	D 5084
	Method for One-Dimensional Consolidation Properties of Soils (Oedometer Test)	T216	D 2435
Compression Properties	Test Methods for One-Dimensional Swell or Settlement Potential of Cohesive Soils	T258	D 4546
	Test Method for Measurement of Collapse Potential of Soils	-	D 5333

Figure 9.3-A — TYPICAL AASHTO AND ASTM ENGINEERING TESTS

loading rates and direction of loads. This Section discusses typical laboratory strength tests including triaxial shear (AASHTO T234, ASTM D 4767), direct shear (AASHTO T236, ASTM D 3080) and unconfined compression (AASHTO T208, ASTM D 2166). Review the AASHTO and ASTM specifications for detailed information on these tests.

9.3.3.1 Triaxial Shear

The purpose of triaxial testing is to determine strength characteristics of soils and the variation of strength with lateral confinement, porewater pressures, drainage and consolidation. Strength can be defined in terms of friction angle and cohesion for total or effective stress conditions or in terms of undrained shear strength. The stiffness (modulus) at intermediate to large strains can also be evaluated.

9.3.3.1.1 Sample Requirements and Uses of Triaxial Tests

Four types of triaxial shear tests can be performed in the Geotechnical Laboratory:

1. Unconfined Compression (Q or UC) Test. This test is conducted on a cylindrical sample of cohesive soil; however, in contrast to the UU, CU and CD tests, it is performed without a confining pressure.

2. Unconsolidated Undrained (UU) Tests. This test is conducted on undisturbed samples of silts and clays in a triaxial chamber.

3. Consolidated Undrained (CU) Tests. These tests are similar to the UU test except that the sample is consolidated under the confining chamber pressure before it is loaded axially. Typically, the amount of drainage during consolidation is recorded to confirm that the sample is fully consolidated. Porewater pressures are often recorded during shear. Both total and effective stress strength parameters are determined from the test.

4. Consolidated Drained (CD) Tests*.* This test is similar to the CU test except that the test is conducted with drainage. The intent of the test is to measure soil behavior without excess porewater pressures during shear.

These tests can be conducted on undisturbed or compacted samples of soil. If the tests are intended to establish the strength parameters of in-place soil, it is critical to have high quality samples to test, and it is critical that the tested sample be representative of the layers of interest. Generally, it is possible to conduct triaxial tests on undisturbed samples of cohesive soils and cohesionless soils with sufficient fines content to allow sampling and set up in the test equipment. Triaxial tests can be conducted on both cohesionless and cohesive soils that have been recompacted to a desired density and moisture content. There are, however, particle size limitations when testing cohesionless soils. Typically, the maximum particle size must be less that one-sixth the diameter of the test specimen (MDT typically uses 2.5 in (64 mm)), which limits the maximum particle size to approximately 0.4 in (10 mm) for the Geotechnical Section's triaxial equipment.

The above tests have various advantages and disadvantages relative to their use and the information that is obtained from the test. The unconfined compression test provides an estimate of the undrained strength of cohesive soils. It is the fastest and the least expensive to perform, but the shear strength obtained from this test method can be unreliable for some soils. Unconsolidated undrained tests generally provide a better estimate of undrained strength, but also can be unreliable for some soils. Further, because the UU test is conducted in a confining chamber, the setup of the test requires more time. The CU test allows determination of strength parameters for cohesive and cohesionless soils under both total and effective stress conditions and, therefore, is widely used for projects requiring estimates of strength parameters under various stress states. However, this method requires three samples and, therefore, the costs are higher. The CD is rarely conducted on samples other than for research purposes or when special soils occur because the tests become very expensive when the samples are cohesive due to the slow testing rates. Ladd (1991) provides a discussion of the different test methods in his paper *Stability Evaluation during Staged Construction: 22nd Terzaghi Lecture*.

Triaxial shear tests are conducted for many different applications on MDT projects, as summarized below:

1. UC Tests. UC tests are conducted as a strength index for soils; realizing that the absolute value may not be reliable. For soil testing, the UC test should be calibrated against field measurements (e.g., vane shear test) or augmented with UU or CU test results, where possible, to calibrate the undrained strength against procedures that do not have some of the limitations of the UC test. UC tests are also conducted on rock samples to define the intact strength of rock.

2. UU Tests. UU tests are conducted by the Geotechnical Section to define the undrained strength of the soil for use in pile foundation design and for slope stability analyses. Because of the uncertainties with the UU test, it is usually desirable to supplement these tests with either in-situ vane shear tests, cone penetrometer tests or a limited number of CU tests. This is particularly the case for assessments of slope stability.

3. CU Tests. CU tests are usually the preferred method for determining the strength parameters required during foundation design and for evaluation of slope stability, wherever the effective confining pressure will change from the current conditions. This applies for most foundation design problems, including embankment and cut slope design, shallow foundation design and retaining wall bearing capacity.

4. CD Tests. CD tests are not frequently used because of the time to conduct these tests as noted above. However, in some cases for special soils (e.g., fissured clays), the CD test may give the best long-term definition of strength parameters for effective stress analyses.

9.3.3.1.2 Test Program Requirements

Procedures for setting up and conducting triaxial tests are outlined in the AASHTO and ASTM specifications listed in Figure 9.3-A. The project geotechnical specialist needs to provide direction to the Geotechnical Laboratory on the type of test to be performed and the procedures to be used during the testing. This direction should address the following areas:

1. Sample Number and Description. Designate the sample to be tested and provide a description of the expected soil type, particularly for samples that are stored in Shelby tubes.

2. Test Types. Specify which type of triaxial test (i.e., UU, CU, CD or UC) should be conducted. When specifying confining pressure, consider the existing overburden pressure, as well as the pressure that will occur after the construction of the project.

3. Degree of Saturation. Identify the degree of saturation required for testing. For CU testing, a B-value of at least 95% is required for testing. It is important to have a very high saturation level within the sample to obtain meaningful porewater pressure records.

4. Drainage Conditions. Define the drainage condition required during the consolidation phase of the test and during loading. In the CU and CD tests, the specimen is permitted to drain and consolidate before the sample is tested. On the other hand, the drainage

valves are always closed during the UU test. The volume of water extruded during consolidation should be recorded with time to determine the point of 100% consolidation.

5. Axial Strain Rate. Specify the rate of loading if it differs from conventional loading rates. AASHTO and ASTM Specifications provide guidance on the rate of loading. For CD testing of most soils, the rate must be extremely slow to allow porewater pressures to dissipate. For CU and UU testing, the rates of loading are much faster allowing the test to be completed in less than 1 to 2 hours for many soils.

3. Porewater Pressure Monitoring. Note if porewater pressures will need to be monitored during the triaxial shear test. If CU tests are conducted, the porewater pressures should normally be recorded during the shear phase of the test.

4. Data Required. Identify what data are required from the test and the desired presentation of the data. The AASHTO and ASTM Specifications provide guidance on the information that should be recorded before, during and after the test.

5. Associated Test Information. Provide direction regarding associated test information that should be obtained. Normally, a set of soil classification information should be requested for each test. The classification information should include moisture content and density of the sample. If the sample is cohesive, it is desirable to obtain Atterberg limits and grain-size distributions for a representative set of the test samples.

9.3.3.1.3 Documentation of Test Results

Document the results of the laboratory tests so that the project geotechnical specialist can confirm the strength results from the package of information provided by the Geotechnical Laboratory. Unless requested otherwise by the project geotechnical specialist, the Geotechnical Laboratory will provide the following information:

1. Stress, Strain and Porewater Pressure Plots. Tabulations and plots of stress, strain and porewater pressures, as appropriate, for each triaxial shear test. These results will identify the sample tested and the confining pressure used, as appropriate. A sketch or photograph of the characteristics of the failure mechanism will be provided where visible.

2. CU and CD Results. Plots of CU and CD results in the form of Mohr's circles and strength envelopes or "p-q" diagrams. Effective and total stress friction angles and cohesion intercepts will be defined. The project geotechnical specialist should consult with the Geotechnical Operations Manager or other experienced personnel on the failure criterion to use. These criteria include the maximum principal stress difference ($\sigma_1' - \sigma_3'$), the maximum stress ratio ($\sigma_{1'}/\sigma_{3'}$) and a level of axial strain. Often all three are used.

3. UU and UC Results. Plots of stress versus strain. For the UU and UC results, the project geotechnical specialist should also plot the undrained strength as a function of depth. Compare these results directly with strengths determined from in-situ vane shear measurements, interpretations of cone penetrometer test (CPT) soundings, pocket penetrometer measurements and torvane tests.

9.3.3.2 Direct Shear Tests

The direct shear test provides an alternative method of evaluating the strength properties of soil. This test involves applying a horizontal load to a split-ring device containing the soil sample. The strength of the soil is determined based on the maximum resistance to loading. Direct shear testing is commonly performed on granular soils or compacted materials used for embankment fills and retaining structures. See FHWA *Subsurface Investigations – Geotechnical Site Characteristics* to identify cases where the direct shear test is used during design.

9.3.3.2.1 Sample Requirements and Uses of Direct Shear Results

The direct shear device is a relatively simple method of estimating the strength of cohesionless and cohesive soils. Test requirements can be found in AASHTO and ASTM Specifications listed in Figure 9.3-A. Typical results from the direct shear test include the friction angle of cohesionless soils and the undrained strength of cohesive soils.

Either reconstituted or intact samples of granular and cohesive soils can be tested.

The samples used in the direct shear device are usually reconstituted samples of granular soil; however, reconstituted samples of clay can also be tested. Samples are reconstituted at the anticipated state of compaction in the field. Drainage across the shear plane within the soil cannot be controlled during the direct shear test; therefore, tests on fine-grained soil result in unknown porewater pressure conditions during the test, leading to uncertainty in whether the undrained or partially drained strength of a cohesive soil is being obtained.

It is possible to test undisturbed soil samples with a direct shear device by either trimming the sample into the split ring or using a sampler that has the rings within the sampling tube. Dames and Moore, Inc. developed a system for obtaining somewhat undisturbed samples in a split ring system that could be placed in a direct shear device. MDT does not recommend this practice and, generally, does not accept these test results, especially if the sampler was driven.

There are various limitations associated with the direct shear device. These include the boundary conditions during testing, the imposed failure surface that develops and the inability to control drainage during the test. Often the direct shear test is viewed as an index test for strength, whose application will vary from location to location.

The primary use of the direct shear device on MDT projects is to estimate the friction angle of granular material. The Geotechnical Section typically does not conduct direct shear tests on cohesive soils. There are other special applications where the project geotechnical specialist might consider the use of the direct shear test.

- One involves testing of shear surfaces where the likely failure plane will be along a preferred surface (e.g., slickensides for a slide zone). In this case, the sample is trimmed and aligned so that failure will occur along the surface of interest.
- Another application would be if the soil exhibits sensitivity. For this condition, use the direct shear test to evaluate the residual strength of the soil by manually cycling the sample after measuring the peak strength.

- Finally, use the direct shear device to measure geotextile or geomembrane against soil strengths.

9.3.3.2.2 Test Program Requirements

The project geotechnical specialist needs to provide direction to the Geotechnical Laboratory on the procedures to be used during the testing. This direction should address the following areas:

1. <u>Sample Number and Description</u>. Designate the sample to be tested and provide a description of the expected soil type.
2. <u>Vertical Load</u>. Specify vertical load to impose on the sample. The load is normally selected as either the overburden stress along the failure plane, or multiple tests can be conducted at different vertical loads to develop an envelope of friction angle versus normal load.
3. <u>Dry or Saturated Testing Condition</u>. Provide direction regarding whether the sample will be tested in a dry or saturated condition. Most direct shear test devices include a water reservoir that surrounds the sample system. This allows the sample to be saturated during testing. MDT typically performs direct shear test in a saturated condition.
4. <u>Testing Rate</u>. Define the required rate of testing if it differs from standard rates given in the AASHTO and ASTM Specifications. For granular soils, the rate can be relatively rapid because of the tendency of porewater pressures to rapidly dissipate if any develop. The rate of testing is more of an issue for testing cohesive soils, because there is no control of pore pressure during the test.
5. <u>Data Required</u>. Identify what data are required from the test and the desired presentation of the data. The AASHTO and ASTM Specifications provide guidance on the type of information that should be collected during the test.
6. <u>Associated Test Information</u>. Provide direction regarding associated test information to be obtained. Normally, a set of soil classification information should be requested for each test series. At a minimum, this information should include moisture content and density of the sample. If the sample is cohesive, it is desirable to obtain Atterberg limits and grain-size distributions for a representative set of the test samples.

9.3.3.2.3 Documentation of Test Results

Document the results of the direct shear tests so that the project geotechnical specialist can confirm the strength results received from the Geotechnical Laboratory. Unless requested otherwise by the project geotechnical specialist, the Geotechnical Laboratory will provide the following information:

1. <u>Load and Displacement</u>. Tabulation and plots of the load and displacement during each phase of the test. During the strength test, record the vertical displacement, horizontal displacement and horizontal load.

2. Peak and Residual Strengths. Plots of peak and residual strengths obtained from the direct shear device to show the peak and residual strength as a function of the normal stress imposed during the test. Generally, the peak strength is defined by the maximum force value after correction for area; the residual strength is defined as either the strength after peak strength or the strength after multiple cycles of back and forth movement of the sample before re-shearing.

9.3.4 Consolidation Tests

Where loads (e.g., embankments, spread footings) are placed or constructed on soils, the soils compress. The compression can be either very rapid as in the case of granular soils, or the compression can be slow as in the case of cohesive soils. The calculation of settlement involves many factors, including the magnitude of the load, change in stress at the depths, permeability of soil, water table location and stress history for the soil. Consolidation testing is performed to determine the effects of these factors on the amount and rate of soil compressibility.

9.3.4.1 Sample Requirements and Use of Consolidation Test Results

One-dimensional consolidation tests are conducted in an oedometer. This device involves a confining ring that contains the soil sample and an apparatus for applying a vertical load to a loading platen located on top of the soil specimen.

Tests can be conducted on either cohesionless or cohesive samples, though most consolidation tests are conducted on undisturbed cohesive samples:

1. Cohesionless Soil. Reconstituted samples of cohesionless soil are sometimes tested to determine the compressibility modulus of the soil under one-dimensional loading conditions. For cohesionless soil, the response to load is essentially immediate and, therefore, tests can be conducted very quickly. The amount of displacement is also small relative to most cohesive soils.

2. Cohesive Soil. For cohesive soils, test either undisturbed or remolded samples. For most cases, the rate and amount of compression of undisturbed samples of the native soil are of interest, as this information is used to estimate the amount and rate of settlement of the soil after construction of new embankments or foundations. The response to load will depend on the permeability of the soil sample and the maximum stress imposed on the sample. Typically, the consolidation test on cohesive soil involves multiple load increments, resulting in a testing duration of 1 to 2 weeks.

On some occasions, the compressibility of fine-grained embankment materials is of interest. In these situations, the fine-grained material can be compacted into the consolidation ring. These samples are not normally saturated and consolidation under each load increment occurs very quickly. When conducting consolidation tests on embankment fill materials, the sample can be prepared in the soil confining ring. In this case, compact the sample at the anticipated density and moisture content to be used in the field.

The project geotechnical specialist normally requires consolidation tests to be conducted where the foundation soil includes layers of compressible clays that are located within either two to three foundation widths of the ground surface or where the stress increase from the new foundation loads will be greater than 10%. For most projects, both the amount and rate of settlement are required from the consolidation test.

9.3.4.2 Testing Requirements

Procedures for setting up and conducting the consolidation test are outlined in the AASHTO and ASTM Specifications listed in Figure 9.3-A. The project geotechnical specialist provides direction to the laboratory specialist on the types of tests to be performed and the procedures to be used during the testing. This direction should address the following areas:

1. Sample Number and Description. Designate the sample to be tested and provide a description of the expected soil type.
2. Initial Load Level and Loading Increments. Provide direction regarding the initial load level and the increments of loading above the initial level. Normally, select the initial level of loading so that several measurements can be made below the estimated preconsolidation pressure for the sample to allow determination of the preconsolidation pressure during the test.
3. Saturated Condition Testing. Specify whether the sample should be tested in a saturated condition. Often water is added to the test system immediately after the sample is setup in the test ring and a seating load is applied.
4. Duration and Record of Load Increments. Provide direction regarding the duration of each load increment and whether the rate of settlement should be recorded during each load increment. Usually, the load should be maintained until the end of primary consolidation and the settlement monitored as a function of time during the load increment.
5. Unload-Reload Data and Confining Pressure. Identify whether a set of unload-reload data should be obtained and the confining pressure at which the unloading should occur. Results of these measurements are helpful when evaluating the behavior of the soil during recompression.
6. Associated Test Information. Request a set of soil classification information for each test. At a minimum, this information should include moisture content and density of the sample. If the sample is cohesive, it is desirable to obtain specific gravity, Atterberg limits and grain-size distributions for a representative set of the test samples.
7. Data Required. Identify what data are required from the test and the desired presentation of the data. The AASHTO and ASTM Specifications provide guidance on the type of information that should be collected during the test. This information includes the characteristics of the soil before and after testing, as well as the amount and rate of compression for each load increment.

9.3.4.3 Documentation of Test Results

Results of the consolidation tests need to be documented so that the project geotechnical specialist can confirm compressibility results from the package of information provided by the Geotechnical Laboratory. Unless requested otherwise by the project geotechnical specialist, the Geotechnical Laboratory (GL) will provide the following information:

1. Sample Height Changes. The GL will provide plots of the change in sample height as a function of time for each load increment. The time at which 100% consolidation occurs will be noted on the plot. Either the square root of time (Taylor) method or the log of time (Casagrande) method will be used to make this determination.

2. e-log p' Plots. The GL will provide plots of void ratio versus confining pressure (e-log p') or axial strain versus confining pressure (ε-log p'). The coefficient of consolidation (c_v) will be determined and plotted as a function of load and, where recorded, the rate of secondary compression (c_α) will be defined.

9.3.5 Other Tests

The following describe other soil tests that may be required for an MDT project. The project geotechnical specialist’s role is to decide what tests are appropriate and which samples should be tested. Other tests may include:

1. Proctor Compaction Tests. The purpose of Proctor compaction tests is to determine the maximum dry density attainable under specified nominal compaction energy for a given soil and the (optimum) moisture content corresponding to this density. This test method normally applies to soils that have 30% or less by weight of particles retained on the 0.75-in (19-mm) sieve. Compaction tests are performed using either the Standard Proctor method (AASHTO T99, ASTM D 698) or the Modified Proctor method (AASHTO T180, ASTM D 1557) method. These two methods differ according to the amount of compactive effort during the test, with the Modified Proctor method having roughly four times the compactive effort as the Standard Proctor method. For the same soil, this difference in compactive effort results in a difference in relative compaction. As a rule-of-thumb, a granular soil compacted to 95% compactive effort with the Standard Proctor method is equivalent to a Modified Proctor value of roughly 90%. Typically, the District or the Physical Test Section conducts these tests. The project geotechnical specialist specifies the type of compaction testing and the soil to be tested and decides whether to specify Standard Proctor or Modified Proctor compaction tests. MDT always performs Modified Proctor tests (ASTM D 1557) for soils classifying within the A-1-a or A-1-b groups. For other classifications, use the Standard Proctor test (ASTD D 698). Occasionally, the District may contact the Geotechnical Section during construction to resolve questions on compaction testing.

2. Permeability. The purpose of permeability testing is to determine the rate of flow of water through soils. Information from the permeability is used in selecting road subbase material, backfill for retaining walls and, sometimes, in the design of retention ponds. Permeability tests can be conducted on either undisturbed or remolded soil using either flexible wall (e.g., triaxial testing device) or fixed-wall systems. Either falling head or

constant head tests can be conducted. The selection between the equipment and methods depends on the soil type. Procedures for conducting the permeability tests are given in the AASHTO and ASTM Specifications listed in Figure 9.3-A.

3. Soil Suction. The soil suction test is performed using a thermocouple psychrometer and small cubes of undisturbed soil placed in sealed environmental chambers. The magnitude of soil suction is measured by the psychrometer, and measurements are made on a number of similar cubes with variable moisture contents. The results of these tests are used to estimate the one-dimensional vertical expansion that would be expected from a stratum of similar expansive materials.

4. Swell Potential of Clays. The one-dimensional swell potential test is used to estimate the percent swell and swelling pressures developed by the swelling soils. This test can be performed on undisturbed, remolded or compacted specimens. If the soil structure is not confined (e.g., bridge abutment), swelling may occur laterally and vertically. Triaxial tests can be used to determine three-dimensional swell characteristics. Swelling is a characteristic reaction of some clays to saturation. The potential for swell depends on the mineralogical composition. While montmorillonite (smectite) exhibits a high degree of swell potential, illite has none to moderate swell characteristics and kaolinite exhibits almost none. The percentage of volumetric swell of a soil depends on the amount of clay, its relative density, the compaction moisture and density, permeability, location of the water table, presence of vegetation and trees and overburden stress.

5. Dynamic Tests. In some situations, it may be necessary to conduct dynamic tests to establish the behavior of soils under dynamic loading. The textbook *Geotechnical Earthquake Engineering* (Kramer, 1996) presents several types of dynamic tests including Resonant Column Tests, Cyclic Triaxial Tests and Cyclic Simple Shear Tests. These tests can be used to estimate the shear modulus and material damping as a function of test parameters (e.g., shear strain, confining pressure, soil type).

6. Collapse Potential of Soils. The purpose of this test is to estimate the collapse potential of soils. The collapse potential test is similar to a consolidation test. The sample is placed in the consolidation system and an axial load imposed while the sample is dry. The sample is then flooded and the vertical compression of the sample recorded with time. This type of test is often used when the project site is characterized by loess. At high moisture contents, these soils collapse and undergo sudden changes in volume. The collapse during wetting occurs due to the destruction of clay, lime or calcium carbonate binding which provide the original strength of these soils.

9.4 ROCK PROPERTY TESTS

9.4.1 Overview

Laboratory rock testing is performed to determine the strength and elastic properties of intact specimens and the potential for degradation and disintegration of the rock material. The derived parameters are used for the design of rock fills, cut slopes, shallow and deep foundations, tunnels and the assessment of drainage protection materials (riprap). Deformation and strength properties of intact specimens aid in evaluating the larger-scale rock mass that is significantly controlled by joints, fissures and discontinuity features (spacing, roughness, orientation, infilling), water pressures and ambient geostatic stress state.

9.4.2 Rock Test Methods

Common laboratory tests for intact rocks include measurements of strength (e.g., point load index, unconfined strength, confined compressive strength), stiffness (e.g., ultrasonics, elastic modulus) and durability (e.g., slacking, abrasion). Figure 9.4-A provides summary information on typical rock index and performance tests. Also listed in this Figure are methods of specimen preparation. For many of the rock tests, sample preparation is a key step in the testing process.

9.4.3 Sample Requirements and Uses of Rock Tests

The project geotechnical specialist needs to have a clear understanding of the purpose and requirements before assigning the rock test to the laboratory specialist. These needs involve a different set of considerations from those associated with soil testing. Specifically, secondary factors (e.g., fractures, discontinuities within the rock) are often more important for engineering design than the properties of the intact rock. An example of this would be the stability of a roadside cut. Stability of the cut will usually be determined by the secondary factors rather than the intact rock strength. As a matter of good practice, the project geotechnical specialist should meet with an engineering geologist before assigning rock tests to discuss the types of tests that would be most useful to the project.

9.4.3.1 Unconfined (Uniaxial) Compression Test

The purpose of this test is to determine the uniaxial compressive strength of rock. The uniaxial compression test is the most direct means of determining rock strength. Cylindrical rock specimens are tested in compression without lateral confinement. The test procedure is similar to the unconfined compression test for soils and concrete. The uniaxial test can also be conducted with confining pressure in a triaxial cell. Use of a confining pressure may be particularly valuable for softer rock.

When developing a test program for rock testing, the project geotechnical specialist should consider the following:

1. Sample Examination. Each test sample should be examined to identify inclined fissures, intrusions and other anomalies that may cause premature failures on those planes. Where appropriate, other tests (e.g., triaxial, direct shear tests) may be required.

Test Category	Name of Test	Test Designation	
		AASHTO	ASTM
Point Load Strength	Method for determining point load index (I_s)	-	D 5731*
Compressive Strength	Compressive strength ($q_u = F_u$) of core in unconfined compression (uniaxial compression test)	-	D 2938*
	Triaxial compressive strength without pore pressure	T226	D 2664
Creep Tests	Creep-cylindrical hard rock core in uniaxial compression	-	D 4341
	Creep-cylindrical soft rock core in uniaxial compression	-	D 4405
	Creep-cylindrical hard rock core, in triaxial compression	-	D 4406
Tensile Strength	Direct tensile strength of intact rock core specimens	-	D 3936
	Splitting tensile strength of intact core (Brazilian test)	-	D 3967*
Direct Shear	Laboratory direct shear strength tests - rock specimens, under constant normal stress	-	D 5607*
Permeability	Permeability of rocks by flowing air	-	D 4525
Durability	Slake durability of shales and similar weak rocks	-	D 4644*
	Rock slab testing for riprap soundness, using sodium/magnesium sulfate	-	D 5240*
	Rock-durability for erosion control under freezing/thawing	-	D 5312*
	Rock-durability for erosion control under wetting/drying	-	D 5313
Deformation and Stiffness	Elastic moduli of intact rock core in uniaxial compression	-	D 3148*
	Elastic moduli of intact rock core in triaxial compression	-	D 5407
	Pulse velocities and ultrasonic elastic constants in rock	-	D 2845*
Specimen Preparation	Rock core specimen preparation	-	D 4543
	Rock slab preparation for durability testing	-	D 5121

Note: **Routine rock tests for highway projects involving construction in rock*.

Figure 9.4-A — STANDARDS AND PROCEDURES FOR LABORATORY TESTING OF INTACT ROCK

2. Photographs. Prior to beginning the test, a close-up photograph of the rock sample should be requested. After the test has been completed, additional photographs should be specified. Photographs after the test may show previously undetected fractures and/or deformities that may have affected the testing results.

3. Sample Size. The test specimen should be a rock cylinder of length-to-width ratio (H/D) of 2 with flat, smooth and parallel ends cut perpendicular to the cylinder axis. MDT uses a HQ core diameter of 2.5 in (64 mm); however, other size samples can also be tested.

4. Test Rate and Sample Ends. The rate of loading and the condition of the two ends of the rock will also affect the final results. The test request should require that ends be planar and parallel per ASTM D 4543. Either a spherical seated end platen should be used on one end of the specimen or ends of the specimen should be machined parallel to 0.0001 inches/inch (0.0025mm/mm) to avoid end effects.

5. Reporting. Unless requested otherwise by the project geotechnical specialist, the Geotechnical Laboratory will provide tabulations and plots in the same manner as an unconfined compression test in soil. A lithologic description should be requested and the moisture content of the sample should be determined. At the conclusion of the test, a sketch or photograph of the failure mechanism should be made, and the density and moisture content information should be recorded. Note the rate of loading.

The elastic modulus of an intact rock core specimen can also be obtained during the unconfined compression test. In contrast to a conventional unconfined compression test, the strain for each loading step must be determined if the elastic modulus is measured. Strains will be very small, and therefore the accuracy and resolution of the strain monitoring must be very high. By including lateral strain measurements during this test, it is possible to determine the Poisson’s ratio of the test specimen. If modulus and Poisson's ratio measurements are made, it is critical to have load and deformation transducers accurately calibrated before the test.

9.4.3.2 Point Load Index (Strength) Test

The purpose of point load index, or strength, testing is to determine the strength classification of rock materials. This type of test provides an indication of strength much more quickly and inexpensively than an unconfined compression tests. However, the strength determined from this test is not as accurate as an unconfined compression tests. Therefore, test results are used as an index of strength and generally not used directly for design purposes.

The test can be performed in the field with portable equipment or in the laboratory. However, the Geotechnical Section only allows this test to be conducted in the laboratory and only when the project geotechnical specialist is present.

Procedures for conducting the point load test can be found in ASTM D 5731. These procedures include important limits on the applicable range of rock strengths, specimen sizes, test corrections and typical results.

9.4.3.3 Other Rock Tests

The following describe other rock tests that may be required for a MDT Project:

1. Direct Shear Tests. This type of test is most useful when evaluating the strength along planes of weakness within the rock structure. These weaker seams can serve as failure planes during loading, particularly for slope cuts where the bedding planes dip in a direction with the slope. In this case, it may be important to characterize the strength of the weaker material in the direction of dip. Other examples of discontinuities that can be of interest could be the interface between a rock and a concrete fill. This test is conducted by shearing the specimen in a direct shear machine with the failure plane

oriented parallel to the direct shear box. A normal load is placed on the specimen, and the shear stress is monitored as a function of shear displacement.

2. Shale Slake Durability Test. The purpose of slake durability testing is to determine the durability of shale or other weak or soft rocks subjected to cycles of wetting and drying. This test is typically performed on shales and other weak rocks that may be subject to degradation in the service environment. When some shales are newly exposed to atmospheric conditions, they can degrade rapidly and affect the stability of a rock fill or cut, the subgrade on which a foundation is to be placed, or the base and side walls of drilled shafts prior to placement of concrete. This test involves placing the test specimen in a drum and rotating the drum through a water bath at a specified rate and for a specific duration. The resulting slake durability index is calculated and a photographic record of the retained material made. Further information on this rock test can be found in FHWA *Design and Construction of Shale Embankments* (FHWA-TS-80-219).

3. Micro-Deval Test. This test is used by MDT to determine the durability of crushed aggregated for asphalt surfacing and base course material. The Micro-Deval test is a wet test that determines how aggregates degrade when tumbled in a rotating steel drum with water and steel balls. It is a better indication of aggregate's service when exposed to weather and moisture than the LA Abrasion test. This is particularly true in base and HMA applications where the actions of water and particle-to-particle interaction are important factors. For these applications, having Micro-Deval tests for both the fine- and coarse-aggregate fractions permits the whole aggregate to be evaluated.

9.5 SOIL AND ROCK CLASSIFICATION

9.5.1 General

There are two nationally accepted methods for classifying and describing soils used by geotechnical professionals — Unified Soil Classification System (USCS) and AASHTO soil classification system. These are described as follows:

1. Unified Soil Classification System. The USCS is primarily used for classifying mineral and organic mineral soils for engineering purposes based on particle-size characteristics, liquid limit and plasticity index. It is the most commonly used system in geotechnical work (e.g., foundations, piles, retaining walls) and is used by the Geotechnical Section.

2. AASHTO. The AASHTO classification system is used for classification of highway subgrade material. This system is based on the grain size and plasticity. The AASHTO classification system is used to determine the relative quality of the soil material for use in highway earthwork, particularly embankments, subgrades, subbases and bases. This system is used by the Physical Lab Section and the highway designer. Note that the AASHTO classification is included on the boring logs.

The Geotechnical Section prefers the USCS method of classifying soils for engineering descriptions. Because other units within MDT use the AASHTO Method, the AASHTO classifications are also provided for cross-referencing.

9.5.2 USCS Soil Classification

9.5.2.1 General

Soil description/identification is the systematic, precise and complete naming of individual soils in both written and spoken forms (ASTM D 2488, AASHTO M145), while soil classification is the grouping of the soil with similar engineering properties into a category based on index test results (e.g., group name and symbol (ASTM D 2487, AASHTO M145)). It is important to distinguish between visual identification and classification to minimize conflicts between general visual evaluations of soil samples in the field versus a more precise laboratory evaluation supported by index tests.

9.5.2.2 Field Identification

During advancement of a boring, the project geotechnical specialist or the drilling crew should only describe the soils encountered. Group symbols associated with classification should not be used in the field. Visual descriptions in the field are often subjected to outdoor elements that may influence results. It is important to send the soil samples to a laboratory for accurate visual identification by the laboratory specialist. This single operation provides the basis for later testing and soil profile development.

The project geotechnical specialist should use results from the field tests described in Section 8.3.8 and guidance from the following to identify the soil types:

- ASTM D 2488 “Standard Practice for Description and Identification of Soils (Visual Manual Procedures”; and/or
- NHI *Subsurface Investigations — Geotechnical Site Characterizations*.

9.5.2.3 Lab Classification

The purpose of the lab tests described in this chapter is to classify the soil samples for engineering purposes based on laboratory determination of particle-size characteristics, liquid limit and plasticity index. The project geotechnical specialist should use the results obtained from tests described in this chapter and guidance from the following to classify the soil samples:

- ASTM D 2487 “Standard Practice for Engineering Purposes (Unified Soil Classification System)”; and/or
- NHI *Subsurface Investigations — Geotechnical Site Characterizations*.

9.5.3 Rock Classification

Rock descriptions should use technically correct geological terms, although local terms in common use may be acceptable if they help describe distinctive characteristics. The rocks lithologic description should include, as a minimum, the following items:

- rock type,
- color,
- grain size and shape,
- texture (stratification/foliation),
- mineral composition,
- weathering and alteration,
- strength, and
- other relevant notes.

For additional guidance on classifying rocks, review the following documents:

- “International Society for Rock Mechanics Commission on Standardization of Laboratory and Field Tests”; and/or
- NHI *Subsurface Investigations — Geotechnical Site Characterizations*.

9.5.4 Report Presentation

The boring logs are the basic record of the geotechnical exploration and laboratory analyses. It provides a detailed record of the work performed and the findings of the field investigations and results from the laboratory tests. Information from the field investigation will have been entered into the computer program gINT or other programs approved by the Geotechnical Section. The project geotechnical specialist will revise the field information according to the laboratory results to produce the final boring log. For additional guidance on the presentation of the lab results, see Section 8.4 and Chapter 5.