COLORADO

Department of Transportation

Geotechnical Design Manual

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APPENDIX

DEFINITIONS OF SELECTED TERMS

Project Geotechnical Engineer (Project GEO): The Geotechnical Engineer of Record. A Professional Engineer registered in the State of Colorado and responsible for the geotechnical work performed on the project. The Project GEO may be a CDOT Geotechnical Engineer or a Geotechnical Consultant.

CDOT Soils & Geotechnical Services Representative (SGSR): Representative of the CDOT Soils & Geotechnical Services assigned to a project in cases where the Project GEO is a Geotechnical Consultant.

Geotechnical Field Exploration: A program of exploring surface and subsurface conditions at a site through review of available literature, visual observations, non-destructive testing, subsurface explorations, or any other method that provides geotechnical data for design and construction of the project.

Subsurface Exploration: Any subsurface exploration to determine subsurface conditions or the engineering properties of the subsurface materials. A subsurface exploration may include soil borings, test pits, trenches, rock coring/boring, and in-situ testing such as cone-penetration tests, and field permeability tests.

CHAPTER 1. INTRODUCTION

1.1 PURPOSE

This Geotechnical Design Manual (GDM) is a compilation of procedures and methodologies that should be followed in the completion of geotechnical studies. The requirements of this manual should be followed by both Colorado Department of Transportation (CDOT) engineers and consultant Project Geotechnical Engineers (Project GEOs) for all CDOT projects.

The purposes of this GDM include the following:

- Outline the roles and interaction of CDOT Soils & Geotechnical Services and consultant engineers for CDOT projects.
- Identify standard procedures, practices, manuals, specifications, and computer software for geotechnical work on CDOT projects, including investigations, testing, design, and construction.
- Establish standards for presentation of geotechnical information, including reports, boring logs, and laboratory test results.
- Define CDOT's requirements and expectations for geotechnical work, particularly where CDOT's expectations may differ from or are not clearly addressed by the requirements of the referenced standards.

It is not the intent of this GDM to be all-inclusive. Where this GDM uses the terms "include" or "including," the implied meaning is "including but not limited to." Address all geotechnical issues that are pertinent to the project, regardless of whether a given issue is specifically addressed by this GDM. Consult with CDOT Soils & Geotechnical Services in developing an approach to geotechnical issues not specifically addressed by this GDM or the referenced standards, and for clarification as needed.

Wherever a publication is referenced in this GDM, the reference refers to the current edition and all current interims, unless explicitly stated otherwise in the reference.

As discussed in the GDM, CDOT Soils & Geotechnical Services is available to review submittals. CDOT Soils & Geotechnical Services will provide comments on submittals at its discretion. Allow adequate time (a minimum of 10 business days) for CDOT Soils & Geotechnical Services to provide comments on submittals.

CDOT Soils & Geotechnical Services recognizes the importance of engineering judgment, schedule, and economy in geotechnical work for CDOT projects, and may accept project-specific exceptions to the requirements of this GDM at its discretion. Where the Project GEO concludes that a specific exception is justified and advantageous to the project, document justification for the proposed exception in the geotechnical report.

CDOT Soils & Geotechnical Services maintains and updates this GDM to accommodate advances in geotechnical engineering and American Association of State and Highway Transportation Officials (AASHTO) practice, and welcomes comments and suggestions to be considered for implementation in future editions.

1.2 CDOT INVOLVEMENT IN GEOTECHNICAL DESIGN PROCESS

At the outset of the project, the CDOT Region Project Manager should coordinate with CDOT Soils & Geotechnical Services (SGS) to notify the SGS of project initiation and maintain communications. The CDOT Soils & Geotechnical Services Manager will then assign a CDOT SGSR, who will be available for consultation and coordination with the Project GEO. As necessary, coordinate with the CDOT SGSR to discuss the field investigation program, establish geotechnical design requirements, and to discuss geotechnical design issues. The CDOT Region Project manager should submit draft geotechnical reports via email to the CDOT SGSR. The GEO and CDOT Region Project Manager should allow at least 10 business days for comment prior to finalizing reports. The Project GEO bears the ultimate responsibility for all geotechnical work.

1.3 ALTERNATIVE DELIVERY PROJECTS

Alternative delivery contracting methods utilized by CDOT include design-build (DB) and construction manager / general contractor (CM/GC). Conduct geotechnical work for alternative delivery projects in accordance with the standards listed by priority in the Project Request for Proposal (RFP).

CHAPTER 2. GEOTECHNICAL STANDARDS, REFERENCES, AND SOFTWARE

2.1 GEOTECHNICAL STANDARDS AND ORDER OF PRECEDENCE

Conduct all geotechnical work in accordance with the standards listed in Table 2-1. In the case of conflicting requirements, the requirements of the highest priority standard take precedence.

TABLE 2-1
STANDARDS FOR CDOT GEOTECHNICAL WORK

Priority	Author or Agency	Title
1	CDOT	Contract Documents for the Project
2	CDOT	Standard Specifications for Road and Bridge Construction
3	CDOT	Bridge Design Manual
4	CDOT	M-E Pavement Design Manual
5	CDOT	Geotechnical Design Manual
6	AASHTO	LRFD Bridge Design Specifications (Customary U.S. Units)
7	AASHTO	Guide Specifications for LRFD Seismic Bridge Design
8	AASHTO	LRFD Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals

2.2 GEOTECHNICAL REFERENCES

In addition to the standards listed in Table 2-1, CDOT Soils & Geotechnical Services commonly uses other resources referenced in this GDM and may refer to these references in reviewing geotechnical work, including geotechnical field investigations, reports, and design submittals.

2.3 GEOTECHNICAL SOFTWARE AND CALCULATIONS

Use industry-accepted geotechnical software on CDOT projects. As necessary, use other software or hand calculations to confirm software results. The Project GEO is responsible for the accuracy and suitability of geotechnical software used for design calculations.

In the geotechnical report (or other deliverable as applicable), describe the assumed software input parameters and basis for their selection. Include representative software output showing key input parameters and assumptions.

2.4 FORMS

Official CDOT forms referenced herein are available at https://www.codot.gov/library/forms.

CHAPTER 3. GEOTECHNICAL INVESTIGATIONS

3.1 LITERATURE REVIEW

Prior to commencing subsurface explorations, conduct a review of available literature and records applicable to the project. Common sources of geotechnical and geological literature and data useful for CDOT projects include those listed in Table 3-1.

TABLE 3-1
COMMON SOURCES OF GEOTECHNICAL AND GEOLOGICAL LITERATURE AND DATA

Source	Type of Information
CDOT	Digital files available upon request for recent projects. Older geotechnical reports; construction monitoring, and test reports, etc. are available in hard copy at the North Holly Office Geotechnical Library – arranged by highway and mile point (e.g. I-70 MP 248 is filed as 070-248). Some project files may be available as digital files upon request for certain projects. Geohazard instrumentation database (Contact CDOT Geohazards Program).
United States Geological Survey	Geologic maps, charts, books; probabilistic seismic hazard deaggregations
Colorado Geological Survey	Geologic maps, charts, books
State, County, and Local Governments	Well installation records; geological and geotechnical studies, Lidar
Colorado Department of Natural Resources	Well installation records (Division of Water Resources)
Local Colleges and Universities	Theses and dissertations on geotechnical and geologic topics of local interest; out-of-print geologic publications
Various Government Agencies	Aerial photographs (review with stereoscope may show features/details not obvious to the naked eye); soil surveys (agricultural, engineering, etc.)

3.2 FIELD RECONNAISSANCE

Following the literature review, the Project GEO should complete a site inspection. Obtain as much information as possible prior to performing subsurface explorations, including the following:

- Site accessibility and traffic-control considerations
- Topography
- Surface water and seepage
- Erosion patterns

- Surface features that may affect design, construction, and performance of proposed facility
- Distress of any existing structures

Where applicable, obtain information regarding the soil (nature and thickness of strata) and bedrock (lithology and structure) by observing natural and man-made exposures, including riverbanks, escarpments, quarries, and highway and railway cuts.

3.3 PLANNING OF FIELD EXPLORATIONS

Conduct and finalize planning of field explorations in advance of any field exploration work. Obtain all permits and clearances and take all necessary precautions (such as evaluations of potential hazards at or near the site) ahead of time. The goal of the exploration program is to identify and address risks associated with subsurface conditions and to obtain the necessary subsurface information required for project design.

3.3.1 Right-of-Way Permits

Most projects are anticipated to be within CDOT's right-of-way (ROW) and will require a CDOT Utility/Special Use Permit to perform field investigations. Additional permits may be required by local jurisdictions and other agencies. The Project GEO should obtain all necessary permits required to complete field investigations.

3.3.2 Right-of-Entry

If it is necessary to access private property to perform the field investigations, CDOT regional ROW staff will coordinate right-of-entry (ROE) to the private properties, if feasible. Any required fees will be applied to the Project or may need to be paid by the Project GEO Consultant. The Project GEO may need to sign ROE agreements and provide certificates of insurance, depending on the requirements of the property owner.

3.3.3 Environmental Clearances and Considerations

The Project GEO should obtain any required environmental clearances and permits prior to initiating field investigations. Record and immediately report evidence of contamination observed during the explorations to the CDOT Regional Project Manager and the SGSM.

3.3.4 Traffic Control Requirements

Provide traffic control for field investigations in accordance with the FHWA *Manual on Uniform Traffic Control Devices* (MUTCD). Obtain appropriate traffic control plans and traffic control services.

3.3.5 Utility Locates

Review available utility plans prior to selecting subsurface exploration locations. All utilities within the exploration boundaries shall be cleared per current State and Local laws. Typical steps include marking areas of proposed subsurface explorations with white paint (pavement or hard surfaces) or flagged stakes (soil or vegetated surfaces). Perform utility locates through the Utility Notification Center of Colorado (UNCC) at 811 or 1-800-922-1987 (also can be performed using the online service at www.colorado811.org) at least two business days prior to the start of drilling or digging. Contact any other entities, including Tier II utilities, (e.g., railroads, irrigation companies, and private properties,) that may own or operate utilities in the area, prior to the start of drilling or digging.

An on-site meeting with utility locators should be performed if the proposed subsurface exploration locations are difficult to describe and/or the proposed exploration is relatively close to underground utilities. Where the exploration is near an existing utility, the utility company may also require that their representative be present at the beginning of the investigation, and may require hand digging or potholing to expose the utility.

Retain a private utility locating company if private utilities (i.e. utilities not located through the UNCC), such as service lines and power lines for privately owned overhead lighting, are present.

Visually observe the locations of overhead utilities in subsurface exploration areas. Overhead utilities may limit or prevent safe access and operation of drill rigs.

3.3.6 Notice of Intent

The Code of Colorado Regulation (CCR) requires that a Notice of Intent (Notice) be provided to the Colorado Division of Water Resources before drilling any test hole that penetrates a confining layer or before installing a monitoring and observation hole (2 CCR 402-2). As necessary, file a Notice at least three business days prior to drilling to the Colorado Division of Water Resources by email at DWRpermitsonline@state.co.us.

Key terms defined by the CCR related to geotechnical explorations and groundwater wells include:

Monitoring and Observation Hole: A temporary well constructed for the purpose of repeated observations, measurements, or remediation of groundwater. A monitoring and observation hole may only be constructed upon a notice of intent and must be properly abandoned less than 18 months from the date it was constructed unless a permit is obtained from the State Engineer to become a monitoring and observation well.

Monitoring and Observation Well: Any excavation that is drilled, cored, driven, dug, or jetted for the intended use of monitoring groundwater, collection of water samples, and pumping or aquifer testing. A monitoring and observation well must be permitted by the State Engineer and are not required to be abandoned.

Test Hole: Any excavation that is drilled, cored, driven, dug, or jetted for the intended use of geotechnical, geophysical, or geologic investigation. A test hole usually involves the collection of soil or rock sampling.

Forms and other information are available online at https://dwr.colorado.gov/services/well-permitting.

3.3.7 Health and Safety

All work shall be done in compliance with CDOT Standard Specifications for Road and Bridge Construction Section 107.06 (e), Project Safety & Health Requirements. Work shall also comply with all federal (including Occupational Safety and Health Administration [OSHA]), state, and local laws and ordinances. Conduct drilling using appropriately trained and certified (as necessary) personnel equipped with appropriate safety equipment.

3.3.8 Interaction with the Public

Conduct all interactions with the public with respect and courtesy. Cooperate with property owners, public safety officers, and CDOT personnel to minimize and mitigate potential impacts and hazards of field investigations.

Protect the public from falling and tripping hazards posed by test holes. During operation of heavy equipment, maintain an exclusion zone around the impacted area to protect the public.

Refer specific questions from the public regarding CDOT projects to the CDOT Public Relations Office.

3.4 SUBSURFACE EXPLORATIONS FREQUENCY AND DEPTH

Subsurface explorations should be planned to obtain sufficient information to design the project. Exercise engineering judgment in planning and performing subsurface explorations. Consider the following:

- Type and criticality of Project elements
- Soil and rock formations and characteristics
- Subsurface variability at the site
- Lengths and widths of Project elements
- Loads to be imposed on the foundation materials
- Availability and applicability of previous investigations at the site
- Groundwater characteristics and conditions

Conduct subsurface explorations meeting the minimum frequency and depth requirements listed in Table 3-2. CPT probes may be used for some of the required test holes where appropriate.

TABLE 3-2
MINIMUM REQUIREMENTS FOR SUBSURFACE EXPLORATIONS

Structure	Exploration Frequency	Recommended Minimum Exploration Depth
Pavement Design	No farther apart than 500 feet in continuous cut and fill sections, and no farther apart than 1 mile unless approved by Region Materials Engineer.	Refer to CDOT Pavement Design Manual.
Foundations	See AASHTO LRFD Bridge Design Specifications.	See AASHTO LRFD Bridge Design Specifications.
Retaining Walls	See AASHTO LRFD Bridge Design Specifications.	See AASHTO LRFD Bridge Design Specifications.
Culverts	See requirements for spread footings in AASHTO LRFD Bridge Design Specifications.	See requirements for spread footings in AASHTO LRFD Bridge Design Specifications.
Sign Structures and Signal Poles	Required at foundation locations where CDOT M&S Standards are not used or applicable.	See AASHTO LRFD Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals.
Landslide Evaluation	3 along center of slide and at least one boring above and below sliding area.	15 feet below slip surface or as needed to design proposed mitigation. Include instrumentation for landslide characterization (e.g. inclinometers and piezometers) as appropriate
Cut Slopes	Every 200 to 600 feet, depending on subsurface conditions and proposed construction.	10 feet below base of cut and into stable soil/rock.
Embankments	Every 200 to 600 feet, depending on subsurface conditions and proposed construction.	2.0 times the embankment height, or 5 ft into bedrock, whichever occurs first. Test holes for wide embankments on compressible soils are required to characterize any compressible materials, regardless of embankment height.

The criteria provided in Table 3-2 are minimum requirements. A more extensive exploration program may be appropriate. Base the depth and number of explorations on the variability of subsurface conditions, design requirements, and engineering judgment. In all cases, perform sufficient subsurface explorations to provide the information needed for the design and construction of each project element. Consult with the CDOT SGSM regarding requirements for the subsurface investigation program.

It is not the intent of this GDM to require test holes in excessive quantities or depths. In particular, test holes for walls and embankments need not extend to excessive depths in competent, incompressible strata.

Additional information describing considerations and requirements for subsurface explorations can be found in the following references:

- Geotechnical Site Characterization FHWA Geotechnical Engineering Circular No. 5, (Loehr and others, 2017).
- FHWA Report No. FHWA ED-88-053, FHWA Checklist and Guidelines for Review of Geotechnical Reports and Preliminary Plans and Specifications (FHWA, 2003), Table 2.
- CDOT Field Materials Manual, Chapter 200.
- AASHTO LRFD Bridge Design Specifications.
- Landslides: Investigations and Mitigations, Transportation Research Board (TRB) Special Report 247 (TRB, 1996).

3.5 SUBSURFACE EXPLORATION METHODS

Subsurface explorations may include borings, test pits, trenches, and other methods that obtain measurements or observations of soil and rock. Purposes of explorations include the following:

- Determine the extent and characteristics of natural soil and rock formations.
- Obtain samples representative of the different soil and rock formations for laboratory testing.
- Evaluate jointing or faulting in rock.

Investigate potentially unfavorable conditions such as springs, swamps, bogs, seepage, slide areas, expansive soils or rock, collapsible soils, soft soils, weak soils or rock, compressible soils, liquefiable soils, or other conditions that could affect construction of highway structures or roadbed stability. Conduct field explorations in accordance with the procedures of this GDM and relevant AASHTO and ASTM standards.

3.5.1 Borings

Acceptable boring methods for geotechnical investigations include:

- Solid stem auger drilling. This method is acceptable only where hole collapse or sloughing does not occur. Have other drilling methods available onsite in the event of borehole instability.
- Hollow stem auger (HSA) drilling. Mitigate heave and loosening of saturated, cohesionless soils. Alternative methods, such as mud rotary drilling, may be required to control heave. Note on boring logs samples that may have been impacted by heave.
- Mud or Air rotary drilling. Casing may be required in very loose or porous soils.

- Sonic core drilling.
- Down-the-hole hammer methods.
- Rock coring. Obtain downhole digital images or oriented cores where appropriate.

Drilling methods will vary depending on subsurface conditions. Use drill crews trained and equipped to perform explorations in the anticipated geologic conditions.

Record field observations on a Geological Boring Log – CDOT Form 1334 or equivalent.

3.5.2 Test Pits/Trenches

The Project GEO may use test pits for shallow soil investigations, such as pavement subgrade investigations, and may use exploratory trenches for fault investigations, collapsible soils identification, etc. Test pits and trenches are typically limited in depth to about 10 feet below the ground surface, depending on the trench stability, groundwater, and equipment limitations (e.g. backhoe reach). All trenching shall be in accordance with OSHA guidelines for worker safety.

Take photographs of the sides of the excavation and maintain a log of the test pit or trench.

3.5.3 Borehole/Test Pit Abandonment

Abandon boreholes in accordance with Rule 16 of 2 CCR 402-2 and with any applicable permit requirements. Where borings extend through existing pavements, sidewalks, bridge decks, etc., properly patch the surface of the hole with asphalt, grout, or concrete to maintain public safety. Pavement repairs should be completed in accordance with the requirements of applicable local agencies and the CDOT Region.

Upon completion of test pits or trenches, backfill excavations with the excavated material or other suitable material, such as grout or flow fill. All excavations should be backfilled in accordance with the requirements of applicable local agencies and the CDOT Region. Compact test pit backfill in lifts with a maximum thickness of 8 inches to the degree possible with the equipment used for excavation. Where settlement of test pit backfill could impact future construction, include requirements in the project plans to replace the test pit backfill with structural fill.

Where excavations are located in agricultural areas or other areas used to support plant growth, cover the backfilled excavation with topsoil so that the impacted area will support vegetation. Restore the area to conditions that are equal to or better than the original condition.

3.5.4 Geophysical Surveys

Use geophysical surveys as appropriate for the Project. Refer to ASTM D6429 for guidance in selecting geophysical methods. Guidance is also provided in FHWA Report No. IF-04-021 (Wightman and others, 2004).

Geophysical methods are typically non-destructive and are performed from the ground surface. Success depends on factors including surface features, site activity, subsurface conditions, and groundwater. Perform geophysical methods under the supervision of an experienced geophysicist. Conduct all geophysical methods in accordance with applicable ASTM standards or in accordance with widely accepted guidelines if standards do not exist. If geophysical surveys are conducted, the results should be calibrated using data from a nearby boring in which physical samples are obtained.

Present results in graphs, profiles, tables, or contour maps. Use U.S. Customary units. Convert field measurements to data that is useful in engineering analyses.

3.5.5 Other Exploration Methods

Additional methods or processes for site exploration and characterization not included in this manual are encouraged if there are estimated or measurable benefits towards data quantity and reliability, foundation design and construction cost savings, reductions in project delivery risk for CDOT, or other valuable criteria identified by the consultant. Example methods include CPT, remote sensing methods, or downhole optical surveys. The feasibility of using alternative approaches shall be discussed with the CDOT SGSM prior to final cost estimation and submittal of the scope of work.

3.5.6 Survey of Explorations

Survey exploration locations and report the plan coordinates (northing and easting), elevation, and associated horizontal and vertical datums on the boring logs, test pit logs, or geophysical test results, as applicable. Utilize Colorado State Plane coordinates and the NAVD 88 vertical datum or project-specific coordinates. If survey of exploration locations is not feasible, estimate exploration locations using recreational- or mapping-grade GPS equipment. Report on the explorations logs whether the coordinates were surveyed or estimated.

3.6 IN-SITU TESTING AND SAMPLING

In-situ testing and soil sampling (with subsequent laboratory testing) is performed to determine the index and engineering properties of soil and rock. Perform soil sampling and testing to obtain samples that are representative of subsurface materials and conditions. Conduct sampling and testing in general accordance with FHWA publication Geotechnical Site Characterization, Geotechnical Engineering Circular No. 5 (Loehr and others, 2017) and the NCHRP (2019) *Manual on Subsurface Investigations.*

Potential sampling methods and in-situ tests include those listed in Table 3-3 on the next page.

TABLE 3-3
IN-SITU TESTS AND SAMPLING METHODS FOR SUBSURFACE EXPLORATIONS

Test or Sample Type	Description and Typical Use	Sample?
Becker Penetration Test	Evaluates penetration resistance in deposits of hard and oversize material (gravels and cobbles) where SPT is less meaningful. May obtain sample using open-ended casing.	Yes
Borehole Shear Test	Simulates direct shear test in measuring pullout resistance of borehole sidewalls.	No
Cone Penetration Test	Records continuous profile of soil behavior versus depth in soft/loose to moderately stiff/dense soils. May also be used to measure shear wave velocities, pore pressures, etc.	No
Continuous Penetration Test (Colorado Procedure CP-L-3201)	Typically used to find voids in soil, determine general soil density, or determine bedrock depth. See CDOT Form 334.	No
Field Permeability Test	Estimates in-situ permeability of soil for detention basins and similar applications.	No
Field Vane Shear Test	Provides indication of in-situ undrained strength of soft to stiff fine-grained soils. Particularly useful where sampling disturbance may reduce soil strength.	No
Flat Plate Dilatometer Test	Estimates stratigraphy, lateral stresses, elastic modulus, and shear strength in sands, silts, and clays.	No
Geophysical Testing	Typically performed from the ground surface with sensors that measure soil response to electromagnetic or seismic waves.	No
Modified California Sampler	Sampler that is driven into the soil and obtains a disturbed sample contained in sampler liner tubes. Penetration resistance can be correlated to soil density or consistency.	Yes
Plate Load Test	Models resistance of soil to shallow foundation loads.	No
Pressuremeter Test	Provides indication of deformation characteristics of soil and rock.	No
Rock Core Barrel	Obtains a length of rock core for testing and visual examination.	Yes
Screw Plate Load Test	Measures soil response to vertical loading of plate installed at bottom of boring.	No
Standard Penetration Test	Split-spoon sampler that is driven into the soil under specific requirements and obtains a disturbed sample. Significant published data is available for correlation of penetration resistance to density and consistency of soils.	Yes
Suspension Logging	An instrument array that is lowered into a borehole or casing and used to obtain measurements that can be correlated to shear and compression velocity, resistivity, and other data.	No
Thin-walled Tube Sampler	A tube that is pushed into the soil to collect a relatively undisturbed sample. Depending on soil type may be performed using Shelby tubes, Pitcher barrels, Osterberg samplers, or other piston samplers.	Yes

Use in-situ testing as appropriate to characterize the subsurface materials. Attempt a given type of in-situ testing only with a prior understanding of the applicability and limitations of the method to be employed. Conduct in-situ testing in accordance with the applicable CDOT, AASHTO, and ASTM standards.

Do not exclusively rely upon any type of testing that does not acquire a soil or rock sample. Obtain representative samples for visual-manual classification and laboratory testing. Supplement in-situ testing of strength with laboratory testing to confirm correlated properties.

The following sections describe requirements for common methods of testing and sampling for CDOT projects, but do not provide information on all testing and sampling methods listed in Table 3-3. Conduct sampling and testing in accordance with applicable CDOT, ASTM, and AASHTO Standards.

3.6.1 Standard Penetration Test

The SPT is a common sampling and testing method used for subsurface explorations extending through soil and relatively low-strength rock. Perform the SPT in accordance with ASTM D1586.

Record the number of blows to cause each 6 inches of penetration on a boring log (CDOT Form 1334 or equivalent). If refusal conditions are encountered (i.e. more than 50 blows to cause 6 inches or less of penetration), record the number of blows and corresponding penetration (in inches) on the log and terminate the test (unless further driving is desired to collect additional sample).

Determine number of blows to cause the last 12 inches of penetration (termed the standard penetration resistance or N-value) by adding the number of blows from the 2nd and 3rd 6-inch increment and recorded on the Geological Boring Log. Ignore the number of blows for the first 6-inch increment. Examples of N-value calculations are as follows:

- Blows per 6-inch increments (18 inches driven) = 25, 45, and 30: N-value = 45+30 = 75
- Blows per 6-inch to refusal (<18 inches driven) = 25, 45, and 50/3”: N-value = 45/6”+50/3” = 95/9”
- Blows per 6-inch to refusal (<12 inches driven) = 25 and 50/3”: N-value = 50/3”
- Blows until refusal (<6 inches driven) = 50/3”: N-value = 50/3”

Use of N-values in estimating soil properties for design may require correction of the field measured N-values. These corrections are based on hammer efficiency, borehole diameter, sampler dimensions, and sampling rod length. Details of the hammer (size, weight, type), rod (size, length) and sampler information (size, liners) used during testing shall be recorded on the Geological Boring Log.

Conduct SPT sampling using hammers that have been calibrated in accordance with ASTM D 4633 within two years of the sampling date. Obtain hammer energy transfer measurements from the driller and report the information on boring logs or in the associated geotechnical report.

Examine and classify the sample collected in the split-spoon sampler in accordance with ASTM D 2488. Record the sample descriptions on the boring log. After identification and logging, transfer the sample to air-tight jars or bags labeled with the project name/number, boring designation, sample date, and sample depth. Requirements for sample identification are presented in Section 3.8.1.

3.6.2 Modified California Sampler Penetration Test

Perform MC sampling and penetration testing in accordance with ASTM D3550. This method is similar to the SPT. However, a slightly larger sampler is used, within which brass liners are placed end-to-end to collect a soil sample. The sampler is also typically driven 12 inches instead of 18 inches.

Determine the penetration resistance in blows per foot by adding the measured penetration resistance for each six-inch increment (e.g. 25/6" + 55/6" = 75). Record the penetration resistance, details of the hammer (size, weight, type), rod (size, length) and sampler information (size, liners) used during testing on the boring log.

Conduct MC sampling using hammers that have been calibrated in accordance with ASTM D 4633 within two years of the sampling date. Obtain hammer energy transfer measurements from the driller and report the information on boring logs or in associated geotechnical report.

Examine and classify the sample collected in the MC sampler in accordance with ASTM D 2488. Record the sample description on the boring log. After identification and logging, seal the individual brass liners with tight-fitting caps and label with the project name/number, boring designation, sample date, and sample depth. Requirements for sample identification are presented in Section 3.8.1.

3.6.3 Thin-Walled Tube Samples

Obtain thin-walled (Shelby) tube samples in cohesive soils where laboratory testing of relatively undisturbed samples is required (e.g. consolidation testing, triaxial testing) for design and analysis. Projects requiring the collection of thin-walled tube samples include those with proposed embankments or retaining structures on cohesive soils that could contribute to instability or post-construction settlement.

Collect thin-walled tube samples in accordance with ASTM D1587. In thick deposits of cohesive soils, alternating SPT sampling with thin-walled tube sampling will provide SPT N-values as well as sufficient sample volume for testing. Do not collect thin-walled tube samples without also performing SPTs to evaluate the soil density/consistency.

Only the ends of the tube sample may be observed in the field. The remainder of the sample is observed when the sample is extruded in a laboratory prior to testing. Due to potential interbeds of sand, sample disturbance, and other issues, some samples may not be suitable for testing. Collect enough samples to perform the proposed laboratory engineering tests considering that some samples may not be useful for testing.

Other types of tube samples, including Osterberg samples, Pitcher barrel samples, and piston samples, may be used. Follow applicable AASHTO or ASTM standards for sampling. Do not attempt to use an MC sampler or any other type of driven sample to obtain undisturbed samples.

Seal thin-walled tube samples with rubber stoppers, plastic caps, or paraffin wax, and transport and store in an upright position with the sample oriented in the same direction as the borehole. Make every effort to obtain, transport, and store samples in a manner that ensures and maintains sample integrity and quality. Avoid exposing samples to bumps, jolts, vibrations, or freezing temperatures during transport and storage.

3.6.4 Cone Penetration Testing

The Cone Penetration Test (CPT) consists of pushing an instrumented cone into the ground at a controlled rate to obtain measurements of soil resistance. The cone can be equipped with additional instrumentation to obtain measurements of pore water pressure, shear and compression wave velocity, conductivity/resistivity, and other parameters. Perform CPTs in accordance with ASTM D5778. The CPT method does not obtain a soil sample and should be used as a supplement to methods in nearby borings that acquire a sample.

Present the results of the CPT as plots including (at a minimum): the tip resistance, sleeve resistance, friction ratio, and soil type interpretation versus depth. Use U.S.

Customary units. Include additional information such as pore pressures and seismic sounding information where available. The CPT log should include the CPT designation, date tested, ground elevation, estimated groundwater depth, and other pertinent data. The log should also include the interpreted soil type versus depth as estimated using published methods based on tip and friction resistance. Other test results associated with the CPT (e.g. pore pressure dissipation tests) should also be presented as graphs or tables.

3.6.5 Rock Coring

Rock coring should extend at least 10 feet below the top of bedrock or to depths indicated in Table 3-2, whichever is greater. Either double- or triple-tube core barrels may be used. Single-tube core barrels are not permitted. Select the core barrel type considering the nature of the rock and the required quality for the retrieved core. Utilize N-, H-, or P-size core barrels.

After the core is retrieved from the borehole, examine, log, and photograph the core. Transfer the core to cardboard or wood boxes, and use wood or foam spacers to prevent core pieces from being dislodged in the box. Use spacers to identify zones of core loss and to separate and identify core runs. Do not discard rock core. All recovered core should be placed in the box. Requirements for sample identification are presented in Section 3.8.2. Prepare core photographs clearly indicating the boring designation, run number, run depths, recovery, and rock quality designation (RQD) in accordance with ASTM D6032.

3.6.6 Other In-Situ Tests

Table 3-3 includes numerous in-situ tests that have not been described in the previous sections. Additional tests not listed in Table 3-3 may also be appropriate for the project. Conduct all in-situ tests in accordance with applicable AASHTO or ASTM standards, or in accordance with widely accepted guidelines if standards do not exist.

Present test results in graphs or tables, in U.S. Customary units. Convert field measurements to data that is useful for use in engineering analysis.

3.7 GROUNDWATER OBSERVATIONS

Groundwater observations can be made during drilling, depending on the drilling method used. Groundwater can also be observed in test pit excavations. Groundwater observations made during drilling in clay soils are not necessarily accurate. For some projects, a groundwater monitoring instrument or well may be required to obtain more accurate groundwater measurements over time or to perform groundwater sampling, as discussed below.

3.7.1 Borings

For drilling methods that do not utilize drilling mud or added water, the groundwater level can be estimated during drilling by noting evidence of water on the drill rods or augers. Estimate the groundwater level both during drilling and after drilling is complete.

In many cases, particularly in clay soils, the water level in a test hole will not stabilize to the natural groundwater level until hours or days after drilling is complete. Where necessary, install temporary pipe in test holes to allow subsequent measurements of groundwater levels. Unless access restrictions are prohibitive (e.g. in a live traffic lane), installation of a temporary standpipe, and a minimum of one groundwater measurement at least 24 hours after completion of drilling, are required in clay soils for any project where global stability or settlement calculations will be performed.

If the primary drilling method does not permit reliable measurements of groundwater levels, conduct supplementary test holes to determine the depth to groundwater or install groundwater monitoring devices (see Section 3.7.2 and 3.7.3).

Record groundwater levels in borings, test pits, or trenches during drilling/excavation and upon completion. Include the date and time of each groundwater level measurement on the boring log. Note if artesian conditions are encountered.

3.7.2 Observation Wells

An observation well (or monitoring well, see Section 3.3.6) consists of a casing that is installed in the open borehole. The casing is capped at the bottom end and contains a screened section (typically 10 to 20 feet long) that allows water to enter the casing. Select the screened interval of the well to correspond to the depth of interest. For example, shallow screens may be used in areas for cuts or fills, whereas deeper screens may be used for deep foundations.

Confirm that the well is open to the bottom cap. If any water was used during drilling, the well should be bailed dry. Well development is not required for typical observation wells but may be required for groundwater sampling or hydrogeologic testing (see Section 3.7.4). Protect the top of the well from damage. In areas of traffic, a flush-mounted steel monument may be required. In all cases, a locking cap should be placed on well casing to prevent inflow of water or debris into the well.

Wells should be installed, permitted, and abandoned in accordance with State regulations and requirements set forth by the Colorado Division of Water Resources. As necessary, discuss the timing and responsibility of permitting and well abandonment with the CDOT SGSM. State regulations require that monitoring and observation holes be abandoned within 18 months of installation or permitted as monitoring a monitoring and observation well with the Colorado Division of Water Resources.

3.7.3 Automated Groundwater Monitoring

Instrumentation consisting of pressure loggers or vibrating wire piezometers (VWPs) may be installed in lieu of or in conjunction with observation wells. These instruments can be combined with data loggers to automatically obtain and record groundwater measurements for extended periods of time.

Where used, multiple VWPs may be installed at various depths within a single borehole. Install VWPs in accordance with the manufacturer's recommendations. Coil the VWP cables at the ground surface and place them inside a steel monument or protective system.

3.7.4 In-Situ Sampling and Testing of Groundwater

Measure groundwater levels in monitoring wells using an electronic water level meter. Measure groundwater levels with pressure loggers or VWPs according to manufacturer's instructions.

Observation wells installed solely for measurement of groundwater levels do not typically require development. However, observation wells in which sampling or hydraulic conductivity testing will take place should be developed to remove sediment and establish a hydraulic connection between the well and the aquifer. Develop the well using a surge block, bailer, or other system. Perform pumping or bailing to remove fines and suspended solids from the well casing. Development can be considered complete when the groundwater removed from the well is clear to slightly turbid or when there is no further improvement in groundwater clarity.

If wells are used to determine the direction of groundwater flow/seepage or to characterize hydraulic gradient, install a minimum of three monitoring wells.

3.8 SOIL AND ROCK CLASSIFICATION AND LOGGING

A consistent system of soil and rock classification is required for all CDOT projects. Record all soil and rock classifications on the boring log.

3.8.1 Soil Classification

During drilling and sampling, classify soils in accordance with ASTM D2488 (visual-manual classification). Record the basic soil profile elements in the field, including changes in strata, relative properties of soil types in layered/bedded deposits, and presence of cobbles or boulders. Make corrections and additions to the field classification, where necessary, by conducting laboratory testing of the soil samples, and prepare final boring logs using descriptions based on ASTM D2487 (Unified Soil Classification System).

Record descriptions in the boring log for every soil sample collected. Provide descriptions that are concise, precise, and comprehensive. Additional requirements for soil classification on boring logs are below:

- **Color**: Record the basic color of a soil. Assign colors in accordance with Munsell color charts. Note staining or mottling, as this information may indicate water table fluctuations or contamination.
- **Penetration Resistance**: Use different indicators for different penetration tests/samplers (e.g. SPT, Modified California). Indicate hammer and rod type on boring logs. Add notations where the penetration resistance may have been affected by large gravel, debris, or other disturbance (e.g. heaving or voids) that could affect the validity of the recorded penetration resistance.
- **Consistency of Cohesive Soils**: Indicate the consistency (e.g. soft, stiff, etc.) of cohesive soils based on SPT N-values in the soil description. Also utilize vane shear, miniature vane shear (torvane), or pocket penetrometer testing to evaluate the consistency of cohesive soil and report test results on the boring log.
- **Density of Granular Soils**: Indicate the density (e.g. loose, medium dense, etc.) of granular soils based on SPT N-values in the soil description.
- **Structure**: Describe discontinuities, inclusions and other features, including joints or fissures, slickensides, bedding or laminations, veins, root holes, and wood or other debris.
- **Mineralogy:** Note significant mineralogical information, such as cementation, abundant mica, or unusual mineralogy such as pinhole structure, and other information such as oxidation, ferrous minerals, calcium, organic debris, odor, etc.

- **Other Descriptors**: Include other descriptors if important for the project or for describing the sample, including particle size, range and percentages, particle angularity, particle shape, maximum particle size, hardness of large particles, plasticity of fines, dry strength, dilatancy, toughness, reaction to hydrochloric acid, etc. If possible, describe the relict rock structure and identify the parent rock for residual soils having characteristics of both rock and soil.

Where necessary for pavement design, refer to the requirements of the CDOT Pavement Design Manual.

3.8.2 Rock Classification

Classify rock core samples in accordance with the International Society of Rock Mechanics (ISRM) publication *Suggested Methods for the Quantitative Description of Discontinuities in Rock Masses* (ISRM, 1978).

CHAPTER 4. LABORATORY TESTING

Conduct the geotechnical laboratory testing program in accordance with the requirements of the project and this GDM. Exercise engineering judgment in developing the testing program. Use a testing laboratory accredited by AASHTO or ASTM.

The Project GEO is ultimately responsible to CDOT for the laboratory testing for the project, but may subcontract portions of the work to an accredited laboratory. Prior to commencing any laboratory testing, review the laboratory's policies and procedures. Adjust policies and procedures as necessary to meet project requirements.

4.1 LABORATORY TESTING REQUIREMENTS

Conduct laboratory soil testing in accordance with the following requirements:

- Conduct shear strength tests, such as triaxial shear, direct shear, vane shear, and/or unconfined compression, on samples from each definable soil unit, depending on the soil type and the nature, purpose, and importance of the project element. More information on projects for which these tests are a requirement can be found below.
- Perform pH, resistivity, sulfate, chloride, and soluble salt tests to evaluate potential for corrosion and deterioration of concrete and metal.
- Test to evaluate potential for collapse, swell, and other problematic behavior. More information on projects for which these tests are a requirement can be found below.

In selecting tests for specific project features, comply with the requirements and guidelines of applicable AASHTO and CDOT design specifications and manuals.

4.2 TESTING PROCEDURES

Follow the applicable testing procedures outlined in the current AASHTO and ASTM Standards specified in the CDOT *Laboratory Manual of Test Procedures*.

The extent of the laboratory testing program should be determined considering factors including the scale of the project, potential impacts of soils that may contribute to settlement or instability of structures, and subsurface variability.

4.2.1 Index Testing

Index testing consists of tests that provide useful information about the soil without directly measuring soil properties (e.g. strength tests). Index testing requirements for CDOT projects are listed below:

- Measure the moisture content of all samples except granular soils below the water table.
- Perform Atterberg limits tests on selected cohesive soil samples to provide data for correlation and identification.
- Perform gradation testing to characterize cohesionless soils.
- Conduct unit weight determination tests on cohesive soils from MC and thin-walled tube samples.

4.2.2 Consolidation and Swell/Collapse Testing

Conduct one-dimensional consolidation testing of relatively undisturbed thin-walled tube samples for any project where any cohesive soils that could contribute to post-construction settlement are present. Perform an adequate number of one-dimensional consolidation tests to determine the variation of preconsolidation pressure, compressibility, and time-rate behavior.

Consolidation tests must be completed on relatively undisturbed thin-walled tube samples. Modified California samples shall not be used for consolidation testing.

Test consolidation samples at loads sufficiently large to accurately determine consolidation parameters. Record consolidation measurements versus time over a time period sufficient to determine rates of both primary and secondary consolidation under loads representative of the in-situ soil stresses anticipated during the project. Present the results in U.S. Customary units as plots of load and settlement as well as the settlement versus time plots where useful.

Conduct proper testing for determination of secondary settlement characteristics, amount of surcharge to use, and the percent consolidation to achieve long-term settlement requirements of the project.

For any project where there is a potential for swell- or collapse-susceptible soil or rock to impact infrastructure, one-dimensional swell/collapse testing is required. Testing should be completed in accordance with ASTM D4546 or other widely accepted test methods. Select loading conditions that are representative of field conditions or select appropriate loading conditions for comparison to published correlations.

4.2.3 Shear Strength Testing

Conduct laboratory shear strength tests to supplement the results of field tests and published correlations with index properties, as necessary for design of the project elements.

For any project where undrained stability may control the design (e.g. embankments or retaining structures constructed on cohesive soils), obtain relatively undisturbed thin-walled tube samples and conduct unconsolidated-undrained (UU) and/or consolidated-undrained (CU) triaxial shear strength testing. Complete an adequate number of tests to characterize variability in soil properties at a given site.

Characterize drained shear strength parameters using CU triaxial tests with pore water pressure measurement, consolidated-drained (CD) triaxial tests, direct shear tests, or torsional ring shear tests. If direct shear tests are used, ensure that the test strain rate is determined in accordance with ASTM D3080 and is slow enough to allow dissipation of shear-induced pore water pressures. Relatively long test times will be required for cohesive soils (potentially up to 24 hours).

Published correlations between index properties and fully softened and residual shear strengths, such as those by Stark and Fernandez (2020), may also be used to estimate soil shear strength. Where applicable considering the project scope and budget, consider supplementing drained shear strength correlations with torsional ring shear testing.

Unconfined Compressive Strength (UCS) testing may be used for hard clay soils, claystone, or Intermediate Geo-Materials. Soft to medium stiff clay soils are more susceptible to disturbance from sampling; UCS testing shall not be used for these soil types.

4.2.4 Compaction and Subgrade Support Testing

Perform compaction tests on soils that may be used as fill for a project or may be compacted in place for a structure subgrade. Common compaction and related tests include:

- **Compaction Test** – soil is compacted at multiple moisture contents for a given compactive effort to generate a compaction curve. The results are used as a comparison for evaluating the results of in-place compaction performed during construction.

- **R-Value Test** - measures the response of a compacted sample to an applied pressure. The test results are typically used for pavement design purposes. The CDOT region Materials Engineers also may perform R-Value tests. These tests should be coordinated with the Material Engineer.
- **Resilient Modulus** - testing is performed on either relatively undisturbed or remolded subgrade samples and consist of measuring the stiffness response to rapid cyclic loading at varying confining stresses, simulating conditions experienced below pavements.

4.3 QUALITY ASSURANCE AND QUALITY CONTROL

Conduct laboratory testing in accordance with the laboratory's quality management plan. If samples are disturbed, contaminated, or otherwise compromised, make special note of the condition and its potential impacts on the test results. Make every effort to test only high-quality samples.

4.4 SAMPLE RETENTION

Retain and preserve samples in their original state until final acceptance of the project plans. Consider a longer sample retention period depending on project-specific requirements and coordination with the CDOT PM.

Retain laboratory worksheets and records for verification purposes for at least five years following construction of the project. Consultants may retain laboratory records in accordance with applicable in-house document retention policies.

CHAPTER 5. GEOTECHNICAL DESIGN

This Chapter provides an overview of accepted practices by CDOT for analysis and design. It is not the intent of this Chapter to provide step-by-step procedures for analysis and design. Use expertise and engineering judgment in carrying out the analysis and design necessary to comply with all requirements. The CDOT SGSM is available to review design assumptions and approaches.

To properly accommodate the guidelines presented herein and to incorporate any other project-specific requirements for design and construction, it may be necessary to modify some CDOT standard specifications or drawing details. Submit all such items to the CDOT SGSM prior to incorporation in the project specifications and drawings.

Additional design requirements are presented in the CDOT *Bridge Design Manual*.

5.1 BRIDGE FOUNDATIONS

Comply with the CDOT *Bridge Design Manual* and the AASHTO *LRFD Bridge Design Specifications* for all aspects of bridge design, unless otherwise specified by CDOT Staff Bridge or the CDOT SGSM.

Bridge foundations for CDOT projects typically consist of driven piles, drilled shafts (also referred to as caissons and piers), or spread footings. Spread footings are generally not considered acceptable at stream crossings.

Geosynthetic Reinforced Soil (GRS) is a type of retaining structure that consists of closely spaced (less than 12 inches) geosynthetic soil reinforcement. Geosynthetic Reinforced Soil – Integrated Bridge System (GRS-IBS) is the application of GRS to construct bridge abutments. Although not routinely used, GRS-IBS may be cost-effective and feasible for sites with relatively minor settlement, limited scour potential, and short span lengths. Refer to the CDOT *Bridge Design Manual* for additional selection considerations and design criteria for GRS-IBS.

The foundation types applicable to a given project depend on anticipated loads and scour depths (where applicable), along with consideration of settlement, downdrag, bearing resistance, lateral resistance, seismic hazards, constructability, and other applicable factors.

5.1.1 Driven Piles

Driven piles generally consist of steel H-pile. Steel pipe piles may also be utilized. Additional design requirements and considerations are presented in the CDOT *Bridge Design Manual*.

5.1.2 Drilled Shafts

Rock-socketed drilled shafts are frequently used in Colorado. Determine axial resistance for the design of rock-socketed drilled shafts in accordance with the AASHTO *LRFD Bridge Design Specifications* and FHWA Report No. FHWA-NHI-18-024 (Brown and others,2018).

For projects where drilled shafts may be proposed, rock coring is required in at least 1/3 of bridge borings (minimum of one boring). Rock coring in bedrock should be performed in conjunction with SPT sampling between core runs or in adjacent borings.

For sites with bedrock N-values typically greater than 100 blows per foot and where rock coring produces suitable core recovery (i.e., samples can be recovered for strength testing, and the rock mass can be characterized to an appropriate degree), evaluate axial resistance using design methods based on the unconfined compressive strength, as described in the AASHTO *LRFD Bridge Design Specifications* and FHWA Report No. FHWA NHI-18-024 (Brown and others, 2018).

For sites with bedrock N-values typically less than 100 blows per foot, the “Soil-Like Claystone” design procedure described in CDOT Research Report CDOT-DTD-R-2003-6 (Abu-Hejleh and others, 2003) may be used as appropriate to assess nominal axial resistance. Use a resistance factor of 0.60 with the “Soil-Like Claystone” design procedure.

5.1.3 Lateral Loads for Deep Foundations

Provide the appropriate parameters for p-y lateral analysis of deep foundations using software such as LPILE or AllPile. Coordinate with CDOT Staff Bridge or the Structural Engineer of Record to determine what software will be used for lateral analysis and provide the appropriate soil/rock parameters.

5.1.4 Load Testing of Deep Foundations

Static load tests may be used to justify higher resistance factors for deep foundations in accordance with the AASHTO *LRFD Bridge Design Specifications*. Account for the following factors in determining whether to use static load testing:

- Cost of testing
- Potential savings resulting from increased resistance factors
- Number of foundations to which load tests will apply
- Group effects that may control available foundation resistance
- Schedule implications and timing of testing (design or construction phase)
- Adaptability of foundation design to account for test results

Evaluate site variability and determine the required number of load tests for each site in accordance with the AASHTO *LRFD Bridge Design Specifications*.

5.2 FOUNDATIONS FOR SIGNS, LIGHTING, AND SIGNALS

Conduct subsurface explorations and testing for foundations of signs, lighting, and signals, as specified in Section 3.4. Refer to the following documents to design foundations for these structures:

- LRFD Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals, 1st Edition (AASHTO, 2015) and all interim revisions.
- Current versions of CDOT M & S Standard Plans.

5.3 EMBANKMENTS AND RETAINING WALLS

Evaluate all new embankment fills, retaining walls and modifications of existing fills for settlement, stability, and other applicable geotechnical considerations. For global stability of embankment slopes and retaining walls, meet the requirements of this GDM. Do not utilize embankment slopes steeper than 2H:1V (horizontal to vertical) without coordination with the Project GEO.

5.3.1 Settlement

Estimate magnitudes and time-rates of anticipated settlements associated with embankments and retaining structures in accordance with AASHTO *LRFD Bridge Design Specifications*. Address the potential for immediate settlements and both primary and secondary consolidation.

For cohesive soils, determine settlement properties (including both elastic and consolidation parameters) using laboratory test results and published correlations with index properties. Consider the potential for unsaturated cohesive soils to transition to a saturated condition and exhibit time-dependent settlement behavior due to compression induced by increased loading from embankments or other structures.

Design mitigation of settlements and displacements so as to not be detrimental to the performance of facilities within and outside the project limits.

5.3.2 Utilities

Evaluate settlement impacts on new and existing utilities, and consider the impacts of abandoned utility lines on settlements.

Design settlement mitigation as necessary to allow for effective operation through the design life of utilities.

If any utility line is to be abandoned, coordinate with applicable design disciplines to abandon the utility such that the utility will not detrimentally impact the performance of the completed facility.

5.3.3 Global Stability

Evaluate global stability of embankments using industry-accepted methodologies and applicable computer software listed in this GDM.

For cohesive soils, determine shear strength parameters used in global stability analyses based on laboratory shear strength testing and published correlations with index properties. Evaluate stability considering undrained and drained shear strengths for cohesive soils. Consider the potential for residual or fully softened conditions to apply, and select appropriate shear strength parameters based on laboratory testing and published correlations.

For granular soils, select shear strength parameters based on laboratory testing, or published correlations with index properties or in-situ test results (e.g. N-values).

Care should be taken with utilizing an artificial cohesion intercept to eliminate shallow slip surfaces for the analysis. As an alternative, adjust the search method to produce appropriate slip surfaces for design and analysis.

For analysis of slope failures or landslides, use residual shear strengths and an effective cohesion of zero for the failure surface.

Determine groundwater levels used in global stability analysis in accordance with Section 3.7. Higher groundwater levels may be appropriate to reflect the design flood water surface elevation of adjacent streams/rivers.

Table 5-1 lists the minimum acceptable factors of safety for global stability of temporary and permanent embankments and retaining walls on CDOT projects.

TABLE 5-1
MINIMUM ACCEPTABLE FACTORS OF SAFETY – GLOBAL STABILITY

Category	Condition	Minimum Factor of Safety
A	Construction	1.3
A	Static Long-Term	1.5 (Retaining Walls) 1.3 (Slopes)
A	Pseudo-Static Seismic	1.1
B	Construction	1.3, unless monitored
B	Static Long-Term	1.3
B	Pseudo-Static Seismic	1.1 (Retaining Walls) Not Required for Slopes

NOTES:
Category A = Slopes and walls where failure or significant deformation will affect adjacent bridges or critical facilities.
Category B = All other slopes and walls.

The factors of safety in Table 5-1 were developed based on the AASHTO *LRFD Bridge Design Specifications* and recommendations contained in the Federal Lands Highway Division (FLHD) *Project Development and Design Manual* (FLHD, 2018).

Exceptions to the factors of safety specified in Table 5-1 may be appropriate in some instances. For example, it may be cost-prohibitive or infeasible to mitigate an existing landslide to a factor of safety of 1.3. Provide justification for use of factors of safety lower than those specified in Table 5-1. If a wall or slope will be monitored, then a lower factor of safety may be acceptable during construction. Monitoring in this case should consist of adhering to a written monitoring plan, and should include methods such as geotechnical instrumentation (e.g. inclinometers, VWPs) or survey monitoring.

Evaluate and recommend appropriate means of meeting the factors of safety listed in Table 5-1. Acceptable means of improving factors of safety include modifying embankment slopes, dimensions, and materials, reinforcing embankment and foundation soils, drainage improvements, and ground improvement. For short-term construction-phase stability deficiencies, evaluate the potential benefits of staged fill placement, using instrumentation to monitor stability and embankment/structure performance.

5.3.4 Permanent Cut Slopes

For permanent cut slopes, meet the minimum factors of safety listed in Table 5-1.

Design of permanent cut slopes should consider runoff of surface water, surficial erosion, and future slope maintenance (e.g., mowing of vegetated slopes). Design of rock cuts shall be overseen and reviewed by CDOT Geohazards Services.

5.3.5 Retaining Walls

Select and design retaining walls in accordance with the CDOT *Bridge Design Manual* and the AASHTO *LRFD Bridge Design Specifications.*

For MSE walls, it is recommended that the wall embedment meet the requirements specified in Table 2 of FHWA Report No. FHWA-HIF-24-002 (Taylor and others, 2023). The embedment depth should be selected based on wall stability, frost depth, and subsurface conditions.

Avoid the use of acute corner MSE walls whenever possible.

5.4 FILL AND OTHER GEOTECHNICAL MATERIALS

Fill and geotechnical materials should be in accordance with the CDOT *Standard Specifications for Road and Bridge Construction.*

5.5 SWELLING AND COLLAPSE-PRONE SOIL/ROCK

Swelling and collapse-prone soil/rock has the potential to adversely affect structures. The Project GEO should adequately investigate and characterize swell-susceptible and collapse-prone soil/rock. As necessary, the Project GEO should provide recommendations to mitigate these hazards. Potential mitigation options include over-excavation beneath shallow footings and retaining structures, chemical stabilization, and the use of deep foundations.

5.6 GEOTECHNICAL SEISMIC DESIGN

Typical geotechnical seismic design requirements are described in this section.

For the 1,033-year seismic event (7% probability of exceedance in 75 years, approximate 1,000-year event) evaluated using the General Procedure (as detailed in the AASHTO *LRFD Bridge Design Specifications* and the AASHTO *Guide Specifications for LRFD Seismic Bridge Design),* determine the mapped probabilistic ground motion parameters for the site latitude and longitude in accordance with the AASHTO *Guide*

Specifications for LRFD Seismic Bridge Design and the AASHTO *LRFD Bridge Design Specifications*. These can be obtained by using the current USGS tools found online at https://www.usgs.gov/natural-hazards/earthquake-hazards/design-ground-motions. Do not use PDF or paper maps, or ZIP code lookup tools, to determine ground motion parameters for CDOT projects.

Note that the AASHTO seismic design criteria are in the process of being updated to Risk Targeted Ground Motion (RTGM) accelerations. A preliminary web-based tool can be located at https://earthquake.usgs.gov/ws/designmaps/aashto-2023/.

5.7 GEOTECHNICAL REPORTS

Geotechnical reports should satisfy the requirements of the report checklist provided in the Appendix. Final reports should be signed and sealed by a Professional Engineer registered in the State of Colorado.

Submit draft geotechnical reports to the CDOT SGSM prior to finalizing the report. Allow a minimum of 10 days for CDOT to review the report. Submit the final report to the CDOT SGSM in electronic PDF format.

5.8 ENGINEERING GEOLOGY SHEETS

Prepare signed and sealed engineering geology sheets for inclusion in the plans for each structure. Include pertinent boring logs and laboratory test results. Use the drawing format provided in CDOT Drawing Worksheet B-GEO-1.

CHAPTER 6. CONSTRUCTION-PHASE SERVICES

Geotechnical conditions encountered during construction may affect the design recommendations developed by the Project GEO. Therefore, it is important for the Project GEO to remain involved during the construction phase of the Project. Refer to the CDOT Standard Specifications for Road and Bridge Construction, the CDOT Field Materials Manual, and applicable project special provisions for additional requirements.

6.1 ROLES AND RESPONSIBILITIES

Engage the Project GEO to provide the following services during construction of the project:

- Confirm compliance with geotechnical designs and recommendations.
- Develop and implement an instrumentation program to measure ground and structure movement, groundwater, vibrations, or other conditions.
- Review conditions encountered during construction and revise recommendations, as appropriate.
- Provide clarification related to geotechnical recommendations and specifications.

Provide construction-phase services in accordance with applicable standards. In some cases, these services are provided by GEOs retained by the Contractor. In such cases, the Project GEO may be requested to review the Contractor GEO's work for compliance with the project contract documents.

6.2 RECORD KEEPING

Maintain a log of all field visits and record all observations and recommendations on a daily field report. If requested, submit field reports to the CDOT SGSM. The daily field report should include logs, data sheets, photographs, notes, and other information collected by the field representative.

6.3 TEMPORARY SHORING AND EXCAVATIONS

Evaluation of temporary shoring and excavations is the responsibility of the Contractor. A Colorado licensed professional engineer must design, sign, and seal all plans and calculations for all temporary excavations and retaining structures. Do not incorporate temporary retaining structures or materials into permanent embankments or retaining structures unless the incorporated structures and materials have been designed, constructed, and tested in accordance with the applicable requirements for the permanent construction.

6.4 DRIVEN PILES

6.4.1 Construction Observation

Where requested, observe pile driving in accordance with the Deep Foundations Institute (DFI) *Inspector's Manual for Driven Pile Foundations* (1997). Note any observed or reported anomalies on the pile driving log.

If diesel hammers are used to drive piles, use an ESaximeter to record the hammer blows and stroke in addition to maintaining a handwritten log. The ESaximeter data (blow count, rate, stroke) can be used by the Project GEO to evaluate pile driving conditions and confirm design assumptions.

6.4.2 Static Load Testing

Conduct or provide oversight of static load tests where required. Use the procedures specified in the AASHTO *LRFD Bridge Design Specifications.* Submit load test results, analyses, and conclusions to the CDOT SGSM.

6.4.3 Dynamic Pile Testing with Signal Matching Analysis

Section 502 of the CDOT *Standard Specifications for Road and Bridge Construction* specifies procedures for driven pile installation and PDA testing with signal matching on CDOT projects.

The CDOT Project Engineer will arrange for PDA testing with signal matching analyses to be conducted by a qualified PDA testing firm. The PDA testing firm is responsible for quality management of its work. The CDOT Project Engineer will coordinate with the CDOT SGSM and the Project GEO to resolve deficiencies in driving resistance determined from PDA testing.

On Design-Build and CMCG Projects, unless otherwise specified by the Project RFP, the Design-Builder or CMGC contractor is responsible for PDA testing and signal matching analyses.

Establish production pile driving criteria based on a pile for which the required driving resistance has been verified by PDA testing and signal matching analysis. The pile driving criteria should specify the minimum blow count and either the hammer energy or the hammer stroke corresponding to the minimum blow count.

If any unusual or otherwise unanticipated pile-driving condition are encountered (including not achieving the minimum tip elevation), notify the Project GEO.

Acceptance of piles based on projected setup is not allowed. Where additional setup is anticipated and is necessary to meet the required driving resistance, conduct PDA testing and signal matching analysis after the setup has occurred.

6.5 DRILLED SHAFTS

6.5.1 Construction Observation

Document drilled shaft construction using CDOT Form 1333. Include a log of concrete placement volume by depth and time.

The following documents provide guidance for drilled shaft inspection:

- Drilled Shaft Inspector's Manual (DFI, 2004).
- Drilled Shafts: Construction Procedures and Design Methods, FHWA GEC No. 10, Report No. FHWA-NHI-18-024 (Brown and others, 2018).

6.5.2 Static Load Testing

Conduct or provide oversight of static load tests where required. Use the procedures specified in the AASHTO *LRFD Bridge Design Specifications*. Submit load test results, analyses, and conclusions to the CDOT SGSM or CDOT Project Engineer.

6.5.3 Integrity Testing

Requirements for integrity testing of drilled shafts, including procedures for addressing anomalies indicated by testing, are provided in the CDOT *Bridge Design Manual*.

6.6 MONITORING AND INSTRUMENTATION

The primary objectives of a construction instrumentation program are to:

- Indicate if construction activities are producing ground movement or vibration within specified limits.
- Provide early warning of adverse trends.
- Provide the project engineers and Contractor with sufficient data to determine the source of unanticipated ground movement and to plan remedial measures.
- Determine when remedial measures need to be implemented to protect structures and utilities.

- Monitor the degree to which these protective or remedial measures are limiting damage and to provide early warning when alternative means of protection are necessary.
- Provide data for settling legal disputes either between the Contractor and CDOT or with owners of adjacent facilities.
- Monitor the performance of temporary construction structures.
- Confirm design assumptions and provide data that could improve future designs.

As appropriate, recommend preconstruction surveys and the monitoring of vibrations and settlements at structures, utilities, properties, and facilities potentially impacted by vibrations or settlement caused by construction activities. Instrumentation programs may include monitoring of:

- Settlement of newly placed embankment fills.
- Horizontal and vertical movement of existing structures and utilities adjacent to excavations and embankments.
- Vibration levels as result of construction activities.
- Opening of cracks in adjacent existing facilities.
- Structural condition surveys of adjacent existing facilities.
- Other measurements indicating behavior of structures or the ground in response to construction activities.

Guidance for instrumentation programs is provided in the following sections.

6.6.1 Geotechnical Instrumentation Plan

The types, numbers, and locations of the instruments depend on the Contractor's proposed construction methods, sequence, and durations, as well as on the proximity, characteristics, and conditions of adjacent facilities. As appropriate, develop an instrumentation plan to monitor parameters including settlements, slope/wall stability and movements, movements and vibrations of nearby structures, groundwater levels and flows, pore pressures (as applicable), and other geotechnical parameters during construction. Develop and implement plans to mitigate these impacts, both within and outside the planned Right-of-Way. Where long-term settlement of embankments or facilities may occur, provide long-term settlement instrumentation arrays in secure locations.

The instrumentation plan may include the following:

- A description of the proposed instrumentation, including parameters to be monitored, types of instruments to be used, their specific purposes, and typical duration and frequency of monitoring.
- Specific criteria for identifying locations requiring each type of instrument.
- Alert, alarm, or other action levels for monitored displacements or other critical measurements.
- Identification of the anticipated construction limits and the locations of adjacent features that may be affected by the proposed construction.
- Typical construction drawings showing details for each type of instrument to be used.
- A Special Provision for each type of instrument.
- Details of the outside survey control and procedures that will be used to monitor and account for displacements of instrumentation reference/readout points, such as settlement platform readout boxes.
- Generalized details and location information for long-term instruments, points, targets, or similar devices that will allow long-term monitoring of displacements after project completion.
- Where instruments are used to monitor stability during construction, the acceptable magnitudes and rates of change in the parameters measured by the instruments, and details of an action plan to be implemented in the event the acceptable levels and/or rates are exceeded.
- Construction-phase and long-term instrumentation in sufficient quantity and type to demonstrate compliance with all requirements of the project including replacement or redundancy in case of construction damage.
- Construction plan sheets showing the locations, types, and other applicable parameters (e.g., depths) of all instrumentation to be installed.
- Redundancy in instrumentation of features critical to public safety.
- Transmittal and delivery of data/readings to CDOT.

6.6.2 Monitoring Frequency and Baseline Measurements

Monitoring frequency would vary widely for each of the instrument systems and for each category of construction. Obtain initial measurements in advance of construction so baseline data can be developed.

6.6.3 Action Levels

Audible or visual alarm systems could be added to the instrumentation systems to alert the Contractor and CDOT when displacement measurements have reached pre-set limits. These systems can be programmed to various action levels, depending on the established design tolerances. A clear communication chain should also be established so that if these action levels are reached, procedures for implementation of contingency and emergency plans can be put into action in a timely manner.

6.6.4 Pre-Construction Surveys

Before the beginning of instrumentation or construction, an inspection survey of structures and utilities within the potential influence of the proposed construction may be undertaken. The survey may document the existing condition of each facility with diagrams, sketches, photographs, and video recordings. These records should include the length and width of existing cracks, number of cracks, locations of water marks, condition of door and window jambs, condition of paint, etc.

6.6.5 Vibration Monitoring

Use vibration attenuation relationships published by governmental agencies, applicable equipment manufacturers, and other entities to estimate the zones where vibrations caused by the project may impact adjacent facilities.

Background vibrations should be recorded at representative ground locations before the start of construction

6.6.6 Settlement Monitoring

Settlement monitoring is typically performed by using monitoring points that are surveyed using optical survey equipment. The points may consist of targets mounted on structures, rods embedded in the ground, or other points that can be consistently and reliably surveyed. Settlement monitoring may be implemented during staged construction or to monitor structures located relatively closely to excavations.

6.6.7 Lateral Movement Monitoring

Lateral movement monitoring may be completed for shoring or structures in close proximity to excavations. Potential methods for lateral movement monitoring include:

- **Survey Monitoring Points:** Monitoring points (e.g. targets, nails, etc.) can be placed on shoring, utilities, structures, or in the ground to monitor lateral movement over time (also used for vertical movement monitoring). The points are measured using optical survey equipment at regular intervals during excavation.

- **Inclinometers:** Inclinometers are instruments that monitor lateral displacements. Inclinometers may be used to monitor slope stability and performance. Near sensitive facilities, inclinometers may also be used to monitor ground deformation caused by construction of embankments.

6.6.8 Other Instruments

Based on the proposed construction and sensitivity of existing structures, other instruments may also be used on CDOT Projects:

- **Crack Monitors:** gages that measure cracks and joint openings in structures or rock. It is recommended that these gages be installed on existing cracks and sensitive joints of adjacent existing structures during the preconstruction survey or other time prior to construction. The gages can then be used during or after construction to monitor potential change.
- **Monitoring Wells/VWPs** (see Section 3.7): existing or new wells/VWPs can be used to observe groundwater level change during construction dewatering.
- **Liquid Level Gages:** a system used to measure deformation along a linear feature such as a utility, tunnel, or other long structure.

6.6.9 Data Reduction and Reporting

All data should be collected, reduced, and presented in useful, legible, and well labeled plots in U.S. Customary units. The plots should include construction information on construction activities associated with the monitoring program. Plots might also include geotechnical data, including soil layers and groundwater levels, or other features which may impact the interpretation of the data.

In some instances, an automated data acquisition system (ADAS) may be used to obtain automated readings and to transmit the data electronically. For projects where an ADAS is utilized, coordinate with the CDOT SGSM to configure the ADAS to transmit data to the CDOT web-based monitoring service.

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Appendix
Geotechnical Report Checklist

APPENDIX: GEOTECHNICAL REPORT CHECKLIST

The following checklists are provided to assist a reviewer with geotechnical reports concerning CDOT projects. The checklists are only intended as guides, are not all-inclusive, and not a replacement for a lack of geotechnical experience or knowledge. The checklists are modified from the Federal Highway Administration (FHWA) Publication No. FHWA ED-88-053, *Checklist and Guidelines for Review of Geotechnical Reports and Preliminary Plans and Specifications.*

A. **General Report Information** – Outlines the general geotechnical information that should be in all reports. If there is information missing, the report author should be consulted.

B. **Foundations** – Including Checklist A, the report should include recommendations for all appropriate foundation types and provide both LRFD and ASD parameters as applicable. If bridge approach embankments are to be raised or widened, foundation downdrag and embankment time-dependent settlement need to be addressed (preload, surcharge, wickdrain, etc.).

E. **Retaining Structures** – Including Checklist A, the report should include recommendations for all appropriate foundation types.

F. **Landslides and Slope Stability** – Including Checklist A, the report should include general exploration techniques, monitoring results, and remedial options and their associated estimated costs.

A. GENERAL REPORT INFORMATION	YES	NO	N/A
Is there a general project scope and purpose?	☐	☐	☐
Is there a project location description included or a vicinity map?	☐	☐	☐
Is there a detailed description of the field investigation and procedures?	☐	☐	☐
Is there a detailed description of:			
Soil characteristics (density, color, depth/elevation, etc.)?	☐	☐	☐
Bedrock characteristics (hardness, jointing, depth/elevation, etc.)?	☐	☐	☐
Groundwater (depth/elevation and flow direction)?	☐	☐	☐
Is a geology/profile sheet presented?	☐	☐	☐
Is a legend provided that is easy to use and informative?	☐	☐	☐
Is laboratory data presented?	☐	☐	☐
Does it correlate with results discussed in text?	☐	☐	☐
Are groundwater elevations presented?	☐	☐	☐
Is geologic information provided?	☐	☐	☐
Does it correlate with boring logs (N-values, core vs. auger, unit descriptions, elevations, numbering, etc.)?	☐	☐	☐
Are exploration locations plotted (boring, penetrometer, seismic, etc.)?	☐	☐	☐
Do exploration locations meet requirements in the GDM?	☐	☐	☐
Did exploration locations go deep enough to provide the needed design information?	☐	☐	☐
Are exploration logs (boring, penetrometer, etc.) presented?	☐	☐	☐
Are geologic units presented visually and described in detail?	☐	☐	☐
Are sample types, labels, and depths reported?	☐	☐	☐
Is exploration method reported (wireline, auger, penetrometer, etc.)?	☐	☐	☐
Are testing data presented (blow counts, recovery, RQD, etc.)?	☐	☐	☐
Are laboratory results presented and discussed?	☐	☐	☐
Were samples analyzed for gradation, Atterberg limits, and moisture content to verify field visual descriptions?	☐	☐	☐
Were samples analyzed for compressive strength, shear strength, consolidation, swell/collapse, etc., as necessary for the project type, and are these results discussed?	☐	☐	☐

B.	FOUNDATIONS – DRIVEN PILES	YES	NO	N/A
Is a recommended pile type given along with reasoning for choice?		☐	☐	☐
	Do you agree with recommended pile type?	☐	☐	☐
Are bearing capacities provided?		☐	☐	☐
	Are bearing capacities reasonable?	☐	☐	☐
Are estimated minimum tip elevations provided along with reasoning?		☐	☐	☐
For friction bearing piles, is a bearing capacity vs. depth chart/table provided?		☐	☐	☐
For boulder/cobble units, has driving been analyzed to verify tip elevation and determine if there will be any pile damage?		☐	☐	☐
Is minimum penetration into bedrock provided for end bearing piles?		☐	☐	☐
Is bedrock elevation provided?		☐	☐	☐
Is a minimum pile spacing recommended?		☐	☐	☐
For driving in difficult areas (boulders, cobble, etc.) is predrilling, jetting, tip protection, etc., recommended?		☐	☐	☐
Has lateral load analysis been performed or are analysis parameters provided?		☐	☐	☐
Is PDA required per CDOT Standard Special Provision 502?		☐	☐	☐
Are resistance factors provided per AASHTO LRFD Bridge Design Specifications?		☐	☐	☐
Is hammer size/driving criteria provided?		☐	☐	☐
Is predrilling recommended and does evidence support it?		☐	☐	☐
Are materials testing results for corrosion provided (sulfate, resistivity, pH, chlorides)?		☐	☐	☐
	Do you agree with corrosion protection recommendations?	☐	☐	☐
For piles in scour areas, have the piles been designed so the full pile capacity is below scour depth?		☐	☐	☐
For large projects, is a load test recommended?		☐	☐	☐
	Do you agree?	☐	☐	☐
Have pile driving effects been considered (damage to homes and noise in urban areas, environmental impacts)?		☐	☐	☐

Has the site been analyzed for AASHTO Specifications for LRFD
Seismic Bridge Design? .... ☐.......... ☐ .... ☐

Is the site classified (letter) along with a seismic zone (number)? .... ☐.......... ☐ .... ☐

Do you agree? .... ☐.......... ☐ .... ☐

Are spectral acceleration parameters provided? .... ☐.......... ☐ .... ☐

For large projects, is a load test recommended? .... ☐.......... ☐ .... ☐

C. FOUNDATIONS – DRILLED SHAFT (CAISSON)	YES	NO	N/A
Is bedrock elevation provided?	☐	☐	☐
Based on materials and drilling, is casing or slurry required to maintain hole stability?	☐	☐	☐
Based on groundwater data, could dewatering or tremie concrete placement be required per CDOT Standard Specification 503?	☐	☐	☐
Are capacities (end bearing and side shear) provided?	☐	☐	☐
Are capacities reasonable?	☐	☐	☐
Are estimated minimum tip elevations provided along with reasoning?	☐	☐	☐
Will boulders be encountered and is this addressed?	☐	☐	☐
If yes, are shafts appropriate for site?	☐	☐	☐
For friction bearing shafts, is a capacity vs. depth chart/table provided?	☐	☐	☐
Is minimum penetration into bedrock provided for end bearing shafts?	☐	☐	☐
Has lateral load analysis been performed or are analysis parameters provided?	☐	☐	☐
Are resistance factors provided per AASHTO LRFD Bridge Design Specifications?	☐	☐	☐
Are materials testing results for corrosion provided (sulfate, resistivity, pH, chlorides?	☐	☐	☐
Do you agree with corrosion protection recommendations?	☐	☐	☐
For shafts in scour areas, have the shafts been designed so the full shaft capacity is below scour depth?	☐	☐	☐
For large projects, is a load test recommended?	☐	☐	☐
Do you agree?	☐	☐	☐
Has the site been analyzed for AASHTO Specifications for LRFD Seismic Bridge Design?	☐	☐	☐
Is the site classified (letter) along with a seismic zone (number)?	☐	☐	☐
Do you agree?	☐	☐	☐
Are spectral acceleration parameters provided?	☐	☐	☐

D. FOUNDATIONS – SPREAD FOOTINGS	YES	NO	N/A
Is bearing capacity vs. depth/elevation vs. footing size provided?	☐	☐	☐
If not, is there a recommended depth/elevation, footing size, and bearing capacity?	☐	☐	☐
Are bearing capacities reasonable?	☐	☐	☐
Is base sliding resistance provided?			
Are materials testing results for corrosion provided (sulfate, resistivity, pH, chlorides)?	☐	☐	☐
Do you agree with corrosion protection recommendations?	☐	☐	☐
Are subexcavation and replacement recommendations provided?	☐	☐	☐
Based on groundwater data, is construction dewatering required and discussed?	☐	☐	☐
Is a minimum depth of embedment recommended for frost protection?	☐	☐	☐
Has settlement been evaluated using parameters based on lab testing, and estimated values and time reported?	☐	☐	☐
Are settlement values reasonable?	☐	☐	☐
Has global stability been evaluated using shear strengths based on lab testing?	☐	☐	☐
Have excavation parameters (shoring, sloping, sheeting, etc.) been discussed?	☐	☐	☐
Has the site been analyzed for AASHTO Specifications for LRFD Seismic Bridge Design)?	☐	☐	☐
Is the site classified (letter) along with a seismic zone (number)?	☐	☐	☐
Do you agree?	☐	☐	☐
Are spectral acceleration parameters provided?	☐	☐	☐

E. RETAINING STRUCTURES	YES	NO	N/A
Is recommended wall type appropriate based on site conditions?	☐	☐	☐
Has settlement been evaluated using parameters based on lab testing, and estimated values and time reported?	☐	☐	☐
Are settlement values reasonable, i.e., within limits of wall design?	☐	☐	☐
Has groundwater been considered (drainage, fluctuations, stability, etc.)?			
Are materials testing results for corrosion provided (sulfate, resistivity, pH, chlorides)?	☐	☐	☐
Do you agree with corrosion protection recommendations?	☐	☐	☐
For cut walls, have excavation recommendations been provided (shoring, sloping, sheeting, dewatering, ripping, etc.)?	☐	☐	☐
Have backfill parameters been discussed (class, compaction, lift placement, etc.)?	☐	☐	☐
Are values provided for bearing capacities, earth pressures, and base sliding resistance?	☐	☐	☐
Are foundation base elevations provided?	☐	☐	☐
Is foundation type appropriate based on site conditions?	☐	☐	☐
Is a bearing capacity vs. depth elevation vs. footing size provided?	☐	☐	☐
If not, is there a recommended depth/elevation, footing size, and bearing capacity?	☐	☐	☐
Are bearing capacities reasonable?	☐	☐	☐
Soil parameters provided (unit weight, friction angle, cohesion, etc.)?	☐	☐	☐
Has global stability been evaluated?	☐	☐	☐
Are shear strengths based on lab testing?	☐	☐	☐
Is the factor of safety acceptable?	☐	☐	☐
For soil nail and tieback walls, are estimated bond strengths reasonable?	☐	☐	☐

F. LANDSLIDE AND SLOPE STABILITY	YES	NO	N/A
Is a scaled cross-section provided showing slide characteristics (soil profile, water table, soil unit weights, inclinometers, failure plane, etc.)?	☐	☐	☐
Were sufficient monitoring points (inclinometers, piezometers, etc.), installed to properly characterize the slide?	☐	☐	☐
Is history of the slide area summarized including movement, maintenance work and costs, and any corrective measures taken?	☐	☐	☐
Has modeling been performed to evaluate triggering mechanisms and possible remedial measures?	☐	☐	☐
Are detailed slide features (ground surface cracks, headscarp, toe bulge, etc.) shown on the site plan?	☐	☐	☐
For an active slide, was soil strength along the slide failure plane back-calculated using a F.S. = 1.0 at the time of failure?	☐	☐	☐
For an existing slide, are residual shear strengths used?	☐	☐	☐
Were remedial options discussed?	☐	☐	☐
Cross-section of each proposed alternative?	☐	☐	☐
Estimated safety factor of each proposed alternative?	☐	☐	☐
Is the safety factor at or above 1.3?	☐	☐	☐
Estimated cost of each proposed alternative?	☐	☐	☐
Advantages and disadvantages of each proposed alternative?	☐	☐	☐
If horizontal drains are proposed as part of slide correction, has subsurface investigation located definite water-bearing strata that can be tapped with horizontal drains?	☐	☐	☐
If a toe berm is proposed to remediate the slide, has field exploration confirmed that the slide toe does not extend beyond the proposed toe berm?	☐	☐	☐
Where proposed remediation requires excavation into a slide, has the construction backslope safety factor with open excavation been determined?	☐	☐	☐
Have seasonal fluctuations of groundwater table been considered?	☐	☐	☐
Is stability of excavation backslope to be monitored?	☐	☐	☐
Are special construction features, techniques, and materials described and specified?	☐	☐	☐