STATE OF OKLAHOMA
DEPARTMENT OF TRANSPORTATION
GEOTECHNICAL SPECIFICATIONS FOR ROADWAY DESIGN

June 29, 2011 (Revised July 2, 2015)

GENERAL: These specifications provide the procedures for obtaining the geotechnical information, for highway design and construction, required by the Roadway Design Division of the Oklahoma Department of Transportation (ODOT). These specifications include the general guidelines for conducting geotechnical investigations and are governed by the "Geotechnical Engineering Circular No. 5 - Evaluation of Soil and Rock Properties", FHWA-IF-02-034, April 2002, the most current AASHTO and ASTM test procedures, and AASHTO R-10.

Geotechnical information is obtained through subsurface investigations, field tests, and the corresponding laboratory tests conducted on samples obtained in the field. Direction and oversight of these operations are provided by the Geotechnical Engineer with day to day coordination through the project geotechnical specialist.

A Geotechnical Engineer is a registered professional engineer with geotechnical expertise. A geotechnical specialist is a civil engineer, geologist, engineering geologist, or a trained, experienced, qualified individual that has been certified by the ODOT Materials Division or other approved designated authority.

The Geotechnical Engineer is required to submit a boring, sampling, and testing plan to ODOT for approval prior to beginning the subsurface exploration in order to resolve all matters with regard to sampling, testing and analysis of data. The Department's geotechnical policies and procedures will represent the state of the practice and will govern.

In conducting geotechnical investigations, the Geotechnical Engineer is responsible for and will be compensated for the following items of work:

- Securing right-of-way
- Filing and obtaining U.S. Army Corps of Engineers Wetland Permits.
- Locating and marking utility crossings, with OKIE, where borings, test pits, or trenches are required in the geotechnical investigation.
- Planning and arranging for traffic control when required in conducting the geotechnical investigation. Traffic control is to be subcontracted outside of ODOT and is required to meet the most current Manual on Uniform Traffic Control Device Specifications during the geotechnical investigation.
- Provide the required location of all test borings and pavement core locations conducted in the preliminary soil surveys, detailed soil investigations and geological investigations. The survey shall be referenced to plan station and offset from the centerline of survey, construction reference line (CRL) or base line given on the project plans. If the project is a

new alignment that is beyond the reasonable reach by a measuring tape of 100 ft. from a reference line, then a supplemental survey contract may be approved.

- Dozer services required for access to test boring locations.
- Borehole closing when applicable.

SCOPE: The geotechnical investigation shall consist of performing all or parts of the following surveys and investigations required by the Roadway Design Division of ODOT and as directed by ODOT at the time of contract negotiations.

PRELIMINARY SOIL SURVEYS

1. **Pedological and Geological Survey:** A Pedological and Geological Survey is required for new highway alignments, new construction parallel to existing highway alignments, and new construction requiring a raising of the grade on and above existing highway alignments. A Pedological Soils Survey is reliant on knowledge of the soil series mapping units and the corresponding taxonomic classification system established by the Natural Resources Conservation Service (NRCS). More detailed information about Pedological Soil Surveys and the NRCS Soil Classification System are provided in Appendix 1. The general procedures for conducting the Pedological activities are presented below in option A and option B as directed. This includes the procedures for sampling and testing.

   <u>Option A</u>

   a. The pedological survey requires plotting the Center Reference Line (CRL) or the Centerline (CL) for the proposed highway alignment on the appropriate U.S. Department of Agriculture Soil Conservation (SCS) county soil survey report map sheet(s). The map units are delineated on aerial photographs that comprise the aforementioned sheets. They are usually scaled at 1:20,000 and occasionally 1:24,000; either is acceptable. The plotting procedure is also used to establish the length of each soil series map unit (soil phase) as the alignment crosses the map unit delineation. These lengths or distances are to be summed and provided in the report. The CRL and CL locations are taken from the project plans. In the case of soil series complexes, as map units, e.g. Niotaze-Darnell, each series is to be located and treated separately. The type and degree of assistance, as well as the names of the NRCS, or other soils scientist(s) personnel rendering assistance, shall be documented and referenced in detail.

   b. Take adequate sample quantities at the site of each soil series to ensure proper testing of each soil horizon as well the composite bulk sample(s). Pits are acceptable and may be a preferred method. These are to be made along the CRL or CL or referenced to them. If the map unit repeats within the alignment, it need not be resampled, if the series is confirmed by boring to be the same.

c. A composite bulk sample is defined as a mixture of the total depths (thicknesses) of each of the B and C horizons. For example, if a soil series description lists the B horizons as Bt1, Bt2, Btk, Bt3, and B/C, these together will constitute one composite "B" bulk sample. Subsequently, the C/B and C horizons will constitute a second bulk sample "C", for soil series that contain those particular horizons. In the event that the map unit does not have a B horizon but has an A/C horizon instead, the composite bulk sample shall be taken of the total depth of horizons listed below the A horizon e.g. the A/C or B/C horizon. <u>It is important that the bulk sample be a well blended mixture of soils that are representative of all the respective horizons in the composite sample.</u> In most cases, soil map unit revisions and recorrelations have probably been made to at least a few of the map units encountered along the CRL. This new information is available at the local NRCS field offices, usually located in the county seat or the NRCS State Soil Scientist in Stillwater OK. The NRCS Web Soil Survey, http://websoilsurvey.nrcs.usda.gov/app/ is also a good source for county soils maps and information. Copies of all official soils series descriptions, including the new recorrelated series are required for inclusion in the Pedological report.

d. Use the soil map unit with its associated current official soil series description and classification as a guide for sampling and other engineering interpretations. For example, the official description of Kirkland clay loam, 0 – 1% slope; Fine mixed, superactive, thermic Udertic Paleustoll, 6/99, is to be used as a guide for sampling. The Fine mixed, superactive, thermic, Udertic Paleustaoll is the soil series taxonomic description. It consists of the order, suborder, great group, subgroup modifier, particle size, mineralogy, and soil temperature. In this description the typical thickness of the A horizon is 8 inches, the Btl horizon is typically 8 to 19 inches thick, the 2Bt3 is 75 to 82 inches thick, etc. In the map unit of interest, the depths and thickness of the subhorizons may vary from that of the description given in the county soil survey report and/or in the official soil series description. However, they must be within the "Range in Characteristics," as described in the official soil series description (OSD). A Soil Taxonomy Statement is required for each soil series consisting of a written interpretation of each taxonomy description sub-part for a total of seven parts. Guidelines for preparing the Soil Taxonomy Statement are included in Appendix 1.

e. There may be inclusions of a contrasting or similar soil series within the map unit being sampled. They may be listed and described in the "Competing Series" or the "Geographically Associated Soils" paragraphs in the official soil series descriptions. Select the best-fit soil series description from this list, if possible, for the inclusion in the report.

f. Laboratory tests required for all representative subhorizon samples for each soil series are as follows:

   1. Plastic Limit, AASHTO T90
   2. Liquid Limit, AASHTO T89
   3. Gradation required for complete soil classification, AASHTO T88
   4. pH, AASHTO T289
   5. Electrical Resistivity, AASHTO T288

6. Soluble Sulfates, for projects in ODOT Field Divisions 4,5,6,&7, OHD L-49

g. Laboratory tests required for the bulk composite sample for the B and C horizons of each soil series are as follows:

   1. Plastic Limit, AASHTO T90
   2. Liquid Limit, AASHTO T89
   3. Gradation required for complete soil classification, AASHTO T88
   4. Moisture-Density, AASHTO T99 – (include a minimum of 5 points)
   5. Resilient Modulus, AASHTO T307
   6. Soluble Sulfates, for projects in ODOT Field Divisions 4,5,6,&7, OHD L-49

h. The geologic portion of this survey shall consist of the inclusion of a representative sample of the R horizon. A geologic statement describing the R horizon in geological terminology shall be included in the report. If the R horizon is shale it shall be sampled and subjected to the soil laboratory tests listed under paragraph "f" above. The terminology for describing the R horizon material shall be taken from the "Standard Guide for the Description of Surface and Subsurface Geological Rock Formations of Oklahoma" found in Appendix 3.

i. The quantities of soil required for the tests are provided in AASHTO R-13.

j. Personnel requirements. The person performing the pedological soil survey and providing the report shall hold a Bachelor of Science (BS) degree in Soil Science. The person may hold a BS in a natural science (i.e. geology or forestry) provided the natural science has a minimum of 30 credit hours of natural sciences with 15 of those hours in soil science. Alternatively, a resume of pertinent education and experience shall be submitted to the Geotechnical Engineer of the Oklahoma Department of Transportation for review and approval.

<u>Option B</u>

The CRL or centerline of the proposed project is to be plotted on the soil survey map as in Option A. The soil series are to be organized by the Soil Taxonomy Order. The most predominant soil series (largest lineal extent) for each Order in the project extent is to be sampled and tested as required in Option A

2. **Shoulder Soil Survey:** A Shoulder Soil Survey is required for the widening of existing pavement at grade. This survey shall apply to the adding of shoulders, lanes and medians to existing pavements. The general procedure for conducting the shoulder soil survey is as follows:
   a. The sampling location shall be within the station extents of the widening section using the average width of the improvement and a sampling interval of 500 feet. Sample locations shall apply to all widening extents as detailed in the project plans, i.e., outside pavement shoulder, both pavement shoulders (in the case of two-lane highway or street), inside shoulder (in the case of four-lane highway or street), and in median areas.

b. The sampling depth shall be 36 inches consisting of the top 6 inches and the bottom 30 inches provided that there is a reasonable consistency and similarity of material. If different material is encountered in the bottom 30 inches, subdivide the layers and include a sample from each layer.
c. Report the extent(s) of similar soil classifications within the station extents of the project.
d. Record the depth of groundwater or perched water zones measured from the top of ground elevation at the end of drilling.
e. A composite bulk sample(s) of the full sampling depth representative of the whole project extent or of each different soil extent as identified in item 2c.
f. Laboratory tests required of all sample interval depths and/or soil layers are as follows:
    1. Plastic Limit, AASHTO T90
    2. Liquid Limit, AASHTO T89
    3. Gradation required for complete soil classification, AASHTO T88
    4. Moisture-density, AASHTO T99
    5. Resilient modulus, AASHTO T307
    6. Soluble Sulfates, for projects in ODOT Field Divisions 4,5,6,&7, OHD L-49
g. Guidelines for quantities of soil samples are given in AASHTO R13

3. **In Place Soil Survey:** The In Place Soil Survey is required for new construction when the design calls for separation of the grading and paving contracts. It may also be used to evaluate the subgrade of existing pavement sections which are to be reconstructed with no change in grade or alignment. The general procedure for conducting the In Place Soil Survey is the same as for the Shoulder Soil Survey with the following exceptions:
    a. The sampling interval for grading projects is 1000 ft. or wherever there is a visual change in soil types. Sampling locations for existing pavement sections will most likely be project specific such as at a bridge approaches and underpasses.
    b. The sampling depth shall be 36 inches unless otherwise noted. Sample and test the different soil types encountered in the boring and record the extent(s) of similar soil classifications within the station extents of the project.

4. **Pavement and Subgrade Soil Survey:** A Pavement and Subgrade Soil Survey is required when the properties of an existing pavement structure and the underlying subgrade soils are needed for evaluation of the pavement load capacity and for an overlay design. The Falling Weight Deflectometer (FWD) is required for evaluating the pavement structure (surface, base, and subbase). The general procedure for conducting pavement deflection tests shall meet all requirements of the ASTM D4694 and D4695 with the following additional requirements:

a. FWD tests are to be conducted in the outside wheel path in a staggered pattern at a spacing of 250 feet along the highway centerline. Additional requirements for the FWD analysis are as follows:

   1. The FWD is to be operated during a time frame of April through November or when the ambient temperature has been a minimum of 45 degrees for 3 successive days prior to and during the testing operations.

   2. The air and pavement temperatures are to be recorded by the FWD equipment for each test location and according to ASTM D4695, Subsection 7.1.5.

   3. At each FWD test location, the test procedure shall be according to ASTM D4694, Subsection 9. Load and deflection sensors are to be in current calibration at the time of testing, as required by ASTM D4694, Subsection 8. Deflection testing shall include 2 seating drops and 4 recording drops per test location. The test load for the 4 recording drops are based upon highway classification; Interstate highways will be tested with a 15,000 lb. load, U.S. designated highways will be tested with a 12,000 lb. load, State highways will be tested with a 9,000 lb. load, Local and County roads will be tested with a 7,500 lb. load.

b. Back calculation analysis of the pavement section shall be made using the most current edition of the Modulus program. For asphalt pavement sections, provide the back calculated resilient modulus of the subgrade and the elastic modulus of the composite pavement structure. For concrete pavement sections, provide the modulus of subgrade reaction, the pavement section thickness, and the pavement condition as determined according to the survey described in item 5d. A copy of the FWD report shall be submitted, in Microsoft Excel Format, electronically to the ODOT Pavement Engineer.

c. A minimum of five pavement cores per mile (more if there is an obvious change in pavement structure) shall be taken to document the thicknesses, types, and condition of the payment layers. Take the cores at FWD test locations. Provide a digital, color photograph of each core with scale. Record the layer thicknesses and the degree of stripping or deterioration of asphalt pavement cores. Record honeycomb, deterioration cracking (D-Cracking), and separations in concrete pavements. Examples of the required core logs are provided in Appendix 5. Cores shall be taken in the middle of the slab in PCC Pavements. Ground Penetrating Radar may be used to reduce the number of cores taken to accurately determine the pavement section profile.

d. Pavement surface condition shall be described according to the distress patterns as detailed in the FHWA publication No. FHWA-RD-03-031 “Distress Identification Manual for the Long Term Pavement Performance Program”.

e. For plain jointed, rigid pavements, joint efficiency shall be tested in each direction, in the right wheel path of the right lane, every 600 feet (180m) at the transverse contraction joint. A core shall be cut through the joint at the test site and the core condition reported.
f. The pavement subgrade shall be sampled to a depth of 36 inches below existing pavement. Dynamic Cone Penetration tests, DCPT, may be requested to further evaluate the strength and consistency of the subgrade.
g. Report the extent(s) of similar subgrade soils within the station extents of the project.
h. Record the depth of groundwater or perched water zones measured from the top of ground elevation at the end of drilling.
i. Laboratory tests required of granular bases, subbases, and subgrade soils are as follows:
    1. Plastic Limit, AASHTO T90
    2. Liquid Limit, AASHTO T89
    3. Gradation required for complete soil classification, AASHTO T88
j. Guidelines for quantities of soil samples are given in AASHTO R13.

5. **Borrow Pit Investigation:** A borrow pit investigation is required where selective subgrade topping is requested. The specifications for selective subgrade topping are provided in the most current issue of the ODOT Standard Specifications for Highway Construction, Section 202.02 B.
    a. The size of the borrow pit shall be based on plan estimates of borrow quantities needed.
    b. A borrow pit location within a 30-mile haul distance of the project is acceptable.
    c. As a minimum requirement, a boring shall be drilled at each geometric corner and two near the center. A minimum depth of ten feet per boring shall be analyzed for select material.
    d. Record the depth of groundwater or perched water zones measured from the top of the ground elevation at the end of drilling.
    e. If the borrow source is rock, investigate the rippability by use of seismic velocity. Refer to the seismic velocity charts found in the Appendix 3 to estimate the rippability of rock.
    f. If the borrow sources can be select graded in a cut section of the proposed project site, the above items c. through e. all apply.
    g. If a borrow source is unavailable, then a pavement layer requiring borrow may be substituted with an equivalent layer of chemically stabilized soil or a soil-aggregate blend.

h. Soils that are to be placed within the top 2 ft. of the grading section shall be tested for soluble sulfates according to OHD L-49.

i. Laboratory tests required of borrow pit soil samples are as follows:

   i. Plastic Limit, AASHTO T90
   ii. Liquid Limit, AASHTO T89
   iii. Gradation required for complete soil classification, AASHTO T88
   iv. Soluble Sulfates, for projects in ODOT Field Divisions 4,5,6,&7, OHD L-49

6. **Resilient Modulus Tests:** Resilient modulus testing is required for the pavement design of all State and Federal Aid highway projects. This test is conducted, according to the requirements of AASHTO T-307, on composite bulk samples obtained in Pedological, Shoulder, and In Place Soil Surveys. Resilient Modulus testing for ODOT shall be conducted by a qualified technician having a minimum of 2 years continuous experience in resilient modulus testing.

   ODOT requires two resilient modulus tests for each composite sample:
   <u>For A-1 to A-5 Soils:</u>
   - One test at 95 % of maximum dry density, optimum moisture content
   - One test at 95 % of maximum dry density, 2 % wet of optimum moisture content.

   <u>For A-6 to A-7 Soils:</u>
   - One test at 95 % of maximum dry density, optimum moisture content
   - One test at 95 % of maximum dry density at the corresponding moisture content at which 95% dry density intersects the wet side of the moisture/density curve.

7. **Laboratory Tests:** All laboratory tests required for the Preliminary Soil Surveys shall be performed by technicians certified by the Highway Construction Materials Certification Board in a laboratory qualified by the ODOT Materials Division.

DETAILED SOIL INVESTIGATION: A detailed Soil Investigation is required for analyzing the geotechnical problems related to roadway designs. These geotechnical problems include embankment and foundation soil settlement and stability, cut and natural slope stability, problem soils related to roadway subgrades and embankments, roadway structures, and construction recommendations. A detailed soil investigation of these problems is required in conjunction with the Pedological and Geological Survey. The interpretation and judgment of the pedological and geological site conditions is the responsibility of the Geotechnical Engineer.

1. **Embankment and Foundation Soil Settlement and Stability (Embankments Between 0-10 feet Above Natural Ground Line):** Estimates of embankment and underlying foundation soil settlement, slope stability and design slopes are required. These estimates are made by assuming reasonable parameters for anticipated embankment and foundation soils based

on the soil series types occurring within the project extent. These estimates are required for embankments crossing each soil series encountered along the project alignment. Use NAVFAC D 7.01 to determine estimates of reasonable soil parameters for anticipated embankment and foundation soils as described by the pedological soil units.

2. **Embankment and Foundation Soil Settlement and Stability (Embankments Greater Than 10 Feet Above Natural Ground Line):** Estimates of embankment and underlying foundation soil settlement and stability are required. Borings are to be typically spaced every 200 feet (erratic conditions) to 500 feet (uniform conditions), with at least one boring made in each Pedological soil unit. The primary borings are to be Standard Penetration Test (SPT) borings. These borings, which are for obtaining soil samples and information, should be supplemented with in situ field tests such as the Cone Penetration Test (CPT) or the Flat Plate Dilatometer Test (DMT) to obtain additional information for determining the soil and rock subsurface conditions as follows:

    a. Stratigraphy

        1) Physical description and extent of each stratum

        2) Thickness and elevation of top and bottom of each stratum

    b. For cohesive soils (each stratum)

        1) Natural moisture contents

        2) Atterberg limits

        3) Presence of organic materials

        4) Evidence of desiccation or previous soil disturbance, shearing or slickensides

        5) Swelling characteristics

        6) Shear strength

        7) Compressibility – <u>**NOTE:** The Standard Penetration Test is not to be used for shear strength or compressibility analysis in cohesive soils. Shear strength and compressibility can be determined by laboratory consolidation tests conducted on undisturbed soil samples or by in situ field tests such as the Cone Penetration Test (CPT) or the Flat Plate Dilatometer Test (DMT).</u>

    c. For granular soils (each stratum)

        1) In-situ density (average and range) typically determined from Standard Penetration Tests (SPT) or Cone Penetration Tests (CPT)

        2) Grain-size distribution (gradation)

        3) Presence of organic materials

    d. Ground water (for each aquifer if more than one is present)

        1) Piezometric surface over the site area, existing, past, and probable range in future (observation at several times.)

        2) Perched water table

e. Bedrock

   1) Depth and elevation over the entire site
   2) Type of rock (Lithology)
   3) Extent and character of weathering
   4) Joints, including distribution, spacing, whether open or closed, and joint filing.
   5) Faults
   6) Solution features in limestone or other soluble rocks
   7) Core recovery and soundness (RQD)

f. Engineering Analysis. The minimum guidelines required for engineering analysis, based upon soil classification, are given in Table 1 of Appendix 2. Additional guidelines should be noted for the following conditions:

   1) When soft ground is encountered (SPT 'N' Resistance < 4), conduct in situ tests and/or undisturbed sample exploration in each soil series mapping unit. Conduct continuous in situ tests and/ or undisturbed sampling throughout the foundation soils until firm material (SPT 'N' Resistance > 30) or rock is encountered.
   2) When medium stiff to very stiff (5 < SPT 'N' resistance < 30) is encountered, follow the minimum sampling and testing criteria in Table 2 of Appendix 2.
   3) If rock is encountered within a depth equal to twice the embankment height, conduct continuous rock coring as detailed in Table 2 of Appendix 2.
   4) Groundwater investigations shall be made according to Table 2 of Appendix 2.
   5) For bridge embankment headers, conduct a detailed study of the embankment and foundation soils within 200 feet back and 200 feet forward of each bridge abutment.

3. **Cut and Natural Slope Stability:** Cut slopes greater than 30 feet below the natural ground line in soil shall be analyzed for both end of construction and long germ slope stability conditions. If slope materials are overconsolidated (OCR > 2) then the residual shear strength shall be used in the long term slope stability analysis. Soils coming from cuts that will be placed within the top 2 ft. of the grading section shall be checked for soluble sulfates according to OHD L-49.

4. **Problem Soils Related to Roadway Subgrades and Embankments:** Additional field exploration, laboratory testing and analysis are required to determine the long-term performance and/or suitability of the following soil and rock that may be incorporated into the roadway subgrade and embankment or found in the foundation soils below the roadway embankment:

   a. Organic soils
   b. Normally consolidated clays
   c. Expansive clays and shales
   d. Dispersive soils

e. Collapsible soils

f. Degradable shales

g. Caliche

h. Mine spoils (all types) and caves

i. River or stream meander loops and cutoffs and ox-bow lakes

j. Karst features (e.g., gypsum, limestone)

These soils and conditions are coordinated with the Pedological and Geological Survey and Borrow Pit Investigation. The interpretation and judgment of these soil conditions is the responsibility of the Geotechnical Engineer.

5. **Roadway Structures:** Check the bearing capacity, settlement and stability of roadway structures (i.e. retaining walls) according to the most current AASHTO Standard Specifications for Highway Bridges.

6. **Construction Recommendations:** The Geotechnical Engineer may recommend chemically stabilized bases, subbases and subgrades as directed by ODOT or in lieu of select borrow requirements of the most current edition of the Oklahoma Department of Transportation (ODOT) Standard Specifications for Highway Construction. These recommendations are limited to lime, fly ash, CKD, and Portland cement and the method of evaluation shall follow ASTM D4609, OHD L-50 and OHD L-51.

GEOLOGICAL INVESTIGATION: A Geological Field Investigation is required for any or all of the following:

1. rock cuts of 10 feet or greater
2. shallow rock mapped within a proposed cut section
3. rock mechanics analysis
4. geological hazards
5. rock fills

A geological field investigation may consist of the following elements:

1. borings
2. slope stability analysis
3. rippability ratings
4. evaluation of geological hazards
5. shear strength of rock fills
6. evaluation of excavated rock for use as a source of aggregate
7. Geological statements.

The Geological Investigation is in conjunction with the Pedological and Geological Survey. Dimensions are to be in English or metric units, whichever is compatible with the Plans. Any interpretations and judgements made of the site geologic conditions are the responsibility of the Geotechnical Engineer. The investigation may include the following:

1. **Borings:** Space borings through cut sections within the project extent every 100 feet in the longitudinal centerline (CL or CRL) direction. Provide a minimum of two borings along a straight line perpendicular to the centerline or planned slope face to establish a geological cross-section of the cut. Two of these borings shall be continuously cored to characterize the soil and/or rock properties. The depths of all borings are to extend a minimum of 10 feet below the deepest plan grade. Record the location of perched or permanent water tables for a minimum of 24 hours.

2. **Seismograph Surveys:** Seismograph Surveys of cut sections may be required. The equipment must be capable of determining rock properties throughout the entire depth of the cut, plus 10 feet below plan grade. Depths to each rock layer must be accurate to the nearest foot.

3. **Rock Stability Analysis:** Rock stability analysis is required when the dip of the geological formation exceeds 20 degrees into the slope face. Ensure the analysis meets all the requirements of the kinematic slope stability program, RockPack III (or equivalent), using the stereographic projection procedure. This analysis is necessary to determine the slope stability of closely spaced (2 ft. or less) rock joints (fractures) and/or tilted (dipping greater than 10 degrees) rock strata of the cut slope. These measurements will allow development of the local structural geology, in three dimensions, required for making this analysis. The data that is required for this analysis is the dip, and dip direction of both the rock strata and of the joints (fractures) in the rock. The equipment necessary to obtain the dip, and joint orientation data is a Clar and/or Brunton compass. This device gives magnetic headings and dip angles. Trenching or oriented cores may be necessary in order to expose enough rock strata to make the measurements. The shear strength of the jointed rock shall be based on the requirements of the Hoek-Brown (1988) criteria. If the observations identify joints (fractures) in which shear failures may occur, or fractures that contain soil infilling; then, the shear strength of the infilling or fractures is required to be taken into account in the overall slope stability analysis. In argillaceous massive shales (non-laminar), slope stability analysis shall be based on the use of a soil mechanics approach.

4. **Rippability:** Determine rippability by a refraction seismograph. The seismograph must be capable of providing valid, useable signals for calculating the depth to bedrock to nearest foot. It must be capable of sensing rock layers to the depth of the proposed cut. Calculations of rock rippability shall be made from the resulting sound wave velocities. The rock rippability rating of each layer shall be reported as rippable, marginal, or non-rippable .

5. **Geologic Hazards:** Identify any geologic hazards (e.g. sinkholes, landslides, and others). These are to be precisely located and dimensioned to the nearest foot. Record all occurrences in the final report. GPS coordinates may be used in addition to Public Land Survey legal descriptions. Locations must be referenced to the CL or CRL by plan station and offset.

6. **Rock Fill Embankments:** Determine the shear strength values of rock fill embankments. The model will be generated by using the results of the triaxial shear tests. Conduct the testing on 1-in. size aggregates from the specified rock fill aggregate source.

7. **Geologic Site Assessment:** Provide a geologic site assessment of the rock type and layering conditions in the cuts along the CL or CRL. This report will be based on available geologic maps, bulletins etc., along with a field, on-site investigation. The assessment will pertain to

the geologic conditions and character of the rock strata as provided in the above geologic information sources.

8. **Equipment:** List the equipment used to make the observations (e.g. borings, seismograph surveys, rippability, and stability analysis) in the report. Provide the make, model, and manufacturer.

Descriptive Terminology and Rock Classification: The descriptive terminology and rock classification shall be based upon the "Standard Guide for the Description of Surface and Subsurface Geological Rock Formations of Oklahoma" as presented in Appendix 3. The finished boring log shall be a compilation of all classification and description from laboratory tests and field logging.

GEOTECHNICAL EXPLORATION, IN SITU TEST PROCEDURE:

1. The most current issue of the following ASTM Standards for in situ testing will govern and shall be used.
    a. Standard Test Method for Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils – ASTM D1586
    b. Electronic Friction Cone and Piezocone Penetration Testing of Soils – ASTM D5778
    c. Mechanical Cone Penetration Test – ASTM D3441
    d. Flat Plate Dilatometer Test – ASTM D 6635
    e. Pressuremeter Test – ASTM D 4719
    f. Vane Shear Test – ASTM D 2573
    g. Dynamic Cone Penetrometer Test – ASTM D 6951

2. The most current issue of the following ASTM and AASHTO Standards for sampling will govern and shall be used.
    a. Standard Test Method for Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils – ASTM D1586
    b. Practice for Thin-Walled Tube Geotechnical Sampling of Soils – ASTM D1587
    c. Practice for Rock Core Drilling and Sampling of Rock for Site Investigation – ASTM D2113
    d. Practice for Preserving and Transporting Soil Samples – ASTM D4220
    e. Collection and Preservation of Water Samples – AASHTO R24
    f. Standard Test Method for Determining Subsurface Liquid Levels in Borehole or Monitoring Well (Observation Well) – ASTM D4750

3. **Bore Hole Completion and Site Restoration:** All borings should be properly closed at the end of the field exploration for safety considerations and to prevent cross contamination of soil strata and groundwater. The general procedures for borehole completion and site restoration are as follows:
    a. <u>Responsibility</u> The driller is responsible for properly plugging the borehole.

b. Timetable Ensure borings are plugged within 10 days of completion of drilling or groundwater observations to prevent contamination of groundwater.

c. Backfill Consider the following:

1. For Pedological, shoulder, and in-place borings, backfill and compact the borehole with borehole cuttings.
2. In pavements, backfill the boreholes with cuttings. Compact, by tamping, the cuttings to a depth of 6 in. below the bottom of the pavement. Fill the remainder of the boring with either quick setting concrete or asphalt patch depending upon the pavement type.
3. For embankment and cut section borings, follow the procedures outlined in **AASHTO R-22**.

d. Property Cleanup As practical, the site should be returned to its original conditions. For sensitive locations, take before and after photographs to address possible complaints from the landowner.

4. **Field Logging:** Field logs shall be based upon the descriptive terminology and classification of rock detailed in the "Standard Guide for The Description of Surface and Subsurface Geological Rock Formations of Oklahoma" as presented in Appendix 3.

5. **Method of Drilling:** An appropriate method of rotary drilling shall be used for the foundation and geologic conditions encountered. These are described in the AASHTO Manual on Subsurface Investigations, 1988. There is no restriction on the type of drill equipment other than it shall be capable of performing all of the field sampling and testing as outlined in the above referenced manual. Samples may be taken from the flight augers unless water table conditions are encountered. The practice of auger refusal is **not** an acceptable technique for defining the top of bedrock. The top of bedrock shall be established by sampler refusal as outlined in **ASTM D 1586 - Standard Test Method for Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils.** For borings over water in lakes or rivers, drilling operations shall be performed on a barge supported by spud rods firmly anchored at each corner.

6. **Geologic Statement:** A general geologic review and assessment(s) shall be provided as a statement in the Geologic Investigation. It will include cross section(s) and provide drawings, showing the orientation of the rock masses or layered rock formations at each cut section investigated. The drawings will provide station designations along the centerline of survey or CRL and offset distances left and/or right. The geologic summary will be provided based on all available geologic information. Examples of such sources are as follows:

   a. Oklahoma Geological Survey
   b. Oklahoma Water Resources Board
   c. U.S. Geological Survey
   d. Tulsa Geological Society, and others

LABORATORY TESTS: All laboratory testing shall be performed by technicians certified by the Highway Construction Materials Certification Board in a laboratory qualified by the ODOT Materials Division.

1. Where appropriate, soils and rock samples are to be tested and results reported according to the most current AASHTO/ASTM Standards for the following tests:
    a. Soils Classification, Gradation and Plasticity Index – AASHTO T88 , T89, and T90
    b. Moisture Content, AASHTO T265
    c. Specific Gravity, AASHTO T100
    d. Chunk Density, AASHTO T233
    e. Hydrometer, AASHTO T88
    f. Double Hydrometer, ASTM D4221
    g. Pinhole Test, ASTM D4647
    h. pH, AASHTO T289
    i. Moisture-Density Test
        1) Standard, AASHTO T99
        2) Modified, AASHTO T180
    j. Electrical Resistivity, AASHTO T288
    k. Slake Durability, ASTM D4644
    l. Unconfined Compression Test, AASHTO T208
    m. Point Load Test, ASTM D5731
    n. One-Dimensional Consolidation Test, AASHTO T216
    o. Drained Direct Shear Test, AASHTO T236
    p. Triaxial Sheer Test
        1) Unconsolidated Undrained, ASTM D2850
        2) Consolidated Undrained, ASTM D4767
    q. Residual shear strength, ASTM D6467
    r. One Dimensional Swell or Settlement Potential of Cohesive Soils, ASTM D456

2. Classification and description of soils and compaction shales follow the practice as outlined in ASTM D2487 and D2488. For classification purposes, define, test, and report for the following particle size distribution.

    3 in. (75mm)

    ¾ in. (19mm)

    No. 4 (4.75mm)

    No. 10 (2.00mm)

    No. 40 (425mm)

    No. 200 (75mm)

3. A pocket penetrometer or any other “pocket” measurement device shall **not** be used to determine rock or soil properties for the purposes of this investigation.

FINAL WRITTEN REPORT: The final report shall be written by a Geotechnical Engineer with a broad experience and background in engineering for the type of roadway work identified in the project. All pertinent information to be included in the final report is detailed in Appendix 4 – Guidelines For Preparing Geotechnical Reports. Appendix 5 provides the Standard Forms For Reporting Geotechnical Information .

REFERENCES

1. Ragan, Donald M., “Structural Geology-An Introduction to Geometrical Techniques”, 3rd Edition, John Wiley and Sons, New York, 1985, 393 pages.
2. Geotechnical Engineering Circular No. 5 - Evaluation of Soil and Rock Properties”, FHWA-IF-02-034, April 2002, 386 pages.
3. Goodman, Richard E. “Introduction to Rock Mechanics”, 2nd Edition, John Wiley and Sons, New York, 562 pages.
4. Wyllie, Duncan C., “Foundations on Rock”, 2nd Edition, E & FN SPON, London, 1999, 401 pages
5. Peurifoy, R.L., Ledbetter, W.B., Schexnayder, C.J., “Construction, Planning, Equipment, and Methods”, 5th Edition, McGraw-Hill Companies, Inc. New York, 1996, 633 pages.
6. Water Resources Board Rules, Chapter 35, July 1, 1999.
7. “Manual on Subsurface Investigations”, AASHTO, Washington, D.C. 1988

SUGGESTED REFERENCES

1. American Society for Testing and Materials, Special Technical Publication No. 479, “Special Procedures for Testing Soil and Rock for Engineering Purposes”, 5th Edition, 1968.
2. “Soil Taxonomy”, 2nd Edition, U.S. Department of Agriculture, Natural Resources Conservation Service, Soil Survey Staff, 1999.
3. “Soil Survey Manual”, U.S. Department of Agriculture, Soil Survey Division Staff, Handbook No. 18, 1993.