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SITE INVESTIGATIONS FOR FOUNDATIONS OF NUCLEAR POWER PLANTS

A. INTRODUCTION

Paragraph 100.10(c) and Appendix A, "Seismic and Geologic Siting Criteria for Nuclear Power Plants," to 10 CFR Part 100, "Reactor Site Criteria," establish requirements for conducting site investigations to permit evaluation of the site and to provide information needed for seismic response analyses and engineering design. Requirements include the development of geologic information relevant to the stratigraphy, lithology, geologic history, and structural geology of the site and the evaluation of the engineering properties of subsurface materials.

Safety-related site characteristics are identified in detail in Regulatory Guide 1.70, "Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants." Regulatory Guide 4.7, "General Site Suitability Criteria for Nuclear Power Stations," discusses major site characteristics that affect site suitability.

This guide describes programs of site investigations that would normally meet the needs for evaluating the safety of the site from the standpoint of the performance of foundations and earthworks under most anticipated loading conditions, including earthquakes. It also describes site investigations required to evaluate geotechnical parameters needed for engineering analysis and design. The site investigations discussed in this guide are applicable to both land and offshore sites. This guide does not discuss detailed geologic fault investigations required under Appendix A to 10 CFR Part 100, nor does it deal with hydrologic investigations, except for groundwater measurements.

*Lines indicate substantive changes from previous issue.

This guide provides general guidance and recommendations for developing site-specific investigation programs as well as specific guidance for conducting subsurface investigations, the spacing and depth of borings, and sampling. Because the details of the actual site investigations program will be highly site dependent, the procedures described herein should be used only as guidance and should be tempered with professional judgment. Alternative and special investigative procedures that have been derived in a professional manner will be considered equally applicable for conducting foundation investigations.

Appendix A to this guide provides definitions for some of the terms used in this guide. These terms are identified in the text by an asterisk. Appendix B tabulates methods of conducting subsurface investigations, and Appendix C gives guidelines for the spacing and depth of borings for safety-related structures in regions of favorable or uniform conditions. References cited in the text and appendices are listed in Appendix D.

The Advisory Committee on Reactor Safeguards has been consulted concerning this guide and has concurred in the regulatory position.

B. DISCUSSION

1. General

Site investigations for nuclear power plants are necessary to determine the geotechnical* characteristics of a site that affect the design, performance, and safety of plants. The investigations produce the information needed to define the overall site geology to a degree that is necessary for an understanding of subsurface conditions and for identifying potential geologic and earthquake hazards that may exist at the site. Investigations for hazards such as faulting, landslides, cavernous rocks, ground subsidence, and soil liquefaction are especially important.

Site investigations also provide information needed to define local foundation and groundwater conditions as well as the geotechnical parameters needed for engineering analysis and design of foundations and earthworks. Geotechnical parameters needed for analysis and design include, but are not limited to, those used to evaluate the bearing capacity of foundation materials, lateral earth pressures affecting walls, the stability of cuts and slopes in soil and rock, the effect of earthquake-induced motions transmitted through underlying deposits on the response of soils and structures (including the potential for inducing liquefaction in soils), and those needed to estimate the expected settlement of structures. Geotechnical parameters are also needed for analysis and design of plant area fills, structural fills, backfills, and earth and rockfill dams, dikes, and other water retention or flood protection structures.

Site information needed to assess the functional integrity of foundations with respect to geologic and geotechnical considerations includes:

a. The geologic origin, types, thicknesses, sequence, depth, location, and areal extent of soil and rock strata and the degree and extent of their weathering;

b. The history, type, and extent of geologic deformation;

c. Orientation and characteristics of foliations, bedding, jointing, and faulting in rock;

d. Groundwater conditions;

e. The static and dynamic engineering properties of subsurface materials;

f. Information regarding the results of investigations of adverse geological conditions such as cavities, joints, faults, fissures, or unfavorable soil conditions;

g. Information related to man's activities such as withdrawal of fluids from or addition of fluids to the subsurface, extraction of minerals, or loading effects of dams or reservoirs; and

h. Information detailing any other geologic condition discovered at the site that may affect the design or performance of the plant or the location of structures.

2. Reconnaissance Investigations and Literature Reviews

Planning of subsurface investigations and the interpretation of data require thorough understanding of the general geology of the site. This understanding can be obtained by field reconnaissance and a review, either preceding or accompanying the subsurface investigation, of available documentary materials and results of previous investigations. In most cases, a preliminary study of the site geology can be done by review of existing current and historical documentary materials and by study of aerial photographs and other remote-sensing imagery. Possible sources of current and historical documentary information may include:

a. Geology and engineering departments of State and local universities,

b. State government agencies such as the State Geological Survey,

c. U.S. Government agencies such as the U.S. Geological Survey and the U.S. Army Corps of Engineers,

d. Topographic maps,

e. Geologic and geophysical maps,

f. Engineering geologic maps,

g. Soil survey maps,

h. Geologic reports and other geological literature,

i. Geotechnical reports and other geotechnical literature,

j. Water well boring information and water supply reports,

k. Oil and gas well records,

l. Hydrogeologic maps,

m. Hydrologic and tidal data and flood records,

n. Climate and rainfall records,

o. Mining history, old mine plans, and subsidence records,

p. Seismic data and historical earthquake records,

q. Newspaper records of landslides, floods, earthquakes, subsidence, and other events of geologic or geotechnical significance,

r. Records of performance of other structures in the vicinity, and

s. Personal communication with local inhabitants and local professionals.

Special or unusual problems such as swelling soils and shales (subject to large volume changes with changes in moisture), occurrences of gas, cavities in soluble rocks, subsidence caused by mining or pumping of water, gas, or oil from wells, and possible uplift due to pressurization from pumping of water, gas, or oil into the subsurface may require consultation with individuals, institutions, or firms having experience in the area with such problems.

The site investigation includes detailed surface studies and exploration of the immediate site area and adjacent environs. Further detailed surface exploration also may be required in areas remote to the immediate plant site to complete the geologic evaluation of the site or to conduct detailed investigations of surface faulting or other features. Surface exploration needed for the assessment of the site geology is site dependent and may be carried out with the use of any appropriate combination of geological, geophysical, or engineering techniques. Normally this includes the following:

a. Detailed mapping of topographic, hydrologic, and surface geologic features, as appropriate for the particular site conditions, with scales and contour intervals suitable for analysis and engineering design. For offshore sites, coastal sites, or sites located near lakes or rivers, this includes topography and detailed hydrographic surveys to the extent that they are needed for site evaluation and engineering design.

b. Detailed geologic interpretations of aerial photographs and other remote-sensing imagery, as appropriate for the particular site conditions, to assist in identifying rock outcrops, soil conditions, evidence of past landslides or soil liquefaction, faults, fracture traces, geologic contacts, and lineaments.

c. Detailed onsite mapping of local engineering geology and soils.

d. Mapping of surface water features such as rivers, streams, or lakes and local surface drainage channels, ponds, springs, and sinks at the site.

3. Groundwater Investigations

Knowledge of groundwater conditions, their relationship to surface waters, and variations associated with seasons or tides is needed for foundation analyses. Groundwater conditions are normally observed in borings* at the time they are made; however, for engineering applications, such data are supplemented by groundwater observations made by means of properly installed wells or piezometers* that are read at regular intervals from the time of their installation at least through the construction period. The U.S. Army Corps of Engineers' manual on groundwater and pore pressure observations in embankment dams and their foundations (Ref. 1) provides guidance on acceptable methods for the installation and maintenance of piezometer and observation well* instrumentation. Criteria for measuring groundwater conditions at a site and for assessing dewatering requirements during construction are given in regulatory position 3 of this guide. This guide does not cover groundwater monitoring needed during construction in plants that have permanent dewatering systems incorporated in their design.

4. Subsurface Investigations

a. General

The appropriate depth, layout, spacing, and sampling requirements for subsurface investigations are dictated by the foundation requirements and by the complexity of the anticipated subsurface conditions. Methods of conducting subsurface investigations are tabulated in Appendix B to this guide, and recommended guidelines for the spacing and depth of borings for safety-related structures, where favorable or uniform geologic conditions exist, are given in Appendix C.

Subsurface explorations for less critical foundations of power plants should be carried out with spacing and depth of penetration as necessary to define the general geologic and foundation conditions of the site. Subsurface investigations in areas remote from plant foundations may be needed to complete the geologic description of the site and confirm geologic and foundation conditions and should also be carefully planned.

Subsurface conditions may be considered favorable or uniform if the geologic and stratigraphic features to be defined can be correlated from one boring or sounding* location to the next with relatively smooth variations in thicknesses or properties of the geologic units. An occasional anomaly or a limited number of unexpected lateral variations may occur. Uniform conditions permit the maximum spacing of borings for adequate definition of the subsurface conditions at the site.

Occasionally, soil or rock deposits may be encountered in which the deposition patterns are so complex that only the major stratigraphic boundaries are correlatable, and material types or properties may vary within major geologic units in an apparently random manner from one boring to another. The number and distribution of borings needed for these conditions are determined by the degree of resolution needed in the definition of foundation properties. The thicknesses of the various material types, their degree of variability, and ranges of the material properties should be defined.

If there is evidence suggesting the presence of local adverse anomalies or discontinuities such as cavities, sinkholes, fissures, faults, brecciation, and lenses or pockets of unsuitable material, supplementary borings or soundings* at a spacing small enough to detect and delineate these features are needed. It is important that these borings penetrate all suspect zones or extend to depths below which their presence would not influence the safety of the structures. Geophysical investigations may be used to supplement the boring and sounding program.

In planning the exploration program for a site, consideration should also be given to the possibility that the locations of structures may be changed and that such changes may require additional exploration to adequately define subsurface conditions at the final locations.

The location and spacing of borings, soundings, and exploratory excavations should be chosen carefully to adequately define subsurface conditions. A uniform grid may not provide the most effective distribution of exploration locations unless the site conditions are very uniform. The location of initial borings should be determined on the basis of conditions indicated by preliminary investigations. Locations for subsequent or supplemental explorations should be chosen in a manner so as to result in the best definition of the foundation conditions on the basis of conclusions derived from earlier exploratory work.

Wherever feasible, subsurface explorations should be located to permit the construction of geological cross sections through foundations of safety-related structures and other important locations at the site.

It is essential to verify during construction that in situ conditions have been realistically estimated during analysis and design. Excavations made during construction provide opportunities for obtaining additional geologic and geotechnical data. All construction excavations for safety-related structures and other excavations important to the verification of subsurface conditions should be geologically mapped and logged in detail. Particular attention should be given to the identification of geologic features that may be important to foundation behavior but were previously undetected in the investigations program. If subsurface conditions substantially differ from those anticipated, casting doubt on the adequacy of the design or expected performance of the foundation, there may be a need for additional exploration and redesign.

b. Investigations Related to Specific Site Conditions

Investigations for specific site conditions should include the following:

(1) Rock. The engineering characteristics of rocks are related primarily to their structure, bedding, jointing, fracturing, weathering, and physical properties. Core samples are needed to observe and define these features. Suitable coring methods should be employed in sampling, and rocks should be sampled to a depth below which rock characteristics do not influence foundation performance. Deeper borings may be needed to investigate zones critical to the evaluation of the site geology. Within the depth intervals influencing foundation performance, zones of poor core recovery, low Rock Quality Designation (RQD),* zones requiring casing, and other zones where drilling difficulties, including loss of drilling fluid circulation and dropping of drill rods, are encountered should be investigated by means of suitable logging or in situ observation methods to determine the nature, geometry, and spacing of any discontinuities or anomalous zones. Where there is evidence of significant residual stresses, they should be evaluated on the basis of in situ stress or strain measurements.

(2) Coarse-Grained Soils. Investigations of coarse-grained soils should include borings with split spoon sampling and Standard Penetration Tests with sufficient coverage to define the soil profile and variations of soil conditions. Soundings with cone penetration tests may also be used to provide useful supplemental data if the cone and test data are properly calibrated to site conditions.

Suitable samples should be obtained for soil identification and classification, in situ density determinations where appropriate, mechanical analyses, and anticipated laboratory testing. When obtaining samples for cyclic loading tests, it is important to obtain good-quality undisturbed samples* for testing. The need for, number, and distribution of samples will depend on testing requirements and the variability of the soil conditions. In general, however, samples should be included from at least one principal boring* at the location of each safety-related structure. Samples should be obtained at regular intervals in depth and when changes in materials occur. Criteria for the distribution of samples are given in regulatory position 6.

Coarse-grained soils containing gravels and boulders are among the most difficult materials to sample. Obtaining good quality samples in these coarser soils often requires the use of trenches, pits, or other accessible excavations* into the zones of interest. Also, extreme care is necessary in interpreting results from the Standard Penetration Test in these materials. Often such data are misleading and may have to be disregarded. When sampling of these coarse soils is difficult, information that may be lost when the soil is later classified in the laboratory should be recorded in the field. This information should include observed estimates of the percentage of cobbles, boulders, and coarse material and the hardness, shape, surface coating, and degree of weathering of coarse materials.

(3) Moderately Compressible or Normally Consolidated Clay or Clayey Soils. The properties of a fine-grained soil are related to the in situ structure of the soil,* and therefore the recovery and testing of good undisturbed samples are necessary. Criteria for obtaining undisturbed samples are discussed in regulatory position 6 of this guide.

(4) Subsurface Cavities. Subsurface cavities may occur in water-soluble rocks, lavas, weakly indurated sedimentary rocks, or in other types of rocks as the result of subterranean solutioning and erosion. Cavities can also be found where mining has occurred or is in progress. Because of the wide distribution of carbonate rocks in the United States, the occurrence of features such as cavities, sinkholes, and solution-widened joint openings is common. For this reason, it is best to thoroughly investigate any site on carbonate rock for solution features to determine their influence on the performance of foundations. Because of the possibility that incomplete or inaccurate records exist on mining activities, it is equally important to investigate areas where mining has or may have occurred.

Investigations may be carried out with borings alone or in conjunction with accessible excavations, soundings, pumping tests, pressure tests, geophysical surveys, or a combination of such methods. The investigation program will depend on the details of the site geology and the foundation design. Various geophysical techniques used for detecting subsurface cavities are discussed in Reference 2.

Indications of the presence of cavities (e.g., zones of lost drilling fluid circulation, water flowing into or out of drillholes, mud fillings, poor core recovery, dropping or settling of drilling rods, anomalies in geophysical surveys, or in situ tests* that suggest voids) should be followed up with more detailed investigations. These investigations should include excavation to expose solution features or additional borings that define the limits and extent of such features.

The occurrence, distribution, and geometry of subsurface cavities are highly unpredictable, and no preconstruction exploration program can ensure that all significant subsurface voids will be fully revealed. Experience has shown that solution features may remain undetected even where the area has been investigated by a large number of borings. The fact that cavities are often filled or partially filled with residual material and debris makes it particularly difficult to detect cavities on the basis of boring data and results of fluid pressure and grout-take tests. Therefore, where a site is on solution-susceptible rock, it may sometimes be necessary to inspect the rock after stripping or excavation is complete and the rock is exposed.

(5) Materials Unsuitable for Foundations. Borings and representative sampling and testing should be completed to delineate the boundaries of unsuitable materials. These boundaries should be used to define the required excavation limits.

(6) Borrow Materials. Exploration of borrow sources requires the determination of the location and amount of borrow fill materials available. Investigations in the borrow areas should be at horizontal and vertical intervals sufficient to determine the material variability and should include adequate sampling of representative materials for laboratory testing.

Investigations of problem foundation conditions are discussed in Appendix A to Reference 3 and in Reference 4.

c. Sampling

Representative samples* of all soil and rock should be obtained for testing. In many cases, to establish physical properties it is necessary to obtain undisturbed samples that preserve the in situ structure of the soil. The recovery of undisturbed samples is discussed in Section B.6 of this guide.

Sampling of soils should include, as a minimum, recovery of samples for all principal borings at regular intervals and at changes in strata. A number of samples sufficient to permit laboratory determination of average material properties and to indicate their variability is necessary. Alternating split spoon and undisturbed samples with depth is recommended. Where sampling is not continuous, the elevations at which samples are taken should be staggered from boring to boring so as to provide continuous coverage of samples within the soil column. In supplementary borings, sampling may be confined to the zone of specific interest.

Relatively thin zones of weak or unstable soils may be contained within more competent materials and may affect the engineering characteristics or behavior of the soil or rock. Continuous sampling in subsequent borings is needed through these suspect zones. Where it is not possible to obtain continuous samples in a single boring, samples may be obtained from adjacent closely spaced borings in the immediate vicinity and may be used as representative of the material in the omitted depth intervals. Such a set of borings should be considered equivalent to one principal boring.

d. Determining the Engineering Properties of Subsurface Materials

A general discussion of the classifications of soils and rocks and methods of determining their engineering properties is included in Reference 5.

The shear strengths of foundation materials in all zones subjected to significant imposed stresses should be determined to establish whether they are adequate to support the imposed loads with an appropriate margin of safety. Similarly, it is necessary both to determine the compressibilities and swelling potentials of all materials in zones subjected to significant changes of compressive stresses and to establish that the deformations will be acceptable. In some cases, these determinations may be made by suitable in situ tests and classification tests. Other situations may require the laboratory testing of undisturbed samples. Determination of dynamic moduli and damping ratios over applicable strain ranges of soil strata is needed for earthquake response analyses. Dynamic moduli and damping may be evaluated in situ, but usual procedures provide information only for low shear strain amplitudes. Laboratory tests on undisturbed samples can provide additional modulus and damping values to cover the range of strains anticipated under earthquake loading conditions.

5. Methods and Procedures for Exploratory Drilling

In nearly every site investigation, the primary means of subsurface exploration are borings and borehole sampling. Drilling methods and procedures should be compatible with sampling requirements and the methods of sample recovery.

The top of the hole should be protected by a suitable surface casing where needed. Below ground surface, the borehole should be protected by drilling mud or casing, as necessary, to prevent caving and disturbance of materials to be sampled. The use of drilling mud is preferred to prevent disturbance when obtaining undisturbed samples of coarse-grained soils.

However, casing may be used if proper steps are taken to prevent disturbance of the soil being sampled and to prevent upward movement of soil into the casing. Washing with open-ended pipe for cleaning or advancing sample boreholes should not be permitted. Bottom-discharge bits should be used only with low-to-medium fluid pressure and with upward-deflected jets.

In addition to pertinent information normally recorded for groundwater measurements and the results of field permeability tests, all depths and amounts of water or drilling mud losses, together with depths at which circulation is recovered, should be recorded and reported on boring logs and on geological cross sections. Logs and sections should also reflect incidents of settling or dropping of drill rods; abnormally low resistance to drilling or advance of samplers, core losses, instability or heave of the side and bottom of boreholes; influx of groundwater; and any other special feature or occurrence. Details of information that should be presented on logs of subsurface investigations are given in regulatory position 2.

Depths should be measured to the nearest tenth of a foot (3 cm) and should be correlatable to the elevation datum used for the site. Elevations of points in the borehole should also be determined with an accuracy of ±0.1 ft (±3 cm). Surveys of vertical deviation should be run in all boreholes that are used for crosshole seismic tests and in all boreholes where vertical deviations are significant to the use of data obtained. After use, it is advisable to grout each borehole with cement to prevent vertical movement of groundwater through the borehole.

6. Recovery of Undisturbed Soil Samples

The best undisturbed samples are often obtained by carefully performed hand trimming of block samples in accessible excavations. However, it is normally not practical to obtain enough block samples at the requisite spacings and depths by this method alone. It is customary, where possible, to use thin-wall tube samplers in borings for the major part of the undisturbed sampling. Criteria for obtaining undisturbed tube samples are given in regulatory position 6.

The recovery of undisturbed samples of good quality is dependent on rigorous attention to details of equipment and procedures. Proper cleaning of the hole by methods that minimize disturbance of the soil is necessary before sampling. The sampler should be advanced in a manner that minimizes disturbance. For example, when using fixed-piston-type samplers, the drilling rig should be firmly anchored or the piston should be fixed to an external anchor to prevent its moving upward during the push of the sampling tube. Care should be taken to ensure that the sample is not disturbed during its removal from the borehole or in disassembling the sampler. References 6 and 7 provide descriptions of suitable procedures for obtaining undisturbed samples.

With the conscientious use of proper field techniques, undisturbed samples in normally consolidated clays and silts can usually be recovered by means of fixed-piston-type thin-wall tube samplers without serious difficulty. Recovery of good undisturbed samples in sands requires greater care than in clays, but, with proper care and attention to detail, they can also be obtained with fixed-piston-type thin-wall tube samplers in most sands that are free of boulders and gravel-sized particles. Good-quality undisturbed samples are sometimes difficult to obtain in dense and very loose sands. Therefore, it may be necessary to consider alternative sampling techniques for these materials. Appendix B to this guide lists a number of sampling methods that are often used in these and other materials.

Undisturbed samples of boulders, gravels, or sand-gravel mixtures generally are difficult to obtain, and often it is necessary to use hand-sampling methods in test pits, shafts, or other accessible excavations to get good samples.

Dewatering by means of well points or other suitable methods may sometimes be necessary to obtain good-quality undisturbed samples of coarse-grained soils below the groundwater table. Osterberg and Varaksin (Ref. 8) describe a sampling program using dewatering of a shaft in sand with a frozen surrounding annulus. Samples suitable for density determination, though not for tests of mechanical properties, may sometimes be obtained from boreholes with the help of chemical stabilization or impregnation (Refs. 9 and 10). Special precautions are required when toxic chemicals are used. Also, where aquifers are involved, it may not be advisable to inject chemicals or grouts into them. Useful discussions of methods of sampling coarse-grained soils are given by Hvorslev (Ref. 11) and Barton (Ref. 12).

7. Handling, Field Storage, and Transporting of Samples

Treatment of samples after their recovery from the ground is as critical to their quality as the procedures used in obtaining them. Samples of cohesionless soils are particularly sensitive to disturbance in handling and require extreme care during removal from the borehole, removal from the sampler, and subsequent handling in order to prevent disturbance from impact and vibration (Ref. 6). Special precautions are required in transporting undisturbed samples of cohesionless soils because of their sensitivity to vibration and impact. They should be kept in a vertical position at all times, should be well padded to isolate them from vibration and impacts, and should be transported with extreme care. Transportation by commercial carriers is not advisable. Block samples should be handled by methods that give them equivalent protection from disturbance. All undisturbed samples should be properly sealed and protected against moisture loss.

Disturbed samples* may be sealed in the same way as undisturbed samples, if in tubes, or may be placed in noncorroding, airtight containers with identification tags, one on the interior and one on the exterior. Large representative samples may be placed in plastic bags, in tightly woven cloth, or in noncorroding cans or other vessels that do not permit loss of fine particles by sifting. Such samples may be transported by any convenient means.

Rock cores need to be stored and transported in durable boxes provided with suitable dividers to prevent shifting of the cores in any direction. They should be clearly labeled to identify the site, the boring number, the core interval, the length of core lost or not recovered in each core interval, and the top and bottom depths of the core interval. If the box has a removable lid, labeling should be placed on both the outside and inside of the box, as well as on the lid. Special containers may be required to protect samples to be used for fluid content determinations and shale samples to be used for tests of mechanical properties from changes in fluid content. Core samples should be transported with the care necessary to avoid breakage or disturbance.

C. REGULATORY POSITION

The site investigations program needed to determine foundation conditions at a nuclear power plant site is highly dependent on actual site conditions. The program should be flexible and adjusted as the site investigation proceeds with the advice of experienced personnel familiar with the site. The staff will review the results of each site investigation program on a case-by-case basis and make an independent evaluation of foundation conditions in order to judge the adequacy of the information presented.

1. General Site Investigation

Site investigations for nuclear power plants should be adequate, in terms of thoroughness, suitability of the methods used, quality of execution of the work, and documentation, to permit an accurate determination of the geologic and geotechnical conditions that affect the design, performance, and safety of the plant. The investigations should provide information needed to assess foundation conditions at the site and to perform engineering analysis and design with reasonable assurance that foundation conditions have been realistically estimated.

Information to be developed should include, as appropriate, (1) topographic, hydrologic, hydrographic, and geologic maps; (2) plot plans, showing locations of major structures and explorations; (3) boring logs and logs of exploratory trenches and excavations; (4) geologic profiles showing excavation limits for structures; and (5) geophysical data such as time-distance plots, profiles, and inhole surveys. Positions of all boreholes, piezometers, observation wells, soundings, trenches, exploration pits, and geophysical investigations should be surveyed in both plan and elevation and should be shown on plot plans, geologic sections, and maps. All surveys should be related to a fixed datum. The above information should be in sufficient detail and be integrated to develop an overall view of the project and the geologic and geotechnical conditions affecting it.

2. Logs of Subsurface Investigations

Boring logs should contain the date when the boring was made, the location of the boring with reference to the coordinate system used for the site, the depths of borings, and the elevations with respect to a permanent benchmark.

The logs should also include the elevations of the top and bottom of borings and the level at which the water table and the boundaries of soil or rock strata were encountered, the classification and description of the soil and rock layers, blow count values obtained from Standard Penetration Tests, percent recovery of rock core, quantity of core lost or not recovered for each core interval or drill run, and Rock Quality Designation (RQD). Results of field permeability tests and borehole logging should also be included on logs. The type of tools used in making the boring should be recorded. If the tools were changed, the depth at which the change was made and the reason for the change should be noted. Notes should be provided of everything significant to the interpretation of subsurface conditions, such as lost drilling fluid, rod drops, and changes in drilling rate. Incomplete or abandoned borings should be described with the same care as successfully completed borings. Logs of exploratory trenches and other excavation features should be presented in a graphic format in which all important components of the soil matrix and structural features in rock are shown in detail sufficient to permit independent evaluation. The location of all explorations should be shown on the geologic section together with elevations and important data.

3. Groundwater Investigations

Groundwater conditions should be observed during the course of the site investigation, and measurements should be made of the water level in exploratory borings. The groundwater or drilling mud level should be measured at the start of each workday for borings in progress, at the completion of drilling, and when the water levels in the borings have stabilized. In addition to the normal borehole groundwater measurements, piezometers or wells should be installed in as many locations as needed to adequately define the groundwater environment. Pumping tests are a preferable method for evaluating local permeability characteristics and assessing dewatering requirements for construction and operation of the plant. For major excavations where construction dewatering is required, piezometers or observation wells should be used during construction to monitor the groundwater surface and pore pressures beneath the excavation and in the adjacent ground.

When the possibility of perched groundwater tables or artesian pressures is indicated by borings or other evidence, piezometer installation should be made to measure each piezometric level independently. Care should be taken in the design and installation of piezometers to prevent hydraulic communication between aquifers. The occurrence of artesian pressure in borings should be noted on boring logs, and their heads should be measured and logged.

4. Procedures for Subsurface Investigations

Some techniques widely used for subsurface investigations are listed in Appendix B, which also cites appropriate standards and references procedures from published literature with general guidelines on the applicability, limitations, and potential pitfalls in their use. The use of investigations and sampling techniques other than those indicated in this guide is acceptable when it can be shown that the alternative methods yield satisfactory results. The attainment of satisfactory results in drilling, sampling, and testing is dependent on the techniques used, on care in details of operations, and on timely recognition of and correction of potential sources of error.

Field operations should be supervised by experienced professional personnel at the site of operations, and systematic standards of practice should be followed. Procedures and equipment used to carry out the field operations should be documented, as should all conditions encountered in all phases of investigations. Experienced personnel thoroughly familiar with sampling and testing procedures should also inspect and document sampling results and transfer samples from the field to storage or laboratory facilities.

5. Spacing and Depth of Subsurface Investigations

General guidelines for the spacing and depth of subsurface exploration at locations of safety-related structures for favorable or uniform geologic conditions are given in Appendix C to this guide. The actual distribution, number, and depth of borings needed for a site should be based on consideration of the complexity of geologic conditions and foundation requirements. The application of these guidelines is discussed in Section B.4 of this guide. The investigative effort required for a nuclear power plant should be greatest at the locations of safety-related structures and may vary in density and scope in other areas according to their spatial and geological relations to the site.

6. Sampling

Sampling of soils should include, as a minimum, the recovery of samples at regular intervals and at changes in materials. Alternating split spoon and undisturbed samples with depth is recommended.

For coarse-grained soils, samples should be taken at depth intervals no greater than 5 feet (1.5 meters). Beyond a depth of 50 feet (15 meters) below foundation level, the depth interval for sampling may be increased to 10 feet (3 meters). Also it is recommended that one or more borings for each major structure be continuously sampled. The boring should be reamed and cleaned between samples. Requirements for undisturbed sampling of coarse-grained soils will depend on actual site conditions and requirements for laboratory testing. Some general guidelines for recovering undisturbed samples are given in Sections B.4.b(2) and B.6 of this guide. Experimentation with different sampling techniques may be necessary to determine the method best suited to local soil conditions.

For compressible or normally consolidated clays, undisturbed samples should be continuous throughout the compressible strata in one or more principal borings for each major structure. These samples should be obtained by means of suitable fixed-piston-type thin-wall tube samplers or by methods that yield samples of equivalent quality.

Borings used for undisturbed sampling of soils should be at least 3 inches (7.6 cm) in diameter. Criteria for obtaining undisturbed tube samples include the following:

a. Tubes should meet the specifications of ASTM Standard D1587-67 (Ref. 13);

b. The Area Ratio* of the sampler should not exceed 13 percent and preferably should not exceed 10 percent;

c. The Specific Recovery Ratio* should be between 90 and 100 percent; tubes with less recovery may be acceptable if it appears that the sample may have broken off and otherwise appears essentially undisturbed;

d. The Inside Clearance Ratio* should be the minimum required for complete sample recovery; and

e. Samples recovered should contain no visible distortion of strata or opening or softening of materials brought about by the sampling procedure.

7. Retention of Samples, Rock Core, and Records

Samples and rock cores from principal borings should be retained at least until the power plant is licensed to operate and all matters relating to the interpretation of subsurface conditions at the site have been resolved. The need to retain samples and core beyond this time is a matter of judgment and should be evaluated on a case-by-case basis. For example, soil samples in tubes will deteriorate with time and will not be suitable for any undisturbed testing. However, they may be used as a visual record of what the foundation material is like. Similarly, cores of rock subject to slaking and rapid weathering such as shale will also deteriorate. It is recommended that photographs of soil samples and rock cores together with field and final logs of all borings and record samples with material descriptions be preserved for a permanent record. Other important records of the subsurface investigations program should also be preserved.

D. IMPLEMENTATION

Except in those cases in which the applicant proposes an acceptable alternative method for complying with specified portions of the Commission's regulations, this guide will be used by the staff to evaluate the results of foundation investigations submitted in connection with construction permit applications docketed after March 30, 1979. The staff will also use this guide to evaluate the results of foundation investigations performed after March 30, 1979, for new construction or major changes in plant layout or design by a person whose construction permit was issued on or before March 30, 1979.

APPENDIX B (Continued)

METHODS OF SUBSURFACE EXPLORATION

METHOD	PROCEDURE	APPLICABILITY	LIMITATIONS
1. Methods of Access for Sampling, Test, or Observation (Continued)			
Continuous Sampling or Displacement Boring	Boring advanced by repeated pushing of sampler or closed sampler is pushed to desired depth and sample is taken. (Ref. 11)	Recovery of representative samples of cohesive soils and undisturbed samples in some cohesive soils.	Effects of advance and withdrawal of sampler result in disturbed sections at top and bottom of sample. In some soils, entire sample may be disturbed. Best suited for use in cohesive soils. Continuous sampling in cohesionless soils may be made by successive reaming and cleaning of hole between sampling.
2. Methods of Sampling Soil and Rock			
Hand-Cut Block or Cylindrical Sample	Sample is cut by hand from soil exposed in excavation. (Refs. 16 and 17)	Highest quality undisturbed samples in all soils and in soft rock.	Requires accessible excavation and dewatering if below water table. Extreme care is required in sampling cohesionless soils.
Fixed-Piston Sampler	Thin-walled tube is pushed into soil, with fixed piston in contact with top of sample during push. (Refs. 6 and 11)	Undisturbed samples in cohesive soils, silts, and sands above or below the water table.	Some types do not have a positive means to prevent piston movement.
Hydraulic Piston Sampler (Osterberg Sampler)	Thin-walled tube is pushed into soil by hydraulic pressure. Fixed piston in contact with top of sample during push. (Refs. 6, 18, and 19)	Undisturbed samples in cohesive soils, silts, and sands above or below the water table.	Not possible to determine amount of sampler penetration during push. Does not have vacuum-breaker in piston.
Free-Piston Sampler	Thin-walled tube is pushed into soil. Piston rests on top of soil sample during push. (Ref. 6)	Undisturbed samples in stiff cohesive soils. Representative samples in soft-to-medium cohesive soils and silts.	May not be suitable for sampling in cohesionless soils. Free piston provides no control of specific recovery ratio.
Open Drive Sampler	Thin-walled, open tube is pushed into soil. (Refs. 11 and 16)	Undisturbed samples in stiff cohesive soils. Representative samples in soft-to-medium cohesive soils and silts.	Small diameter of tubes may not be suitable for sampling in cohesionless soils or for undisturbed sampling in uncased boreholes. No control of specific recovery ratio.

METHODS OF SUBSURFACE EXPLORATION

METHOD	PROCEDURE	APPLICABILITY	LIMITATIONS
2. Methods of Sampling Soil and Rock (Continued)			
Swedish Foil Sampler	Sample tube is pushed into soil while stainless steel strips unrolling from spools envelop sample. Piston, fixed by chain from surface, maintains contact with top of sample. (Refs. 17 and 20)	Continuous undisturbed samples up to 66 feet (20 m) long in very soft to soft clays.	Not suitable for use in soils containing gravel, sand layers, or shells, which may rupture foils and damage samples. Difficulty may be encountered in alternating hard and soft layers with squeezing of soft layers and reduction in thickness. Requires experienced operator.
Pitcher Sampler	Thin-walled tube is pushed into soil by spring above sampler while outer core bit reams hole. Cuttings removed by circulating drilling fluid. (Ref. 17)	Undisturbed samples in stiff, hard, brittle, cohesive soils and sands with cementation and in soft rock. Effective in sampling alternating hard and soft layers. Representative samples in soft-to-medium cohesive soils and silts. Disturbed samples may be obtained in cohesionless materials with variable success.	Frequently ineffective in cohesionless soils.
Denison Sampler	Hole is advanced and reamed by core drill while sample is retained in nonrotating inner core barrel with corecatcher. Cuttings removed by circulating drilling fluid. (Refs. 16 and 17)	Undisturbed samples in stiff-to-hard cohesive soil, sands with cementation, and soft rocks. Disturbed sample may be obtained in cohesionless materials with variable success.	Not suitable for undisturbed sampling in loose cohesionless soils or soft cohesive soils. Difficulties may be experienced in sampling alternating hard and soft layers.
Split-Barrel or Split Spoon Sampler	Split-barrel tube is driven into soil by blows of falling ram. Sampling is carried out in conjunction with Standard Penetration Test. (Ref. 13)	Representative samples in soils other than coarse-grained soils.	Samples are disturbed and not suitable for tests of physical properties.
Auger Sampling	Auger drill used to advance hole is withdrawn at intervals for recovery of soil samples from auger flights. (Ref. 13)	Determine boundaries of soil layers and obtain samples for soil classification.	Samples not suitable for physical properties or density tests. Large errors in locating strata boundaries may occur without close attention to details of procedure. (Ref. 17) In some soils, particle breakdown by auger or sorting effects may result in errors in determining gradation.

APPENDIX B (Continued)

METHODS OF SUBSURFACE EXPLORATION

METHOD	PROCEDURE	APPLICABILITY	LIMITATIONS
2. Methods of Sampling Soil and Rock (Continued)			
Rotary Core Barrel	Hole is advanced by core bit while core sample is retained within core barrel or within stationary inner tube. Cuttings removed by circulating drilling fluid. (Ref. 13)	Core samples in competent rock and hard soils with single-tube core barrel. Core samples in poor or broken rock may be obtainable with double-tube core barrel with bottom-discharge bit.	Because recovery is poorest in zones of weakness, samples generally fail to yield positive information on soft seams, joints, or other defects in rock.
Shot Core Boring (Calyx)	Boring advanced by rotating single core barrel, which cuts by grinding with chilled steel shot fed with circulating wash water. Used shot and coarser cuttings are deposited in an annular cup, or calyx, above the core barrel. (Ref. 11)	Large-diameter cores and accessible boreholes in rock.	Cannot be used in drilling at large angles to the vertical. Often ineffective in securing small-diameter cores.
Oriented Integral Sampling	Reinforcing rod is grouted into small-diameter hole, then overcored to obtain an annular core sample. (Ref. 21).	Core samples in rock with preservation of joints and other zones of weakness.	Samples are not well suited to tests of physical properties.
Wash Sampling or Cuttings Sampling	Cuttings are recovered from wash water or drilling fluid.	Samples useful in conjunction with other data for identification of major strata.	Sample quality is not adequate for site investigations for nuclear facilities.
Submersible Vibratory (Vibracore) Sampler	Core tube is driven into soil by vibrator. (Ref. 22)	Continuous representative samples in unconsolidated marine sediments.	Because of high area ratio and effects of vibration, samples may be disturbed.
Underwater Piston Corer	Core tube attached to drop weight is driven into soil by gravity after a free fall of controlled height. Cable-supported piston remains in contact with soil surface during drive. (Ref. 23)	Representative samples in unconsolidated marine sediments.	Samples may be seriously disturbed. (Ref. 24)
Gravity Corer	Open core tube attached to drop weight is driven into soil by gravity after free fall. (Ref. 23)	Representative samples at shallow depth in unconsolidated marine sediments.	No control of specific recovery ratio. Samples are disturbed.

METHODS OF SUBSURFACE EXPLORATION

METHOD	PROCEDURE	APPLICABILITY	LIMITATIONS
3. Methods of In Situ Testing of Soil and Rock[2]			
Standard Penetration Test	Split-barrel sampler is driven into soil by blows of free falling weight. Blow count for each 6 in. (15 cm) of penetration is recorded. (Ref. 13)	Blow count may be used as an index of consistency or density of soil. May be used for detection of changes in consistency or density in clay or sands. May be used with empirical relationships to estimate relative density of clean sand.	Extremely unreliable in silts, silty sands, or soils containing gravel. In sands below water table, positive head must be maintained in borehole. Determination of relative density in sands requires site-specific correlation or highly conservative use of published correlations. Results are sensitive to details of apparatus and procedure.
Dutch Cone Penetrometer	Steel cone is pushed into soil and followed by subsequent advance of friction sleeve. Resistance is measured during both phases of advance. (Ref. 26)	Detection of changes in consistency or relative density in clays or sands. Used to estimate static undrained shear strength of clay. Used with empirical relationships to obtain estimate of static compressibility of sand.	Strength estimates require onsite verification by other methods of testing.
Field Vane Shear Test	Four-bladed vane is pushed into undisturbed soil, then rotated to cause shear failure on cylindrical surface. Torsional resistance versus angular deflection is recorded. (Ref. 13)	Used to estimate in situ undrained shear strength and sensitivity of clays.	Not suitable for use in silt, sand, or soils containing appreciable amounts of gravel or shells. May yield unconservative estimates of shear strength in fissured clay soils or where strength is strain-rate dependent.
Drive-Point Penetrometer	Expendable steel cone is driven into soil by blows of falling weight. Blow count versus penetration is recorded. (Ref. 17)	Detection of gross changes in consistency or relative density. May be used in some coarse-grained soils.	Provides no quantitative information on soil properties.
Plate Bearing Test (Soil)	Steel loading plate is placed on horizontal surface and is statically loaded, usually by hydraulic jack. Settlement versus time is recorded for each load increment. (Ref. 17)	Estimation of strength and moduli of soil. May be used at ground surface, in excavations, or in boreholes.	Results can be extrapolated to loaded areas larger than bearing plate only if properties of soil are uniform laterally and with depth.

[2]See also Reference 25.

APPENDIX B (Continued)

METHODS OF SUBSURFACE EXPLORATION

METHOD	PROCEDURE	APPLICABILITY	LIMITATIONS
3. Methods of In Situ Testing of Soil and Rock (Continued)			
Plate Bearing Test or Plate Jacking Test (Rock)	Bearing pad on rock surface is statically loaded by hydraulic jack. Deflection versus load is recorded. (Ref. 27)	Estimation of elastic moduli of rock masses. May be used at ground surface, in excavations, in tunnels, or in boreholes.	Results can be extrapolated to loaded areas larger than bearing pad only if rock properties are uniform over volume of interest and if diameter of bearing pad is larger than average spacing of joints or other discontinuities.
Pressure Meter Test (Dilatometer Test)	Uniform radial pressure is applied hydraulically over a length of borehole several times its diameter. Change in diameter versus pressure is recorded. (Refs. 27 and 28)	Estimation of elastic moduli of rocks and estimation of shear strengths and compressibility of soils by empirical relationships.	Test results represent properties only of materials in near vicinity of borehole. Results may be misleading in testing materials whose properties may be anisotropic.
Field Pumping Test	Water is pumped from or into aquifer at constant rate through penetrating well. Change in piezometric level is measured at well and at one or more observation wells. Pumping pressures and flow rates are recorded. Packers may be used for pump-in pressure tests. (Refs. 29 and 30)	Estimation of in situ permeability of soils and rock mass.	Apparent permeability may be greatly influenced by local features. Effective permeability of rock is dependent primarily on frequency and distribution of joints. Test result in rock is representative only to extent that the borehole intersects a sufficient number of joints to be representative of the joint system of the rock mass.
Borehole Field Permeability Test	Water is added to an open-ended pipe casing sunk to desired depth. With constant head tests, constant rate of gravity flow into hole and size of casing of pipe are measured. Variations include applied pressure tests and falling head tests. (Ref. 16)	Rough approximation of in situ permeability of soils and rock mass.	Pipe casing must be carefully cleaned out just to the bottom of the casing. Clear water must be used or tests may be grossly misleading. Measurement of local permeability only.

METHODS OF SUBSURFACE EXPLORATION

METHOD	PROCEDURE	APPLICABILITY	LIMITATIONS
3. Methods of In Situ Testing of Soil and Rock (Continued)			
Direct Shear Test	Block of in situ rock is isolated to permit shearing along a preselected surface. Normal and shearing loads are applied by jacking. Loads and displacements are recorded. (Ref. 31)	Measurement of shearing resistance of rock mass in situ.	Tests are costly. Usually variability of rock mass requires a sufficient number of tests to provide statistical control.
Pressure Tunnel Test	Hydraulic pressure is applied to sealed-off length of circular tunnel, and diametral deformations are measured. (Ref. 27)	Determination of elastic constants of the rock mass in situ.	Volume of rock tested is dependent on tunnel diameter. Cracking due to tensile hoop stresses may affect apparent stiffness of rock.
Radial Jacking Test	Radial pressure is applied to a length of circular tunnel by flat jacks. Diametral deformations are measured. (Refs. 32 and 33)	Same as pressure tunnel test.	Same as pressure tunnel test.
Borehole Jack Test	Load is applied to wall of borehole by two diametrically opposed jacks. Deformations and pressures are recorded. (Ref. 34)	Determination of elastic modulus of rock in situ. Capable of applying greater pressures than dilatometers.	Apparent stiffness may be affected by development of tension cracks.
Borehole Deformation Meter	Device for measurement of diameters (deformation meter) is placed in borehole, and hole is overcored to relieve stresses on annular rock core containing deformation meter. Diameters (usually 3) are measured before and after overcoring. Modulus of rock is measured by laboratory tests on core; stresses are computed by elastic theory. (Ref. 35)	Measurement of absolute stresses in situ.	Stress field is affected by borehole. Analysis subject to limitations of elastic theory. Two boreholes at different orientations are required for determination of complete stress field. Questionable results in rocks with strongly time-dependent properties.

APPENDIX B (Continued)

METHODS OF SUBSURFACE EXPLORATION

METHOD	PROCEDURE	APPLICABILITY	LIMITATIONS
3. Methods of In Situ Testing of Soil and Rock (Continued)			
Inclusion Stressmeter	Rigid stress indicating device (stressmeter) is placed in borehole, and hole is overcored to relieve stresses on annular core containing stressmeter. In situ stresses are computed by elastic theory. (Ref. 35)	Measurement of absolute stresses in situ. Does not require accurate knowledge of rock modulus.	Same as above.
Borehole Strain Gauge	Strain gauge is cemented to bottom (end) of borehole, and gauge is overcored to relieve stresses on core-containing strain gauge. Stresses are computed from resulting strains and from modulus obtained by laboratory tests on core. (Ref. 35)	Measurement of absolute stresses in situ. Requires only one core drill size.	Same as above.
Flat Jack Test	Slot is drilled in rock surface producing stress relief in adjacent rock. Flat jack is grouted into slot and hydraulically pressurized. Pressure required to reverse deformations produced by stress relief is observed. (Refs. 35 and 36)	Measurement of one component of normal stress in situ. Does not require knowledge of rock modulus.	Stress field is affected by excavation or tunnel. Interpretation of test results subject to assumption that loading and unloading moduli are equal. Questionable results in rock with strongly time-dependent properties.
Hydraulic Fracturing Test	Fluid is pumped into sealed-off portion of borehole with pressure increasing until fracture occurs. (Ref. 35)	Estimation of minor principal stress.	Affected by anisotropy of tensile strength of rock.
Crosshold Seismic Test	Seismic signal is transmitted from source in one borehole to receiver(s) in other borehole(s), and transit time is recorded. (Ref. 37)	In situ measurement of compression wave velocity and shear wave velocity in soils and rocks.	Requires deviation survey of boreholes to eliminate errors due to deviation of holes from vertical. Refraction of signal through adjacent high-velocity beds must be considered in interpretation.

METHODS OF SUBSURFACE EXPLORATION

METHOD	PROCEDURE	APPLICABILITY	LIMITATIONS
3. Methods of In Situ Testing of Soil and Rock (Continued)			
Uphole/Downhole Seismic Test	Seismic signal is transmitted between borehole and ground surface, and transit time is recorded. (Ref. 37)	In situ measurement of compression wave velocity and shear wave velocity in soils and rocks.	Apparent velocity obtained is time-average for all strata between source and receiver.
Acoustic Velocity Log	Logging tool contains transmitting transducer and two receiving transducers separated by fixed gage length. Signal is transmitted through rock adjacent to borehole, and transit time over the gage length is recorded as difference in arrival times at the receivers. (Refs. 38 and 39)	Measurement of compression wave velocity. Used primarily in rocks to obtain estimate of porosity.	Results represent only the material immediately adjacent to the borehole. Can be obtained only in uncased, fluid-filled borehole. Use is limited to materials with P-wave velocity greater than that of borehole fluid.
3-D Velocity Log	Logging tool contains transmitting transducer and receiving transducer separated by fixed gage length. Signal is transmitted through rock adjacent to borehole, and wave train at receiver is recorded. (Ref. 40)	Measurement of compression wave and shear wave velocity ties in rock. Detection of void spaces, open fractures, and zones of weakness.	Results represent only the material immediately adjacent to the borehole. Can be obtained only in uncased, fluid-filled borehole. Correction required for variation in hole size. Use is limited to materials with P-wave velocity greater than that of borehole fluid.
Electrical Resistivity Log	Apparent electrical resistivity of soil or rock in neighborhood of borehole is measured by in-hole logging tool containing one of a wide variety of electrode configurations. (Refs. 38 and 39)	Appropriate combinations of resistivity logs can be used to estimate porosity and degree of water saturation in rocks. In soils, may be used as qualitative indication of changes in void ratio or water content, for correlation of strata between boreholes, and for location of strata boundaries.	Can be obtained only in uncased boreholes. Hole must be fluid filled, or electrodes must be pressed against wall of hole. Apparent resistivity values are strongly affected by changes in hole diameter, strata thickness, resistivity contrast between adjacent strata, resistivity of drilling fluid, etc.

METHODS OF SUBSURFACE EXPLORATION

METHOD	PROCEDURE	APPLICABILITY	LIMITATIONS
3. Methods of In Situ Testing of Soil and Rock (Continued)			
Neutron Log	Neutrons are emitted into rock or soil around borehole by a neutron source in the logging tool, and a detector isolated from the source responds to either slow neutrons or secondary gamma rays. Response of detector is recorded. (Refs. 38 and 39)	Correlation of strata between boreholes and location of strata boundaries. Provides an approximation to water content and can be run in cased or uncased, fluid-filled or empty boreholes.	Because of very strong borehole effects, results are generally not of sufficient accuracy for quantitative engineering uses.
Gamma-Gamma Log ("Density Log")	Gamma rays are emitted into rock around the borehole by a source in the logging tool, and a detector isolated from the source responds to backscattered gamma rays. Response of detector is recorded. (Ref. 38)	Estimation of bulk density in rocks, qualitative indication of changes in density of soils. May be run in empty or fluid-filled holes.	Effects of borehole size and density of drilling fluid must be accounted for. Presently not suitable for qualitative estimate of density in soils other than those of "rock-like" character. Cannot be used in cased boreholes.
Borehole Cameras	Film-type or television camera in a suitable protective container is used for observation of walls of borehole. (Ref. 41)	Detection and mapping of joints, seams, cavities, or other visually observable features in rock. Can be used in empty, uncased holes or in holes filled with clear water.	Results are affected by any condition that affects visibility.

APPENDIX C

SPACING AND DEPTH OF SUBSURFACE EXPLORATIONS FOR SAFETY-RELATED[1] FOUNDATIONS

TYPE OF STRUCTURE	SPACING OF BORINGS[2] OR SOUNDINGS	MINIMUM DEPTH OF PENETRATION
General	For favorable, uniform geologic conditions, where continuity of subsurface strata is found, the recommended spacing is as indicated for the type of structure. At least one boring should be at the location of every safety-related structure. Where variable conditions are found, spacing should be smaller, as needed, to obtain a clear picture of soil or rock properties and their variability. Where cavities or other discontinuities of engineering significance may occur, the normal exploratory work should be supplemented by borings or soundings at a spacing small enough to detect such features.	The depth of borings should be determined on the basis of the type of structure and geologic conditions. All borings should be extended to a depth sufficient to define the site geology and to sample all materials that may swell during excavation, may consolidate subsequent to construction, may be unstable under earthquake loading, or whose physical properties would affect foundation behavior or stability. Where soils are very thick, the maximum required depth for engineering purposes, denoted d_{max}, may be taken as the depth at which the change in the vertical stress during or after construction for the combined foundation loading is less than 10% of the in situ effective overburden stress. It may be necessary to include in the investigation program several borings to establish the soil model for soil-structure interaction studies. These borings may be required to penetrate depths greater than those depths required for general engineering purposes. Borings should be deep enough to define and evaluate the potential for deep stability problems at the site. Generally, all borings should extend at least 30 feet (9 meters) below the lowest part of the foundation. If competent rock is encountered at lesser depths than those given, borings should penetrate to the greatest depth where discontinuities or zones of weakness or alteration can affect foundations and should penetrate at least 20 feet (6 meters) into sound rock. For weathered shale or soft rock, depths should be as for soils.

[1]As determined by the final locations of safety-related structures and facilities.
[2]Includes shafts or other accessible excavations that meet depth requirements.

APPENDIX C (Continued)

SPACING AND DEPTH OF SUBSURFACE EXPLORATIONS FOR SAFETY-RELATED[1] FOUNDATIONS

TYPE OF STRUCTURE	SPACING OF BORINGS[2] OR SOUNDINGS	MINIMUM DEPTH OF PENETRATION
Structures including buildings, retaining walls, concrete dams	Principal borings: at least one boring beneath every safety-related structure. For larger, heavier structures, such as the containment and auxiliary buildings, at least one boring per 10,000 ft^2 (900 m^2) (approximately 100-foot (30-meter) spacing). In addition, a number of borings along the periphery, at corners, and other selected locations. One boring per 100 linear feet (30 linear meters) for essentially linear structures.[3]	At least one-fourth of the principal borings and a minimum of one boring per structure to penetrate into sound rock or to a depth equal to d_{max}. Others to a depth below foundation elevation equal to the width of structure or to a depth equal to the foundation depth below the original ground surface, whichever is greater.[3]
Earth dams, dikes, levees, and embankments	Principal borings: one per 100 linear feet (30 linear meters) along axis of structure and at critical locations perpendicular to the axis to establish geological sections with groundwater conditions for analysis.[3]	Principal borings: one per 200 linear feet (60 linear meters) to d_{max}. Others should penetrate all strata whose properties would affect the performance of the foundation. For water-impounding structures, to sufficient depth to define all aquifers and zones of underseepage that could affect the performance of structures.[3]
Deep cuts,[4] canals	Principal borings: one per 200 linear feet (60 linear meters) along the alignment and at critical locations perpendicular to the alignment to establish geologic sections with groundwater conditions for analysis.[3]	Principal borings: one per 200 linear feet (60 linear meters) to penetrate into sound rock or to d_{max}. Others to a depth below the bottom elevation of excavation equal to the depth of cut or to below the lowest potential failure zone of the slope.[3] Borings should penetrate previous strata below which groundwater may influence stability.[2]
Pipelines	Principal borings: This may vary depending on how well site conditions are understood from other plant site borings. For variable conditions, one per 100 linear feet (30 linear meters) for buried pipelines; at least one boring for each footing for pipelines above ground.[5]	Principal borings: For buried pipelines, one of every three to penetrate into sound rock or to d_{max}. Others to 5 times the pipe diameters below the invert elevation. For pipelines above ground, depths as for foundation structures.[3,5]
Tunnels	Principal borings: one per 100 linear feet (30 linear meters),[3] may vary for rock tunnels, depending on rock type and characteristics, and planned exploratory shafts or adits.	Principal borings: one per 200 linear feet (60 linear meters) to penetrate into sound rock or to d_{max}. Others to 5 times the tunnel diameter below the invert elevation.[4,5]

[3]Also supplementary borings or soundings that are design dependent or necessary to define anomalies, critical conditions, etc.
[4]Includes temporary cuts that would affect ultimate site safety.
[5]Supplementary borings or soundings as necessary to define anomalies.

SPACING AND DEPTH OF SUBSURFACE EXPLORATIONS FOR SAFETY-RELATED[1] FOUNDATIONS

TYPE OF STRUCTURE	SPACING OF BORINGS[2] OR SOUNDINGS	MINIMUM DEPTH OF PENETRATION
Reservoirs, impoundments	Principal borings: In addition to borings at the locations of dams or dikes, a number of borings should be used to investigate geologic conditions of the reservoir basin. The number and spacing of borings should vary with the largest concentration being near control structures and the coverage decreasing with distance upstream.	Principal borings: at least one-fourth to penetrate that portion of the saturation zone that may influence seepage conditions or stability. Others to a depth of 25 feet (7.6 meters) below reservoir bottom elevation.[5]

APPENDIX D

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