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RECORD OF REVISIONS

Rev	Date	Description	POC	OIC
0	6/28/99	Initial issue in Facility Eng 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*

Contact the Structural Standards POC
for upkeep, interpretation, and variance issues

Ch. 5 Section IV	**Structural POC/Committee**

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IV GEOTECHNICAL INVESTIGATIONS

1.0 GENERAL

A. The following subsections present soil/rock testing and subsurface investigation requirements for determining engineering properties for soil/rock materials required to design structural foundations, earth embankments, and related excavation and excavation support systems required for new construction, additions, or modifications. These subsections apply specifically to facilities classified as Performance Category (PC) -0, PC-1 and PC-2, as designated in DOE-STD-1020.

B. Soil/rock testing and subsurface investigation requirements for PC-3 and PC-4 facilities should be uniquely developed for specific projects and documented in the facility DBD; material in this Section provides a starting point for geotechnical investigations for PC-3 and PC-4 facilities. For these facilities site response analyses and soil-structure interaction analyses may be performed, as discussed in Section III. As noted earlier in this chapter, these type of analyses typically require the following geotechnical data input as a function of soil depth:

- low strain shear modulus (or low-strain shear wave velocity),
- low-strain shear modulus (or low-strain shear wave velocity),
- low-strain elastic modulus (or low-strain compression wave velocity),
- Poisson's ratio,
- unit weight,
- degradation curves indicating the variation of shear modulus with shear strain,
- low strain soil material damping, and
- degradation curve indicating the variation of soil material damping with shear strain, and the elevation beneath the structure where rock is encountered.

C. Note: The seismic design basis parameters presented in Section III for PC-3 and PC-4 facility design were derived by enveloping site-specific response at TA-3, TA-16, TA-55, and CMRR. For new PC-3 and PC-4 construction these spectra shall be regenerated to capture site-specific response unless it can be adequately demonstrated to the ESM Structural POC that the site characteristics for new construction are adequately represented by those at one of the four sites aforementioned.

2.0 GEOTECHNICAL INVESTIGATION

2.1 General Criteria for Boring Program

A. The field and laboratory investigation program needs to be conducted in at least two (2) phases, namely, a preliminary phase to obtain general characteristics of the site and a final phase to add additional site information as required for adequate foundation design. The preliminary phase should consist of widely spaced holes carried to sufficient depth to reasonably characterize the site. The final phase then should be planned using the results from the preliminary phase to select the appropriate spacing and depth of all borings in the program. The combination of the preliminary and final phases, together with other information available for the site, should satisfy the spacing, depth of investigation and

sampling criteria described below. The planned program needs to be evaluated and approved by a licensed geotechnical engineer.

B. The boring program should make use of methods of drilling that can maintain the hole open without significant caving of the sides. Casing or viscous drilling fluid can be used to advance the borings if there is danger of collapse of the uncased hole. If perched or other ground water is encountered at the site, the drilling fluid should be of the revert type. Above the ground water table, the borehole should be advanced using dry methods of drilling. All procedures to be used to advance and maintain the hole and take and protect samples should be clearly described and submitted for approval before the onset of the exploration program.

2.2 Test Hole Spacing

A. For new construction utilizing shallow foundations (footings, slabs), borings should be located uniformly every 2,500 square feet (50 ft by 50 ft grid) across the plan area of the facility. 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. A minimum of three (3) borings are required for each structure to be constructed. For existing facilities, the number and location of borings needs to be evaluated on a case-by-case basis.

B. The spacing of borings can be increased to allow for 1 boring per 10, 000 square feet (i.e., spacing at 100’ x 100’) of building area provided sufficient justification is provide for the reduced scope of the investigation. This justification should be based on the results from the preliminary program together with other information available for the site and only after evaluation by a licensed geotechnical engineer. Items such as whether the facility will be founded on rock or soil, uniformity of material properties encountered across the plan area and average design foundation pressures need to be evaluated to justify the increased spacing.

C. For facilities that will be supported on deep foundations (piles, piers, caissons, etc.), the required spacing of borings may be reduced to about 1,600 square feet (40 ft by 40 ft grid). This spacing cannot be increased unless the piles are to be founded in rock (or tuff) and adequate information is provided to assure relatively uniform properties of the supporting foundation material. For facilities supported on heavily loaded caissons, one boring should be provided at each caisson location.

2.3 Depth of Borings

A. The depth of exploration depends on the size and type of the facility foundation and should 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. The depth of borings placed in the preliminary phase of the program shall be based on the “10% rule” typically used in foundation analysis, if the borings are founded in soil. This critical depth is defined as the depth at which the vertical stress increment caused by the foundation is equal to 10% of the initial effective overburden stress beneath the foundation. The depth of the remaining borings can be reduced if the preliminary exploration program indicates that the proposed bearing strata has adequate thickness or is underlain by stronger formations.

B. Borings encountering rock (or soil of exceptional bearing capacity) need not extend beyond 20 ft into the stratum to assure that sound material has been encountered and not merely boulders. The minimum depth of any borings shall be 25 feet below the ground surface, provided all other criteria listed above are satisfied. The boring depth may have to be greater

than this for PC-3 and PC-4 structures.

2.4 Sampling

A. All borings taken during the preliminary boring phase shall include Standard Penetration Test (SPT) split spoon sampling of all soils encountered during the program. These samples shall be taken at five-foot intervals throughout the depth of each boring. Each soil sample so obtained shall be visually classified following the criteria of the Unified Soil Classification System (USC). SPT samples shall be jarred (and sealed if wet) for further laboratory testing and evaluation. The field boring log shall record the depth range of the SPT sample, blow counts for each 6-inch increment of the sample drive, visual soil classification, description of the material encountered (including color) and any water encountered.

B. 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 should include rock type, hardness, recovery ratio and Rock Quality Designator (RQD). For tuff material, the descriptors in Table IV-1 should be used. The recovered core shall be boxed and stored for future evaluation.

C. If perched or ground water is encountered in the boring and if ground water is considered important in the foundation evaluation, screened well points shall be placed in about 10% of the borings after completion of the borings to monitor water levels.

D. Undisturbed soil samples can be considered during the final boring phase if soil types are encountered during the exploration where these samples are considered appropriate to develop foundation parameters of interest to the foundation design. Undisturbed samples, if required, should be taken with a sampler having a low area ratio (less than 15%), should have a recovery of at least 95% and should show no significant visual disturbance of the sample when extruded. The samples must be adequately protected from disturbance during shipment and handling. The program for undisturbed sampling, if required, shall be presented for approval prior to the onset of the boring program. Enough undisturbed samples should be taken of the strata to allow reasonable estimate of the average strength and stiffness of the material. Typically, such samples are spaced at 10 ft increments through the depth where such samples are appropriate.

E. A continuous final log of the boring shall be provided that indicates the drilling method used to place the boring and take samples, location of the borehole, sample types, and a graphic log with elevations and depths of the ground surface, major strata and samples. For soil samples, the log should include sample blow counts (if appropriate), a description of the material encountered (including color of tuff, and a visual classification), soil classification according to the USC system, and location of any water encountered. The final boring log prepared for the program shall additionally include 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 in the program. For rock samples, the log should indicate as a minimum rock descriptors, rock hardness, and recovery and RQD ratios. Any abnormalities in the strata shall be noted.

Table IV - 1 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

2.5 Geotechnical Analysis and Recommendations

A. All recommendations, calculations, and analysis performed as part of the geotechnical investigation shall be based on the results of the boring program and the ensuing testing program. The parameters used in these analyses shall include the effect of uncertainty in properties available from the program. All parameters used in design for load combinations associated with both static and seismic loads shall be provided, together with the basis for their selection. A geotechnical report shall be provided in the format presented in Table IV-2.

B. The recommendations for foundation types should include criteria for design of foundations, including: 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 and horizontal displacements for the various load combinations used in the foundation designs. The minimum recommended depth to the bottom of footings and slabs foundations shall account for the potential effects of frost penetration.

Table IV - 2 Geotechnical Report Format

Title Page	A title page which states the nature of the investigation, which project it is being accomplished for, the Technical Area(s), the organization that it is being accomplished for (Los Alamos National Laboratory), prepared by (Organization, and geotechnical engineer) and approved by (responsible engineer in the Organization). Place the seal of the responsible Professional Engineer(s) on this page.
Table of Contents	Include report sections and appendices.
Summary of Conclusions	An executive summary which lists the conclusions reached through this subsurface investigation.
Introduction	An introduction, which describes the purpose of the geotechnical investigation, including a description of the facilities to be located at that site. Also included in this paragraph should be existing facilities, known utilities and other structures/items which could be affected by the construction.
Site Description	A description of the site along with existing building(s), surface drainage, trees, vegetation, applicable elevation information, top soil, man made fills, undisturbed tuff, general description of the underlying tuff.
Conclusions and Recommendations	Detailed conclusions and recommendations made in accordance with this Standard.
Appendix A	The location of the area investigated in terms pertinent to the project. This may include sketch maps or aerial photos on which the test pits, boreholes, and sample areas are located, as well as geomorphological data relevant to the determination of the various soil and rock types. Such data includes elevation contours, streambeds, outcroppings, existing and planned structures, and utility locations.
Appendix B	Log of test borings and pits. Laboratory Test Results.
Appendix C	Results of in-situ testing accomplished.
Appendix D	Calculations to support conclusions.
Appendix E	Recommended Specifications, Field control requirements, etc.
Appendix F	Results of the soil resistivity measurements in accordance with ASTM G57 per ESM Chapter 7-Electrical
Appendix G	Quality Control Plan implemented on the project.

C. If retaining structures (basement walls, retaining walls, etc.) are included in the project, the final design report shall provide recommended lateral design forces using soil lateral 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.

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

E. For engineered fill/backfill materials, the final design report shall include recommendations for lift thickness, grain size requirements, moisture content and quality control testing. 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.

F. The report should also provide recommendations for design of temporary excavation support and soil embankments, if applicable, together with criteria used for their design.