

CHAPTER 4

FIELD IDENTIFICATION AND IN-SITU TESTING

4.0 INTRODUCTION

This section considers the various in-situ tests that are performed to determine the physical and engineering properties of soils in the field. Many new field geotechnical testing techniques have been developed during the last two decades; however, the focus in this chapter will only be on conventional field tests that are routinely carried out within INDOT to meet or exceed the minimum requirements of this manual as well as INDOT Standard Specifications.

Extreme care in selecting a representative sample should be taken, so that the test values truly characterize the in-situ mass of soil. When AASHTO or ASTM specifications govern, the most current standard or interim specification shall be used for reference.

4.1 SOILS

Identification of soil types in the field, which is typically limited to defining the color and estimating the basic characteristics of texture and plasticity, is normally done without the benefit of major equipment, supplies, or time. It is necessary to perform a general site assessment during field reconnaissance activities and during the initial phases of more detailed work, such as the investigation of an emergency remediation or a planned geotechnical or pavement survey. It may, in some instances, be the only effort expanded towards classifying the encountered soils, but in most cases, it will serve as an aid in assigning more detailed or elaborate laboratory tests.

4.1.1 TEXTURE

The following methods may be used in the field to estimate the soil's texture, which is defined as the relative size and distribution of the individual soil particles or grains.

4.1.1.1 VISUAL EXAMINATION

By carefully looking at the soil, it can be divided by particle size: gravel, sand, and fine (silt and clay combined). Since the naked eye can only distinguish particle sizes down to about 0.05 millimeters, silt and clay sized particles cannot be separated without further magnification.

The examination is done by drying a sample, spreading it on a flat surface, and then simply segregating it into its various components and estimating the relative percentage of each. The percentage refers to the dry weight of each soil fraction, as compared to the dry weight of the original sample. Table 4.1 provides the defined particle sizes for each component and a common reference to aid in identifying the various particle sizes.

4.1.1.2 SEDIMENTATION/DISPERSION

This test is done by shaking a portion of the sample into a jar of water and allowing the material to settle. The material will settle in layers. The gravel and coarse sand will settle almost immediately, the fine sand within about a minute, the silt requiring as much as about an hour, and the clay remaining in suspension indefinitely. The percentage of each component

is estimated by comparing the relative thickness of each of the layers in the bottom of the jar, keeping in mind that the larger sized particles will typically settle into a denser mass than the fines.

Table 4.1 Visual Grain Size Identification

| Approximate Size Limits | | | |
|------------------------------------|---------------------|------------------|---|
| Classification | Measured | Sieve | Comparison Example |
| Boulder and Cobbles | Over 3 in. | > 3 in. | Grapefruit size |
| Gravel Coarse Medium Fine | 3 in. - 1 in. | 3 in -1 in. | Lemon size |
| | 1 in - 3/8 in. | 1 in - 3/8 in. | Diameter of penny |
| | 3/8 in -2.0 mm | 3/8 in -No. 10 | Pencil diameter to pea or rock salt |
| Sand Coarse Fine | 2.0 mm - 0.42 mm | No. 10 - No. 40 | Broom straw diameter to sugar or table salt |
| | 0.42 mm - 0.075 mm | No. 40 - No. 200 | Human hair diameter to powdered sugar |
| Silt | 0.075 mm - 0.002 mm | < No. 200 | Cannot be discerned with the naked eye |
| Clay | < 0.002 mm | | Cannot be discerned with the naked eye |

4.1.2 PLASTICITY

The ability to be molded within a certain range of moisture contents is termed plasticity, which is dependent upon the percentage and type of clay component; therefore, it requires differentiation between silt (non-plastic fines) and clay (plastic fines). The following methods can be used in the field for this differentiation.

4.1.2.1 RIBBON/THREAD

In the ribbon/thread test a roll of soil moist enough to have workability, approximately one-half to three-quarters inch in diameter and about three to five inches in length, is pressed between the thumb and index finger into a ribbon about one-eighth inch thick. The longer the ribbon can be formed before the soil breaks under its own weight, the higher the soil's plasticity. Highly plastic clays can be ribboned to four inches longer than their original cast. Clays of low plasticity can be ribboned only with some difficulty into short lengths while non-plastic materials cannot be ribboned at all. The relationship between plasticity to ribbon/thread length is summarized in Table 4.2.

4.1.2.2 DRY STRENGTH/BREAKING

The dry strength/breaking test is normally made on a dry pat of soil about ½ inches thick and about 1-1/4 inches in diameter that has been allowed to air dry completely. Attempts are made to break the pat between the thumb and fingers. Highly plastic clays are resistant to breakage or powdering and may take great effort to be broken. Caution must be exercised with highly plastic clays to distinguish between a fresh break and shrinkage cracks; the latter of which is common in such soils. Clays of low plasticity can be broken and powdered with increasing ease, while non-plastic soils have very little dry strength, crumbling or powdering when picked up by hand.

Table 4.2 Ribbon/Thread Plasticity Test

| Plasticity | Length of Ribbon (inches) |
|-----------------------------|---------------------------|
| Non Plastic | 0 |
| Slightly Plastic to Plastic | 0 – ½ |
| | ½ - 1 |
| | ¼ - 1 |
| | 0 – 1 |
| Plastic to Highly Plastic | 1 - 2 |
| Highly Plastic | > 2 |

4.1.2.3 SHAKING/DILATENCY

In the shaking/dilatency test, a pat of soil about three-quarters inch in diameter is moistened to a putty-like state and placed in the palm of the hand. The hand is then shaken vigorously or jarred on a table or other firm object. If the sample’s surface begins to glisten, it is an indication that moisture within the sample has risen to the surface. When this does not occur, the soil is probably clayey. Where this occurs sluggishly or slowly, the soil is predominantly silty, perhaps with a small amount of clay. For silts or very fine sands, the moisture will rise to the surface rapidly and the test can be repeated by simply remolding and then reshaking the pat. INDOT does not generally do this test.

4.1.3 COLOR

Colors tend to be relative to each individual since some are color blind, especially in the red-green spectrums. Most soils fall into the gray to brown range with combinations quite common. Use combinations and hues to make the soil descriptions more exact, such as light gray, yellowish brown, or dark reddish-brown to help differentiate between strata.

Changes in color should be noted. The changes in colors can help determine the changes in mineral content of the soils, or indicate fluctuations in groundwater, such as mottling. Dark soils can indicate organics such as peat, while light-greenish colors can indicate marly soils.

4.2 BEDROCK DESCRIPTION

Rocks are highly variable in composition and much practical experience must go into detailed and accurate geologic descriptions of rock materials. In most cases an accurate, detailed, geologic description can be made only by a qualified geologist. However, field personnel can produce a usable description of bedrock materials encountered in the field using a basic rock classification system. This will facilitate correlation between borings and outcrops and may provide insight into engineering properties and rock material behavior, which is necessary for the design and construction of projects that encounter bedrock. In addition to describing the rock, the extent of its occurrence relative to the project must also be documented.

Rock classification for geotechnical purposes consists of two basic assessments:

1. Sample characteristics, consisting of classification of the intact rock specimen or core; as to its formation and constituent minerals; and its texture, color and degree of weathering, and

2. Rock mass characteristics, consisting of classification of the in-place rock mass including descriptions of structural or lithological discontinuities, such as bedding, joints, faults, and formational contacts.

An important facet of rock classification is the determination of what constitutes rock, as opposed to extremely weathered material which approaches soil in its character and engineering properties. Geologists and geotechnical engineers determine the degree of weathering in rock and determine whether its properties have become “soil-like” and will thus be referred to as residual soil. The contact between residual soil and rock is labeled the “top of bedrock” and should be noted on boring logs, profiles, and cross sections. For small projects, or during the early stages of large projects, rocks are initially classified by visual means.

4.2.1 SAMPLE CHARACTERISTICS

4.2.1.1 LITHOLOGY

Rocks are divided into three general categories according to their origin: igneous, sedimentary and metamorphic. *Igneous rocks* are formed by the cooling of magma. *Sedimentary rocks* are formed by the breakdown through weathering of an existing rock mass, then deposition as a sediment, followed by lithification. *Metamorphic rocks* are formed by alteration of existing rocks under conditions of high temperature and/or pressure. In Indiana, sedimentary rocks are the only bedrock encountered in INDOT’s work for highways. The only igneous or metamorphic rocks encountered during a geotechnical investigation in Indiana will be glacial erratics such as boulders, cobbles, and gravel. Therefore, the discussion of bedrock in this section will be limited to sedimentary rocks.

Sedimentary rocks are classified on the basis of their depositional mode, grain size, mineralogy, mode and extent of lithification, and relationship between grains. Sedimentary rocks are separated into two major categories, clastic or chemical, depending on their depositional mode. The basic classification system for sedimentary rocks is shown in the table for classification and identification of sedimentary rocks.

4.2.1.1.1 CLASTICS

Clastic sedimentary rocks are composed of rounded or angular fragments of previous rocks, and are classified by their particle size, ranging from gravel to clay.

4.2.1.1.1a Conglomerate and Breccia

These are sedimentary rocks in which clastic sediments contain obvious portions of gravel size or larger. The term conglomerate is usually applied to rocks in which the coarse fragments are sub-angular or more completely rounded, whereas the term breccia is used if the grains are angular. The individual fragments that make up a conglomerate or breccia may be of any lithology.

4.2.1.1.1b Sandstone

Sandstones are often composed predominantly of quartz grains, cemented with silica, carbonate, clays, or iron. Sandstones are typically described by their grain size, mineral constituents, and degree of cementation (friability). A well sorted sandstone that contains more than 95% quartz grains is given the name quartzose sandstone. Other special terminologies for sandstones include arkose - rich in feldspar, or graywacke - a mixture of quartz, feldspar, and fragments of other rock in a fine-grained matrix. Arkose and graywacke are not common in Indiana, so we would normally encounter quartzose sandstone in Indiana.

Commonly, the rate of groundwater flow through sandstones is high, which may cause drainage or erosional problems in deep excavations or cuts. Sandstones are also generally competent for loading of structural footings when confined but are susceptible to erosion or scour when exposed to the elements. Sandstones are most common in the Pennsylvanian Period in the south and west part of the state.

Table 4.3 Classification and Identification of Sedimentary Rocks (Modified from *Petrology of Sedimentary Rocks*, R. L. Folk, 1980.)

| Table A: COARSE-GRAINED CLASTIC SEDIMENTARY ROCKS | | |
|--|----------------------|------------------------|
| COMPOSITION | COMMENTS | ROCK CLASSIFICATION |
| Gravelly | Rounded grains | Conglomerate |
| | Angular grains | Breccia |
| Sand | Mostly quartz grains | Quartzose or Sandstone |

| Table B: FINE-GRAINED CLASTIC SEDIMENTARY ROCKS | | |
|--|------------------------------------|----------------------------|
| PREDOMINANT GRAIN SIZE | BREAKING CHARACTERISTIC | |
| | Massive (Non-Fissile) | Flaggy, Flakey or Fissile |
| Grain Size Proportions Unknown | Mudstone | Shale (Commonly used term) |
| Silt > Clay: | Siltstone (Common in Borden Group) | Silty Shale |
| Clay > Silt: | Claystone | Clayey Shale |

| Table C CHEMICAL SEDIMENTARY ROCKS | | | |
|--|--|-------------------------|---|
| Composition | Comments | Rock Classification | |
| Mainly Calcite (Calcium Carbonate) CaCO ₃ | Crystals formed as precipitates | Limestone | C A R B O N A T E |
| | Spherical grains with concentric laminations | Oolitic Limestone | |
| | Abundant fossils | Fossiliferous Limestone | |
| Mainly Dolomite CaMg (CO ₃) ² | Commonly altered from limestone | Dolomite | |
| Quartz - SiO ₂ | Layers, lenses, & nodules | Chert | |
| Gypsum - CaSO ₄ .2H ₂ O | Crystals formed as precipitates | Gypsum | |

4.2.1.1.1c *Siltstone and Shale*

This group of sedimentary rock includes all those in which the grain sizes are smaller than sand size (silt and clay). Siltstone is a term applied to fine grained rocks that are composed of more silt, than clay, and lack the fissility of shale. In practical terms, silt and clay sizes are too small to be visible to the unaided eye, but silts can be detected by their gritty nature between the teeth. In contrast, clay sizes behave as a paste between the teeth. The term shale is often used to describe the remaining rocks in this

group, although technically, the term shale should be applied only to those rocks which show bedding-plane fissility or lamination. Table 4.3 B shows the less often used terms of mudstone and claystone which can be applied to silt and clay sized massively non-fissile sedimentary rocks.

Siltstones are often misclassified as shale, (if fissile), or as sandstone (if massive). The most common occurrence of siltstone is the Sanders Group's Muldraugh Formation and Borden Group's the Spickert Knob Formation in Indiana.

Shales are typically platy and have thin zones or beds that are typically more sandy or more silty, fossiliferous, or contain sedimentary features. Erosion and landslides are potential problems in shales. Special criteria are specified for use of shale as fill material. Shale requires special moisture and density and compaction control and testing to meet specifications.

4.2.1.1.1d *Coal*

Coal is a readily combustible rock containing more than 50 percent by weight and 70 percent by volume of carbonaceous material, formed from the compaction or indurations of variously altered plants remains similar to those of peaty deposits (Boggs 1995). Coal in Indiana is found primarily in the Mississippian and Pennsylvanian rocks of the southwestern portion of the state and comprises an important economic resource.

4.2.1.1.2 CHEMICAL PRECIPITATES

Chemical sedimentary rocks include all those rocks that precipitate from solution, such as carbonates (limestone and dolomite) and chert.

4.2.1.1.2a *Carbonates*

Calcium carbonate (calcite) is precipitated out of water by chemical or biologic means, or it collects as a mass of fossil fragments termed elastic limestones. Subsequent lithification and chemical alteration produces crystalline limestone. Dolomitization is the chemical replacement of Mg^{2+} for some of the Ca^{2+} in limestone yielding dolomite, or dolomitic limestone $[CaMg(CO_3)_2]$ depending on the amount of magnesium ion replacement. Dolomite crystals cut across the original limestone, which usually obscures primary structures, such as bedding or fossils. Limestone will effervesce freely in dilute hydrochloric acid. In contrast, dolomite will react with acid only after powdering, which is a good way for differentiating between limestone and dolomitic. Carbonates situated near the water table—either presently or in the ancient geologic past—may have undergone dissolution by slightly acidic groundwater, creating enlarged cavities along rock discontinuities known as caves. There may be more than one horizon of caves or dissolution due to changes in groundwater level through time. Surface depressions known as sinkholes are the result of loss of soil into these solution cavities due to cave roof collapse of deeper systems or shallow, near-surface caves. The topography produced by the progressive dissolution and ultimate collapse is known as karst. Areas of karst topography or known caves may have poor foundation conditions due to past collapses and continued dissolution of the bedrock. The majority of Indiana's karst topography is located in the south-central part of the state, and is common in Monroe, Lawrence, Orange, Washington, Crawford and Harrison counties, in the regional physiographic unit called the Mitchell Plain.

4.2.1.1.2b *Chert*

Chert is a microcrystalline rock, composed of minute quartz crystals with submicroscopic pores, having a conchoidal to splintery fracture. Chert is hard, typically white to light gray, and weathers to a soft, dull white, chalky crust, often around an unchanged chert core. Appreciable quantities of chert may occur as nodules in limestones or shales and may cause difficulty in drilling borings, shafts, or piers due to its hardness and toughness. Chert nodules are common in the Harrodsburg Limestone formation in Indiana.

4.2.1.1.2c *Evaporites*

Evaporites are composed of minerals that precipitate from saline solutions from the evaporation of seawater. Anhydrite and gypsum are the most important evaporates in Indiana and they are mined in Lawrence and Martin Counties for use in the manufacture of Portland cement and wallboard.

4.2.1.2 COLOR

When describing color, only common colors, such as brown, black, gray or white, in addition to simple prefixes representing density of the color (e.g. light or dark) and other colors to represent shading (e.g., reddish or grayish) should be used.

4.2.1.3 TEXTURE

Texture describes the size, shape, surface characteristics, and arrangement of individual grains or crystals in a rock. A significant and readily identifiable texture identification, such as fine, medium, or coarse grained, should be used.

4.2.1.4 WEATHERING

Weathering is the physical and chemical alteration of solid rock, which is an important aspect of rock classification due to the significant relationship between the degree of weathering and the engineering properties of the rock mass. In its earliest stages weathering causes the discoloration of intact rock with only slight changes in rock hardness, strength, and compressibility. In later stages of weathering the rock mass is altered until the rock is eventually reduced to soil. Shale weathers faster than other rocks. This differential weathering can result in highly weathered shale strata adjacent to slightly weathered limestone, which occurs in the Dearborn Upland physiographic region of Indiana. Chemical alteration may occur at depths far below that of normal rock weathering.

Table 4.4 Terms to Describe Rock Weathering and Alteration (ISRM, 1981)

| Degree of Weathering | Description |
|------------------------------|--|
| Fresh | Rock shows no discoloration, loss of strength, or other effects of weathering/alteration |
| Slightly Weathered/Altered | Rock slightly discolored, but not noticeably lower in strength than fresh rock |
| Moderately Weathered/Altered | Rock is discolored and noticeably weakened, but less than half is decomposed: minimum 2 inch diameter sample cannot be broken readily by hand across the rock fabric |
| Highly Weathered/Altered | More than half of the rock is decomposed; rock is weathered so that a minimum 2 inch diameter sample can be broken readily by hand across the rock fabric |
| Completely Weathered/Altered | Original minerals of rock have been almost entirely decomposed to secondary minerals even though the original fabric may be intact; material can be granulated by hand |
| Residual Soil | Original minerals of rock have been entirely decomposed to secondary minerals, and original rock fabric is not apparent; material can be easily broken by hand |

The empirical weathering criteria given in the following Table 4.5 is applicable to quartzose sandstones that are predominantly free of finer grained (silt or clay) constituents. The primary determining factor is the *N* value, or number of blows per foot obtained from the standard penetration test.

Table 4.5 Sandstone *N* Values

| TERM | DESCRIPTION | TYPICAL SPT, OR <i>N</i> (bpf) |
|---|--|--------------------------------|
| Sandstone Sand(Sandy Soil from Sandstone) | Sand, generally, uniform of size and color, composed predominantly of rounded quartz grains; may contain up to 50% foreign glacial type sand or fine gravel | 30 to 50 |
| Sandstone, weathered | Typical sandstone without foreign material. If present, such material is designated as the "Top of Bedrock" *(Note: Three tenths of a foot penetration is borderline or transitional into fresh sandstone.) | 50/0.7' to 50/0.3 |
| Sandstone, fresh | Dense, typical quartzose sandstone. Frequently, no samples are recovered. | 50/0.3' to 50/0 |

The following table relates shale classification to its SPT value. It applies principally to thick shale units without thin beds of limestone or sandstone.

Table 4.6 Weathering Criteria (Shale)

| TYPE OF SHALE | | TYPICAL SPT (bpf) OR N |
|--|---|------------------------|
| WEATHERED | a. Greater than 50% Mixed, (not in-place); - clayey shale with foreign material inter-mixed. (For < 50% shale, use soil description with indication of presence of weathered shale). | <30 |
| | b. <u>Disturbed (not in-place)</u> (1) <u>Disturbed clayey shale*</u> -fragments or bedding plane remnants that are not horizontally oriented. Bedding plane remnants are frequently difficult to see. | <30 |
| | (2) <u>Disturbed fractured shale**</u> -fragments or small pieces of relatively firm to hard fresh shale with bedding planes that are not horizontally oriented. | 30-70 |
| WEATHERED | c. <u>In-place (top of weathered bedrock)</u> (1) In-place clayey shale -has not been moved. Bedding plane remnants are horizontal | <30 |
| | (2) In-place fractured shale -fragments or small pieces of relatively fresh horizontally oriented shale. Essentially similar to fresh shale below, except for blow count | 30-70 |
| FRESH SHALE (Top of Bedrock) | Dense, fractured, somewhat brittle. Bedding planes are horizontal. | >50/0.7 |
| <p>Notes: Transitional forms between categories are likely to be encountered. <i>* Shale type material, which is generally quite plastic, uniform in texture, and has physical properties similar to clay.</i> <i>** When a sample is broken open, small cubic or rectangular pieces of rather firm shale are evident. The pieces bounded by fracture planes are relatively unweathered, thus less plastic and more firm in contrast to clayey shale.</i></p> | | |

4.2.2 ROCK MASS CHARACTERISTICS

Structural elements of the rock mass should be assessed in an attempt to define the overall engineering characteristics of the mass. Discontinuities are major elements of rock mass classification. These features should be described in terms of frequency, spacing, roughness, bonding quality, and general continuity.

4.2.2.1 GEOLOGIC DISCONTINUITIES

Geologic discontinuities are breaks or visible planes of weakness in the rock mass that separates it into discrete units. Discontinuities may include structural features, such as joints and faults in addition to depositional features, such as bedding planes. Fractures include all breaks in a rock body or core sample, regardless of origin. Fractures may be of geological origin or they may be induced. Bedding planes in Indiana are usually nearly horizontal, while joints are usually at a high angle, usually near vertical. While voids are not geologic discontinuities they will be discussed in this section as they affect the overall structure of a rock mass.

4.2.2.1.1 JOINTS

A joint is a surface of fracture or parting in a rock, along which there has been no visible movement parallel to the joint surface. Movement may occur at right angles to the joint surface causing the joints to separate or “open up”. Joint surfaces are usually planar, and often occur with parallel joints to form a “joint set.” Two or more joint sets that intersect define a joint system. Joints may range from perpendicular to parallel in orientation with respect to bedding but are most commonly perpendicular in Indiana.

4.2.2.1.2 BEDDING SURFACES

Bedding surfaces are generally a planar, or nearly planar, and usually nearly horizontal surface that visibly separates each successive layer of stratified rock (of the same or different lithology) from the preceding or following layer. It may or may not be physically separated (appearing as a fracture). Bedding surfaces that are not planar include channel features and sandstone cross-bedding, which may give the erroneous impression of post-deposition tilting, especially in core samples.

4.2.2.1.3 FAULTS

A fault is a major fracture along which there has been appreciable displacement. The presence of gouge (pulverized rock), bedding offset, or slick-sided surfaces (commonly with mineral or clay coating) may be indicators of fault movement.

4.2.2.1.4 VOIDS

Voids are open spaces in the subsurface rock that are generally due to the removal of rock materials by chemical dissolution or the action of running water. Voids can be related either to intact properties or to rock mass properties, depending on their size, as described in the following table.

Table 4.7 Description of Void Sizes

| Description of Void Sizes. | | |
|-----------------------------------|--------------------|---|
| Term | Description | Size of Voids |
| Pit | Pitted | Hard to see unaided, up to 0.25 inches (6 mm) in diameter |
| Vug | Vuggy | 0.25 in. (6 mm) to 2 in. (50 mm) in diameter |
| Cavity | with Cavities | 2 in. (50 mm) to 24 in. (600 mm) in diameter. |
| Cave | with Caverns | Larger than 24 in. (600 mm) in diameter |

4.2.2.2 DESCRIPTIONS OF DISCONTINUITIES

All geologic discontinuities that are visible in a core sample should be logged, whether or not they are manifested as a fracture. Care should be taken to distinguish between geologic discontinuities and fractures that are induced by drilling or handling. Induced fractures are not logged.

Some properties of geologic discontinuities that can be measured in core samples include: attitude, spacing, rock quality designation (RQD), percent recovery, average core length, fractures per two-foot spacing, and average lithology type thickness.

4.2.2.2.1 ATTITUDE

Attitude refers to the inclination of a discontinuity measured from the horizontal. The inclination may be expressed in degrees or by using the quantitative descriptive terms given in the following table.

Table 4.8 Description of Attitude

| Term | Angle (degrees) |
|---------------------------|------------------------|
| Horizontal | 0-5 |
| Shallow or low angle dip | 5-35 |
| Moderately dipping | 35-55 |
| Steep or high angle dip | 55-85 |
| Vertical or near vertical | 85-90 |

4.2.2.2.2 SPACING

Spacing refers to the distance between discontinuities in the core, either joints or beds. Faults are normally identified as joints since displacement is difficult to observe in the core. Joint and bedding terms used to describe spacing are given in the following table.

Table 4.9 Description of Spacing

| Joint Spacing | Bedding Term | Spacing (in.) |
|----------------------|---------------------|----------------------|
| ----- | Laminated | <0.5 |
| Very Close | Very thin | 0.5-2 |
| Close | Thin | 2-12 |
| Moderately close | Medium | 12-36 |
| Wide | Thick | >36 |

4.2.2.2.3 ROCK QUALITY DESIGNATION

Rock quality designation (RQD) is expressed as a percentage. It is the total length of intact pieces of rock core greater than four inches (100 mm) in length divided by the total length of core run. RQD is determined for each core run. Fresh breaks created by field personnel or by drilling operations are counted as not broken when calculating RQD. RQD may not be applicable for rocks of very low strength, are highly fissile or are foliated; such as shales, as they may break apart easily making identification of natural versus mechanical breaks nearly impossible.

$$RQD (\%) = \frac{\text{Sum of Core Pieces} \geq 4 \text{ inches (10 cm)}}{\text{Total Length Drilled}} \times 100$$

RQD has been related to the overall engineering quality of the rock with higher RQD values indicating more intact and better performing rock as shown in the following Table.

Table 4.10 Relationship between RQD and Rock Quality (from Deere and Miller, 1966).

| RQD% | Rock Quality |
|-------------|---------------------|
| 0-25% | Very Poor |
| 25-50% | Poor |
| 50-75% | Fair |
| 75-90% | Good |
| 90-100% | Excellent |

4.2.2.2.4 CORE RECOVERY

Recovery is the length of rock core retrieved from the core hole divided by the total length of the core run, expressed as a percentage. Recovery is often an indicator of rock quality—higher percentages suggesting a more intact rock mass.

4.2.2.2.5 AVERAGE CORE PIECE LENGTH

Average core piece length (ACPL) is the average measurement of the length of core segments that are greater than four inches long. This value is a further indication of the relative spacing of the discontinuities and calculated for any specified interval.

4.2.2.2.6 FRACTURES PER TWO-FOOT INTERVAL

Fractures per two-foot interval refer to the total number of fractures, excluding those induced by drilling or handling, which occur in a two-foot interval of core.

Intervals with more than 10 discontinuities are recorded as >10. Zones within a two-foot interval that have more fractures than can be readily measured are designated as “rubble”.

4.2.2.2.7 AVERAGE LITHOLOGY TYPE THICKNESS

Average lithology type thickness is useful in describing rock core samples with alternating thin beds of different lithologies, such as limestone and shale, as in the Ordovician formations in southeastern Indiana. The thicknesses of similar rock type units are averaged over any specified chosen interval. A note describing maximum length of a one-piece length of core for each type of rock can also be descriptive of strength.

4.2.2.2.8 DESCRIPTIONS OF DISCONTINUITIES IN OUTCROPS

In some cases, it may be desirable to further investigate the rock mass characteristics of a rock body. Additional descriptions might include orientation of discontinuities (strike and dip) and continuity (lateral extent of a discontinuity). These types of assessments are important when designing items such as the angle of rock back slope, tunnel support, bearing capacity near rock cuts, or excavation methods.

4.2.2.3 RELATIVE ROCK HARDNESS

Rock hardness is a measure of rock strength and is controlled by many factors including degree of induration, cementation, crystal bonding, or degree of weathering. Rock hardness may be estimated through field tests on core samples or outcrops, as described in Table 4.11, which can be refined with additional laboratory testing. The relative hardness of rock should be determined for each rock core sample or outcrop. Multiple designations would be required for variable rock conditions, such as lithological changes or weathering.

Table 4.11 Field Identification of Rock

| Term | Field Identification |
|----------------|---|
| Extremely Soft | Loose sand to soft core, crumbles or falls apart (poorly-cemented) upon removal from core barrel/split tube, or under slight pressure; (un-cemented sandstone). |
| Very Soft | Can be indented by thumbnail. May be moldable or friable with finger pressure. In outcrop, can be excavated readily with point of a geology hammer/pick. Sandstone can be deformed or crushed with fingers. |
| Soft | Can be scratched with a fingernail. Can be peeled with a pocketknife. Crumbles under firm blows with geology hammer/pick. Sandstone cannot be deformed with a finger, but grains can be rubbed from the surface and small pieces can be crushed between fingers with some difficulty. |
| Hard | Can be scratched by knife or geology pick only with difficulty. Several hard hammer blows are required to fracture a specimen. |
| Very Hard | Cannot be scratched by knife or geology pick. Specimens require many blows of hammer to fracture or chip. Hammer rebounds after impact. |

4.2.2.4 STRENGTH TESTS

When quantitative values for rock strength are desired, strength tests, such as unconfined compressive strength, Schmidt hammer, or point load tests can be performed.

4.2.3 SAMPLE DESCRIPTION

It is important to give a complete description of the appearance and occurrence of rock materials in the field for use in a preliminary engineering design. The following is a recommended list for the description of rock as viewed in an outcrop in the field or in the lab as core samples:

- **Lithology:** with modifying mineral description, if possible
- **Color**
- **Grain Size and/or texture**
- **Weathering**
- **Discontinuities:** frequency and orientation of joint faults and beds
- **Rock Unit:** Formation, member, or unit name
- **Occurrence:** extent of outcrop or depth below surface

An example description of a rock outcrop would be:

Limestone: gray to dark gray, microcrystalline, with fossils, slightly weathered, thin to medium bedded, many high-angle and low-angle joints. Joint spacing averages 12 inches apart, likely St. Louis Formation; outcrops between Station 150+00 and Station 160+00, approximately 10 feet above shoulder.

Habitual use of such a list will help in ensuring completeness and consistency of rock descriptions and aid in comparability of descriptions prepared by different field personnel.

4.3 IN-SITU TESTING

4.3.1 HAND AUGERS

Hand auger soundings are shallow exploratory soundings used to supplement a more thorough subsurface investigative techniques such as HSA drilling or CPT testing. They are frequently used in locations where access is limited or impossible for large equipment. Hand auger soundings should never be used as the sole source of subsurface information for design engineering.

4.3.2 POCKET PENETROMETER (PP)

The pocket penetrometer (PP) is a hand held calibrated penetration device and is commonly used to obtain an approximation of the unconfined compression test. It has a calibrated spring and 0.25 in. diameter piston encased inside a metal casing. The test is performed in the field on split spoon samples. Occasionally, the penetrometer has been used on the ends of Shelby tube samples for a quick field strength determination. When the piston is forced by hand to penetrate into the soil sample a distance of 0.25 in. at a constant rate, the calibrated spring is compressed into the penetrometer, providing an unconfined compression strength Q_u reading on the scale of the penetrometer.

The use of the PP is valuable only as a supplement to more precise strength determinations. They should not be used for design recommendations, stability, or settlement analysis. Engineering judgment should be used with PP tests.

4.3.3 CONE PENETROMETER TEST (CPT)

Cone penetrometer testing is a modern, expedient and cost-effective approach to soil exploration. It involves pushing an instrumented electronic probe into the soil while continuously recording multiple measurements at the depth pushed. Results are immediately available for soil types and delineation, tip resistance, sleeve friction and pore water pressure and, in some cones, shear wave or seismic wave testing.

The CPT system has five components; an electrical penetrometer, a hydraulic pushing system, which includes rods, a cable transmission device, depth recorder and a data acquisition unit. Cone penetration rates should not exceed 2 cm/s during normal sounding operations. When shear wave velocity profiling is being completed, velocity measurements should be taken at intervals between 3 and 5 feet. The chosen interval should be consistent throughout the sounding.

4.3.4 DYNAMIC CONE PENETROMETER TEST (DCP)

Dynamic cone penetrometer testing is a test which provides a measure of a material's in-situ resistance to penetration. The test is performed by driving a metal cone into the ground by repeated striking of a 17.6 lb. hammer from a distance of 22.6 in. The penetration of the cone is measured and recorded after each drop with a test range of 6-12 in. below the ground surface. Results of the DCP tests can be correlated to in-situ density, resilient modulus, and bearing capacity of the soils.

4.3.5 STANDARD PENETRATION TEST (SPT)

The SPT is performed for two, primary, purposes: to obtain a representative sample of the subsoil strata for purposes of identification, classification, moisture and density tests; and to obtain a

measure of the relative density and/or consistency of the soils. SPT test results generally correlate with the relative density of granular cohesionless soils. However, the consistency or compressive strength of fine-grained cohesive soils often do not compare with the STP test results.

4.3.6 LIGHT WEIGHT DEFLECTOMETER (LWD)

A light weight deflectometer (LWD) is a very portable apparatus that is used to determine the stiffness of unconsolidated materials during construction by measuring the deflection under an applied load, or simply to ensure that the in place foundation materials are compacted enough to provide a stable foundation for the pavement.

The device is hand operated and takes measurements of the surface deflection impacted by a falling weight. It measures deflection and estimates a modulus value based on the force required to generate a given deflection for that soil type. INDOT developed a test method, ITM 508, so that aggregates, granular soils, and chemically modified soils could be tested.

4.3.7 PRESSURE METER (PM)

A pressure meter test is an in-situ, stress-strain test, performed by inserting a cylindrical probe into an open borehole, supporting it at the test depth, and then inflating a flexible membrane in the lateral direction to a radial strain of as much as 40% depending on the probe design. To obtain viable test results, the hole must be pre-drilled and there must be knowledge of the type of soil or rock which will be tested. It can be conveniently used with drilling equipment or pushed in with direct push equipment.

While tests can be done in soft clay or loose sands, the test is best used in dense sands, hard clays, and weathered rock which cannot be tested with push equipment. An extensive database of load test results allows the geotechnical engineer to accurately design for shallow foundations and for lateral and axial capacity of deep foundations. This test should be used with the permission of INDOT.

4.4 DRILLER'S FIELD LOGS

Soil types are directly related to the parent materials of the area whether it be glacial, alluvial, loess, residual or combinations. However, soil types may differ in urban areas, constructed areas, or where surface mining has changed the landscape. In these locations, the soils are unpredictable from inconsistent fills or strata. Until the soils can actually be tested in the lab the drillers' field log is the prime source of information for the geotechnical engineer or geologist, so it is a requirement that logs be filled out in a consistent format with the most accurate information possible.

4.4.1 PROJECT AND BOREHOLE LOCATION

All boring logs should contain the following information to describe the project and individual borehole location:

- INDOT designation number
- Project location (road, county and reference)
- Boring number
- Station, line and offset
- Latitude and longitude (Decimal Degree)

- Surface elevation
- Drilling method
- Drill rig type
- Drilling date
- Weather
- Driller
- Inspector/helper

4.4.2 SAMPLE DESCRIPTION

All boring logs should contain the appropriate information as shown below:

- Complete description of each stratigraphic unit containing:
 - Color
 - Moisture
 - Strength or density
 - Visual classification of soil or rock
- Number of blows per 6-inch interval for SPT samples
- Percent recovery of SPT, Shelby tube or rock core
- RQD of rock cores

4.4.3 GROUNDWATER ELEVATIONS

All groundwater information is important, and any observations should be recorded on the drilling logs to verify or establish the water table at the boring locations. Groundwater observations should be recorded at the following intervals:

- During Sampling: Note water on the rods, split spoon or Shelby tube samples at the time of extraction from the test hole. If the boring was drilled without the use of water, the groundwater elevation is related to the permeable strata, or it may also represent a temporary or perched water table. Permeability is increased by fissures and blocky or crumbly soil structures with these structures being a direct result of frequent wetting and drying, commonly near the surface. Thus, the groundwater elevation in the borehole may be a function of the piezometric conditions in the more permeable strata. Uniform deposits of fine grained, especially cohesive, soils are practically impermeable and groundwater flow through such strata is negligible.
- If water has been used during drilling, it should be noted on the drillers' field log.
- At the time of completion of the soil boring: carefully measure the elevation of the water, after the augers are removed and also measure the cave-in depth (if any). Again, if water has been used during drilling, it should be noted on the drillers' field log. It may be necessary to pump or bail out the borehole to observe the groundwater elevation changes.
- 24 hour water reading: 24 hours is the accepted minimum time required for the groundwater in most soil borings to reach equilibrium. Unless high permeability granular material is encountered in the entire boring throughout the site, a subsequent groundwater elevation should not be made before the 24 hours has elapsed and if the field personnel determine this equilibrium has not yet been established, then additional readings may be necessary. When groundwater depth measurements are less than 6 feet on the existing road, the monitoring period should be extended.

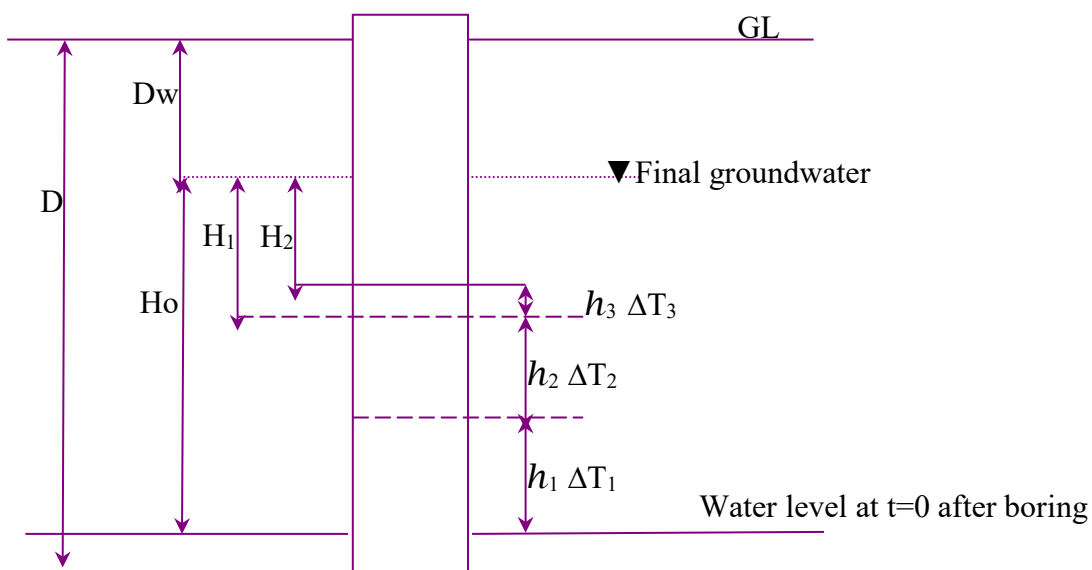
On projects where it is impossible to leave open borings for 24 hours, a sounding of equal depth must be performed as close to the original boring as possible for 24-hour groundwater elevation measurement.

All boreholes shall be backfilled in strict compliance with the current Indiana Department of Transportation’s Aquifer Protection Guidelines. Borings drilled through existing pavement should be suitably patched.

Sand heave is a condition that occurs when an exceptionally permeable layer (usually medium to fine grained sands) is saturated with groundwater creating a high-pressure area. Heave should be noted on the drillers’ and finished logs.

Computation of final groundwater levels may be done using Hvorslev’s method by measuring the rise and fall for two or more equal intervals. Methods of computing groundwater levels are given below:

Figure showing computation of final groundwater



$$\begin{aligned}
 D &= D_w + H_o \\
 &= D_w + H_1 + h_1 + h_2 \\
 &= D_w + H_2 + h_1 + h_2 + h_3
 \end{aligned}$$

$$\Delta T_1 = \Delta T_2 = \Delta T_3 = \Delta T$$

$$H_o = \frac{h_1^2}{h_1 - h_2}$$

$$H_1 = \frac{h_2^2}{h_1 - h_2}$$

$$H_2 = \frac{h_3^2}{h_2 - h_3}$$

4.4.4 AUGER REFUSAL

Auger refusal is a relative term and engineers should discuss the need with the chief geotechnical engineer for various foundation options. Auger refusal may be considered when the penetration rate of the hollow stem auger (HSA) is less than 6 inches for 10 minutes at a down pressure of 500 psi. The penetration rate of the HSA into shale or soft rock shall be attempted with various down pressures such as 300 psi, 400 psi, and 500 psi and a record of the down pressure and penetration rate shall be noted on the boring logs.

4.4.5 SOIL STRENGTHS, TEXTURES AND GENERAL TERMINOLOGY

The standard penetration test (SPT) is used for in-situ soil testing. In most cases 50 hammer blows is the maximum penetration resistance taken for each 6-inch interval. Before termination in ground, a minimum 6-inch increment in extremely hard soils or soft rock, having 50 hammer blows or more, is needed for visual classification.

Cohesive Soils (Clay and Plastic Combinations)

| Blows per foot | Consistency |
|----------------|--------------|
| 0 – 3 | Very Soft |
| 4 – 5 | Soft |
| 6 – 10 | Medium Stiff |
| 11 – 15 | Stiff |
| 16 – 30 | Very Stiff |
| Over 30 | Hard |

Cohesionless Soils (Sands, Silts and Non-plastic combinations)

| Blows per foot | Consistency |
|----------------|--------------|
| 0 – 5 | Very Loose |
| 6 – 10 | Loose |
| 11 – 30 | Medium Dense |
| 31 – 50 | Dense |
| Over 50 | Very Dense |

Percentage Modifiers

Modifiers should be added to classifications to further help identify materials contained in the soils. These materials could be gravel, rock fragments or various man-made items and can be described as given below based on the percentage amount.

| | |
|-----------------|------------|
| With a Trace of | 0 to 10% |
| With Little | 11% to 20% |
| With Some | 21% to 35% |
| And | 36% to 50% |

Organics or marl contents have a different range of percentages. See Section 5.3.2 for this information.

4.4.6 GENERAL NOTES AND GUIDELINES

Fill or embankment material should also be tested and classified with the depths of the strata included on the logs. Also, when drilling through a bridge deck and into water, all thicknesses of the deck, space to water, and water depth is to be recorded. The actual depths of the strata should be included on the logs. The actual depth the boring starts shall be that point at which a sample can be obtained and shall be considered as sample number one. It is important to record all the information since it is used in determining pay quantities for consultants drilling.

4.4.7 ABBREVIATIONS ON LOGS

For consistency in log writing and interpretation, abbreviations for commonly used terms are listed below. Terms that do not appear on the chart are probably uncommon and should be spelled out for clarity.

Table 4.12 Abbreviations to Be Used on Boring Logs

| Abbreviations of Geotechnical Terms | | | |
|-------------------------------------|--------------------------|----------|--------------------------------|
| agg | Aggregate | fm | Formation |
| amt | Amount | fos | Fossiliferous |
| & | And | frag | Fragments |
| approx | Approximate | Gvl | Gravel |
| AR | Auger Refusal | gry | Gray |
| asph | Asphalt | > | Greater than or Greater |
| @ | At | grn | Green |
| B-F | Backfilled | HA | Hand Auger |
| bdd | Bedded | hd | Hard |
| blk | Black | HSA | Hollow Stem Auger |
| blu | Blue | I | Interstate |
| br | Brown | JS | Jar Sample |
| BTH | Bottom of Test Hole | km | Kilometer |
| Ca/mg | Calicum/Magnesium | < | Less than or Less |
| ch | Chert | lo | Loam |
| CI | Centerline | m | Meter |
| CL | Clay | LS | Limestone |
| compl | Completion | mat'l | Material |
| CFA | Continuous Flight Auger | marl | Marl |
| Dk | Dark | med | Medium |
| den | Dense | mi | Mile |
| diff | Different | mm | Millimeter |
| Dis | Disintegrated | mo | Moist |
| DC | Dry at Completion | mot | Mottled |
| D24 | Dry after 24 hours | N | North |
| E | East | org | Organic |
| elev | Elevation | Pt | Peat |
| % | Percent | S-5 | Sample Number 5 etc. |
| PHA | Power Hand Auger | SS | Split Spoon |
| PT | Push Tube | SR | State Route |
| RC | Rock Core | st | Stiff |
| RQD | Rock Quality Designation | tr | Trace |
| R. Bit | Roller Bit | US | United States Road (Route) |
| Sa | Sand, Sandy | USC & GS | U.S. Coastal & Geologic Survey |
| Sh | Shale | V | Very |
| Si | Silt, Silty | wthrd | Weathered |
| Sl | Slightly | W | West |
| so | Soft | w/ | With |