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New in this revision (older revisions addressed in 6.0 Record of Revisions)

Incorporation of NQA-1 Subpart 2.20 per SD330, graded approach for nuclear and non-nuclear structures. Added section regarding ML-4 structures that do not require geotechnical investigations. Clarified that geotechnical calculations, analyses, and reports shall be reviewed and accepted by LANL. Provided additional guidance for selecting the depth of boreholes and determination of surface deformation due to Quaternary faults.

Please contact the Structural Standards POC for interpretation, variance, and upkeep issues.

Section IV – GEOTECHNICAL INVESTIGATIONS

NOTE: Use this Section IV together with Section I, *General Criteria*, which includes definitions of many acronyms and terms herein, including GIP (meaning geotechnical investigation plan).

1.0 GENERAL

1.1 Applicability

A. This section is applicable to all Los Alamos National Laboratory (LANL) projects where structures, systems, and components (SSC) being constructed, either supporting or are supported by soil.

B. A geotechnical investigation is required to determine site-specific surface and subsurface soils, geology and seismology conditions that might affect the safety, design, construction, and execution of a project, such as: (Requirement 5-4001)

1. For new construction – all new SSCs.
2. For new paving areas to be utilized by vehicular traffic.
3. Existing SSCs – normally applicable to all LANL modification projects where[1]:
   a. The modification creates a condition outside of the scope considered in the original design which significantly (1) increases the demand the SSC imposes on the soil, (2) increases the demand the soil imposes on the SSC, or (3) reduces the capacity of the SSC to resist demand by the soil, and
   b. The failure of the SSC foundation could lead to either 1) serious injury or loss of life of personnel, or 2) loss of function critical to mission or program needs.
4. Existing SSCs with failing or failed existing foundations.[2]

Exception: LANL Building Official (LBO) is permitted to waive the requirement for a geotechnical investigation per IBC Section 1803.2.[3]

C. Geotechnical investigations are not required (i) if geotechnical parameters based on existing geotechnical report(s) for the area of interest or nearby structures are justified to LBO, or (ii) if presumptive load-bearing values in accordance with IBC Section 1806 are used for the following ML-4 RC-I or II structures (or similar structures with Structural Standards and LBO written permission):

1. New pedestrian sidewalks and paved areas that are not utilized by vehicular traffic.
2. Temporary facilities such as transportables or structures utilized for temporary construction or remediation purposes.

[1] Geotechnical investigations for existing SSCs are often complex, expensive, time consuming and face significant challenges due to the constrains imposed by the existing SSCs (e.g., access or disruption to operations). Therefore, the need and value of such investigation must be carefully considered and justified before proceeding.
[2] Failures of existing foundations are often due to local environment changes, water leaks, new adjacent construction work (e.g., piling or excavation), load increases, etc. Such possible failure causes should be examined before proceeding with the geotechnical investigation.
[3] Waiver requests must be submitted using Form 2137, CoE Request for Variance or Alternate Method.

3. "Prefab" structures listed in ESM Chapter 16 Section IBC-GEN *(Rev. 12, Table Prefab-1*).
4. Retaining walls 4 ft. or less in height measured from the bottom of the footing to the top of the wall, unless used for supporting a surcharge.
5. Parking lot light poles (IBC 2021 Section 1807.3).

1.2 Graded Approach

A. The graded approach, based on Management Level (ML) and Seismic Design Criteria (SDC), is summarized below. (Requirement 5-4002)

Project involves…	**Requirements**
ML-3 and ML-4 SSCs	as graded in this document[4]
SDC-1 and 2 SSCs	IBC Section 1803 and DOE-STD-1020-2016, Section 3.3.2 as modified by this Chapter and this Section IV
New ML-1 and ML-2 SSCs and "major modifications" (a defined term) thereto (hereafter referred to only as ML-1/2)	ASME NQA-1-2008/NQA-1a-2009 [Part II, Subpart 2.20 as applied by this document] and this document
New SDC-3 SSCs for nonreactor nuclear facilities and major modifications thereto	IBC and DOE-STD-1020-2016 Sections 3.3.1 and 3.4

B. Where conflicts occur between requirements, the more stringent shall apply.

C. The scale of the geotechnical investigation is driven by the geotechnical engineering properties required by the designer of the SSC and the complexity/variability of the soil/subsurface conditions encountered at the site. This ESM section provides guidelines for sampling and testing; however, it does not prescribe the sampling and tests that need to be performed due to the variability in the information required from project to project. The extent of sampling and testing required shall be determined on a project-by-project basis.

D. For all geotechnical investigations, a Geotechnical Investigation Plan (GIP) shall be developed by a registered design professional specializing in the field of geotechnical engineering, based on the scope of the project, knowledge of the subsurface conditions in the vicinity of the site either through experience or nearby existing geotechnical reports. The GIP shall describe the proposed test pits, trenches, shafts, excavations, borings and the suite of both in-situ and laboratory tests that will be performed in order to adequately define the geotechnical information needed by the project.[5] (Requirement 5-4003)

E. All geotechnical investigations, evaluations, and reports (including soil borings, test pits, geophysical surveys, soil sampling, in situ and laboratory testing) shall be per ASTM D420 and other applicable ASTM standards to the fullest practical extent. (Requirement 5-4004)

[4] For ML-3 this incorporates the ASME NQA-1-2008/NQA-1a-2009, Part II, Subpart 2.20, graded approach described in Table B-2 of SD330 r13 (p79).
[5] The Geotechnical investigation plan should be flexible and modified as needed to adjust for unexpected or significant variations in subsurface conditions encountered during the site exploration.

1.3 Quality Requirements

Quality assurance requirements are substantially based on NQA-1, Subpart 2.20 which basically requires that geotechnical investigations be:

1. *Planned to provide the required information,*
2. *Performed according to approved procedures or work instructions,*
3. *Performed by qualified workers,*
4. *Verified to ensure items 2 and 3 are fulfilled, and*
5. *Documented adequately to demonstrate that items 1, 2, 3, and 4 have been fulfilled.*

These five high level requirements are good practice for all geotechnical investigations, regardless of the project Management Level. Therefore, quality requirements will have similarities between Management Levels. Sections 1.3A through 1.3C discuss some of the QA requirements that are unique to certain Management Levels.

A. Planning Requirements — GIP Preparation, Review, and Approval

Projects required to have a geotechnical investigation must submit a Geotechnical Investigation Plan (GIP) for acceptance by LANL SME review and acceptance prior to the field investigation. GIP content is addressed in Section IV.1.4 (Requirement 5-4005).

1. ML-3/4 SSCs – The GIP must be prepared, and its execution overseen, by a Professional Engineer Licensed in the State of New Mexico and specializing in the field of geotechnical engineering. The LANL project engineer must engage a structural SME to review prior to accepting/proceeding with the investigation.
2. ML-1/2 SSCs– The GIP must be prepared, and its execution overseen by a Professional Engineer Licensed in the State of New Mexico with previous experience in the geotechnical aspects of the design of the type (i.e., non-reactor nuclear, biological, accelerators, etc.) of facility being considered.
    a. The LANL project engineer must engage the Structural Chapter POC who must concur with the intended SME(s) reviewer(s) prior to acceptance/ proceeding.
    b. QA review is required prior to acceptance/proceeding with the field investigation.

B. Qualification Requirements

Personnel directing the overall geotechnical investigation program shall be qualified engineers and geologists specializing in the field of geotechnical engineering, with demonstrated experience and competence in the subsurface investigations described Section IV.2.0, and familiar with the purpose, conditions, and requirements of the geotechnical investigation program, in addition to the following requirements. (Requirement 5-4006)

1. Geotechnical testing laboratory and personnel shall meet the qualification and quality requirements of ASTM D3740, *Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction*.

2. All foundation and soils investigations shall meet the requirements of ASTM D420, *Standard Guide to Site Characterization for Engineering Design and Construction Purposes.*

3. Further qualification requirements:

ML-4 SSCs	As required by ESM Chapter 16, testing firms performing geotechnical field or lab analysis work shall be listed on the ESM Chapter 16 "Listing of Approved IBC Testing Agencies and Fabricators." *This normally requires AASHTO re:source accreditation (when available) for the ASTM procedures being used.*
ML-3 SSCs	Same requirement as above. In addition, the organization that conducts the field exploration activities inherent to a subsurface investigation shall be controlled by a QA program. This organization shall be responsible for establishing and implementing a documented QA program, and shall furnish the necessary resources such as personnel, equipment, procedures and instructions, and other services necessary to implement the requirements of the QA program.
ML-1/2 SSCs	Same requirements as above. In addition, unless Subcontractor services are dedicated (CGD) per ASME NQA-1, Part II, Subpart 2.14, firms performing investigations are required to establish and implement an ASME NQA-1 compliant QA Plan (and be listed for ML-1/2 work on LANL's IESL when LANL procures).

C. Verification Requirements

Verification refers to the checks made by those not performing the work to ensure the requirements of the plan are being implemented. This is to verify the right procedure is specified, and that the procedure is being followed, by trained personnel, using the proper equipment as follows. (Requirement 5-4007)

1. ML-3/ML-4 SSCs

   a. For each process for which documentation is required, the documents shall contain the signature and date of the preparer or initiator and the signature and date of a checker and approver. The checker cannot be the person who performed the work but may be a person involved in the work.

   b. Audits or surveillances may be conducted by LANL if deemed appropriate for the work being performed.

   c. Calculations, analyses, and reports must be reviewed and accepted by LANL.

2. ML-1/ML-2 SSCs

   a. In addition to the requirement for checkers and approvers for ML-3/ML-4 SSCs, checking and verifying of the GIP, field, laboratory, and engineering activities shall be per ASME NQA-1, Part II, Subpart 2.20, Section 300, *Verification Requirements*.

1.4 GIP Content

The GIP shall, at a minimum, include the following information. (Requirement 5-4008)

A. A brief description of the purpose of the investigation, the proposed SSC(s) and the geotechnical engineering parameters and recommendations required for the design of the facility.

B. The proposed personnel in responsible charge of the investigation including any subcontractors used to perform field or laboratory work.

C. A scaled plot showing the project area, with the proposed location of any SSCs, and the proposed location of the field exploration borings (including proposed or anticipated depth), tests, samples, test pits and/or geophysical surveys. The location of the items on the plot shall be tied to some type of benchmark which can be used to accurately locate the exploration points in the field relative to the actual location of the SSC. (See part 2.1 of this section.)

D. A description of the field exploration necessary to obtain data or samples needed to derive the required engineering parameters and recommendations. Each field exploration process (e.g., geophysical survey, boring, testing, sampling, sample handling) shall reference the applicable ASTM procedure or company specific written work instruction. Include examples of field log forms.

E. A description of the laboratory testing necessary to obtain the required engineering parameters. Each laboratory test shall reference an applicable ASTM procedure or company specific written work instruction.

F. A description of the geotechnical analyses and/or calculations necessary to provide the required engineering parameters.

G. An outline of the proposed geotechnical engineering report.

H. GIPs for ML-3 and ML-4 SSCs shall meet the requirements of ASTM D420 and the IBC including LANL amendments (*at time of writing, these Section II amendments include changes to 1803.5.12 regarding determination of dynamic seismic lateral earth pressures and 1809.13 regarding footing seismic ties.)*

I. GIPs for ML-3 SSCs shall also include:

   a. Identification of engineering data required for design.

   b. Specification of suitable field and laboratory testing equipment

   c. Definition of required records and documentation[6].

J. GIPs shall meet the requirements of DOE-STD-1020-2016 Section 3.3.1 (for SDC-3) and Section 3.3.2 (for SDC-1 and 2). GIPs for ML-1/ML-2 SSCs shall include additional information required by ASME NQA-1, Part II, Subpart 2.20, Paragraph 201, *Planning*. In addition, at time of writing, ESM Ch. 5 Section III discusses geotechnical requirements under the Lateral Soil Pressure Loads (H) and Foundation Design headings.

The GIP format and layout should be concise, avoiding the inclusion of excessive verbiage and attachments. ASTM and other nationally recognized procedures need only be referenced and do not need to be submitted. Company specific work instructions shall be submitted with the GIP for acceptance by LANL. Justification shall be provided when a company specific work instruction is used for a process covered by an existing ASTM procedure.

Proposed deviations from the accepted GIP shall be submitted in writing by addendum to the original plan for review and acceptance by the LANL project engineer and original SME reviewers prior to performing work affected by the change. All revisions and changes to company specific work instructions and procedures shall be submitted as deviations.

[6] Statement is based on SD330, Table B-2 NQA-1 Requirements for Part II. These requirements do not apply to ML-4 structures housing ML-3 SSCs.

1.5 Geology at LANL

A. Geologic Environment

A majority of LANL is situated in a geologic setting of layered volcanic deposits of tuff. *The following reports are excellent resources for information regarding the structural geology. These reports are available from the LANL Research Library website and may be useful in planning a geotechnical investigation.*

1. *Broxton, D.E. and Reneau, S.L., 1995. "Stratigraphic Nomenclature of the Bandelier Tuff for the Environmental Restoration Project at Los Alamos National Laboratory", Report LA-13010-MS, Los Alamos National Laboratory, Los Alamos, NM.*
2. *Gardner, J.N. et al., 1999. "Structural Geology of the Northwestern Portion of Los Alamos National Laboratory, Rio Grande Rift, New Mexico: Implications for Seismic Surface Rupture Potential from TA-3 to TA-55", Report LA-13589-MS, Los Alamos National Laboratory, Los Alamos, NM.*
3. *Olig, S et al., 2001. "Probabilistic seismic hazard analysis for surface fault displacement at TA-16 Los Alamos National Laboratory". Report LA-UR-01-1957, Los Alamos National Laboratory, Los Alamos, NM.*

B. Conceptual Design Values

Table IV-1 provides geotechnical engineering parameter values that may be used for conceptual design. These are based on previous investigations at LANL. Only values for the upper tuff layers, in which foundations are likely to bear, have been provided. These values are provided for the purpose of planning and bidding and are not to be used as final design values unless supported by a project-specific investigation.

Table IV-1: Conceptual Design Values

Tuff Unit	Moist Unit Weight, pcf[1]	Friction Angle, ϕ, degrees[2]	Apparent Cohesion, c, psi[2]	Unconfined Compressive Strength, psi[2]	Shear Wave Velocity (ft/sec)[3]	Modulus of Elasticity, ksi (E) [2]	Poisson's Ratio[1]
Recompacted tuff fill	114	32	0	N/A	1050	9.5	0.3
Qbt4	76	33	4	262	1000	95	0.24
Qbt3U	101	45	7	585	1640	286	0.16
Qbt3L	89	33	13	20	1050	5.8	0.38
Qbt2	119	60	67	2248	2450	1030	0.24

Notes:

[1] Geotechnical Engineering Report Chemistry and Metallurgy Research Facility Replacement (CMRR) Project, Rev. 0, May 25, 2007, Tables VIII-2a and 2b.

[2] Properties shown are believed to be conservative based on previous investigations at LANL.

[3] Table VIII-3b of CMRR document cited in note 1.

2.0 FIELD EXPLORATIONS

2.1 Survey Control

A. All field exploration elements (e.g., borings, test pits, trenches, shafts, excavations, in situ testing, geophysical surveys) shall be laid out according to the GIP based on an official benchmark. Coordinate systems and benchmarks shall conform to the

requirements of the LANL Engineering Standards Manual Chapter 3- *Civil*, Section G10-30GEN General Requirements (*Part 5.0-Surveying*). Surveying for ML-1/ML-2 shall also meet the requirements of ASME NQA-1, Part II, Subpart 2.20, Paragraph 404, *Surveying Requirements*. (Requirement 5-4009)

2.2 Boring Methods

To obtain soil samples of suitable quality, the boring method must be compatible with the soil and groundwater conditions. The following guidelines shall be followed to define the type of borings required for the geotechnical investigation (Requirement 5-4010)

A. All procedures to be used to advance and maintain the hole, take and protect samples shall satisfy the requirements of ASTM D420, *Standard Guide for Site Characterization for Engineering Design and Construction Purposes; and should be clearly described and included in the GIP before the onset of the exploration program*.

B. Unless otherwise specified in the GIP, instructions, or procedures, borings shall be advanced in such a manner as to satisfy the requirements of ASTM D 1452, ASTM D 1586, ASTM D 1587, or other accepted standards.

C. Site characterization borings for seismic-related hazards shall meet the requirements of DOE-STD-1020-2016 Section 3.3.1 (for SDC-3 SSCs) and Section 3.3.2 (for SDC-1 and 2 SSCs).

D. Casing or viscous drilling fluid can be used to advance the borings if there is danger of borehole collapse. The type of casing shall consider the compatibility with any required subsequent geophysical measurements.

E. If perched or groundwater is encountered, provide the stabilized groundwater elevation with its anticipated variation and the causes for such variation.

2.3 Spacing of Borings

The location and frequency of sampling depends on the type and critical nature of the structure, the soil and rock formations, the known variability in stratification, and the foundation loads. The following guidelines shall be followed to define the number of borings required for the geotechnical investigation (Requirement 5-4011).

A. A minimum of three (3) borings is required for a proposed geotechnical investigation.

B. For new construction utilizing shallow foundations (e.g., footings, spread footings, mat foundation), borings are required approximately every 2,500 square feet (50 ft. by 50 ft. grid) across the plan area of the SSC or as identified in the GIP. The plan area to be considered in the investigation includes the footprint of the facility together with sufficient area outside the building footprint within the zone of influence of the foundation. *One boring should be provided at each heavily loaded area of the SSC*.

C. The spacing of borings can be increased to allow for one (1) boring per 10,000 square feet (i.e., spacing at 100' x 100')[7] of building footprint area, provided sufficient justification is provided for the reduced scope of the investigation. This justification shall be provided in the GIP for LANL approval. Items such as facility area, other geotechnical information available for the site, whether the facility will be founded on rock or soil,

[7] As a guide, a minimum of three boreholes should be drilled for a building area of about 2500 ft^2 and about five for a building area of about 10,000 ft^2. For building areas greater than 10000 ft^2, one additional borehole is recommended every 10000 ft^2. For additional guidelines refer to Chapter 3 of Budhu, M. (2010). Soil mechanics and foundations. John Wiley & Sons.

uniformity of material properties encountered across the plan area and average design foundation pressures need to be evaluated to justify the increased spacing.

D. For facilities using heavily loaded caissons or shafts, one boring shall be provided at each caisson location.

2.4 Depth of Borings

The depth of exploration depends on the size and type of the facility foundation and shall be sufficient to assure that the supporting soil/rock has sufficient bearing capacity to provide adequate safety factor against foundation failure and adequate stiffness to minimize settlements under the design loads. In general, the following guidelines shall be followed. (Requirement 5-4012)

A. The depth of borings for surface foundations (e.g., footings, spread footings, mat foundation) shall be based on the area of influence of the structure on the supporting subgrade. *This depth is in the order of twice the foundation/structure width for static loads and four times the foundation/structure width (100 ft. minimum) for dynamic/seismic loads.*

B. Borings encountering rock[8] (or soil of exceptional bearing capacity) do not need to extend beyond 10 ft. into the stratum to assure that sound material has been encountered and not merely boulders.

C. The minimum depth of any borings for surface foundations shall be 25 feet below the lowest foundation element, provided all other criteria listed above are satisfied.

D. For depth foundations supported on soil, borings shall extend below the anticipated pile or shaft tip elevation a minimum of 20 ft., or a minimum of two times the maximum pile group dimension, whichever is deeper.

E. For piles bearing on rock, a minimum of 10 ft. of rock core shall be obtained at each boring location to verify that the boring has not terminated on a boulder.

F. For shafts or caissons supported on or extending into rock, a minimum of 10 ft. of rock core, or a length of rock core equal to at least three times the shaft diameter for isolated shafts or two times the maximum shaft group dimension, whichever is greater, shall be extended below the anticipated shaft tip elevation to determine the physical characteristics of rock within the zone of foundation influence.

G. For retaining walls, 4 ft. in high and above from the bottom of foundation, extend borings to a depth below final ground line between 0.75 and 1.5 times the height of the wall[9]. *Where stratification indicates possible deep stability or settlement problem, borings should extend to hard stratum*.

H. For retaining walls supported on deep foundations use the criteria presented above for piles and shafts.

I. For SDC-3 SSCs, in addition to above requirements, the boring depth shall be adequate for site response and soil-structure interaction analysis, as detailed in ANSI/ANS-2.27, *Criteria for Investigations of Nuclear Facility Sites for Seismic Hazard Assessments*, Section 4.

[8] ASCE 4-98, Section 1.2 defines rock as "any material with shear wave velocity of 3,500 ft/s or greater."
[9] As a guide, minimum 1 borehole should be drilled every 50 ft to 100 ft along the retaining wall length.

2.5 In-situ Testing

The following guidelines shall be followed when performing in-situ tests to define the stratigraphy and obtain direct measurements of soil properties or geotechnical parameters. (Requirement 5-4013)

A. Location – The planned location and/or frequency of in-situ testing shall be clearly indicated in the GIP.

B. Procedures – All in-situ testing shall conform to procedures included in the GIP.

C. Equipment – All equipment used for in-situ testing shall have current calibration and be used according to the appropriate procedure by personnel trained in its use.

D. Personnel – Personnel performing the testing shall be trained in the use of the testing equipment according to the test procedure, in accordance with ASTM D3740.

E. All borings shall include Standard Penetration Testing (SPT) in accordance with ASTM D 1586. Generally, tests shall be taken every 2.5 ft. at depths shallower than 10 ft, and at 5.0 ft. intervals thereafter. The use of liners and/or sample retainers, if any, shall be clearly noted in the boring logs.

2.6 Sampling

An adequate number of soil samples of satisfactory size and with minimal disturbance shall be obtained for visual observation and laboratory tests, in accordance with the following requirements and guidelines. (Requirement 5-4014)

A. Disturbed Samples

1. Representative samples shall be taken at maximum five-foot intervals throughout the depth of each boring and at each change of stratum level.

2. Each disturbed soil sample shall be visually described and identified following the procedures provided in ASTM D2488 *Standard Practice for Description and Identification of Soils (Visual-Manual Procedures).*

3. Disturbed samples shall be sealed in containers to minimize moisture loss if required for further laboratory testing, evaluation, and classification per ASTM D2487 *Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System*).

B. Rock and Rock-like Samples

1. If foundation rock is encountered (SPT blow counts exceeding 100 bpf), the material shall be sampled by NX-size diamond drill core barrel (or approved equal) to obtain continuous core samples of the foundation rock. Description of the material shall include rock type, hardness, recovery ratio and Rock Quality Designator (RQD). For tuff material, the descriptors in Table IV-2 shall be used. The retention and storage of recovered core that is not used for testing shall be coordinated with the Project Engineer.

2. Preservation, transportation, storage, cataloging, retrieval, and post-test disposition of rock core samples obtained for testing purposes and geologic study shall be in accordance with ASTM D5079 - *Standard Practices for Preserving and Transporting Rock Core Samples*.

Table IV-2: Terminology for In-Situ Tuff

General Property	Descriptive Term	Visual or Physical Properties
Weathering	Very Weathered	Abundant fractures coated with oxides, carbonates, sulfates, mud, etc., thorough discoloration, rock disintegration, mineral decomposition
	Moderately Weathered	Some fracture coating, moderate or localized discoloration, little to no effect on cementation, slight mineral decomposition
	Slightly Weathered	A few stained fractures slight discoloration, little to no effect on cementation, no mineral decomposition
	Fresh	Unaffected by weathering agents, no appreciable change with depth
Fracturing	Intensely Fractured	Less than 1 in. spacing
	Very Fractured	1 in. to 6 in. spacing
	Moderately Fractured	6 in. to 12 in. spacing
	Slightly Fractured	12 in. to 36 in. spacing
	Solid	36 in. spacing or greater
Stratification	Thinly Laminated	Less than 1 /10 in.
	Laminated	1 /10 in. to ½ in.
	Very Thinly Bedded	½ in. to 2 in.
	Thinly Bedded	2 in. to 2 ft.
	Thickly Bedded	more than 2 ft.
Hardness	Soft	Can be dug by hand and crushed by fingers
	Moderately Hard	Friable, can be gouged deeply with knife and will crumble readily under light hammer blows
	Hard	Knife scratch leaves dust trace, will withstand a few hammer blows before breaking
	Very Hard	Scratched with knife with difficulty, difficult to break with hammer blows

C. Undisturbed Samples

1. The program for undisturbed sampling, if required, shall be presented for approval in the GIP.
2. Undisturbed samples are required if stipulated by the lab testing procedures indicated in the GIP.
3. Undisturbed soil samples can be considered if required to develop geotechnical parameters of interest to the foundation design.
4. Undisturbed samples, if required, shall satisfy the requirements of ASTM D1587 or ASTM D7015.
5. Enough undisturbed samples shall be taken of the strata to provide a statistically defensible estimate of the average strength and stiffness of the material. *Typically, such samples are spaced at 10 foot-increments through the depth where such samples are appropriate*.

6. The samples must be adequately protected from disturbance immediately after they are obtained in the field and during shipment and handling in accordance with ASTM D4220/D4220M - *Standard Practices for Preserving and Transporting Soil Samples*.

D. General Sample Requirements

1. Representative samples shall be obtained for each subsurface material that is significant to the project design and construction.
2. Identification of samples shall be affixed to the sample tubes or containers, which will maintain the integrity of the samples for the specified period of storage.
3. Samples shall be stored in locations where they will be protected from damage.
4. Labels shall be affixed to sample tubes with all pertinent information.
5. Tube and boring numbers shall be marked in duplicate.
6. Undisturbed samples shall be stored in a controlled environment in which the ambient temperature and humidity are maintained at predetermined levels.
7. Samples shall be shipped, protected with suitable resilient packing material to reduce shock, vibration, and disturbance.
8. Test specimens shall be prepared in accordance with applicable ASTM Standards unless otherwise specified.

2.7 Boring Logs

The boring log shall provide a detailed record of the work performed and the findings of the investigation. *It should be legible and should be kept as clean as possible*. The following is a list of items which shall be included in a boring log to describe exploration procedures and subsurface conditions encountered during drilling, sampling, and coring.[10] (Requirement 5-4015)

A. Start and completion dates and times of borings and water level measurements.

B. All the sections of the logs shall be completed in the field prior to the completion of the exploration.

C. Include a unique identifier tied to the GIP drawing and final report including coordinates and elevation. Deviations from the planned boring locations shall be accurately documented.

D. A continuous final log of the boring shall be provided that indicates the drilling method used to advance, stabilize the hole, and take samples, location of the borehole, sample types, and a graphic log with elevations of the ground surface, depths of major strata, soil samples, and groundwater if encountered.

E. For soil samples, the log shall include sampler type, depth, penetration, recovery, blow counts (if appropriate), a description of the material encountered according to the ASTM D2488 - *Standard Practice for Description and Identification of Soils (Visual-Manual Procedures)*. The practice of completing descriptions in the laboratory is not acceptable.

F. For rock samples, the log shall indicate as a minimum rock descriptors rock type, color, hardness, weathering and alteration, strength, recovery and RQD ratios. Any abnormalities in the strata shall be noted.

[10] For additional guidance refer to ASTM D5434 Standard Guide for Field Logging of Subsurface Explorations of Soil and Rock.

G. The final boring log shall additionally include the soil classification according to ASTM D2487, estimated dry density, moisture content, Atterberg limits (if appropriate), soil strength parameters, resistivity and other geophysical parameters determined during the field and laboratory testing program for all materials encountered during the geotechnical investigation, along with the boring closure method.

2.8 LANL-Specific Considerations Related to Geotechnical Investigations

There are several LANL-specific requirements that could potentially apply to geotechnical investigations field exploration activities. These include, but are not limited to:

A. Integrated Work Management safety process.

B. Excavation/Fill/Soil Disturbance Permit.

C. Security consideration for use of cameras or working in or near security areas.

D. Radiation protection –bringing radioactive sources on-site (i.e., nuclear densometer equipment) or working in potentially contaminated areas.

E. Environmental – NEPA planning.

F. Cultural and Biological Resources review.

These LANL processes should be coordinated with the LANL project engineer.

3.0 LABORATORY TESTING

Laboratory tests to characterize the physical and mechanical (strength and deformation) properties of subsurface materials shall be conducted in accordance with the following requirements. (Requirement 5-4016).

A. Laboratory Quality Assurance Programs shall be per Sections IV.1.2 and IV.1.3.2.

B. Procedures – All laboratory testing shall conform to procedures included in the GIP.

C. Equipment – All equipment used for testing shall have current calibration and be used according to the appropriate procedure.

D. Personnel – All personnel involved in testing activities shall be trained to an approved procedure.

4.0 ENGINEERING CALCULATIONS & ANALYSES

A. Calculations and analyses prepared to support determination of engineering properties used in the design of the facility shall be prepared in accordance with LANL Engineering AP 341-605, "Calculations" or a company-specific procedure approved by the project's LANL QA representative or included in the Subcontractor's approved QA plan. (Requirement 5-4017)

5.0 REPORT AND RECOMMENDATIONS

Following the completion of the field investigation and laboratory tests, the geotechnical engineer shall compile, evaluate, interpret the data, and perform engineering analyses for the design of foundations, cuts, embankments, and other facilities as applicable. A report shall be prepared to document the investigation, the data obtained, the analysis performed, and the design recommendations, in accordance with the IBC Section 1803.6 and the following requirements and guidelines. (Requirement 5-4018)

A. The geotechnical report must be provided to the LANL project engineer for review and acceptance prior to its use for foundation design.

B. The final report shall be signed and sealed by a Professional Engineer licensed in the state of New Mexico and specializing in the field of geotechnical engineering.

C. The final report shall include detailed descriptions of the field exploration methods, in situ-tests, geophysical surveys, laboratory testing, analyses, and interpretation of soil and rock properties completed during the investigation.

D. Written and graphic subsurface profiles showing the elevation of important features found during the geotechnical investigation. Profiles must provide soil and rock stratigraphy, groundwater data, penetration resistance, and any other information deemed necessary.

E. The final report shall include recommendations for all engineering design parameters requested by the designer of the SSC.

F. When rock is encountered, classify rock in accordance with the unified rock classification system (URCS) detailed in ASTM D5878, "Standard Guide for Using Rock-Mass Classification Systems for Engineering Purposes" and report the characteristics determined for the specific engineering purpose of the investigation. For tuff material, the descriptors in Table IV-2 shall be used.

G. The recommendations for foundation types shall include the following criteria/parameter for design of foundations: ultimate bearing pressure, the factors of safety and allowable bearing pressures including the effect of both horizontal and vertical loads on the foundation elements, the ultimate and allowable capacities for lateral loads, modulus of subgrade reaction, and estimated vertical settlement and horizontal displacements for the various load combinations used in the foundation design.

H. The minimum recommended depth to the bottom of footings and slab foundations shall account for the potential effects of frost penetration. The minimum required foundation depth at LANL is 36 inches.[11]

I. If retaining structures (basement walls, retaining walls, etc.) are included in the project, the final design report shall provide soil/slope stability during excavation and recommended lateral design forces using lateral soil pressure coefficients applicable to the structural restraint provided. The coefficients of active, at rest and passive lateral pressure appropriate for both static and dynamic load conditions shall be provided. When lateral earth pressure recommendations are presented as equivalent fluids, calculations shall be submitted showing the derivation for the equivalent fluid properties.

J. Recommendations for the design for seismic lateral earth pressures shall be included. These recommendations shall, at a minimum, include the PGA; the magnitude, vertical distribution and point of application of the seismic lateral earth pressures, and any modification factors that should be applied to the acceleration values used for design.

K. Stability of all earth or rock slopes both natural and manmade (e.g., cuts, fill, embankments) whose failure, under any of the conditions to which they may be exposed during the structure's life, could adversely affect its safe operation.

L. If the potential for surface deformation due to Quaternary faults exists (e.g., existing faults within 50 ft from the structure), describe the effect of each cause of surface

[11] From ESM Ch. 5 Section II rev. 12, IBC 1809.5 Frost protections

deformation on the structure, and estimate its magnitude based on existing literature or field investigations if deemed necessary.[12]

M. For both shallow and deep foundations, the recommended methods for their installations shall be provided together with the potential impact of their installation on adjacent structures.

N. Site preparation recommendations with any special precautions, such as equipment limitations and/or special requirements (e.g., over-excavation and replacement).

O. If applicable, recommended pavement sections, as well as variables used for the pavement design (e.g., subgrade CBR, modulus k, traffic, equivalent single axle load).

P. For engineered fill/backfill materials, the final design report shall include recommendations for lift thickness, grain size requirements and/or the presence of suitable excavated backfill material, moisture content, quality control testing, and compaction methods. These shall include frequency of grain size measurements, moisture content measurements and density tests as well as acceptance criteria for each. The report shall provide recommendations regarding equipment to be used for site preparation and grading including of presence of existing fill material which must be treated or removed.

Q. Use of recompacted tuff as backfill material.

1. Where recompacted tuff is planned to be used, the report shall include a note regarding appropriate methods for compaction and frequency of density tests.

2. Experience has shown that the tuff can be overworked making achievement of target densities difficult. Furthermore, the fines created by overworking may lead to frost heave issues in areas with a potential water source (drainage or broken pipe).

3. Sheepsfoot-type compaction has the greatest tendency to overwork the material. Smooth vibratory type compaction is recommended.

R. The report shall provide excavation and cut requirements (e.g., safe slopes for open excavations), and recommendations for design of temporary excavation support and soil embankments, if applicable, together with criteria used for their design.

S. Appendices to the report shall include, but not be limited to, the following items if applicable.[13]

Item	Required for all Work	Only Required for ML-1/2
1. Plan drawing(s) of the project area with actual locations of field exploration activities	X	
2. Surveying records	X	
3. Field and laboratory logs and test data	X	
4. Calculations and analyses	X	
5. Laboratory and in-situ test reports	X	
6. Measuring and test equipment control and calibration records	X	

[12] Refer to LABC Information Bulletin P/BC 2023-129 for guidance on this regard.
[13] See ASME NQA-1, Subpart 2.20, Paragraph 700

7. Test deviations or exceptions records	X	
8. Checks, verifications, and examination records		X
9. Procurement control records		X
10. Reports of nonconforming equipment		X
11. Procurement control records		X

T. Bearing Capacities – Code minimum bearing capacities shall only be used when a geotechnical investigation is not required. Where the necessary engineering properties are available, calculations shall be submitted showing the derivation of the recommended bearing capacities.

U. Use of existing data – When existing data (e.g., friction angles and unit weights based on soil classification) is used in lieu of values based on measured data, it shall be clearly identified as existing data, the source shall be clearly identified, and justification for using published data shall be provided. Existing data does not include information that is accepted by the scientific and engineering community as an established fact (e.g., engineering handbooks, density tables, gravitational laws, etc.).

1. Use of existing data for ML-1/ML-2 activities requires LANL approval and shall be qualified in accordance with AP-341-511, *Design Information Reconstitution* (instead use AP-341-513, *Qualification of Existing Data*) or a company-specific procedure (approved by the project's LANL QA representative or included in the Subcontractor's approved QA plan) based on the guidance provided in ASME NQA-1-2008, Part III, Subpart 3.3, Nonmandatory Appendix 3.1, *Guidance on Qualification of Existing Data*.

V. The format of the report shall be logical and legible. Conclusions, recommendations, and analyses shall be supported by calculations and/or field exploration and laboratory testing findings. References, factors of safety, soil models, and other information used in support of the above shall be included as deemed necessary.

6.0 RECORD OF REVISIONS

Rev	Date	Description	POC	OIC
0	6/28/99	Initial issue in Facility Engineering Manual	Doug Volkman, *PM-2*	Dennis McLain, *FWO-FE*
1	2/9/04	Incorporated IBC & ASCE 7 in place of UBC 97; incorporated DOE-STD-1020-2002 versus 1994; incorporated concepts from DOE O 420.1A; FEM became ESM, an OST.	Mike Salmon, *FWO-DECS*	Gurinder Grewal, *FWO-DO*
2	5/17/06	Added PC-0; minor editorial changes; OST became ISD.	Mike Salmon, *D-5*	Mitch Harris, *ENG-DO*
3	10/27/06	Administrative changes only. ISD number changed based on new Conduct of Engineering IMP 341.	Mike Salmon, *D-5*	Kirk Christensen, *CENG*
4	6/19/07	Added caution note for new projects at 1.0.C based on data from 2007 Update of Probabilistic Seismic Hazards Assessment and resulting increased seismic design basis.	Mike Salmon, *D-5*	Kirk Christensen, *CENG*
5	4/30/12	Admin change to 2.2.B.	Mike Salmon, *CENG*	Lawrence Goen, *CENG*
6	3/27/15	Incorporation of ASME NQA-1 2008/9, IBC 2015, and CMRR lessons.	Mike Salmon, *AET-5*	Mel Burnett, *ES-FE*

7	3/22/23	Incorporation of NQA-1 Subpart 2.20 per SD330, graded approach for nuclear and non-nuclear structures. Added section regarding ML-4 structures that do not require geotechnical investigations. Clarified that geotechnical calculations, analyses, and reports shall be reviewed and accepted by LANL. Provided additional guidance for selecting the depth of boreholes and determination of surface deformation due to Quaternary faults.	Carlos Coronado, *ES-SPD*	Michael Richardson, *ES-DO*