LOUISIANA DEPARTMENT OF
TRANSPORTATION & DEVELOPMENT

GEOTECHNICAL DESIGN MANUAL

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Pavement & Geotechnical Services - Section 67
Louisiana Department of Transportation and Development
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Chapter 1. Introduction

1.1 OBJECTIVE & SCOPE

The objective of this Geotechnical Design Manual (GDM) is to establish the state of practice for geotechnical engineering services rendered on Louisiana Department of Transportation and Development (DOTD) projects. This manual's scope includes geotechnical investigation, design, and construction support services provided by the DOTD Geotechnical Design Section (GDS) as well as those provided by Geotechnical Consultants (Consultants). Within the context of this GDM, a "Consultant" includes any party other than the GDS tasked to provide geotechnical services for DOTD. Other sections within DOTD (and their subcontractors) tasked to provide services to the GDS are considered Consultants.

When this manual is referenced in a scope of services, contract, or specification, procedures described with "shall" are to be considered a requirement. Unless superseded by the Contract Documents, the requirements of the GDM shall be applied to all geotechnical services provided for DOTD projects (regardless of contracting method, including permit requests).

Projects initiated by other entities with the potential to become DOTD projects or infrastructure shall fall under the scope of this GDM.

1.1.1 GDM Status

This manual is a living document and the GDS will periodically add or update chapters as necessary. The most up-to-date version can be found here: Geotechnical Manuals and Policies. Skipped or missing chapters are intentionally omitted.

1.1.2 References

The intent of this manual is to convey expectations for geotechnical work provided for DOTD projects, not to serve as a textbook-style reference. In most cases, instead of providing specific equations, figures, etc., this GDM will provide a list of key references needed to perform the work at the beginning of each chapter. Other references will also be cited and included at the end of each chapter.

The primary geotechnical references used in the GDM are nationally accepted standards and guidelines, including American Association of State Highway Officials (AASHTO), National Highway Institute (NHI), and Federal Highway Administration (FHWA) publications. These are supplemented by research conducted by the Louisiana Transportation Research Center (LTRC) and other state DOTs, as well as institutional experience gained by the GDS.

1.1.3 Deviations

Although many valid exploration, testing, and design methods are available, it is our intent that geotechnical practices performed on behalf of DOTD be consistent among the parties providing those services. When not already covered by the contract documents, deviations from this GDM shall be approved in writing by a GDS representative. For work conducted under a GDS retainer contract, this approval shall come from either the Geotechnical Contracts Specialist or Geotechnical Task Manager. Deviations to geotechnical requirements on projects managed by other sections shall be approved by the Pavement & Geotechnical Section Administrator or the Assistant Geotechnical Administrator.

1.2 GEOTECHNICAL DESIGN SECTION

The Geotechnical Design Section (GDS) is located within the Pavement & Geotechnical Design Section of DOTD. The GDS is located within the Office of Engineering and is responsible for providing geotechnical engineering expertise in the areas of planning, design, construction, and maintenance for Louisiana's bridge foundations, embankments, earth retaining structures, and other transportation-related structures and facilities. These responsibilities include the following:

- Scoping of geotechnical investigation services. Specific responsibilities for geotechnical investigations are described in Section 1.3.1.
- Management of geotechnical Retainer Contracts held by the GDS.
- Performing geotechnical analyses and preparing geotechnical reports and plans for use in the design, construction, and maintenance of DOTD infrastructure.
- Reviewing consultant designs and reports for technical content and compliance with the GDM.
- Reviewing plans, permits, and contract documents to verify that the geotechnical requirements have been properly interpreted and incorporated.
- Providing geotechnical subject matter expertise during consultations with other agencies, LTRC, and other DOTD sections or districts.
- Reviewing, accepting, or approving of Contractor geotechnical submittals.
- Providing additional geotechnical construction support services including developing, monitoring, and evaluating foundation testing programs (load and integrity testing), geotechnical instrumentation programs (settlement, stability, pore water pressure, etc.), and ground improvement programs.

1.2.1 GDS Personnel

The following positions may be referenced in this manual:

- **Pavement & Geotechnical Section Administrator:** The engineer administrator of both Pavement and Geotechnical Units.
- **Assistant Geotechnical Administrator:** The engineer supervisor of the GDS.
- **Geotechnical Contract Specialist:** The engineer within the GDS in charge of the administration of geotechnical retainer contracts.
- **Geotechnical Task Manager:** The engineer within the GDS responsible for the technical work associated with a specific task. Relative to a geotechnical retainer contract or task order, the Contract Specialist handles contract items such as the proposal, notice to proceed, and invoic-

ing, whereas the Task Manager defines technical requirements and reviews submittals such as Subsurface Investigation Plans or engineering reports.

1.3 GEOTECHNICAL SERVICES

All geotechnical services shall be performed under the supervision of a qualified Geotechnical Engineer-of-Record (GEOR). This includes planning, geotechnical analysis, plan development, forensic work, construction support, instrumentation, etc. The GEOR may be employed by the GDS or by a Consultant, and may be different during different phases of a project. For a typical DOTD project, the GEOR and/or Consultant is involved as follows:

- **Geotechnical Investigation:** Soil borings are typically requested at 60% Preliminary Plans (see the DOTD Project Delivery Manual [1] for specific milestones). The GEOR develops the Subsurface Investigation Plan, oversees the geotechnical investigation, and issues a signed and sealed Geotechnical Data Report (GDR);
- **Geotechnical Design:** The GEOR is engaged again during Final Design after roadway alignment and bridge type are finalized. The GEOR conducts analyses and provides recommendations for the proposed construction or improvements in a signed and sealed Geotechnical Interpretation Report (GIR). Depending on the type of project delivery, the GEOR may change between the geotechnical investigation and design phases; and
- **Construction Support:** The GEOR associated with the design phase is engaged again to oversee the scope of construction phase testing (including instrumentation, load testing, and integrity testing) as well as to review Contractor submittals and provide general construction support.

1.3.1 Division of Labor & Design Responsibility

The following subsections provide a more detailed description of the various ways that geotechnical services may be incorporated into DOTD projects. Additional information about the contents of Subsurface Investigation Plans and geotechnical reports can be found in Chapter 15.

1.3.1.1 All In-House Services

For all in-house services projects, all subsurface exploration, laboratory testing, and design are handled by DOTD personnel. Subsurface investigations and laboratory testing are conducted by DOTD's Materials Lab. Development of the Subsurface Investigation Plan and geotechnical design are handled by the GDS. This is typically done for projects that can be accessed by the DOTD drilling crew, do not require specialized lab testing, and have time/budgetary constraints that preclude contract work. Construction support, such as dynamic monitoring, is provided by the GDS. Projects developed entirely in-house usually proceed as follows:

- Another DOTD section (Bridge Design, Road Design, Project Management, etc.) or district furnishes a formal boring request via the Geotechnical Request Form located on the Pavement & Geotechnical webpage. The request includes any relevant project information, such as general bridge plans, as-built plans, existing geotechnical information, etc.
- The boring request is reviewed by a GDS engineer who evaluates the necessary scope of the

geotechnical investigation based on the anticipated construction, improvements, repairs, etc. The engineer develops a Subsurface Investigation Plan (see Section 3.3.1) and furnishes it to the GDS Contracts Specialist.

- The Contracts Specialist assigns the work to the Materials Lab.
- The Drilling Manager visits the site and performs reconnaissance to determine whether the in-house drill crew can perform the fieldwork. After determining that the work can be done by the in-house crew, the fieldwork is performed.
- Soil samples are extruded and classified by the Materials Lab under supervision of the GEOR/GDS, unless deferred entirely to the Materials Lab. The extruded samples and test assignments are provided to the geotechnical laboratory at the Materials Lab.
- The Materials Lab's geotechnical laboratory performs all fieldwork (see Chapter 3) and laboratory testing (see Chapter 4) and issues a Geotechnical Data Report (GDR) (see Section 15.5) to the GDS for review and acceptance. This report includes soil boring logs, laboratory testing results, and a brief description of the work and methods used. The Materials Lab also furnishes the geotechnical data to the GDS in an approved data interchange format as discussed in Section 15.5.5.1.
- The DOTD section that requested the soil borings furnishes a formal design request, including plans, design loads, cross-sections, etc. This is done using the same Geotechnical Request Form on the Pavement & Geotechnical webpage.
- The GDS performs design analyses and writes a GIR (see Section 15.6) to document the design assumptions. Plan-related design recommendations are typically furnished to the originator of the design request in the cover letter of the report or in a separate memo.
- If the recommendations require construction services (dynamic monitoring, review of foundation installation plans, static load test interpretation, etc.), the district Project Engineer contacts the GDS to schedule the work after the project has been awarded. The GDS may prepare additional reports to document the fieldwork depending upon project needs (see Chapter 15).

1.3.1.2 Consultant Subsurface Investigation (Retainer Contract) / In-House Design

For projects with Consultant subsurface investigation and in-house geotechnical design, all subsurface explorations and laboratory testing are performed by a Consultant who holds a retainer contract with the GDS. All design work and construction support is performed by the GDS. Projects developed with retainer subsurface investigations and in-house design usually proceed as follows:

- Another DOTD section (Bridge Design, Road Design, Project Management, etc.) or district furnishes a formal boring request via the Geotechnical Request Form located on the Pavement & Geotechnical webpage. The request includes any relevant project information, such as general bridge plans, as-built plans, existing geotechnical information, etc.
- The boring request is reviewed by a GDS engineer who evaluates the necessary scope of the geotechnical investigation based on the anticipated construction, improvements, repairs, etc.

The engineer develops a Subsurface Investigation Plan (see Section 3.3.1) and furnishes it to the GDS Contracts Specialist.

- Using a predefined Secondary Selection Process, the GDS Contracts Specialist selects a Consultant from the GDS' active retainer contracts, then solicits a scope of work and cost estimate for the work. The Contracts Specialist writes a Task Order (TO), requests funding, and provides Notice to Proceed (NTP) to the Consultant.
- The Consultant performs all fieldwork (see Chapter 3) and laboratory testing (see Chapter 4) and issues a Geotechnical Data Report (GDR) (see Section 15.5) to the GDS for review and acceptance. This report includes soil boring logs, laboratory testing results, and a brief description of the work and methods used. The Consultant also furnishes the geotechnical data to the GDS in an approved data interchange format as discussed in Section 15.5.5.1.
- The DOTD section that requested the soil borings furnishes a formal design request, including plans, design loads, cross-sections, etc. This is done using the same Geotechnical Request Form on the Pavement & Geotechnical webpage.
- The GDS performs design analyses and writes a GIR (see Section 15.6) to document the design assumptions. Plan-related design recommendations are typically furnished to the originator of the design request in the cover letter of the report or in a separate memo.
- If the recommendations require construction services (dynamic monitoring, review of foundation installation plans, static load test interpretation, etc.), the district Project Engineer contacts the GDS to schedule the work after the project has been awarded. The GDS may prepare additional reports to document the fieldwork depending upon project needs (see Chapter 15).

1.3.1.3 All Services via Consultant (GDS Retainer Contract)

For geotechnical projects performed entirely via GDS retainer contract, all subsurface exploration, laboratory testing, and design are handled by a Consultant who holds a retainer contract with the GDS. The Consultant also handles the construction support. Projects performed entirely on GDS retainer contract proceed as follows:

- Another DOTD section (Bridge Design, Road Design, Project Management, etc.) or district furnishes a formal boring request via the Geotechnical Request Form located on the Pavement & Geotechnical webpage. The request includes any relevant project information, such as general bridge plans, as-built plans, existing geotechnical information, etc.
- The boring request is reviewed by a GDS engineer who evaluates the necessary scope of the geotechnical investigation based on the anticipated construction, improvements, repairs, etc. The engineer develops a Subsurface Investigation Plan (see Section 3.3.1) and furnishes it to the GDS Contracts Specialist.
- Using a predefined Secondary Selection Process, the GDS Contracts Specialist selects a Consultant from the GDS' active retainer contracts, then solicits a scope of work and cost estimate for the work. The Contracts Specialist writes a Task Order (TO), requests funding, and provides Notice to Proceed (NTP) to the Consultant.
- The Consultant performs all fieldwork (see Chapter 3) and laboratory testing (see Chapter 4) and

issues a Geotechnical Data Report (GDR) (see Section 15.5) to the GDS for review and acceptance prior to completing the design work. This report includes soil boring logs, laboratory testing results, and a brief description of the work and methods used. The Consultant also furnishes the geotechnical data to the GDS in an approved data interchange format as discussed in Section 15.5.5.1.

- After receiving the design information, the Consultant performs design analyses and issues a GIR (see 15.6).
- If the recommendations require construction services (dynamic monitoring, review of foundation installation plans, static load test interpretation, etc.), the Project Manager (PM) coordinates with the GDS representative to ensure that funding exists to retain the Consultant during the construction phase. The GDS, PM, and district Project Engineer coordinate in order to the keep the Consultant engaged during construction. The Consultant may prepare additional reports to document the fieldwork depending upon project needs (see Chapter 15).

1.3.1.4 All Services via Consultant (Other Contract)

For projects where all geotechnical work is done via contract (non-geotechnical retainer), all subsurface investigation and design efforts are handled by a Consultant who holds a contract with another DOTD section. The Consultant may be a subcontractor on another section's retainer contract. Alternatively, the Consultant may be a prime or subcontractor on a project-specific contract. For this type of scenario, several critical points should be kept in mind:

- The GDS should be engaged during the selection process to ensure that reputable and capable geotechnical firms are selected.
- It is critical that the PM keeps the Consultant engaged throughout the construction process, since the GDS does not perform construction services for projects where a Consultant GEOR was used. As of this writing, there is not a consistent mechanism for retaining design consultants throughout construction. Therefore, this needs to be considered during the design phase to ensure that funding will exist to pay the Consultant for construction phase engineering services.
- We strongly recommend that Consultants using a geotechnical subconsultant arrange a meeting with the GDS prior to completing Final Design. This meeting would confirm that the correct design criteria were used and that the appropriate notes from the subconsultant's geotechnical report are placed in the plans and contract documents.

1.3.1.5 Other Scenarios

Geotechnical exploration, design, and review may also be provided in other ways, including:

- A GDS retainer contract is used to perform specific work later in a project, such as construction support. This is not desired and is done due to unforeseen circumstances on a project.
- A general-purpose civil firm uses its geotechnical engineers to furnish geotechnical design or review as part of a contract not being managed by the GDS. The GDS should be engaged during this process to provide oversight and review.

- A Local Public Agency (LPA) procures its own engineering services on a project with DOTD oversight. In most cases, the Consultant is selected without any input from DOTD. In these cases, it is critical that the LPA selects a reputable and capable firm that has prior experience with DOTD projects. All exploration and design on projects with DOTD oversight shall be done in accordance with this manual and other DOTD standards.
- A permit applicant procures its own engineering services. The Consultant is selected without any input from DOTD, however, the portion of the work that is relevant to the permit shall be performed in accordance with this manual and other DOTD standards, or the permit will not be approved.

1.4 DESIGN PHILOSOPHY

It is DOTD's intent that designers produce designs and contract documents that yield a safe, efficient, cost-effective, constructible, and maintainable product. The following sections provide a general design philosophy that applies to all geotechnical design. Specific technical and procedural requirements are discussed in individual, subject-focused chapters.

1.4.1 Reliability, Variability, & Risk

The DOTD GDS utilizes Load and Resistance Factor Design (LRFD) [2] for all designs. The Allowable Stress Design (ASD) approach and/or factors of safety will only be allowed for analyses that have not been calibrated for LRFD and the Resistance Factor (ϕ) is essentially the inverse of the factor of safety (e.g., slope stability and sheet pile wall design). The factor of safety approach shall not be used for foundation design.

Designers shall consider variability and risk in all cases, even when these are not accounted for quantitatively in the design methodology.

1.4.2 Site Investigation

Site investigations shall be carried out in accordance with GDM Chapters 3 through 5.

1.4.3 Site Characterization

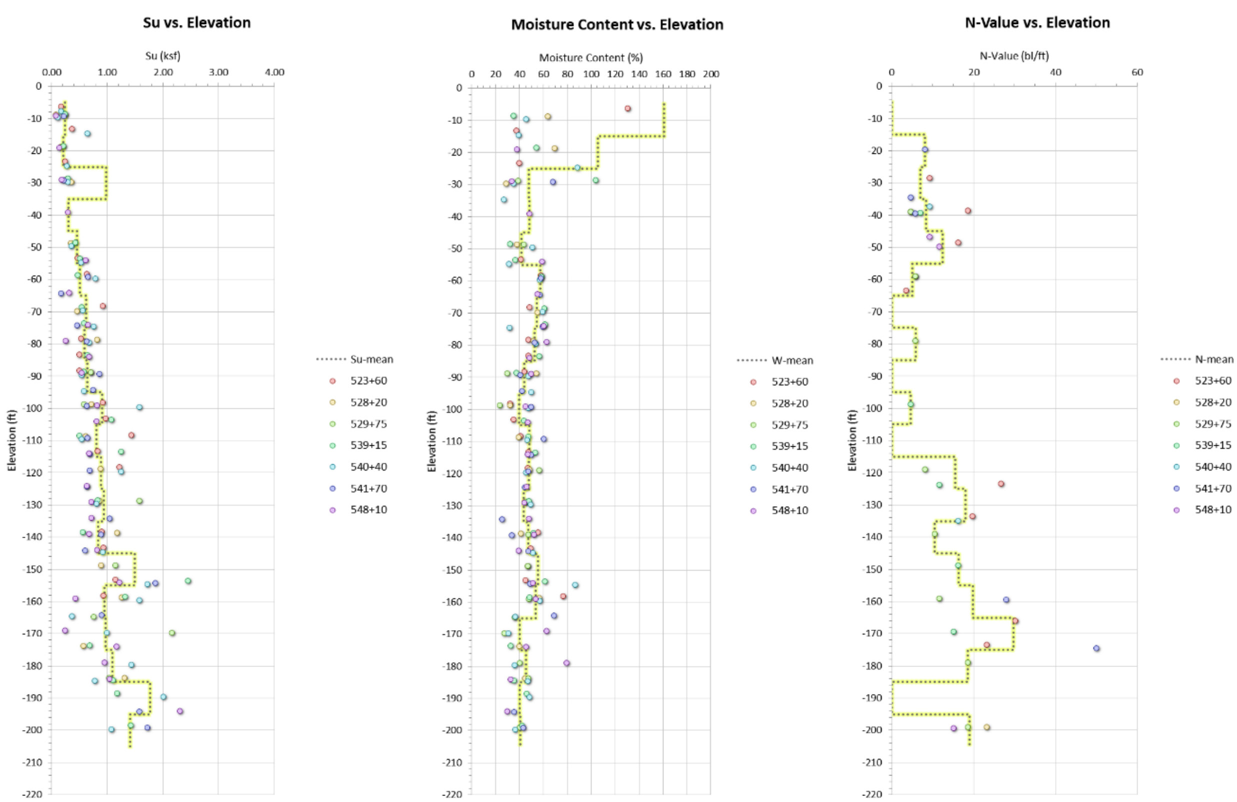
Within the context of this manual, site characterization is the process of developing representative model parameters from the data obtained during the geotechnical investigation. During the site characterization phase, the project site may be split into various reaches, or Design Areas. Each Design Area should be consistent enough that a single design model can be developed to reasonably represent all foundations or geotechnical elements within that Design Area. The GEOR shall attempt to group the data such that the variability among critical design parameters is minimized per Design Area.

Site characterization should consider the sources of variability and uncertainty discussed in FHWA's *Geotechnical Engineering Circular No. 5* [3]. When determining the number of borings to use in a Design Area, the design engineer should consider the influence of number of measurements on the reliability of the estimate of the parameter in question. A soil model made using the measured properties from a single boring nearest to the modeled location may not be more accurate than a soil model comprised of parameters from a group of representative soil borings.

Similarly, when combining properties from multiple borings, the GEOR shall consider the variability and uncertainty of the combined data set in terms of its suitability to serve as a single model parameter representing a particular stratum. For this approach, the Coefficient of Variation (COV) methodology described in *GEC No. 5* [3] should be considered as a guideline. Specifically, selecting Design Areas such that COV_{model} is below 0.3 for critical design parameters is a reasonable starting point for minimizing the effects of variability.

The maximum of 0.3 for COV_{model} shall not be strictly enforced under the 10th Edition of the *LRFD Bridge Design Specifications* [2]. (Note, however, that future editions of the code are likely to incorporate Resistance Factors (ϕ) that vary based on number of measurements and variability). Engineering judgment may be used to reject outliers or select some trend other than the mean when combining data into a single representative model parameter. The GEOR shall develop and present plots showing measured data points on the same set of axes as the interpreted representative design values for all critical/relevant design parameters (see Figure 1.1). The selection of model parameters shall be defensible and consistent throughout a given project. A reviewer should generally be able to recreate the design using these plots, and it should be clear which plots represent the final design.

Figure 1.1: Example Design Parameter Plots



1.4.4 Plans and Engineering Reports

The GDS recognizes that most geotechnical Consultants provide recommendations in the form of a geotechnical report. These reports may also provide varying recommendations or instruction to consult with the GEOR depending upon conditions encountered in the field. It should be noted that the end result of DOTD project design is a set of plans, which may be accompanied by special provisions. The goal of the plans, specifications, and special provisions is to provide a clear directive to the Contractor.

Although this GDM calls for Consultants to provide GDRs and GIRs for documentation and DOTD review, geotechnical Consultants should recognize that much of the language in a geotechnical report is not adequate for providing clear direction to the Contractor, and therefore cannot be included in the plans. Recommendations should be clear enough for the Contractor to provide a fixed bid price, and therefore the "if-then" language that may be a part of the report cannot be enforced. Recommendations involving "if-then" scenarios or ambiguity can result in claims or change orders and are undesirable. This is especially true for design-bid-build projects, although different dynamics and reporting situations may arise for other types of procurement.

The Consultant shall be familiar with the *Louisiana Standard Specifications for Roads and Bridges (LSSRB)* [4] and shall understand that the only recommendations appropriate for the plans are those that can be measured and paid for, or are otherwise governed by the LSSRB. For situations where the LSSRB does not clearly cover what will be measured and paid for, the Consultant shall write a special provision instructing the Contractor on how to construct the design recommendations. The special provision shall also cover testing, acceptance, measurement, and payment.

1.4.5 Cost-Benefit Analysis

Projects where foundation quantities vary depending upon Resistance Factor (ϕ) and degree of field verification shall include a cost-benefit consideration of the foundation cost versus test foundation and field monitoring cost. This applies primarily to driven pile projects, as the GDS prefers that load testing be performed on drilled shaft projects.

This type of analysis may be conducted using average unit costs (outliers may be omitted) based on DOTD historical bids for foundations, load tests, Test Piles/Shafts, Indicator Piles, dynamic monitoring assistance, and other relevant items. The GDS recognizes that there may be various reasons to recommend a load testing program, and cost is not the final determining factor. However, the GIR shall present a rational explanation in cases where the GEOR's recommendation is not the least expensive option.

Recent bid histories for estimating the costs of the various scenarios may be found at the Cost Estimation and Value Engineering webpage under "Cost Estimation Tools."

1.4.6 Construction-Phase Services

The GDS recognizes that, in many cases, the geotechnical design for a project is not completed during the plan development phase. This is because most field testing is done during the subsequent construction phase, and the final engineered product is dependent upon observation and measurement of field conditions.

The GDS will coordinate with Project Managers to make contractual provisions for the GEOR to be retained during construction-phase testing. This is especially true for projects with foundation load testing; however, the GDS will also attempt to make provisions for the GEOR to be available to review submittals and answer general construction questions.

The GDS believes that it is the GEOR's responsibility and right to follow the geotechnical design through its successful construction. However, this may not be possible where funding or scheduling limitations prevent DOTD from engaging the GEOR during construction contractually. This situation may arise when the GEOR is hired as a subcontractor or when the original project scope is vague. When applicable, we recommend that the GEOR discusses the potential for construction-phase services with the prime consultant as well as the DOTD Project Manager during the scoping phase of the project.

Although DOTD generally attempts to avoid making decisions for the GEOR, it should be recognized that, as the owner of the final product, DOTD will sometimes make these decisions out of necessity. In any case, Consultants shall be prepared to answer questions related to their designs during construction, regardless of their contractual engagement. Consultants shall not produce excessively conservative designs to minimize their exposure at the Department's expense, such as specifying long piles to avoid resistance issues during construction.

Chapter 3. Subsurface Investigations

3.1 OBJECTIVE & SCOPE

The objective of this chapter is to provide minimum standards for conducting subsurface investigations for Louisiana Department of Transportation and Development (DOTD) projects. Within the context of this Geotechnical Design Manual (GDM), a subsurface investigation consists of planning the fieldwork, performing soil borings, and obtaining soil samples for characterizing the subsurface conditions at a project site for the purposes of geotechnical design or forensic evaluation.

This chapter focuses on conventional investigations conducted to retrieve soil samples. Laboratory testing is discussed in Chapter 4. In situ and geophysical testing, which may also comprise a portion of the subsurface investigation, are discussed in Chapter 5. In general, required processes and testing methodologies are presented in this chapter, but additional reference to Section 15.5 may be made for specific reporting requirements.

3.2 REFERENCES

Various American Society for Testing and Materials (ASTM) and American Association of State Highway Officials (AASHTO) standards and test methods are listed in this chapter. When listed alongside a particular test, activity, or method (e.g., drilling, sampling, or laboratory testing), the published standard shall be followed when conducting DOTD work, unless otherwise specified by the Geotechnical Design Section (GDS). In some cases, a secondary acceptable method is listed in parentheses. Please contact the GDS in the event that any of the standards listed herein have been withdrawn.

Additionally, the following resources should be referenced for more detailed information and best practices when conducting a subsurface investigation:

- AASHTO, *Manual on Subsurface Investigations, 2nd Ed.* (2022) [5]
- FHWA, *Geotechnical Engineering Circular, No. 5* (2016) [3] (GEC No. 5)

3.3 SUBSURFACE INVESTIGATIONS

The goal of conducting a subsurface investigation is to characterize the subsurface conditions of the subject site to the degree necessary to achieve an acceptable level of reliability in geotechnical design. Note that future revisions to the AASHTO LRFD Bridge Design Specifications place a greater focus on variability and reliability. This GDM is maintained to stay aligned with these expected changes. The subsurface investigation supports the following:

- Identification of the geological formations present (e.g., formation name, age, depositional characteristics that may affect engineering properties).
- Identification, stratification, and estimation of engineering properties of soil layers.

- Delineation of subsurface Design Areas and Construction Control Areas with similar general stratification and low variability among engineering properties.
- Evaluation of groundwater conditions at the time of the investigation.
- Identification of ground surface topography (e.g., swamp land, alluvial deposits, outcrops, farm land, developed land).
- Identification of local ground considerations that may affect the project design (e.g., soft soils, poor subgrade, expansive/dispersive soils, seismic soil shear strength loss potential, underground voids).

3.3.1 Subsurface Investigation Planning

Prior to commencing fieldwork, an experienced geotechnical engineer having knowledge of the project's design requirements shall prepare a Subsurface Investigation Plan and submit to the GDS for acceptance. The plan is usually prepared by the GEOR for the geotechnical investigation and/or design phase of the project. In some cases, the boring layout will be furnished by the GDS.

The minimum requirements of the Subsurface Investigation Plan are provided in Section 15.3. The Consultant should consider the following sources of information when developing the Subsurface Investigation Plan, regardless of whether boring locations were furnished by the GDS:

- Review of project plans and the Boring Request.
- Desk study of nearby projects, preliminary investigations, or existing geotechnical databases.
- Review of other data sets, such as regional topography, geology, satellite, and aircraft imagery from sources such as United States Geological Survey (USGS), Louisiana Geologic Survey (LGS), and DOTD.
- A site reconnaissance visit (for more complex, sites with difficult access issues, or sites that may need traffic control).
- Consent from landowners to enter onto private property as necessary. In the case that consent is not granted, the Consultant shall contact the GDS project engineer to execute a Forced Entry, as per Louisiana Revised Statute 48:217. Forced entry access will be granted via written notice from the Project Manager (PM).

As indicated in the DOTD *Project Delivery Manual* [1], a subsurface investigation is typically requested after 60% Preliminary Plans during Stage 3 of the Standard Operating Procedures. This investigation generally serves as the final subsurface investigation; however, it is the GDS' position that it may be beneficial to utilize preliminary and final subsurface investigations on some projects. Ideally, preliminary investigations could take place before 60% Preliminary Plans and would consist primarily of Cone Penetrometer Test (CPT) soundings and geophysical testing. This preliminary investigation would then inform the scope of the final investigation.

3.3.2 Subsurface Investigation Requirements

The minimum frequency and spacing of testing locations for various geotechnical features/improvements is presented in Table 3.1. These requirements are based on AASHTO recommendations but have been slightly modified in some cases. Therefore, the list may resemble the list in the AASHTO *Manual on Subsurface Investigations*, but it is not identical. Project-specific conditions may dictate additional exploration requirements beyond these minima. Note that the following abbreviations are used in the table:

- B_{ftg}, L_{ftg} = width and length of footing, respectively
- B_{wall}, H_{wall} = width and height of retaining or sound barrier wall, respectively
- B_{emb} = width of embankment

Unless otherwise indicated, deep soil borings and CPT soundings shall be used to meet all minimum testing requirements. Within the context of the GDM, the term “boring” may be used to describe any type of exploratory geotechnical hole or sounding.

3.3.2.1 Traffic Signals, High-Mast Lighting, & Sign Truss Foundations

For most of the state, foundation lengths for traffic signals, high-mast lighting, and sign trusses are set by standard plans. These standards are based around assumed worst-case soil conditions and wind loading zones. For certain zones where these assumptions may not represent a worst case, a special design is required.

In some cases, DOTD may request borings for these features, either to provide information to a Contractor, or to also support a special design. In cases where DOTD does not explicit proposed exploration locations, Consultants should perform an investigation at each foundation location. Where a special design is not needed, borings shall extend at least 20 ft below the bottom of the foundation. Where a special design is needed, boring depths should be selected based upon anticipated loads and soil conditions.

3.3.2.2 Ground Modification Methods

Certain Ground Modification (GM) methods may require additional geotechnical investigations or techniques. The GEOR for the GM design is responsible for establishing the scope of work needed to meet the requirements for the anticipated method. The need for GM may be known prior to the initial investigation, or could be determined after the initial investigation or even during construction. When preparing subsurface investigations to support the design of GM, the type and scope of modification shall be discussed with the GDS prior to finalising the Subsurface Investigation Plan.

3.3.2.3 Modifications to the Subsurface Investigation Plan

The Consultant performing the subsurface investigation shall maintain communication with the GEOR and the GDS during all phases of the subsurface investigation to report any unanticipated conditions and to allow the GEOR to adjust the subsurface exploration plan as needed to obtain sufficient geotechnical subsurface information for design.

Any proposed modifications to the accepted Subsurface Investigation Plan or to these requirements shall

Table 3.1: Minimum Exploration Requirements

Feature	Minimum No. Exploration Points	Minimum Depth of Exploration
Bridges: Shallow Footings	• $B_{ftg} < 100$ ft: One per footing • $B_{ftg} \geq 100$ ft: Two per footing • Additional locations if uncertain/variable subsurface conditions are encountered	• $2B_{ftg}$ (for $L_{ftg} \leq B_{ftg}$) • $3B_{ftg}$ (for $2B_{ftg} < L_{ftg} < 5B_{ftg}$) • $4B_{ftg}$ (for $L_{ftg} \geq 5B_{ftg}$)
Bridges: Deep Foundations	• $B_{ftg} < 100$ ft: One per bent/footing • $B_{ftg} \geq 100$ ft: Two per bent/footing • Slab spans: One per 100 ft of structure • Additional locations if uncertain/variable subsurface conditions are encountered	• 120 ft below ground surface (without prior geotech investigation data) • 20 ft below anticipated tip elevation (with prior geotech investigation data) • 2x maximum group dimension below anticipated tip elevation for groups
Earth Retaining Structures	• $B_{wall} < 100$ ft: Two per wall, near ends • $B_{wall} \geq 100$ ft: One per 50 ft of wall, alternating between front and back of wall • Anchored Walls: As above, plus one per 100 ft within anchorage zone • Soil Nail Walls: As above, plus one per 100 ft within $1H_{wall}$ to $1.5H_{wall}$ behind wall.	• $2H_{wall}$ below bottom of the wall (MSE) • $5H_{wall}$ below bottom of the wall (sheet piles) • Potentially deeper for walls near/on slopes
Roadway: Embank-ments	• One per 200 to 400 ft, depending upon variability of conditions along centerline • At critical locations (max. height or max. depth of soft strata): Three locations along transverse direction • At bridge approaches: One per abutment	• $2B_{emb}$ below bottom of the embankment
Roadway: Cuts	• One per 200 to 400 ft, depending upon variability of conditions along centerline • At critical locations (max. height or max. depth of soft strata): Three locations along transverse direction	• 15 ft below lowest cut elevation
Pavements	• One per 1000 ft, more frequent if variable conditions are encountered	• 8 ft below finished roadway or natural ground, whichever is greater • For overlays: 4 ft below top of existing pavement or 2 ft below base course, whichever is deeper
Culverts & Pipes	• One at each end of the crossing for boxes wider than 40 ft • For extensions: One every 50 to 100 ft	• Box culverts: same as bridge foundations • Pipes: 10 ft below anticipated invert
Sound Barrier Walls	• One at each end of the wall • One every 200 ft along the wall	• $2H_{wall}$ (for shallow spread footings) • 5 ft below anticipated shaft tip

be approved in writing by the GDS. These modifications include:

- Early termination of soil borings or CPT soundings.
- Modification of the specified sampling intervals or types of sampling.
- Relocation of boring locations distances greater than 20 feet.
- Omission of boring locations or substitution of soil borings with CPT soundings.

3.3.2.4 Depth of Exploration

All specified boring depths shall be referenced Below Ground Surface (BGS) at the boring location unless otherwise specified. Borings taken through or from structures or vehicles such as bridge decks and barges shall account for the additional depth needed to reach the ground surface or mudline. In general, all borings should be extended below any soft compressible material into competent material, with the exception of borings made for deep foundations whose primary resistance is expected to be derived from side friction.

Borings shall be sampled to the depth BGS specified in the Subsurface Investigation Plan. Sample identifications and soil boring logs shall not imply that the boring was taken deeper than the maximum depth of drilling or sampling. For example, a boring drilled to 115 feet, then sampled from 115 feet to 117 feet, shall not meet the requirements for a 120-foot boring.

Boring depths proposed by the Consultant shall be the responsibility of the Consultant; however, the GDS may request modifications to the boring depths based on project scope or future data needs. The Consultant shall consider the following when selecting boring depths:

- High foundation loads may require borings deeper than the typical 120’ depth.
- Foundation resistance may be reduced due to scour or other effects that may not be present or evident at the time of drilling.
- The proposed drilling and sampling methods may not be adequate to satisfy this GDM in certain geologies.

When in doubt that any of the above conditions has been satisfied, contact the GDS prior to demobilizing from the site.

3.3.2.5 Applicability of CPT

CPT soundings may be substituted for soil borings if appropriate for the project’s exploration and design needs. These substitutions shall be documented on the Subsurface Investigation Plan and accepted by the GDS prior to use.

CPT soundings shall not be used if they cannot penetrate to the depth required to adequately characterize the site for the required improvements or foundations. The GEOR shall be responsible for scoping CPT soundings with an understanding that certain correlations may not be applicable locally, or may require additional calibration to be used.

Additionally, borings and CPT shall be spaced such that a correlation can be made between CPT and soil boring data (ground-truthing) for each anticipated Design Area. Additional requirements for CPT use are presented in Chapter 05.

3.4 SOIL BORINGS

The following sections describe the typical soil boring methods used on DOTD projects as well as additional requirements for all boring types:

3.4.1 General Soil Boring Requirements

The following subsections discuss various requirements that apply to all types of soil borings and subsurface explorations.

3.4.1.1 Borehole Performance & Abandonment

Boreholes and CPT soundings shall be performed and backfilled in accordance with all local, State, and Federal regulations. Refer to the *Construction of Geotechnical Boreholes and Groundwater Monitoring Systems Handbook* [6] for State regulations regarding the making of boreholes.

3.4.1.2 Boring Location & Elevation

Boring and sounding locations may be located initially using a handheld GPS. Final coordinates and elevations shall be surveyed or otherwise located to an accuracy of ±6 inches in all directions. Locations shall be verified using conventional mapping software prior to submission of the digital data or GDR.

Borings taken from a bridge deck shall have measurements from the deck to the water surface as well as from the water surface to the mudline.

3.4.1.3 Soil Boring Logs/Field Logs

All soil borings, including Subgrade Soil Surveys, shall be documented with a Field Log (see Section 15.5.1 for specific requirements). Copies of field logs shall be furnished to the GDS Task Manager on a weekly basis, at a minimum.

Borings that produce soil samples or cuttings shall be classified in the field using the Visual-Manual Procedure [7] as described in Appendix 3.A. Logging of soil borings and classification of samples shall be performed by an engineer, geologist, or experienced technician. In cases where samples aren't extruded in the field, an attempt should be made to classify the soils via cuttings, the material at the end of the Shelby tube (or other sampler), or material inside the split-spoon. Where samples are extruded in the field, the requirements of Section 3.6.2 shall be followed. The visual classification should be used, along with the driller's observations, to select the most appropriate type of sampling procedure for the subsequent sample.

All GDRs shall contain a brief description of the subject site, including characteristics like existing structures, drainage features, standing water, evidence of previously existing features or structures and type of vegetation. This documentation should be obtained and recorded by the field crew during the soil boring operations.

3.4.2 Soil Boring Methods

The following sections describe the boring method used on geotechnical design projects as well as pavement projects.

3.4.2.1 Deep Soil Borings

Within the scope of this GDM, "deep borings" refer to borings made for the geotechnical design of any structure or earthwork. These may also be referred to as "bridge borings" in contract documents in order to distinguish them from Subgrade Soil Survey borings, although their purpose may be for something other than bridge foundation design.

Deep borings shall first be advanced by dry auger methods (ASTM D1452 [8]) to allow for the observation of the water table. Rotary wash methods (ASTM D5783 [9]) may be used below the water table or 20-foot depth, whichever is encountered first.

3.4.2.1a Water Level Readings

Initial and 15-minute water level readings shall be made in all deep borings. Drilling operations shall be stopped between the initial and 15-minute readings. Exploratory methods that mask the presence of groundwater, such as wash drilling, shall not be used within the upper 20 feet of a boring unless the water table has been encountered and measured.

If the field investigation requires multiple days to complete, at least one 24-hour water level observation shall be made. Due to the possible formation of a filter cake (a mud layer along the side of the borehole wall), wash borings that utilize drilling mud shall be bailed prior to making the 24-hour reading. Alternatively, a separate shallow boring may be made without drilling mud for the sole purpose of a 24-hour water level reading. The Consultant shall discuss the proposed method of long-term water table measurement in the Subsurface Investigation Plan. A 24-foot deep "water table only" boring was added to the DOTD geotechnical drilling rates to encourage the use of a standalone boring for water table observation.

Soil borings performed in sandy soils can be susceptible to caving, which may indicate the water table location. If observed, record the caving depth on the soil boring log.

3.4.2.2 Subgrade Soil Survey Borings

Subgrade soil survey borings are obtained for pavement overlays and for new construction. Generally, the intent of these borings is to obtain samples for index testing and not shear strength testing. Therefore, methods that produce disturbed samples are typically acceptable.

Subgrade soil survey borings can be made utilizing manual augers, continuous-flight augers, pneumatic, or direct-push sampling. Any other method shall be approved by the GDS prior to implementation. Refer to Table 3.1 for additional requirements. The accepted methods for advancing Subgrade Soil Survey borings are as follows:

- **Manual Augers:** Manual auger borings are typically used where access is limited and may be limited in depth by soil strength, collapsible soils, and the presence of groundwater. See *ASTM D1452: Standard Practice for Soil Exploration and Sampling by Auger Borings* [8] (*AASHTO T 207: Standard Method of Test for Thin-Walled Tube Sampling of Soils* [10]).

- **Continuous-Flight Augers:** Continuous-flight augers are typically machine operated with drilling rigs. See *ASTM D1452: Standard Practice for Soil Exploration and Sampling by Auger Borings* [8] (*AASHTO T 207: Standard Method of Test for Thin-Walled Tube Sampling of Soils* [10]).
- **Pneumatic or Direct-push:** These single rod systems may be an alternative to auger borings, depending upon the amount and type of soil sample necessary to conduct the required laboratory testing. See Geoprobe MC5 or MC7 system, or similar method approved by the GDS.

3.4.2.3 In Situ Testing

Other in situ tests are discussed in Chapter 5; however, the Standard Penetration Test (SPT) is presented in this chapter due to its function as a sampling event. Refer to Section 3.5.1.1 for additional information on the SPT.

CPT soundings can be used to supplement the subsurface investigation by refining stratification of soils, identifying transitions between Design Areas, and reducing the number of soil borings on a project. In the context of this GDM, it is assumed that CPT refers to Piezocone (CPTu) soundings with pore water pressure measurements taken at the U2 position, unless otherwise stated. CPT may also be used to obtain seismic or dissipation data as well as direct design data for deep foundations. Direct design methods for driven piles are discussed in Chapter 7.

The Consultant shall report gaps in the data as early as possible where conventional sampling and testing are inadequate (e.g., where strength testing cannot be conducted, samples cannot be obtained, or where SPT shows a significant amount of WOH material). In these cases, additional in situ testing may be needed. For example, in clay deposits where samples are too soft to be sampled or placed into a membrane for triaxial testing, a Field Vane Test (FVT) may be needed to characterize the soils' shear strength.

3.5 SAMPLING

Unless specified otherwise, continuous sampling shall be conducted within the upper 10 feet of deep borings, followed by 3- to 5-foot sampling intervals on-center to the boring termination depth, depending upon the type of soils encountered in the borehole.

Within the continuous sampling zone, samples shall be taken consecutively such that the gap between each sample is minimized or eliminated. For deep borings, the maximum sample length within the continuous sampling zone is 24 inches. The continuous sampling limits may sometimes be modified for projects where the strength or compressibility of near-surface soils is a design concern, such as tall embankments on soft soils.

Below the continuous sampling zone:

- In cohesionless soils, disturbed samples shall be obtained on 3-foot centers, using a split-barrel (split-spoon) sampler, in conjunction with the Standard Penetration Test (SPT).

- In cohesive soils, undisturbed samples shall be obtained on 5-foot centers.

Subgrade soil survey borings shall be sampled continuously (or at no greater than 1-foot intervals if grab samples are taken).

3.5.1 Split-Barrel Sampling

The split-barrel sampler (standard split-spoon) shall be used to obtain disturbed samples in cohesionless soils in conjunction with the SPT, which is described in Section 3.5.1.1. These disturbed samples are suitable for visual classification, index testing, and electro-chemical tests.

The split-spoon shall not be driven further than its interior length into the subsurface soils. After sample retrieval, the sample shall be placed into an airtight container such as a jar or sealable plastic bag. If the sampling event encounters a change in stratigraphy, a sample of each soil type shall be placed in separate containers. The approximate recovery of each portion of the sample shall be recorded.

3.5.1.1 Standard Penetration Test (SPT)

SPTs shall be performed in accordance with *ASTM D1586: Standard Test Method for Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils* [11] (*AASHTO T 206: Standard Method of Test for Penetration Test and Split-Barrel Sampling of Soils* [12]). Only automatic hammers shall be used to perform SPTs on DOTD projects.

The blow counts for each 6-inch interval and observed N-value (N_{meas}) shall be indicated on the boring logs at each sampling depth where an SPT is conducted. Early termination of the test and the associated partial SPT N-values may be recorded as indicated below:

- 50 blows within a 6-inch interval (see Section 7.2.1 of [11])
- 100 blows total (see Section 7.2.2 of [11])
- No advancement for 10 blows (see Section 7.2.3 of [11])

The SPT shall not be terminated in a nonstandard fashion. Note that although 50 blows per 6 inches is a convenient termination criterion, it will often be rejected by data validation routines in data management software. The typical case of N_{meas} = 50 blows per 6 inches should either be 50 blows within some distance just under 6 inches (e.g., 50 blows per 5.9 inches), or the driller should have started a new sequence of blows at the next 6-inch interval.

3.5.1.1a SPT in Cohesive Soils

Strength properties of cohesive soils shall not be characterized using the SPT, except where samples cannot be procured with undisturbed sampling. If a cohesive soil sample is encountered in a split-spoon sampler, an undisturbed sample shall be obtained immediately below the split-spoon sampler depth. In the event that a Shelby tube sample cannot be obtained in Weight of Hammer (WOH) material, piston sampling or field vane shear tests should be attempted. Boring logs that show evidence of persistent split-spoon sampling in cohesive soils will not be accepted and may require redrilling at the Consultant’s expense.

3.5.1.1b SPT Sampler Plugging

When the SPT is performed in soil layers containing large shells, gravel, wood, or similar materials, the sampler may become plugged. A plugged sampler will cause the N-value to be larger than for an unplugged sampler and, therefore, is not a representative index of the soil properties. In this circumstance, a realistic design requires reducing the N-value used for design to the trend of the N-values which do not appear distorted; however, the observed N-values shall be presented on the boring logs (see Section 15.5.2) with a note indicating that the sampler was likely plugged.

3.5.1.1c SPT Energy Correction

The SPT measurements can vary greatly from hammer to hammer, or even among sampling events with the same hammer depending on various factors. As a result, all hammers used on DOTD projects shall be calibrated annually, using *ASTM D4633: Standard Test Method for Energy Measurement for Dynamic Penetrometers* [13]. The hammer efficiency shall be reported on the soil boring logs (see Section 15.5.2).

3.5.2 Undisturbed Sampling

A thin-walled steel Shelby tube shall be used to obtain undisturbed samples in cohesive soils in accordance with *ASTM D1587: Standard Practice for Thin-Walled Tube Sampling of Soils for Geotechnical Purposes* [14] (*AASHTO T 207: Standard Method of Test for Thin-Walled Tube Sampling of Soils* [10]). This method produces (relatively) undisturbed samples suitable for shear strength and consolidation testing.

If an undisturbed sampling event produces cohesionless soils or no recovery, an SPT shall be performed immediately below the sampling attempt.

All tubes shall be thoroughly inspected for defects and cleaned before reuse. Use a file to maintain a sharp cutting edge on used tubes in order to repair damage that would disturb or obstruct passage of the sample core. Tubes that are dirty, corroded, deformed, or contain a damaged cutting end shall not be used on DOTD projects. For samples that will be transported to a lab, the tube shall be sealed on both ends with a cap or expansion packer to prevent excessive moisture loss. Prior approval from the GDS is required to use tubes longer than 30 inches.

In general, undisturbed sampling shall be performed with a fixed head attachment to the drill string; however, other undisturbed sampling methods may be employed for specific soil conditions with approval from the GDS, such as various piston samplers in soft soils and the pitcher barrel sampler in hard soils.

3.5.3 Disturbed/Grab Samples

Highly disturbed samples may consist of grab samples as well as those obtained from pneumatic or direct-push sampling. Disturbed sampling may be done at discrete locations or obtained in bulk as representative samples of embankments or other soil deposits. Although pneumatic or direct-push sampling is typical for Subgrade Soil Survey borings, grab sampling should not be used on DOTD projects except where other methods fail to procure a sample.

Disturbed samples are generally useful for visual classification, soil index testing, and electro-chemical tests. Although disturbed samples may be used to make remolded specimens for shear strength testing, the GDS does not allow the use of remolded samples as a substitute for undisturbed samples. If a remolded sample is used for shear strength testing, it shall be clearly denoted on the soil boring log.

3.5.3.1 Subgrade Soil Survey Samples

Sampling for Subgrade Soil Surveys may consist of disturbed samples. They shall be sampled continuously and divided into specimens representing 12-inch increments for testing.

3.6 SAMPLE TRANSPORT, EXTRUSION, & RETENTION

All samples shall be properly obtained, stored, and transported to a laboratory testing facility in a manner that preserves the samples as best as is practical for the anticipated laboratory testing program. See *ASTM D4220: Standard Practices for Preserving and Transporting Soil Samples* [15] for best practices.

3.6.1 Sample Transport

Samples shall be transported vertically in the same orientation in which they were sampled, with care taken to avoid excessive temperature variation, vibration, storage time, or any other source of excessive sample disturbance.

3.6.2 Sample Extrusion

The Consultant may field-extrude samples, provided that sample quality is not reduced; however, the GDS reserves the right to require laboratory extrusion of samples for any reason. Laboratory extrusion shall take place at a facility specifically prepared full-time for sample extrusion, classification, handling, and storage. Samples shall be extruded by means of a continuous pressure hydraulic ram directly onto a sample trough. Samples shall be extruded in the same direction as they were retrieved from the ground. Extrusion by any other method, such as water pressure, is prohibited.

All extruded soil borings, including Subgrade Soil Survey borings, shall be documented with an Extrusion Log (see Section 15.5.1 for specific requirements). In the case of field extrusion, the Field Log and Extrusion Log are the same document.

Photographs shall be taken of each sample prior to testing, preferably with a portion of excess sample cut in half to show its center. Sample recovery length shall also be measured and recorded. Pocket penetrometer tests shall be made on representative ends (not the curved side) of the trimmed sample. In the event that the pocket penetrometer reading is less than 0.50 tsf, a miniature vane shear (Torvane) test shall also be performed. In the case of laboratory extrusion, samples shall be re-classified based on the Visual-Manual Procedure [7].

The GDS reserves the right to observe sample extrusion of DOTD projects at any time. The Consultant laboratory shall be prepared to leave samples in the tubes, bags, and/or jars for up to a week in order to accommodate the GDS's schedule. The GDS will notify the Consultant's laboratory prior to completion of the fieldwork if observation is necessary.

3.6.3 Sample Retention

Samples shall be retained by the Consultant laboratory for at least 3 months after acceptance of the GDR. See Chapter 15 for details about the GDR submittal contents.

Appendix

3.A VISUAL-MANUAL CLASSIFICATION

As per Sections 3.4.1.3 and 3.6.2, all field logs and extrusion logs shall include Visual-Manual classification for all samples. The Visual-Manual classifications and the laboratory results shall be used to further refine the final soil classifications on the soil boring logs (see Chapter 4). Refer to *ASTM D 2488: Standard Practice for Description and Identification of Soils (Visual Manual Procedure)* [7]. Strict adherence to the entire standard is not necessary; however, the procedure should be followed closely enough to produce classifications consistent with local practice and as described herein. To summarize, soils are classified as follows:

- Soil is first determined to be either coarse- (less than 50% fines) or fine-grained (more than 50% fines);
- For coarse-grained soils, the primary constituent (either sand or gravel) is selected based upon grain size (see Table 3.A.3);
- For fine-grained soils, the primary constituent (organic clay, fat clay, lean clay, silt, or elastic silt) is selected based upon an estimate of plasticity (see Table 3.A.4). Note that the A-Line is defined by the Atterberg Limit test, which is discussed in Section 4.3.3.3;
- For further refinement of coarse-grained soils, the remainder of the classification is selected based upon the gradation, the type of fines material present, and the fraction of other coarse soils present (see Table 3.A.5);
- For further refinement of fine-grained soils, the remainder of the classification is selected based upon the type and fraction of the coarse particles present (see Table 3.A.6);
- Soils on the borderline between two classifications may need a special group symbol, as discussed in Section 3.A.3; and
- Other descriptors are applied to the classification, as discussed in Appendix 3.A.1.

3.A.1 Soil Descriptors

The soil descriptors in [7] are extensive and may not be necessary to describe all soils. At a minimum, soils shall be described as follows:

[CONSISTENCY or RELATIVE DENSITY] [COLOR] [CLASSIFICATION] [with ADDITIONAL COMMENTS]

Additional descriptors such as angularity, shape, odor, moisture condition, cementation, and structure should be used when applicable. Additional comments/observations should be detailed, especially during the extrusion process when the entire sample can be observed, compared with a trimmed laboratory specimen that may not exhibit all of the features of the full sample.

For Visual-Manual classification, the indicator of consistency or relative density will typically be a pocket penetrometer or SPT, respectively. The Terzaghi and Peck estimates shall be used for the consistency (Table 3.A.1) and relative density (Table 3.A.2) descriptions, as summarized in ASTM D1586, X2 [11].

Table 3.A.1: Consistency of Clay, based on N-Value & Unconfined Strength [11]

No. of Blows [N]	q_u [tsf]	Consistency
< 2	< 0.25	Very Soft
2-4	0.25-0.50	Soft
4-8	0.50-1.00	Medium
8-15	1.00-2.00	Stiff
15-30	2.00-4.00	Very Stiff
> 30	> 4.00	Hard

Table 3.A.2: Relative Density of Sands, based on N-Value [11]

No. of Blows [N]	Relative Density
0-4	Very Loose
4-10	Loose
10-30	Medium-Dense
35-50	Dense
> 50	Very Dense

3.A.2 Identification of Coarse-Grained and Fine-Grained Soils

Classification of coarse- and fine-grained soils should generally adhere to the following summary tables:

Table 3.A.3: Coarse-Grained Soil Gradation

Soil Type	Passing Sieve	Retained on Sieve
Gravel	3-inch (75-mm)	No. 4 (4.75-mm)
Sand	No. 4 (4.75-mm)	No. 200 (75-μm)

Table 3.A.4: Plasticity of Fine-Grained Soils

Soil Type	Description	Plasticity Index
Clay	Soil that exhibits plasticity (putty-like) properties within a range of water contents and that exhibits considerable strength when air dry	PI $\geq$7 or above A-Line
Silt	Soil that is nonplastic or very slightly plastic and that exhibits little or not strength when air dry	PI < 4 or below A-Line

Table 3.A.5: Identification of Coarse-Grained Soils (from ASTM D 2488 [7])

Soil Type	Fines	Grade	Type of Fines	Group Symbol	Sand/Gravel	Group Name
Gravel (% Gravel > % Sand)	≤5%	Well	-	GW	<15% sand	Well-graded GRAVEL
					≥15% sand	Well-graded GRAVEL with sand
		Poorly		GP	<15% sand	Poorly-graded GRAVEL
					≥15% sand	Poorly-graded GRAVEL with sand
	10%	Well	ML or MH	GW-GM	<15% sand	Well-graded GRAVEL with silt
					≥15% sand	Well-graded GRAVEL with silt & sand
			CL or CH	GW-GC	<15% sand	Well-graded GRAVEL with clay
					≥15% sand	Well-graded GRAVEL with clay & sand
		Poorly	ML or MH	GP-GM	<15% sand	Poorly-graded GRAVEL with silt
					≥15% sand	Poorly-graded GRAVEL with silt & sand
			CL or CH	GP-GC	<15% sand	Poorly-graded GRAVEL with clay
					≥15% sand	Poorly-graded GRAVEL with clay & sand
	≥15%	-	ML or MH	GM	<15% sand	SILTY GRAVEL
		-			≥15% sand	SILTY GRAVEL with sand
		-	CL or CH	GC	<15% sand	CLAYEY GRAVEL
		-			≥15% sand	CLAYEY GRAVEL with sand
Sand (% Sand > % Gravel)	≤5%	Well	-	SW	<15% gravel	Well-graded SAND
					≥15% gravel	Well-graded SAND with gravel
		Poorly		SP	<15% gravel	Poorly-graded SAND
					≥15% gravel	Poorly-graded SAND with gravel
	10%	Well	ML or MH	SW-SM	<15% gravel	Well-graded SAND with silt
					≥15% gravel	Well-graded SAND with silt & gravel
			CL or CH	SW-SC	<15% gravel	Well-graded SAND with clay
					≥15% gravel	Well-graded SAND with clay & gravel
		Poorly	ML or MH	SP-SM	<15% gravel	Poorly-graded SAND with silt
					≥15% gravel	Poorly-graded SAND with silt & gravel
			CL or CH	SP-SC	<15% gravel	Poorly-graded SAND with clay
					≥15% sand	Poorly-graded SAND with clay & gravel
	≥15%	-	ML or MH	SM	<15% gravel	SILTY SAND
		-			≥15% gravel	SILTY SAND with gravel
		-	CL or CH	SC	<15% gravel	CLAYEY SAND
		-			≥15% gravel	CLAYEY SAND with gravel

Table 3.A.6: Identification of Coarse-Grained Soils (from ASTM D 2488 [7])

Group Symbol	Coarse Fraction	Coarse Fraction Composition	Sand or Gravel	Group Name
CL	<30% plus No. 200	<15% plus No. 200	—	Lean CLAY
		15-25% plus No. 200	% sand ≥% gravel	Lean CLAY with sand
			% sand < % gravel	Lean CLAY with gravel
	≥30% plus No. 200	% sand ≥% gravel	<15% gravel	SANDY lean CLAY
			≥15% gravel	SANDY lean CLAY with gravel
		% sand < % gravel	<15% sand	GRAVELLY lean CLAY
			≥15% sand	GRAVELLY lean CLAY with sand
ML	<30% plus No. 200	<15% plus No. 200	—	SILT
		15-25% plus No. 200	% sand ≥% gravel	SILT with sand
			% sand < % gravel	SILT with gravel
	≥30% plus No. 200	% sand ≥% gravel	<15% gravel	SANDY SILT
			≥15% gravel	SANDY SILT with gravel
		% sand < % gravel	<15% sand	GRAVELLY SILT
			≥15% sand	GRAVELLY SILT with sand
CH	<30% plus No. 200	<15% plus No. 200	—	Fat CLAY
		15-25% plus No. 200	% sand ≥% gravel	Fat CLAY with sand
			% sand < % gravel	Fat CLAY with gravel
	≥30% plus No. 200	% sand ≥% gravel	<15% gravel	SANDY fat CLAY
			≥15% gravel	SANDY fat CLAY with gravel
		% sand < % gravel	<15% sand	GRAVELLY fat CLAY
			≥15% sand	GRAVELLY fat CLAY with sand
MH	<30% plus No. 200	<15% plus No. 200	—	Elastic SILT
		15-25% plus No. 200	% sand ≥% gravel	Elastic SILT with sand
			% sand < % gravel	Elastic SILT with gravel
	≥30% plus No. 200	% sand ≥% gravel	<15% gravel	SANDY elastic SILT
			≥15% gravel	SANDY elastic SILT with gravel
		% sand < % gravel	<15% sand	GRAVELLY elastic SILT
			≥15% sand	GRAVELLY elastic SILT with sand
OL/OH	<30% plus No. 200	<15% plus No. 200	—	ORGANIC SOIL
		15-25% plus No. 200	% sand ≥% gravel	ORGANIC SOIL with sand
			% sand < % gravel	ORGANIC SOIL with gravel
	≥30% plus No. 200	% sand ≥% gravel	<15% gravel	SANDY ORGANIC SOIL
			≥15% gravel	SANDY ORGANIC SOIL with gravel
		% sand < % gravel	<15% sand	GRAVELLY ORGANIC SOIL
			≥15% sand	GRAVELLY ORGANIC SOIL with sand

3.A.3 Borderline Symbol

Soils that appear to fall on the borderline between two soil groups may be described using the Borderline Symbols below:

Table 3.A.7: Borderline Symbols

Apparent Condition	Borderline Symbol(s)
45% $\leq$%-200 $\leq$55%	GM/ML or CL/SC
%Sand / %Gravel	GP/SP, SC/GC, or GM/SM
Well- to Poorly-Graded	GW/GP or SW/SP
Dominant fine-grained silt or clay	CL/ML, CH/MH, or SC/SM

The group name for a soil with a borderline symbol should be the group name for the first symbol, except for:

- CL/CH, lean to fat clay;
- ML/CL, clayey silt; and
- CL/ML, silty clay.

Chapter 4. Laboratory Testing

4.1 OBJECTIVE & SCOPE

The objective of this chapter is to provide minimum standards for the conduct of geotechnical laboratory testing for Louisiana Department of Transportation and Development (DOTD) projects. Within the context of this Geotechnical Design Manual (GDM), laboratory testing refers to testing performed to develop geotechnical design parameters or forensic testing to characterize existing geotechnical assets, assess risk, and evaluate failures and construction issues. This chapter does not cover acceptance testing for construction materials.

This chapter focuses on conventional investigations that are intended to test physical soil samples. In situ and geophysical testing, which may also comprise a portion of the subsurface investigation, are discussed in Chapter 5. Required methodologies are presented in this chapter, but additional reference to Chapter 15 may be made for specific reporting requirements.

4.2 REFERENCES

Various standards and test methods from the American Society for Testing and Materials (ASTM) and American Association of State Highway Officials (AASHTO) are listed in this chapter. When listed alongside a particular test, activity, or method (e.g., drilling, sampling, or laboratory testing), the published standard shall be followed when conducting DOTD work, unless otherwise specified by the Geotechnical Design Section (GDS). In some cases, a secondary acceptable method is listed in parentheses. Laboratories shall only conduct tests for which they are accredited, per the contract documents.

Additionally, the following resources should be referenced for more detailed information and best practices when conducting a subsurface investigation:

- AASHTO, *Manual on Subsurface Investigations, 2nd Ed.* (2022) [5]
- Federal Highway Administration (FHWA), *Geotechnical Engineering Circular, No. 5* (2016) [3] (GEC No. 5)

4.3 LABORATORY TESTING

The following sections discuss the geotechnical laboratory testing requirements for DOTD projects. Specific reporting requirements for test results in boring logs and Geotechnical Data Report (GDR)s are discussed for each test.

4.3.1 General Requirements

The following general requirements shall be followed when performing testing for DOTD projects:

- Unless otherwise stated in the contract documents, all geotechnical testing performed for DOTD projects shall be performed by an AASHTO-accredited laboratory holding accreditation for all tests listed in Table 4.1 and Table 4.2, plus one-dimensional consolidation testing.

- All tests shall be assigned by a geotechnical engineer familiar with the project scope and having adequate and relevant design experience.
- Routine testing shall be performed in the same location as the Laboratory Supervisor's domicile. Specialized or overflow testing may be shipped to another lab with written approval from the GDS.
- All testing shall be performed in a laboratory space specifically used for sample extrusion, handling, and geotechnical lab testing.
- Dry preparation methods shall not be used for any borings other than Subgrade Soil Survey borings.

4.3.2 Test Type & Quantity

The type, distribution, and quantity of geotechnical laboratory tests should be adequate for design as well as for stratification and classification of soils using the Unified Soil Classification System (USCS) [16] or AASHTO [17] systems for deep borings and Subgrade Soil Survey borings, respectively. Additional requirements for presentation of soil boring logs are discussed in Chapter 15. The following minimum testing requirements shall be observed:

4.3.2.1 Deep/Bridge Borings

The following minimum test requirements shall be observed for each deep boring:

Table 4.1: Minimum Testing Requirements for Bridge Borings

Test Name	Test Standard	Frequency of Testing
Moisture Content	ASTM D2216 [18]	100% of all samples
Unconsolidated-Undrained Triaxial Compressive Strength	ASTM D2850 [19]	75% of all cohesive samples
Atterberg Limits	ASTM D4318 [20]	75% of all cohesive samples
Grain Size Testing (cohesive)	ASTM D1140 [21]	All cohesive samples not visually classified as Peat, Organic Clay, or Fat Clay
Grain Size Testing (non-cohesive)	ASTM D1140 [21] ASTM D6913 [22]	All sand samples As needed to classify soil

One-dimensional consolidation tests (ASTM D 2435 [23]) shall be performed where significant settlement is expected due to fill, and at all deep foundation group locations. A minimum of two (2) consolidation tests shall be performed per applicable boring.

4.3.2.2 Subgrade Soil Survey Borings

The following minimum test requirements shall be observed for each Subgrade Soil Survey boring. Note that these are minimum requirements, and the purpose of the testing is to classify the soils via the AASHTO system [17]:

Table 4.2: Minimum Testing Requirements for Subgrade Soil Survey Borings

Test Name	Test Standard	Frequency of Testing
Moisture Content	ASTM D2216 [18]	100% of all samples
Atterberg Limits	ASTM D4318 [20]	100% of all cohesive samples
Grain Size Testing (non-cohesive)	ASTM D1140 [21] ASTM D6913 [22]	All sand samples As needed to classify soil
Hydrometer	ASTM D7928 [24]	75% of all cohesive samples
Percent Organics	ASTM D2974 [25]	As needed
pH & Resistivity	ASTM G51 [26] AASHTO T 288 [27]	As needed at applicable pipe crossings

4.3.3 Index Testing

Index testing is used primarily for soil classification but may also be used to assess soil behavior and to select samples for engineering property testing (e.g., shear strength, consolidation, permeability).

4.3.3.1 Grain Size Analysis

Grain size analyses consist of determining the particle size distribution (i.e., percent passing) in coarse-grained soils and fine-grained soils. The sieve analysis (with wash over the No. 200 sieve) is performed on coarse-grained soils to determine gravel and sand fractions, while the hydrometer test is used for fine-grained soils to determine clay and silt fractions. The wash over the No. 200 sieve without the full sieve stack is also used to determine coarse and fine-grained soil percentages. Tests are conducted based on grain size as follows:

- Use *ASTM D6913: Standard Test Method for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis* [22] for particle sizes between the 3-inch and the No. 200 sieve.
- Use *ASTM D1140: Standard Test Methods for Determining the Amount of Material Finer than 75-µm (No. 200) Sieve by Washing* [21] to determine the fraction passing the No. 200 sieve.
- To determine the grain size distribution of the material passing the No. 200 sieve (75-µm), use *ASTM D7928: Standard Test Method for Particle-Size Distribution (Gradation) of Fine Grained Soils Using the Sedimentation (Hydrometer) Analysis* [24] (*AASHTO T 88: Standard Method of Test for Particle Size Analysis of Soils* [28]).

The percent passing the No. 200 sieve shall be reported on the soil boring logs as a percentage with one decimal. Additionally, grain size analyses containing more than one sieve shall be reported in the GDR appendix on a grain size distribution curve showing the percentage passing of the specimen versus a continuous logarithmic particle size scale. The curve shall also report, at a minimum: D_{50}, D_{90}, Coefficient of Uniformity (C_u), and Coefficient of Curvature (C_c).

4.3.3.2 Moisture Content

The moisture content (water content) is defined as the ratio of the weight of water in a sample to the weight of solids. Moisture content shall be determined using *ASTM D2216: Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass* [18] (*AASHTO T 265: Standard Method of Test for Laboratory Determination of Moisture Content of Soils* [29]). Moisture content shall be reported on the soil boring logs as an integer percentage.

4.3.3.3 Atterberg Limits

Atterberg limits are moisture-plasticity relationships that describe the behavior of the soil as moisture content changes. At moisture contents below the Shrinkage Limit (SL), the soil behaves like a solid. As moisture increases above the SL, the soil behaves as a semi-solid approaching the Plastic Limit (PL), then behaves plastically until reaching the Liquid Limit (LL). At moisture contents higher than the LL, the soil begins to flow like a liquid. The PL and LL tests shall be conducted as follows:

- Liquid and Plastic limits shall be determined in accordance with *ASTM D4318: Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils* [20].
- Only samples from Subgrade Soil Survey borings shall use the dry preparation method in accordance with Section 11.2 of ASTM D4318 [20].
- Samples from all other borings shall use the wet preparation method in accordance with Section 11.1 of ASTM D4318 [20].

The Plasticity Index (PI) is the difference between the liquid limit and the plastic limit. The LL, PL, and PI shall be reported numerically on the boring logs as an integer percentage. Alternatively, a “whisker diagram” depicting the LL, PL, and moisture content may be presented graphically on the logs. The SL is not typically required for DOTD projects.

Consultants shall take care to ensure that strength/consistency, moisture, and Atterberg results are consistent (e.g., stiff clays should not have moisture content values in excess of the LL). Consultants should be prepared to re-run tests that exhibit inconsistent relationships.

4.3.3.4 Organic Testing

Soils exhibiting signs of high organic content, such as dark color and musty odor, should be tested for organic content when the engineering properties of these soils could impact the design, such as for slope stability or settlement. The ignition loss and organic content testing shall be performed in accordance with *ASTM D2974: Standard Test Methods for Moisture, Ash, and Organic Matter of Peat and Other Organic Soils* [25] (*AASHTO T 267: Standard Method of Test for Determination of Organic Content in Soils by Loss on Ignition* [30]).

When the organic content is greater than 3% and less than 15%, it shall be reported as a percentage on the boring logs following the soil description, e.g. "Soft, gray, FAT CLAY, (CH) with organics (4%). Soils with an organic content greater than 15% shall be classified as an organic soil. These ranges are based on organic content discussion in *Geotechnical Engineering Circular No. 5* [3].

4.3.3.5 Wet Unit Weight

Wet unit weight, or wet density, (γ) is measured from prepared soil specimens obtained from undisturbed sampling. The unit weight for a soil specimen shall be determined in accordance with Method B (direct measurement) of *ASTM D7263: Standard Test Methods for Laboratory Determination of Density and Unit Weight of Soil Specimens* [31]. Wet unit weight shall be reported on the soil boring logs in pounds per cubic foot (pcf) as an integer.

4.3.3.6 Specific Gravity

The specific gravity of soil, (G_s) is defined as the ratio of the dry unit weight of a given material to the unit weight of water (62.4 pcf). This test is typically performed on soils composed of particles smaller than the No. 4 sieve (4.75 mm) and shall be performed in conjunction with all consolidation tests. See *ASTM D854: Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer* [32] (*AASHTO T 100: Standard Method of Test for Specific Gravity of Soils* [33]). If the soil contains particles larger than the No. 4 sieve, use *ASTM C127: Standard Test Method for Relative Density (Specific Gravity) and Absorption of Coarse Aggregate* [34].

4.3.4 Electrical-Chemical Tests

Electro-chemical tests provide quantitative information about the aggressiveness of the subsurface or surface water environment, as well as the potential for deterioration of foundation materials. These include pH, resistivity, sulfate, and chloride contents. When requested, electro-chemical tests shall be performed on soil samples as follows:

- **pH:** *ASTM G51: Standard Test Method for Measuring pH of Soil for Use in Corrosion Testing* [26] (*AASHTO T 289: Standard Method of Test for Determining pH of Soil for Use in Corrosion Testing* [35]).
- **Resistivity:** *AASHTO T 288: Standard Method of Test for Determining Minimum Laboratory Soil Resistivity* [27]. Note that AASHTO T 288 will produce a resistivity at 100 percent saturation and a second resistivity when the soil is in a slurry condition (supersaturated).
- **Chloride:** *AASHTO T 291: Standard Method of Test for Determining Water-Soluble Chloride Ion Content in Soil* [36].
- **Sulfate:** *ASTM C1580: Standard Test Method for Water-Soluble Sulfate in Soil* [37] (*AASHTO T 290: Standard Method of Test for Determinding Water-Soluble Sulfate Ion Content in Soil* [38]).

Surface water should also be tested in coastal regions where brackish water may intrude, or in areas where groundwater contamination is suspected. Tests on water samples shall be conducted as follows:

- **pH:** *ASTM D1293: Standard Test Methods for pH of Water* [39].

- **Resistivity**: *ASTM D1125: Standard Test Methods for Electrical Conductivity and Resistivity of Water* [40].
- **Chloride:** *ASTM D512: Standard Test Methods for Chloride Ion in Water* [41].
- **Sulfate:** *ASTM D516: Standard Test Method for Sulfate Ion in Water* [42].

4.3.5 Shear Strength Testing

Shear strength is the soil's internal resistance to shear failure and is expressed using the Mohr-Coulomb model, which has two shear strength components:

- Cohesion (c), expressed in units of force/area; and
- Angle of Internal Friction (ϕ), expressed in degrees.

These parameters may also be presented as effective strength (c', ϕ'), depending upon the loading and pore water pressure conditions during the test. Remolded samples shall not be used to satisfy shear strength testing requirements. All samples tested for shear strength shall also be tested for Atterberg limits, moisture content, and wet unit weight.

The following sections present various types of strength testing that may be used on DOTD projects. Depending on the type of shear strength test conducted, the results may be depicted on the soil boring log differently. However, the GDR shall include the following minimum information for all shear strength tests:

- Sample Identification.
- Visual-manual soil classification.
- Index testing results.
- Type of test conducted with test parameters (e.g, confining stress, consolidation stress, failure criteria).
- Stress vs. strain plots as well as tabulated measurements provided as digital data (in a spreadsheet or other digital file approved by the GDS).
- Failure mode for triaxial and UC tests, (e.g., multiple shear (M.S.), slickensides (S/S), vertical shear (V.S.), 60S. (shear angle denoted), yield (YLD.), or slump (SL.) as well as photos or a sketch of the shearing relative to the specimen.

4.3.5.1 Triaxial Testing

Triaxial tests can be used to approximate the in situ stress state at failure. The Geotechnical Engineer-of-Record (GEOR) shall be responsible for selecting the required confining pressure (σ^3) and failure criteria. Refer to the *AASHTO Manual on Subsurface Investigations, 2nd Ed.* [5] for additional explanation of the test methods as well as interpretation practices.

4.3.5.1a Unconsolidated-Undrained (UU)

The unconsolidated undrained (UU) test is the most common method of estimating the undrained shear strength of cohesive soils on DOTD projects. The confining pressure is set to estimate the in situ effective overburden stress up to the anticipated final effective stress, but the sample is not allowed to undergo consolidation, and thus strength gain. The UU test shall not be used to estimate friction angles. The test shall be conducted in accordance with *ASTM D2850: Standard Test Method for Unconsolidated-Undrained Triaxial Compression Test on Cohesive Soils* [19] (*AASHTO T 296: Standard Method of Test for Unconsolidated, Undrained Compressive Strength of Cohesive Soils in Triaxial Compression* [43]).

The compressive stress at failure ($\sigma^1 - \sigma^3$) shall be reported on the boring log in tsf rounded to two decimals. Confining pressure (σ^3) shall be reported on the boring log in psf as an integer. Note that it is critical that the quantity and units are clearly maintained throughout the laboratory testing and reporting process due to the potential for errors converting between compressive strength and undrained shear strength as well as between tsf and ksf.

4.3.5.1b Unconfined Compression

Unconfined compression is a specific case of the UU test where $\sigma^3 = 0$, and shall not be used unless specified by the GDS. Unconfined compression tests specified by the GDS shall be performed in accordance with *ASTM D2166: Standard Test Method for Unconfined Compressive Strength of Cohesive Soil* [44] (*AASHTO T 208: Standard Method of Test for Unconfined Compressive Strength of Cohesive Soil* [45]).

The Unconfined Compressive Strength shall be reported on the soil boring log in tsf to two decimal places. The logs shall be clear that the test is an unconfined test, as opposed to another type of triaxial test.

4.3.5.1c Consolidated-Undrained (CU)

The consolidated-undrained triaxial shear (CU) test can be used to determine undrained shear strength as well as drained strength parameters when pore water pressure measurements are taken (CUw/pp). Typically, three specimens are isotropically consolidated CIU to estimate changes due to vertical effective stress. Shearing shall occur in compression TC or extension TE, depending on the anticipated in situ soil shear strength failure mode. Consolidated-undrained tests shall be conducted in accordance with *ASTM D4767: Standard Test Method for Consolidated Undrained Triaxial Compression Test for Cohesive Soils* [46].

The effective cohesion intercept (c') and effective friction angle (ϕ') shall be reported on the soil boring logs in ksf to two decimal places and in degrees as an integer, respectively.

The following figures shall be developed and presented in the GDR. The development and interpretation of the parameters is discussed in both [5] and [46].

- Principal stress difference (deviator stress) vs. axial strain.
- Change in pore water pressure vs. axial strain.
- p' – q diagram (stress path plot).
- Mohr's Circles showing total and effective shear envelopes.

4.3.5.1d Consolidated-Drained (CD)

The consolidated-drained triaxial shear (CD) test is like the consolidated-undrained test except that drainage is permitted during loading and the rate of loading is very slow to avoid pore water pressure buildup. Due to the duration of the test in cohesive soils, it is typically only performed on cohesionless soils with a fines content of 12 percent or less and a PI of 10 or less. The CD test models the long term (drained) condition in the soil. The results are expressed in effective soil shear strength parameters (c', ϕ'). The consolidated-drained test shall be conducted in accordance with *ASTM D7181: Standard Test Method for Consolidated Drained Triaxial Compression Test for Soils* [47].

The effective cohesion intercept (c') and effective friction angle (ϕ') shall be reported on the soil boring logs in ksf to two decimal places and degrees as an integer, respectively.

The following figures shall be developed and presented in the GDR. The development and interpretation of the parameters is discussed in both [5] and [47].

- Principal stress difference (deviator stress) vs. axial strain.
- Change in volume vs. axial strain.
- p' – q diagram (stress path plot).
- Mohr's Circles showing total and effective shear envelopes.

4.3.5.2 Direct Shear

The direct shear (DS) test is generally suitable for determining the effective shear strength parameters (c', ϕ') for relatively well-drained cohesionless soils. Due to the effects of pore water pressure buildup in cohesive/fine-grained soils, this test shall only be performed on cohesionless soils with a fines content of 20 percent or less and a PI of 10 or less. The test is generally performed on three specimens at different normal stresses, which shall be selected by the GEOR based on the anticipated range of in situ stresses. The DS test shall be performed in accordance with *ASTM D3080: Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions* [48] (*AASHTO T 236: Standard Method of Test for Direct Shear Test of Soils Under Consolidated Drained Conditions* [49]).

The effective cohesion intercept (c') and effective friction angle (ϕ') shall be reported on the soil boring logs in ksf to two decimal places and degrees as an integer, respectively.

The following figures shall be developed and presented in the GDR:

- Relative lateral displacement vs. shear force.
- Relative lateral displacement vs. change in specimen height.
- Normal force vs. shear force.

4.3.5.3 Miniature Vane Shear and Pocket Penetrometer

The miniature vane shear (Torvane) and the pocket penetrometer tests are performed to obtain preliminary undrained shear strength (S_{u-tv} or S_{u-pp}) for cohesive soils. Both of these tests consist of hand-held devices that are pushed into the sample and either a torque resistance (Torvane) or a tip resistance (pocket penetrometer) is measured. These tests can be performed in the lab or in the field to estimate the sample's consistency during visual classification. The Torvane test shall be performed in accordance with *ASTM D4648: Standard Test Method for Laboratory Miniature Vane Shear Test for Saturated Fine-Grained Clayey Soil* [50]. Torvane testing should be limited to saturated, fine-grained soils with an undrained shear strength less than 1.0 tsf.

Pocket penetrometer and Torvane tests shall be reported on the soil boring logs in tsf to 2 decimal places. Pocket penetrometer values shall have a "P" after the test results, whereas Torvane results shall be followed by "T." Both pocket penetrometer and Torvane tests shall be performed on ends of the sample that are representative of the sample's overall consistency and shall not be performed on the curved side of an extruded sample.

4.3.6 Consolidation Testing

When specified by the GEOR or GDS, laboratory oedometer tests shall be used to estimate the one-dimensional consolidation properties of soils in accordance with *ASTM D2435: Standard Test Methods for One-Dimensional Consolidation Properties of Soils Using Incremental Loading* [23] (*AASHTO T 216: Standard Method of Test for One-Dimensional Consolidation Properties of Soils* [51]).

After samples have been visually classified, the GEOR shall be contacted to select samples for testing. The Consultant's lab shall notify the GEOR if selected samples appear to be cohesionless, disturbed, or otherwise unsuitable for consolidation testing. Atterberg Limits, moisture content, grain size analysis with wash 200 sieve, and specific gravity shall be performed on all samples tested using this test method. *ASTM D4186: Standard Test Method for One-Dimensional Consolidation Properties of Saturated Cohesive Soils Using Controlled-Strain Loading* [52] shall only be used by a Consultant demonstrating prior experience with the test method.

Test Method A (24-hour load increments) shall be used unless otherwise specified by the design GEOR or contract documents. Longer increments may be necessary to establish the secondary compression index. When requested, the Consultant shall be prepared to submit interpreted root-time and log-time plots to the GEOR prior to advancing the load increment. Consolidation testing shall include at least one rebound cycle occurring at least one load increment past the preconsolidation pressure. In order to estimate the preconsolidation pressure, correlations based on Liquidity Index or CPT data in GEC No. 5, Chapter 6 [3] may be considered.

Samples tested with oedometer testing shall be denoted on the soil boring log by placing a square around the sample identification.

The following figures shall be developed and presented in the GDR:

- Dial reading vs. square root of time for each load (with T_{90} interpreted using Taylor's method).

- Dial reading vs. elapsed time on a log scale for each load (with T_{50} interpreted using Casagrande's method).
- Void ratio (e) vs. vertical effective stress (σ'_v) on a log scale with tabulated soil property summary.
- Strain (ε) vs. vertical effective stress (σ'_v) on a log scale with tabulated soil property summary.
- Coefficient of consolidation (c_v) vs. vertical effective stress (σ'_v) on a log scale.

4.4 SOIL CLASSIFICATION

Appendix 3.A refers to the Visual-Manual classification method [7] for field classification of extruded samples. Following the laboratory testing program, the soil borings shall be fully classified and grouped by similar strata based on a combination of visual observation and laboratory test results.

For subgrade soil surveys, soil shall be classified according to the AASHTO method [17] and tabulated on a plan sheet in accordance with Chapter 15. For deep soil borings, soil shall be classified as described in Appendix 4.A. The soil classification and test results shall be reported on a boring log following the requirements in this chapter for test result presentation and units and in Chapter 15 for overall contents and layout.

Appendix

4.A DEEP BORING CLASSIFICATION

As discussed in Section 4.4, soil layers in report descriptions and boring logs shall be refined beyond the Visual-Manual classification made during sample extrusion. For all cases except Subgrade Soil Surveys, the Unified Soil Classification System (USCS) [16] shall be used.

4.A.1 Refinement of Estimates

The laboratory test program should be conducted, in part, to refine the classification estimates made during the visual-manual classification.

- **Consistency:** Consistency of clay soils shall be refined using the compressive strength tests from the lab (typically unconsolidated undrained (UU)). Pocket penetrometer, Torvane, and manual estimates may be used to classify samples that were not tested for compressive strength; however, consistency estimates shall be consistent with other test results. Stiff samples that are damaged or that fail along predetermined failure planes shall not be given a soft consistency to match the triaxial test result. In such cases, a note may be necessary in addition to recording the failure mode on the soil boring log. Consideration shall be given to re-running tests whose compressive strength, moisture content, and Atterberg Limits are inconsistent. Clay consistencies shall not be assigned to soils having cohesionless properties, such as sandy silt.
- **Relative Density:** The relative density in cohesionless soils generally will not change from the field observations. It should be noted that while corrected N-values are used in calculations, DOTD reports the observed, uncorrected N-values on the soil boring logs.
- **Plasticity:** Soil plasticity shall be refined using the Atterberg Limit tests. The results of these tests dictate the USCS classification, therefore it is important to compare lab results against field estimates, especially in borderline cases. Note that DOTD requires Atterberg Limit testing on 75% of cohesive samples; therefore, testing should be assigned on representative samples.
- **Grain Size:** Grain size and fines content shall be refined using a sieve analysis. The results of the percent passing the No. 200 sieve test are critical to the USCS classification. Since the total percentages of fine- and coarse-grained soils cannot be perfectly estimated by visual classification, it is important to compare lab results against field estimates, especially in borderline cases. Classification of coarse-grained soils also depends on the sieve analysis. Note that well-graded sands typically do not occur in Louisiana; therefore, additional sieves may need to be added if well-graded classifications occur regularly.
- **Additional Descriptors & Comments:** Additional observation of the samples after testing may reveal additional features, especially when undisturbed samples cannot be fully examined in the field.

4.A.2 Classification of Soils

A geotechnical engineer should finalize the soil classification by comparing field logs/extrusion logs with the laboratory test results. In general, the laboratory results will take precedence over field observations; however, both records should provide similar results. Cases where field observations are not similar to lab results shall be double checked for errors.

After refining the field classifications, reconciling borderline differences, and retesting as necessary, the engineer shall use the USCS to select a Group Symbol and Group Name using Table 1 in ASTM D2487 [16]. When reporting Group Symbols and Group Names in reports and logs, both shall be printed in all caps. Other descriptors shall not be printed in all caps and shall be comma-separated like the following:

- Stiff, tan, SANDY LEAN CLAY, (CL).
- Very dense, gray, SILT, (ML) with Fe nodules.
- Dense, gray, poorly-graded SAND with silt, (SP-SM).

4.A.3 Grouping of Layers

When depicting stratigraphy in reports and on soil boring logs, soil layers shall be grouped to simplify the stratigraphy where possible. Grouping shall occur as follows:

- Only group soils having the same group name.
- Only group soils having consecutive consistencies.
- Do not group more than two soil consistencies.

For example, a dense sand layer and a very dense sand layer could be merged as dense to very dense sand. A very soft clay layer and a soft clay layer could be merged as very soft to soft clay. When several consecutive consistencies exist, such as soft, medium, and stiff clay, the Lab Engineer should use judgment to combine the layers in a way that best simplifies the overall depiction of the subsurface stratigraphy. This may require review of adjacent borings to ensure consistency among borings.

Chapter 15. Geotechnical Reports

15.1 OBJECTIVE & SCOPE

The objective of this chapter is to define the requirements for geotechnical reports and related deliverables that are submitted to or reviewed by the Louisiana Department of Transportation and Development (DOTD) Geotechnical Design Section (GDS).

According to the Federal Highway Administration (FHWA), a geotechnical report is "the tool used to communicate the site conditions and design and construction recommendations to the roadway design, bridge design, and construction personnel." [53] This chapter recognizes several types of geotechnical reports and the distinction is made between the reporting of factual data and the reporting of engineering recommendations. This is due to the variety of ways that DOTD geotechnical work may be handled, and the fact that the engineer responsible for the geotechnical investigation may not be the same as that responsible for the design. Although Consultants may typically provide the factual subsurface data and engineering opinion/analysis in the same report for other clients, these often need to be broken up for DOTD work.

15.1.1 References

This chapter provides minimum requirements for reports and related deliverables. Additional best practices for developing investigation plans, reports, and report Quality Assurance/Quality Control (QA/QC) may be found in:

- American Association of State Highway Officials (AASHTO), *Manual on Subsurface Investigations, 2nd Ed.* (2022) [5]
- FHWA, *Geotechnical Engineering Circular, No. 5* (2016) [3] (GEC No. 5)
- FHWA, *Geotechnical Engineering Circular, No. 14* (2016) [53] (GEC No. 14)

Note that this chapter provides the basic requirements for several types of reports; however, reporting requirements for subject-specific (e.g., piles, drilled shafts, walls) analyses may be discussed in more detail in another chapter.

15.1.2 Report Format

Unless specified otherwise, all deliverables described herein shall be generated and submitted in electronic format as a searchable .pdf file. Electronic reports and similar documents shall have bookmarks denoting the various sections of the report and appendices. Report and appendix body, charts, and figures shall be generated directly from the source applications in order to minimize file size. Documents scanned as raster images shall only be used when no other option exists for their inclusion into the document. All pages shall print to either 8.5" x 11" or 11" x 17" without the need for manual scaling or adjustment.

15.2 GEOTECHNICAL QA/QC

Geotechnical Engineering Circular No. 14 [53] broadly defines QC as including the "checking of all subsurface information, analyses, specifications, details, and special requirements for accuracy and their ability to meet the requirements provided by the owner or by the standards of practice," whereas QA is described as the "process by which QC is verified for those documents." [53]

15.2.1 Geotechnical QA/QC Documents

Although all consultants working under a retainer contract with the GDS are required to submit a formal QA/QC plan, all submitted geotechnical design and reporting documents shall be subject to a QA/QC process regardless of contracting method. The QC reviewer shall co-sign the report or memo along with the Geotechnical Engineer-of-Record (GEOR).

15.2.2 Geotechnical QA/QC Responsibilities

Note that the person responsible for the QC review (peer review) shall not be the GEOR, but shall "understand the technical details of the calculations, exploration logs, laboratory test results, etc., and confirm the accuracy of these undertakings through a system of checking, updating, and confirming noted deficiencies have been resolved." [53]

Furthermore, the QA reviewer shall not be the GEOR or the QC reviewer. Therefore, the reporting process shall involve at least three professionals qualified to produce and review the subject work.

All data reports shall be signed and sealed by a Professional Civil Engineer registered in the State of Louisiana with specific knowledge of the scope of lab testing for the subject project. All data reports shall be co-signed by the QC reviewer.

All reports containing geotechnical design or construction recommendations shall be signed and sealed by the GEOR and co-signed by the QC reviewer. The GEOR shall be a Professional Civil Engineer registered in the State of Louisiana with adequate local geotechnical engineering experience to provide geotechnical design and construction support for the subject project.

15.3 SUBSURFACE INVESTIGATION PLAN

Per Section 3.3.1, a qualified geotechnical engineer (often the GEOR) shall prepare a Subsurface Investigation Plan for review and approval by the GDS prior to the commencement of any field investigations. This plan shall include, at a minimum:

- A table of boring names, investigation types (borehole, Cone Penetrometer Test (CPT), field vane, etc.), proposed Latitude/Longitude, minimum depths of exploration, and other special per-boring instructions.
- Sampling intervals and methods.
- Other special instructions for the drill crew (site access instructions, sampling or water table reading requirements, any nonstandard procedures, etc.).
- Description of any geophysical testing and layouts of associated test lines/limits.

- A site plan depicting the boring locations and key features;
- Vicinity map(s) detailed enough to locate the subject site relative to nearby landmarks or intersections.
- List of known permit needs/requests (traffic, levee, utilities, coastal use permit).
- Required lane closures and modifications to bridge decks.

In some cases, the scope of geotechnical fieldwork (boring layout, sampling requirements, etc.) will be provided to a Consultant by the GDS. In these cases, the Consultant shall still provide a Subsurface Investigation Plan.

15.4 GEOTECHNICAL DESIGN CRITERIA DOCUMENT

At the beginning of any project requiring geotechnical design, the GEOR shall submit a Geotechnical Design Criteria table stating the following:

- All anticipated geotechnical design elements.
- Proposed design methodologies (including references).
- Proposed design criteria (resistance factors, limiting deflections/settlements, etc.).

The intent of the design criteria document is to ensure that Prime Consultants, Project Managers, and representatives of the various DOTD Sections have a consistent understanding of the scope of work prior to Final Design.

15.5 GEOTECHNICAL DATA REPORT

The Consultant shall document all subsurface investigations with a Geotechnical Data Report (GDR). The GDR will be included in the bid documents and shall therefore contain only factual information and no opinions or engineering recommendations. The GDR shall include the following items, at a minimum:

1) Cover letter with executive summary describing the overall scope of the subsurface investigation;
2) Table of contents;
3) Report Body containing the following sections, at a minimum:
    a. Project Description;
    b. Site Description (location, existing structures, drainage features, standing water, vegetation cover, evidence of previously existing features or structures, etc.);
    c. Geologic setting (general description based on geological maps);
4) Scope and procedures for field investigation, including:
    a. Table of all borings/sounding names, dates, actual depths, surveyed Latitude, surveyed Longitude, and surveyed ground surface elevation;

b. Observed groundwater conditions;

c. Description of drilling equipment used, including Standard Penetration Test (SPT) hammer calibration date and efficiency;

d. Description of drilling and sampling methods and standards used; and

e. Description of backfilling operations.

5) Scope and procedures for geophysical investigations (as applicable);

6) Scope and procedures for laboratory testing, including:

a. A summary of all test methods/standards used.

7) Appendix containing the following items, at a minimum:

a. Boring plan showing actual borehole, CPT sounding, and other test locations;

b. Geophysical testing plan (showing test lines, areas, or locations as applicable);

c. Subsurface Investigation Plan as accepted by the GDS;

d. General bridge plan and profile sheet used to establish the boring locations;

e. Field/extrusion logs;

f. Finalized soil boring and in situ test logs;

g. SPT Hammer Calibration certificate/report;

h. Plots of grain size distribution curves and consolidation tests, as applicable; and

i. All supporting laboratory test data sheets, including stress vs. strain plots for triaxial testing, consolidation test deformation vs. time plots, Atterberg Limit worksheets, etc.

15.5.1 Field/Extrusion Logs

The Consultant's field crew and/or laboratory shall document the drilling, sampling, and extrusion process on a Field Log. If samples are extruded in the lab, the extrusion process shall be documented on a separate Extrusion Log. Field/Extrusion logs shall contain the following information, at a minimum:

1) Project Information:

a. Boring ID, Project Number, and Project Name.

2) Location Information:

a. Estimated Latitude [decimal degrees to 5-6 decimals], Longitude [decimal degrees to 5-6 decimals], and estimated Ground Surface Elevation (GSE) [ft]; or

b. A sketch with dimensions that can be used to confirm the boring location after the survey is completed.

3) Depth Information:

    a. All results shall be referenced to depth Below Ground Surface (BGS) [ft].

4) Soil Classification:

    a. Soil classification using the Visual-Manual Procedure [7].

5) Sample Information:

    a. Graphical representation of sample type; and

    b. Sample identification.

6) Groundwater Information:

    a. Graphical and text representation of groundwater table observations.

7) Test Results:

    a. Pocket penetrometer value [tsf] (as applicable);

    b. Torvane value [tsf] (as applicable);

    c. SPT Driving Resistance results for each 6-inch increment [blows/ft], reported N-Value [blows/ft], and SPT Termination Code; and

    d. Dynamic Cone Penetrometer (DCP) results, for subgrade soil survey borings.

8) Fieldwork Information:

    a. Drilling Contractor, Rig Operator/Crew Chief, Logger, Equipment/Rig Description, SPT Hammer Type, Boring Advancement Method, Backfill Method, Date(s) of Fieldwork; and

    b. Other relevant notes describing observations made during the fieldwork.

Field/Extrusion logs shall be produced on 8.5" x 11" sheets (see Appendix 15 for an example). They may also be created digitally via a tablet or portable device running specialized software intended for logging borings. In this case, the logging software shall be configured to print the logs for inclusion in the GDR appendix.

15.5.2 Soil Boring Logs

The Geotechnical Consultant may present soil boring logs in their own 8.5" x 11" format or DOTD's 11" x 17" format. All soil boring logs shall display the following results in the specified units, at a minimum:

1) Project Information:

    a. Boring ID, Project Number, Project Name, Bridge Recall Number, and Parish.

2) Location Information:

a. Surveyed Latitude [decimal degrees to 5-6 decimals], Longitude [decimal degrees to 5-6 decimals], and Ground Surface Elevation [ft].

3) Depth Information:

a. All results shall be referenced to both depth BGS [ft] and GSE [ft] (two separate scales shown).

4) Soil Classification:

a. Soil classification using the Unified Soil Classification System (USCS) [16] Group Name and Group Symbol; and

b. Graphical representation of the soil stratigraphy.

5) Sample Information:

a. Graphical representation of sample type (e.g., Shelby tube, split-spoon, no recovery);

b. Graphical representation of samples selected for consolidation testing (square around sample ID); and

c. Sample identification.

6) Groundwater Information:

a. Graphical and text representation of groundwater table depth and observation time.

7) Test Results:

a. Pocket penetrometer value [tsf];

b. Torvane value [tsf];

c. Wet Density [pcf];

d. Moisture Content [%] and Atterberg Limits [%];

e. Percent Fines/Passing the No. 200 Sieve [%];

f. Compressive Strength [tsf], Triaxial Cell Pressure [psi], and Failure Mode; and

g. SPT Driving Resistance results for each 6-inch increment [blows/ft] and reported N-Value [blows/ft].

8) Fieldwork Information:

a. Drilling Contractor, Rig Operator/Crew Chief, Logger, Equipment/Rig Description, SPT Hammer Type, Hammer Efficiency [%], Backfill Method, Date(s) of Fieldwork.

b. Other relevant notes describing observations made during the fieldwork or laboratory testing.

In addition to the USCS classification, the soil descriptions shall include soil consistency/strength, color, and other details or inclusions such as seams, nodules, organics, etc. Combine soil strata of the same USCS Group Name, but limit grouping to two adjacent soil consistency/density categories (e.g., “Stiff to Very Stiff, LEAN CLAY, (CL)” or “Loose to Medium Dense, SILTY SAND, (SM)”, but not “Soft to Stiff, FAT CLAY, (CH)”). Refer to Appendices 3.A and 4.A for preliminary Visual-Manual and ”final” soil classification requirements, respectively.

Test results that cannot be shown on the soil boring logs, such as grain size curves, consolidation curves, and stress vs. strain plots shall be included in the GDR appendix.

15.5.3 Cone Penetrometer Test Logs

The Consultant may present CPT logs in their own 8.5” x 11” format. All CPT logs shall display the following results in the specified units, at a minimum:

1) Project Information:
   a. Sounding ID, Project Number, Project Name, Bridge Recall Number, and Parish.
2) Location Information:
   a. Surveyed Latitude [decimal degrees to 5-6 decimals], Longitude [decimal degrees to 5-6 decimals], and GSE [ft].
3) Depth Information:
   a. All results shall be referenced to both depth BGS [ft] and GSE [ft]; and
   b. Logs shall indicate if the CPT sounding met refusal.
4) CPT Measurements:
   a. Tip resistance, q_c [tsf], side friction, f_s [tsf], pore water pressure, u2 [tsf], friction ratio, R_f [%].
5) Soil Behavior Estimation using either:
   a. The Zhang and Tumay “Statistical to Fuzzy Approach” [54], or
   b. The Robertson and Campanella Normalized R_f Method [55];
6) Fieldwork Information:
   a. Drilling Contractor, Rig Operator/Crew Chief, Checker, Equipment/Rig Description, Net Area Ratio of Cone, Backfill Method, Date(s) of Fieldwork.
   b. Other relevant notes describing observations made during the fieldwork.

Note that CPT logs are to be furnished as part of a GDR and should therefore not contain engineering recommendations or interpretations. Therefore, correlated values such as undrained shear strength (S_u), overconsolidation ratio (OCR), angle of internal friction (ϕ), etc. shall not be shown on the CPT logs. Interpreted CPT profiles containing these correlated estimates may be used for design, when appropriate, and shall be included in the Geotechnical Interpretation Report (GIR) instead.

15.5.4 Shallow Subgrade Soil Survey Logs

Subgrade layers shall be identified every foot or stratum break at the discretion of the Consultant using the American Association of State Highway Officials (AASHTO) classification system (ASTM D3282 [56], AASHTO M 145 [17]). Classification and laboratory test results shall be presented in a tabular format.

15.5.5 Digital Geotechnical Data

Regardless of contracting and delivery method, all final geotechnical investigation data shall be furnished to the GDS in a digital format after review and acceptance of the GDR.

All geotechnical data shall be furnished in a gINT file cloned from DOTD's standard gINT schema. Other formats or gINT files containing a modified schema/structure will not be accepted. A copy of the standard template will be provided upon request. Raw data files from all CPT soundings shall also be furnished.

Consultants having the capability of furnishing data in Data Interchange for Geotechnical and Geoenvironmental Specialists (DIGGS) may make arrangements to furnish data in that format instead.

15.5.5.1 Avoiding Common Data Errors

Data editing strategies used to circumvent software or template problems shall not be included in the final data submittal. It may be necessary for some Consultants to keep multiple gINT/data files for plotting and for data transmittal. Some examples of preferred practices (based on current gINT file formats) are:

- Soil boring names shall contain a leading zero (for example, B-01 instead of B-1).
- Zero-depth soil lithology layers shall not be used (normally used to force the gINT boring log legend to show a specific material type).
- Lithology layers without a bottom shall not be used to add notes to soil stratigraphy layers. Those remarks or descriptions shall instead be entered into the appropriate table.
- Zero shall not be used to represent a non-tested SPT increment, since zero represents Weight of Hammer (WOH). Additionally, extra care shall be taken to ensure that non-standard terminations are not entered. For example, terminating a test with 50 blows over precisely the first 6 inches is not a valid termination. In such a situation, the test should have been carried to the next increment, or stopped prior to reaching 6 inches of penetration (such as 50 blows/5.9").
- Samples split into two specimens shall be further named with "A" and "B." Sample lengths shall be adjusted based on specimen length, and the proper specimen shall be assigned to each test in the various laboratory test tables.

15.6 GEOTECHNICAL INTERPRETATION REPORT

The GEOR shall document all engineering analyses made for the development of plans and contract documents with a Geotechnical Interpretation Report (GIR). The GIR shall detail the GEOR's project understanding, design assumptions, methodologies, scenarios and alternatives considered, and final recommendations.

The intent of the GIR is not to provide direction to the Contractor, but to provide DOTD reviewers supporting information for plan development and review. Because the GIR may contain alternative design scenarios or discussion of risk, it will not be made available to Contractors as a bid document. Therefore, the Consultant should recognize that notes and disclaimers placed in a GIR are not effective unless they are also incorporated into the plans and specifications.

Multiple GIRs may be issued for a given project to document various phases of design. Alternative delivery methods such as design-build may require different types of GIRs with specific requirements for given milestones. The final GIR shall include the following items, at a minimum:

15.6.1 GIR: Cover Letter

The cover letter shall include an executive summary describing the structure type(s), loads, and foundation dimensions/lengths. All plan-related notes and tables shall be included in the cover letter. The objective of the cover letter is to summarize all relevant information that is recommended for inclusion in the plans. The Project Manager (PM) or plan developer should be able to incorporate all of the Consultant's recommendations into the plans without reading the body of the GIR.

One exception may be large tables or plan drawings, such as deep foundation Data Tables, which may be included in the GIR Appendix and referenced in the Cover Letter.

15.6.2 GIR: Table of Contents

The Table of Contents shall show at least the top two levels of numbered headings in the report. A separate Table of Figures or Tables may also be included. The .pdf file generated from the report shall include bookmarks that hyperlink to at least the major headings.

15.6.3 GIR: Report Body

The report body shall include, at a minimum, the following subsections:

15.6.3.1 Project Description

The Project Description shall contain a brief discussion of the overall project as well as the specific geotechnical design elements. The person requesting or authorizing the work shall also be referenced along with the date of authorization. A brief discussion of the subsurface investigation and reference to the GDR shall also be included.

15.6.3.2 Subsurface Conditions

The Subsurface Conditions section shall include a general description of the overall site geology based on statewide or local geological maps. The section shall also include generalized subsurface profiles based on the Geotechnical Engineer-of-Record (GEOR)'s interpretation of the subsurface investigation. A summary of groundwater conditions observed during the geotechnical investigation shall also be provided.

15.6.3.3 Design Assumptions & Recommendations

The body of the Geotechnical Interpretation Report (GIR) shall contain separate sections for each type of geotechnical element that was analyzed (i.e., driven piles, drilled shafts, and Mechanically Stabilized Earth (MSE) walls shall all be described in separate sections). Additional reporting requirements for specific technical items may be provided in the GDM chapter for that subject. Each design section of the GIR shall include:

- Summary of design codes and specifications followed.
- Description of analysis method(s) used as well as any relevant assumptions.
- Discussion of the evaluation of various Load and Resistance Factor Design (LRFD) resistance factors, field verification methods, and associated costs.
- Discussion of possible alternatives and risks (if within the scope of the project).
- Discussion of necessary mitigation or Ground Modification (GM) measures.
- Recommended foundation dimensions, tip elevations, lengths, etc.
- Recommended instrumentation and/or monitoring.
- Discussion of constructability, sequencing, preliminary wave equation analysis for driven piles, identification of potential difficult installation conditions, etc.

15.6.4 GIR: Appendix

The Appendix shall contain the following subsections, at a minimum:

- Any documents revised since the GDR, such as boring plans or soil boring logs.
- Plots of relevant soil Design Parameters versus elevation, including the interpreted design profile for each Design Area.
- Nominal deep foundation resistance versus elevation plots for each Design Area and pile/shaft size and type.
- Plan sheets such as driven pile and drilled shaft data tables; wick drain layouts, surcharge layouts, and MSE wall plans.
- Input and output from settlement, slope stability, and ERS analysis software.

15.7 LOAD TEST REPORT/ORDER LENGTH MEMORANDUM

Projects with Indicator Piles, Test Piles, and Test Shafts require additional construction-phase engineering in order to develop foundation Order Lengths. The results of these testing activities shall be reported in a Load Test Report including the following, at a minimum:

15.7.1 Load Test Report: Cover Letter

As with the GIR, the cover letter shall include an executive summary and any information needed to update the plans. Differences between the Plan Lengths and Order Lengths shall be summarized (a full data table shall be provided in the appendix). In general, no additional changes to plan sheets or quantities should be needed at this time, other than updates to the Order Lengths.

15.7.2 Load Test Report: Table of Contents

Follow 15.6.2.

15.7.3 Load Test Report: Body

The report body shall include, at a minimum, the following subsections:

15.7.3.1 Project Description

The Project Description shall contain a brief discussion of the project scope and the load testing program for the subject test foundation or design element. The description shall specify which foundations/bents are covered under the scope of the load testing. Any specific decisions or considerations relevant to the load testing program shall be summarized.

The Project Description section shall include a subsection describing the generalized soil conditions at the subject site.

15.7.3.2 Fieldwork

This section shall document the test foundation information, such as:

- Dimensions and length.
- Tip elevation and casing/preboring excavation diameter and elevation (if applicable).
- Foundation Contractor.
- Latitude/Longitude and ground surface elevation at the test foundation location.
- Installation methods and equipment.
- Any relevant observations made during the installation of the test foundations.

Following the test foundation information, the section shall include a subsection for each field testing event (e.g., initial drive, 24-hour restrike, static load test, 14-day restrike), documenting:

- Dates and times.
- Testing Contractor or personnel present.
- Test methods and equipment.
- Locations of instrumentation (internal and attached).
- Relevant monitoring data such as stresses, driving resistances, permanent set, etc.
- Any other relevant observations made during the foundation testing that could influence the test results.

15.7.3.3 Test Results

This section shall discuss the interpreted test results, which may include the following, depending on the type of foundation and testing employed:

15.7.3.3a Case Pile Wave Analysis program (CAPWAP)

Case Pile Wave Analysis Program (CAPWAP) results shall be tabulated as follows:

- Date and time of monitoring event, elapsed time since initial installation.
- Ultimate CAPWAP resistance (R_{ult}) [tons] and CAPWAP end bearing (R_{tip}) [tons].
- CAPWAP Match Quality (MQ) and Case Damping ($J(R_x)$).

Dynamic methods having a damping constant that is determined using some method other than CAPWAP shall include a description of the separation of total resistance into static and dynamic components.

15.7.3.3b Static Load Testing (Top Down)

The interpreted failure load (or maximum test load, if failure did not occur) shall be presented in this section. The load vs. deflection plot may be shown in this section or in the Appendix. If the foundation was instrumented with internal strain transducers, a table of unit side friction and end bearing vs. depth shall be included.

15.7.3.3c Static Load Testing (Bi-Directional)

The interpreted failure load (or maximum test load, if failure did not occur) shall be presented in this section. The equivalent top-down load vs. deflection plot may be shown in this section or in the Appendix. If the foundation was instrumented with internal strain transducers, a table of unit side friction and end bearing vs. depth shall be included.

15.7.3.4 Recommendations

The Order Length recommendations based on the results of the load testing program shall be discussed. Major changes to the design models shall be sufficiently justified. If the testing does not yield major changes to the design models, discussion may be minimal.

Note that the Supplemental Standard Specifications [57] and the Standard Specifications [4] currently instruct the Contractor as follows:

- "Provide pile driving equipment including crane, hammer, leads, and template capable of handling and driving piles 25 percent longer than the plan pile length"
- "Drilling equipment shall have adequate capacity, including power, torque, and down thrust, to excavate the maximum plan diameter to a depth of 20-foot or 20 percent beyond the maximum plan shaft depth, whichever is greater"

Therefore the GEOR should strive to maintain order lengths for piles and drilled shafts that are less than 25% and 20% of the Plan Lengths, respectively.

15.7.3.4a Driving Criteria

For pile projects with dynamic monitoring, a refined Wave Analysis Program (WEAP) analysis may be used to generate an Inspector's Chart. This chart can be furnished to the pile driving inspector to aid in pile acceptance for piles that do not have dynamic monitoring. This chart helps the inspector estimate whether a pile has enough resistance at the End-of-Initial-Drive (EOID) to accept the pile. The GEOR should exercise care when generating an Inspector's Chart on a project that is expected to require significant pile set-up to achieve the Required Nominal Resistance. However, this chart should be furnished when driving resistance versus stroke at EOID is the most practical way to evaluate foundation acceptance.

Based on the field observations and/or dynamic monitoring measurements, additional criteria may be provided, such as the maximum number of blows to allow on a hammer cushion as well as thresholds to increase or decrease a hammer's energy/fuel setting.

Note that driving criteria may also be provided as a separate memo.

15.7.4 Load Test Report: Appendix

The Load Test Report Appendix shall contain the following subsections, at a minimum:

An updated Pile/Shaft Data Table with the relevant Order Lengths completed. It is assumed that the Contractor is responsible for updating the required foundation tip elevations during construction based on the new order lengths, as there is not a column on the standard Data Table for the GEOR to update the tip elevation;

The Appendix shall also contain the following subsections, where applicable:

- Signed and sealed Interpretation reports from specialty testing contractors (these may already contain the following items).
- Logs from installation of the test foundation (pile driving logs, shaft excavation logs, concrete logs, etc.).
- Handwritten/backup logs from static load testing.

- PDIPLOT output from dynamic monitoring events, with the following quantities plotted vs. tip elevation: CSX, TSX, ETR, STK, BLC, and RMX (or appropriate capacity estimate). Quantities may be plotted vs. blow number for restrikes.
- Output files from CAPWAP.
- Applied load vs. deflection curves, including depiction of failure criterion and interpreted failure load.
- Nominal pile resistance vs. time (pile set-up) curves, when applicable to the foundation design and acceptance criteria.
- Inspector's Charts.
- Calibration curves and reports for jacks, load cells, strain transducers, accelerometers, etc.

15.8 DYNAMIC MONITORING TESTING REPORT

Projects with Monitor Piles require construction-phase testing of permanent piles with the Pile Driving Analyzer (PDA). Monitor Piles may be tested in order to check pile stresses, assess pile resistance, and monitor hammer performance, among other reasons. The testing results for each Monitor Pile shall be submitted in a Dynamic Monitoring Report to the GDS within two weeks from completion of collecting data for that particular pile. Each PDA Testing report shall include the following, at a minimum:

15.8.1 Dynamic Monitoring Report: Cover Letter

The cover letter shall include a brief summary identifying the scope of testing covered in the report.

15.8.2 Dynamic Monitoring Report: Table of Contents

Follow 15.6.2.

15.8.3 Dynamic Monitoring Report: Report Body

The report body shall include, at a minimum, the following subsections:

15.8.3.1 Project Description

The project description shall contain a brief overview of the project and a description of Monitor Piles covered in the report.

15.8.3.2 Fieldwork

This section shall document the test foundation information, such as:

- Foundation Contractor;
- Pile identification, type, dimensions, and length;
- Tip elevation and preboring excavation diameter and elevation (if applicable);

- Template elevation and any other reference elevation;
- Latitude/Longitude and ground surface elevation at the test foundation location;
- Installation methods and equipment; and
- Any relevant observations made during the installation of the test foundations.

Following the test foundation information, the section shall include a subsection for each field testing event (e.g., initial drive, 24-hour restrike, 14-day restrike), documenting:

- Dates and times;
- Testing Contractor or personnel present;
- Equipment used by the Contractor including hammer type with fuel settings;
- Test methods and equipment used for pile testing;
- Locations of instrumentation;
- Relevant monitoring data such as stresses, driving resistances, permanent set, etc.;
- Observations such as work stoppages, equipment problems, pile cracking, pile damage, etc. with associated depth of penetration; and
- Any other relevant observations made during the foundation testing that could influence the test results.

15.8.3.3 Test Results

This section shall present the interpreted test results, including:

- Date and time of monitoring event, elapsed time since initial installation;
- Ultimate CAPWAP resistance (R_{ult}) [tons] and CAPWAP end bearing (R_{tip}) [tons];
- CAPWAP MQ and Case Damping ($J(R_x)$);

Dynamic methods having a damping constant that is determined using some method other than CAPWAP shall include a description of the separation of total resistance into static and dynamic components.

15.8.3.4 Conclusions and Recommendations

Provide a summary comparing the CAPWAP results to the required resistance from the pile data table. If necessary, provide a setup curve. Construction of pile setup curves should follow the Skov-Denver method and should consider the recommendations made by Bullock in [58]. Finally, provide any general comments and/or recommendations based on field observations and results.

15.8.4 Dynamic Monitoring Report Appendix

The Dynamic Monitoring Report appendix should contain the following items, at a minimum:

- The Pile Driving Equipment Data Form.
- Field Log Sheet with (date, personnel, pile information, hammer information, etc.).
- Pile Driving Record which can be obtained from the Contractor and/or Inspector and must be completely filled out with blow counts and stroke heights accurate to within 0.1'.
- PDIPLOT output from dynamic monitoring events, with the following quantities plotted vs. tip elevation: CSX, TSX, ETR, STK, BLC, and RMX (or appropriate capacity estimate). Quantities may be plotted vs. blow number for restrikes.
- CAPWAP Analysis Results.

Glossary

AASHTO American Association of State Highway Officials 1, 11, 13, 27–29, 31, 36, 39, 46

ASD Allowable Stress Design 7

ASTM American Society for Testing and Materials 11, 27, 28, 30, 46

BGS Below Ground Surface 15, 43–45

CAPWAP Case Pile Wave Analysis Program 50, 52–54

CD consolidated-drained triaxial shear 34

CIU isotropically consolidated undrained 33

COV Coefficient of Variation 8

CPT Cone Penetrometer Test 12, 13, 15, 16, 18, 40, 42, 45, 46

CPTu Piezocone 18

CU consolidated-undrained triaxial shear 33

DCP Dynamic Cone Penetrometer 43

DIGGS Data Interchange for Geotechnical and Geoenvironmental Specialists 46

DOTD Louisiana Department of Transportation and Development 1–7, 9–13, 16, 17, 19–21, 27, 30, 32, 33, 37, 39, 41, 46, 47

DS direct shear 34

EOID End-of-Initial-Drive 51

ERS Earth Retaining Structures 48

FHWA Federal Highway Administration 1, 7, 11, 27, 39

FVT Field Vane Test 18

GDM Geotechnical Design Manual 1, 2, 7, 9, 11, 13, 15, 17, 18, 27, 48

GDR Geotechnical Data Report 3–6, 9, 16, 21, 27, 29, 32–35, 41, 43, 45, 46, 48

GDS Geotechnical Design Section 1–7, 9–13, 15–18, 20, 21, 27, 28, 32, 33, 35, 39–42, 46, 52

GEOR Geotechnical Engineer-of-Record 3, 4, 6–10, 12, 13, 15, 32, 34, 35, 40, 41, 47, 48, 51

GIR Geotechnical Interpretation Report 3–6, 9, 46–49

GM Ground Modification 13, 48

GSE Ground Surface Elevation 42, 44, 45

LGS Louisiana Geologic Survey 12

LL Liquid Limit 30

LPA Local Public Agency 7

LRFD Load and Resistance Factor Design 7, 8, 48

LSSRB Louisiana Standard Specifications for Roads and Bridges 9

LTRC Louisiana Transportation Research Center 1, 2

MQ Match Quality 50, 53

MSE Mechanically Stabilized Earth 48

NHI National Highway Institute 1

NTP Notice to Proceed 5

PDA Pile Driving Analyzer 52

PI Plasticity Index 30

PL Plastic Limit 30

PM Project Manager 6, 12, 47

QA Quality Assurance 40

QA/QC Quality Assurance/Quality Control 39, 40

QC Quality Control 40

SL Shrinkage Limit 30

SPT Standard Penetration Test 18–20, 23, 42–44, 46

TC triaxial compression 33

TE triaxial extension 33

TO Task Order 5

USCS Unified Soil Classification System 28, 37, 38, 44, 45

USGS United States Geological Survey 12

UU unconsolidated undrained 33, 37

WEAP Wave Analysis Program 51

WOH Weight of Hammer 18, 19, 46

References

[1] LADOTD, "Project delivery manual," Louisiana Department of Transportaton and Development, Baton Rouge, Tech. Rep., 2013. [Online]. Available: https://dotd.la.gov/media/0kdhjbmm/project-delivery-manual.pdf.

[2] AASHTO, *LRFD bridge design specifications, 10th edition*, ed. by A. A. of State Highway and T. Officials, version Tenth Edition, Washington, D.C., 2024.

[3] FHWA, "Fhwa-nhi-16-072: Geotechnical engineering circular no. 5 (geotechnical site characterization)," Federal Highway Administration, Washington, D.C., Tech. Rep., 2016. [Online]. Available: https://www.fhwa.dot.gov/engineering/geotech/pubs/nhi16072.pdf.

[4] LADOTD, *Louisiana standard specifications for roads and bridges*, ed. by L. D. of Transportation and Development, Baton Rouge, LA, 2016. [Online]. Available: https://dotd.la.gov/media/yznhen52/2016-standard-specifications-complete-manual.pdf.

[5] AASHTO, *Manual on subsurface investigations, 2nd edition*, ed. by A. A. of State Highway and T. Officials, version Second Edition, Washington, D.C., 2022.

[6] LDEQ, "Construction of geotechnical boreholes and groundwater monitoring systems," Louisiana Department of Transportation & Louisiana Department of Environmental Quality, Baton Rouge, Tech. Rep., 2000. [Online]. Available: http://www.dnr.louisiana.gov/assets/OC/env_div/gw_res/200010_GREENBOOK.pdf.

[7] ASTM, "Astm d2488: Standard practices for description and identification of soils (visual-manual procedure)," American Society for Testing and Materials, West Conshohocken, PA, Tech. Rep., 2009.

[8] ASTM, "Astm d1452: Standard practice for soil exploration and sampling by auger borings," American Society for Testing and Materials, West Conshohocken, PA, Tech. Rep., 2016.

[9] ASTM, "Astm d5783: Standard guide for use of direct rotary drilling with water-based drilling fluid for geoenvironmental exploration and the installation of subsurface water-quality monitoring devices," American Society for Testing and Materials, West Conshohocken, PA, Tech. Rep., 2018.

[10] AASHTO, "Aashto t 207: Standard method of test for thin-walled tube sampling of soils," American Association of State Highway and Transportation Officials, Washington, DC, Tech. Rep., 2016.

[11] ASTM, "Astm d1586: Standard test method for standard penetration test (spt) and split-barrel sampling of soils," American Society for Testing and Materials, West Conshohocken, PA, Tech. Rep., 2008.

[12] AASHTO, "Aashto t 206: Standard method of test for penetration test and split-barrel sampling of soils," American Association of State Highway and Transportation Officials, Washington, D.C., Tech. Rep., 2019.

[13] ASTM, "Astm d4633: Standard test method for energy measurement for dynamic penetrometers," American Society for Testing and Materials, West Conshohocken, PA, Tech. Rep., 2016.

[14] ASTM, "Astm d1587: Standard practice for thin-walled tube sampling of soils for geotechnical purposes," American Society for Testing and Materials, West Conshohocken, PA, Tech. Rep., 2008.

[15] ASTM, "Astm d4220: Standard practices for preserving and transporting soil samples," American Society for Testing and Materials, West Conshohocken, PA, Tech. Rep., 2007.

[16] ASTM, "Astm d2487: Standard practice for classification of soils for engineering purposes (unified soil classification system)," American Society for Testing and Materials, West Conshohocken, PA, Tech. Rep., 2011.

[17] AASHTO, "Aashto m 145 - standard specification for classification of soils and soil–aggregate mixtures for highway construction purposes," American Association of State Highway and Transportation Officials, Washington, D.C., Tech. Rep., 2017.

[18] ASTM, "Astm d2216: Standard test methods for laboratory determination of water (moisture) content of soil and rock by mass," American Society for Testing and Materials, West Conshohocken, PA, Tech. Rep., 2019.

[19] ASTM, "Astm d2850: Standard test method for unconsolidated-undrained triaxial compression test on cohesive soils," American Society for Testing and Materials, West Conshohocken, PA, Tech. Rep., 2015.

[20] ASTM, "Astm d4318: Standard test methods for liquid limit, plastic limit, and plasticity index of soils," American Society for Testing and Materials, West Conshohocken, PA, Tech. Rep., 2017.

[21] ASTM, "Astm d1140: Standard test methods for determining the amount of material finer than 75-µm (no. 200) sieve in soils by washing," American Society for Testing and Materials, West Conshohocken, PA, Tech. Rep., 2017.

[22] ASTM, "Astm d6913: Standard test methods for particle-size distribution (gradation) of soils using sieve analysis," American Society for Testing and Materials, West Conshohocken, PA, Tech. Rep., 2017.

[23] ASTM, "Astm d2435: Standard test methods for one-dimensional consolidation properties of soils using incremental loading," American Society for Testing and Materials, West Conshohocken, PA, Tech. Rep., 2011.

[24] ASTM, "Astm d7928: Standard test method for particle-size distribution (gradation) of fine-grained soils using the sedimentation (hydrometer) analysis," American Society for Testing and Materials, West Conshohocken, PA, Tech. Rep., 2017.

[25] ASTM, "Astm d2974: Standard test methods for determining the water (moisture) content, ash content, and organic material of peat and other organic soils," American Society for Testing and Materials, West Conshohocken, PA, Tech. Rep., 2020.

[26] ASTM, "Astm g51: Standard test method for measuring ph of soil for use in corrosion testing," American Society for Testing and Materials, West Conshohocken, PA, Tech. Rep., 2018.

[27] AASHTO, "Aashto t 288 – standard method of test for determining minimum laboratory soil resistivity.," American Association of State Highway and Transportation Officials, Washington, D.C., Tech. Rep., 2016.

[28] AASHTO, "Aashto t 88: Standard method of test for particle size analysis of soils," American Association of State Highway and Transportation Officials, Washington, D.C., Tech. Rep., 2019.

[29] AASHTO, "Aashto t 265: Standard method of test for laboratory determination of moisture content of soils," American Association of State Highway and Transportation Officials, Washington, D.C., Tech. Rep., 2019.

[30] AASHTO, "Aashto t 267 - standard method of test for determination of organic content in soils by loss on ignition," American Association of State Highway and Transportation Officials, Washington, D.C., Tech. Rep., 2018.

[31] ASTM, "D7263: Standard test methods for laboratory determination of density and unit weight of soil specimens," American Society for Testing and Materials, West Conshohocken, PA, Tech. Rep., 2021.

[32] ASTM, "Astm d854: Standard test methods for specific gravity of soil solids by water pycnometer," American Society for Testing and Materials, West Conshohocken, PA, Tech. Rep., 2014.

[33] AASHTO, "Aashto t 100 - standard method of test for specific gravity of soils," American Association of State Highway and Transportation Officials, Washington, D.C., Tech. Rep., 2019.

[34] ASTM, "Astm c127: Standard test method for relative density (specific gravity) and absorption of coarse aggregate," American Society for Testing and Materials, West Conshohocken, PA, Tech. Rep., 2015.

[35] AASHTO, "Aashto t 289 - standard method of test for determining ph of soil for use in corrosion testing," American Association of State Highway and Transportation Officials, Washington, D.C., Tech. Rep., 2018.

[36] AASHTO, "Aashto t 291 – standard method of test for determining water-soluble chloride ion content in soil290 – standard method of test for determining water-soluble sulfate ion content in soil," American Association of State Highway and Transportation Officials, Washington, D.C., Tech. Rep., 2018.

[37] ASTM, "Astm c1580: Standard test method for water-soluble sulfate in soil," American Society for Testing and Materials, West Conshohocken, PA, Tech. Rep., 2015.

[38] AASHTO, "Aashto t 290 – standard method of test for determining water-soluble sulfate ion content in soil," American Association of State Highway and Transportation Officials, Washington, D.C., Tech. Rep., 2016.

[39] ASTM, "Astm d1293: Standard test methods for ph of water," American Society for Testing and Materials, West Conshohocken, PA, Tech. Rep., 2018.

[40] ASTM, "Astm d1125: Standard test methods for electrical conductivity and resistivity of water," American Society for Testing and Materials, West Conshohocken, PA, Tech. Rep., 2014.

[41] ASTM, "Astm d512: Standard test methods for chloride ion in sdffwater," American Society for Testing and Materials, West Conshohocken, PA, Tech. Rep., 2012.

[42] ASTM, "Astm d516: Standard test method for sulfate ion in water," American Society for Testing and Materials, West Conshohocken, PA, Tech. Rep., 2016.

[43] AASHTO, "Aashto t 296 - standard method of test for unconsolidated, undrained compressive strength of cohesive soils in triaxial compression," American Association of State Highway and Transportation Officials, Washington, D.C., Tech. Rep., 2016.

[44] ASTM, "Astm d2166: Standard test method for unconfined compressive strength of cohesive soil," American Society for Testing and Materials, West Conshohocken, PA, Tech. Rep., 2016.

[45] AASHTO, "Aashto t 208 - standard method of test for unconfined compressive strength of cohesive soil," American Association of State Highway and Transportation Officials, Washington, D.C., Tech. Rep., 2019.

[46] ASTM, "Astm d4767: Standard test method for consolidated undrained triaxial compression test for cohesive soils," American Society for Testing and Materials, West Conshohocken, PA, Tech. Rep., 2011.

[47] ASTM, "Astm d7181: Standard test method for consolidated drained trixaxial compression test for soils," American Society for Testing and Materials, West Conshohocken, PA, Tech. Rep., 2020.

[48] ASTM, "Astm d3080: Standard test method for direct shear test of soils under consolidated drained conditions," American Society for Testing and Materials, West Conshohocken, PA, Tech. Rep., 2011.

[49] AASHTO, "Aashto t 236 - standard method of test for direct shear test of soils under consolidated drained conditions," American Association of State Highway and Transportation Officials, Washington, D.C., Tech. Rep., 2016.

[50] ASTM, "D4648: Standard test methods for laboratory miniature vane shear test for saturated fine-grained clayey soil," American Society for Testing and Materials, West Conshohocken, PA, Tech. Rep., 2016.

[51] AASHTO, "Aashto t 216 - standard method of test for one-dimensional consolidation properties of soils," American Association of State Highway and Transportation Officials, Washington, D.C., Tech. Rep., 2016.

[52] ASTM, "Astm d4186: Standard test method for one-dimensional consolidation properties of saturated cohesive soils using controlled-strain loading," American Society for Testing and Materials, West Conshohocken, PA, Tech. Rep., 2012.

[53] FHWA, "Fhwa-hif-17-016: Assuring quality in geotechnical reporting documents," Federal Highway Administration, Washington, D.C., Tech. Rep., 2016. [Online]. Available: https://www.fhwa.dot.gov/engineering/geotech/pubs/nhi16072.pdf.

[54] M. T. Tumay, M. Y. Abu-Farsakh, and Z. Zhang, "From theory to implementation of a cpt-based probabilistic and fuzzy soil classification," *From Theory to Implementation of a CPT-Based Probabilistic and Fuzzy Soil Classification*, 2008.

[55] P. Robertson, "Soil behavior type from the CPT: An update," 2010.

[56] ASTM, "Astm d3282: Standard practice for classification of soils and soil-aggregate mixtures for highway construction purposes," American Society for Testing and Materials, West Conshohocken, PA, Tech. Rep., 2015.

[57] LADOTD, *Louisiana standard specifications for roads and bridges, supplemental specifications*, ed. by L. D. of Transportation and Development, Baton Rouge, LA, 2016. [Online]. Available: https://www.dotd.la.gov/media/gzbgaf1h/2016-supplemental-specifications-book-08-22-effective-date-8-10-2022.pdf.

[58] P. J. Bullock, "The easy button for driven pile setup: Dynamic testing," in *Symposium Honoring Dr. John H. Schmertmann for His Contributions to Civil Engineering at Research to Practice in Geotechnical Engineering Congress 2008*.