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SITE INVESTIGATIONS FOR FOUNDATIONS OF NUCLEAR POWER PLANTS

A. INTRODUCTION

Appendix A, "Seismic and Geologic Siting Criteria for Nuclear Power Plants," to 10 CFR Part 100, "Reactor Site Criteria," establishes requirements for conducting site investigations to permit an 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 deal with hydrologic investigations, except for groundwater measurements, nor does it discuss geophysical methods of subsurface exploration.

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. Appendix A 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 criteria 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. Appendix E contains a bibliographical listing of related material.

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 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 against walls, the stability of cuts and slopes in soil and rock, the effect of earthquake-induced motions 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 include:

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

c. Groundwater conditions;

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

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

f. 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

g. 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 can be obtained by a reveiw, 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. Well records and water supply reports,

k. Oil well records,

l. Hydrologic 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 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 (seismic refraction), 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, 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 should be observed in borings at the time they are made; however, for engineering applications, such data must be 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. Piezometer or well installations should be made in as many locations as needed to define groundwater conditions. 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.

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. The 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 subsurface conditions. Methods of conducting subsurface investigations are tabulated in Appendix B, and criteria 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 will exceed those indicated in Appendix C and are determined by the degree of resolution needed in the definition of foundation properties.

The cumulative thicknesses of the various material types, their degree of variability, and ranges of the material properties must 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 should 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.

Whereve feasible, the locations of subsurface explorations should be chosen to permit the construction of geological cross sections in important subsurface views of 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 thin strata or other geologic features that may be important to foundation behavior but, because of their limited extent, 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 RQD (Rock Quality Designation),* dropping of rods, lost drilling fluid circulation, zones requiring casing, and other zones where drilling difficulties 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 anomolous zones. Where soil-filled voids, channels, or fissures are encountered, representative samples* of the filling materials are needed. Where there is evidence of significant residual stresses, they should be evaluated on the basis of in situ stress or strain measurements.

(2) *Granular Soils.* Investigations of granular soils should include borings with splitspoon 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 device is properly calibrated to site conditions.

Suitable samples should be obtained for soil identification and classification, in situ density determinations, mechanical analyses, and anticipated laboratory testing. In these investigations, it is important to obtain the best possible undisturbed samples* for testing to determine whether the sands are sufficiently dense to preclude liquefaction or damaging cyclic deformation. The 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 Category I 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 5.

Granular soils containing coarse 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 percent cobbles, boulders, and coarse material and their 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 its in situ structure,* and therefore the recovery and testing of good undisturbed samples are necessary. Criteria for the distribution and methods for obtaining undisturbed samples are discussed in regulatory position 5.

(4) *Subsurface Cavities.* Subsurface cavities may occur in water-soluble rocks, lavas, or weakly indurated sedimentary rocks as the result of subterranean solutioning and erosion. 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.

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.

Indications of the presence of cavities, such as 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 trace out 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. 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. Remedial grouting or other corrective measures should be employed where necessary.

(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 of sufficient horizontal and vertical intervals small enough to determine the material variability and should include adequate sampling of representative materials for laboratory testing.

c. *Sampling*

All soil and rock samples obtained for testing should be representative. 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 splitspoon 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 properties 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*

The shear strengths of foundation materials in all zones subjected to significant imposed stresses must 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 modulus and damping values for soil strata is required for earthquake response analyses. These determinations may be made by laboratory testing of suitable undisturbed samples in conjunction with appropriate in situ tests.

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 granular 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.

The groundwater or drilling mud level should be measured at the start and end of each work day for borings in progress, at the completion of drilling, and at least 24 hours after drilling is completed. In addition to pertinent information normally recorded, 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 and 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. Deviation surveys should be run in all boreholes that are used for crosshole seismic tests and in all boreholes where 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 in 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 5.

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 do not produce avoidable disturbance of the soil, is necessary before sampling. The sampler should be advanced in a manner that does not produce avoidable 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 2 and 3 provide descriptions of suitable proceedures 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 size particles. Appendix B lists a number of sampling methods that are suitable for use 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.

When obtaining undisturbed samples of granular soils below the groundwater table, dewatering by means of well points or other suitable methods may be required. Osterberg and Varaksin (Ref. 4) 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. 5, 6). 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 granular soils are given by Hvorslev (Ref. 7) and Barton (Ref. 8).

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. 2). Special precautions are required in transporting undisturbed samples 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 suitably marked, noncorroding, airtight containers. 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, and the top and bottom depths of the core. 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, as appropriate, include (1) topographic, hydrologic, hydrographic, and geologic maps; (2) plot plans, showing locations of major structures and explorations; (3) boring logs and logs of trenches and excavations; and (4) geologic profiles showing excavation limits for structures and 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 bench mark.

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, 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 trenches and exploratory excavations should be presented in a format similar to the boring logs. The location of all explorations should be shown on the geologic section together with elevations and important data.

3. Procedures for Subsurface Investigations

Some techniques widely used for subsurface investigations are listed in Appendix B. It also cites appropriate standards and references procedures from published literature with general guidelines on the applicability, limitations, and potential pitfalls in their use. Additional suitable techniques are provided by other literature listed in Appendix D. 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.

4. Spacing and Depth of Subsurface Investigations

Criteria 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. The application of these criteria 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 Category I structures and may vary in intensity and scope in other areas according to their spatial and geolgical relations to the site.

5. Sampling

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

For granular soils, samples should be taken at depth intervals no greater than 5 feet. Beyond a depth of 50 feet below foundation level, the depth interval for sampling may be increased to 10 feet. 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 granular soils will depend on actual site conditions and requirements for laboratory testing. Some general guidelines for recovering undisturbed samples are given in Section B.4.b(2) and Section B.6 of the discussion 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 in diameter. Criteria for obtaining undisturbed tube samples include the following:

a. Tubes should meet the specifications of ASTM Standard D 1587-67 (Ref. 9);

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 just broken off and otherwise appears essentially undisturbed;

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

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

6. 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. 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, core of rock subject to slaking and rapid weathering such as shale will also deteriorate. It is recommended that photographs of soil samples and rock core 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

This guide will be used by the staff to evaluate the results of site investigations, including the adequacy and quality of data provided to define foundation conditions and the geotechnical parameters needed for engineering analysis and design, submitted in connection with construction permit applications docketed after June 1, 1978. The staff will also use this guide to evaluate the results of any new site investigations performed after June 1, 1978, by a person whose construction permit was issued on or before June 1, 1978.

APPENDIX A

DEFINITIONS

For the convenience of the user, the following terms are presented with their definitions as used in this guide:

Accessible excavation—an excavation made for the purpose of investigating and sampling materials or conditions below the ground surface, of such shape and dimensions as to permit the entry of personnel for direct examination, testing, or sampling.

Area Ratio— (C_a) of a sampling device is defined as:

$$C_a = \frac{D_o^2 - D_e^2}{D_e^2}$$

where D_o is the outside diameter of that part of the sampling device that is forced into the soil, and D_e is the inside diameter, normally the diameter of the cutting edge.

Boring—an exploratory hole in soil or rock, or both, made by removal of materials in the form of samples or cuttings (cf. *soundings*).

Disturbed sample—a sample whose internal structure has been altered to such a degree that it does not reasonably approximate that of the material in situ. Such a sample may be completely remolded, or it may bear a resemblance to an undisturbed sample in having preserved the gross shape given it by a sampling device.

Geotechnical—of or pertaining to the earth sciences (geology, soils, seismology, and groundwater hydrology) and that part of civil engineering which deals with the interrelationship between the geologic environment and the works of man.

In situ test—a test performed on in-place soil or rock for the purpose of determining some physical property. As used in this guide, it includes geophysical measurements.

Inside Clearance Ratio (C_i) of a sampling device is defined as:

$$C_i = \frac{D_i - D_e}{D_e}$$

where D_i is the inside diameter of the sample tube or liner and D_e is the diameter of the cutting edge.

Observation well—an open boring that permits measuring the level or elevation of the groundwater table.

Piezometer—a device or instrument for measuring pore pressure or hydraulic potential at a level or point below the ground surface.

Principal borings—those exploratory holes that are used as the primary source of subsurface information. They are used to explore and sample all soil or rock strata within the interval penetrated to define the geology of the site and to determine the properties of the subsurface materials. Not included are borings from which no samples are taken, borings used to investigate specific or limited intervals, or borings so close to others that the information yielded represents essentially a single location.

Representative sample—a sample that (1) contains approximately the same mineral constituents of the stratum from which it is taken, in the same proportions, and with the same grain-size distribution and (2) is uncontaminated by foreign materials or chemical alteration.

Rock Quality Designation (RQD)—an indirect measurement of the degree of rock fracturing and jointing and rock quality. It is calculated by summing the lengths of all hard and sound pieces of recovered core longer than 4 inches (10cm) and dividing the sum by the total length of core run.

Sounding—an exploratory penetration below the ground surface by means of a device that is used to measure or observe some in situ property of the materials penetrated, usually without recovery of samples or cuttings.

Specific Recovery Ratio—(R_s) in the advance of a sample tube is defined as:

$$R_s = \frac{\Delta L}{\Delta H}$$

where ΔL is the increment of length of sample in the tube corresponding to an increment ΔH of sampler advance.

Soil structure—a complex physical-mechanical property, defined by the sizes, shapes, and arrangements of the constituent grains and intergranular matter and the bonding and capillary forces acting among the constituents.

Supplementary borings or *supplementary soundings*—borings or soundings that are made in addition to principal borings for some specific or limited purpose.

Undisturbed sample—a sample obtained and treated in such a way that disturbance of its original structure is minimal, making it suitable for laboratory testing of material properties that depend on structure.

APPENDIX B

METHODS OF SUBSURFACE EXPLORATION[1]

METHOD	PROCEDURE	APPLICABILITY	LIMITATIONS
METHODS OF ACCESS FOR SAMPLING, TEST, OR OBSERVATION			
Pits, Trenches, Shafts, Tunnels	Excavation made by hand, large auger, or digging machinery. (Ref. 7)	Visual observation, photography, disturbed and undisturbed sampling, in situ testing of soil and rock.	Depth of unprotected excavations is limited by groundwater or safety considerations.
Auger Boring	Boring advanced by hand auger or power auger. (Ref. 7)	Recovery of remolded samples, and determining groundwater levels. Access for undisturbed sampling of cohesive soils.	Will not penetrate boulders or most rock.
Hollow Stem Auger Boring	Boring advanced by means of continuous-flight helix auger with hollow center stem. (Ref. 10)	Access for undisturbed or representative sampling through hollow stem with thin-wall tube sampler, core barrel, or split-barrel sampler.	Should not be used with plug in granular soils. Not suitable for undisturbed sampling in loose sand or silt. (Ref. 11)
Wash Boring	Boring advanced by chopping with light bit and by jetting with upward-deflected jet. (Ref. 7)	Cleaning out and advancing hole in soil between sample intervals.	Suitable for use with sampling operations in soil only if done with low water velocities and with upward-deflected jet.
Rotary Drilling	Boring advanced by rotating drilling bit; cuttings removed by circulating drilling fluid. (Ref. 7)	Cleaning out and advancing hole in soil or rock between sample intervals.	Drilling mud should be used in granular soils. Bottom discharge bits are not suitable for use with undisturbed sampling in soils unless combined with protruding core barrel, as in Denison sampler, or with upward-deflected jets.

[1]See also Refs. 32-40.

APPENDIX B (Continued)

METHODS OF SUBSURFACE EXPLORATION

METHOD	PROCEDURE	APPLICABILITY	LIMITATIONS
METHODS OF ACCESS FOR SAMPLING, TEST, OR OBSERVATION			
Percussion Drilling	Boring advanced by air-operated impact hammer.	Detection of voids and zones of weakness in rock by changes in drill rate or resistance. Access for in situ testing or logging.	Not suitable for use in soils.
Cable Drilling	Boring advanced by repeated dropping of heavy bit; removal of cuttings by bailing. (Ref. 7)	Advancing hole in soil or rock. Access for sampling, in situ testing, or logging in rock. Penetration of hard layers, gravel, or boulders in auger borings.	Causes severe disturbance in soils; not suitable for use with undisturbed sampling methods.
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. 7)	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.
METHODS OF SAMPLING SOIL AND ROCK[2]			
Hand-Cut Block or Cylindrical Sample	Sample is cut by hand from soil exposed in excavation. (Refs. 12, 13)	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.

[2]See also Reference 31.

APPENDIX B (Continued)

METHODS OF SUBSURFACE EXPLORATION

METHODS OF SAMPLING SOIL AND ROCK

METHOD	PROCEDURE	APPLICABILITY	LIMITATIONS
Fixed-Piston Sampler	Thin-walled tube is pushed into soil, with fixed piston in contact with top of sample during push. (Refs. 2, 7)	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)	Thin-walled tube is pushed into soil by hydraulic pressure. Fixed piston in contact with top of sample during push. (Refs. 2, 14)	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. 2)	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.

APPENDIX B (Continued)

METHODS OF SUBSURFACE EXPLORATION

METHODS OF SAMPLING SOIL AND ROCK

METHOD	PROCEDURE	APPLICABILITY	LIMITATIONS
Open Drive Sampler	Thin-walled, open tube is pushed into soil. (Refs. 7, 12)	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.
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. 13, 15)	Continuous undisturbed samples up to 20m 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. 13)	Undisturbed samples in hard, brittle, cohesive soils and sands with cementation. 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.

APPENDIX B (Continued)

METHODS OF SUBSURFACE EXPLORATION

METHODS OF SAMPLING SOIL AND ROCK

METHOD	PROCEDURE	APPLICABILITY	LIMITATIONS
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. 12, 13)	Undisturbed samples in stiff to hard cohesive soil, sands with cementation, and soft rocks. Disturbed samples may be obtained in cohesionless materials with variable success.	Not suitable for undisturbed sampling in loose cohesionless soils or soft cohesive soils.
Split-Barrel or Splitspoon Sampler	Split-barrel tube is driven into soil by blows of falling ram. Sampling is carried out in conjunction with Standard Penetration Test. (Ref. 9)	Representative samples in soils other than coarse granular 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. 9)	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. 13) In some soils, particle breakdown by auger or sorting effects may result in errors in determining gradation.

APPENDIX B (Continued)

METHODS OF SUBSURFACE EXPLORATION

METHODS OF SAMPLING SOIL AND ROCK

METHOD	PROCEDURE	APPLICABILITY	LIMITATIONS
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. 9)	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. 7)	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. 16)	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.

APPENDIX B (Continued)

METHODS OF SUBSURFACE EXPLORATION

METHOD	PROCEDURE	APPLICABILITY	LIMITATIONS
METHODS OF SAMPLING SOIL AND ROCK			
Submersible Vibratory (Vibracore) Sampler	Core tube is driven into soil by vibrator. (Ref. 17)	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 controlled height of free fall. Cable-supported piston remains in contact with soil surface during drive. (Ref. 18)	Representative samples in unconsolidated marine sediments.	Samples may be seriously disturbed. (Ref. 19)
Gravity Corer	Open core tube attached to drop weight is driven into soil by gravity after free fall. (Ref. 18)	Representative samples at shallow depth in unconsolidated marine sediments.	No control of specific recovery ratio. Samples are disturbed.
METHODS OF IN SITU TESTING OF SOIL AND ROCK			
Standard Penetration Test	Split-barrel sampler is driven into soil by blows of falling weight. Blow count for each 6 in. of penetration is recorded. (Ref. 9)	Blow count may be used as an index of consistency or density of soil. May be used for detection of changes in consistency or relative 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.

APPENDIX B (Continued)

METHODS OF SUBSURFACE EXPLORATION

METHODS OF IN SITU TESTING OF SOIL AND ROCK

METHOD	PROCEDURE	APPLICABILITY	LIMITATIONS
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. 20).	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. 9)	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. 13)	Detection of gross changes in consistency or relative density. May be used in some coarse granular 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. 9)	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.

METHODS OF SUBSURFACE EXPLORATION

METHODS OF IN SITU TESTING OF SOIL AND ROCK

METHOD	PROCEDURE	APPLICABILITY	LIMITATIONS
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. 21)	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. (Ref. 21)	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. (Refs. 22, 23)	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 segment penetrated by borehole is representative of joint system of rock mass.
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. 24)	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.

APPENDIX B (Continued)

METHODS OF SUBSURFACE EXPLORATION

METHODS OF IN SITU TESTING OF SOIL AND ROCK

METHOD	PROCEDURE	APPLICABILITY	LIMITATIONS
Pressure Tunnel Test	Hydraulic pressure is applied to sealed-off length of circular tunnel, and diametral deformations are measured. (Ref. 21)	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.	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. 25)	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. 26)	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
METHODS OF IN SITU TESTING OF SOIL AND ROCK			
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. 26)	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. 26)	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. 26, 27)	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.

APPENDIX B (Continued)

METHODS OF SUBSURFACE EXPLORATION

METHOD	PROCEDURE	APPLICABILITY	LIMITATIONS
	METHODS OF IN SITU TESTING OF SOIL AND ROCK		
Hydraulic Fracturing Test	Fluid is pumped into sealed-off portion of borehole with pressure increasing until fracture occurs. (Ref. 26)	Estimation of minor principal stress.	Affected by anisotropy of tensile strength of rock.
Crosshole Seismic Test	Seismic signal is transmitted from source in one borehole to receiver(s) in other borehole(s), and transit time is recorded. (Ref. 28)	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.
Uphole/Downhole Seismic Test	Seismic signal is transmitted between borehole and ground surface, and transit time is recorded. (Ref. 28)	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. 29, 30)	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.

METHODS OF SUBSURFACE EXPLORATION

METHOD	PROCEDURE	APPLICABILITY	LIMITATIONS
	METHODS OF IN SITU TESTING OF SOIL AND ROCK		
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. 31)	Measurement of compression wave and shear wave velocities 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. 29, 30)	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.
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. 29, 30)	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.

APPENDIX B (Continued)

METHODS OF SUBSURFACE EXPLORATION

METHODS OF IN SITU TESTING OF SOIL AND ROCK

METHOD	PROCEDURE	APPLICABILITY	LIMITATIONS
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 back-scattered gamma rays. Response of detector is recorded. (Ref. 29)	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. 32)	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[3] FOUNDATIONS

TYPE OF STRUCTURE	SPACING OF BORINGS[4] OR SOUNDINGS	MINIMUM DEPTH OF PENETRATION
General	For favorable, uniform geologic conditions, where continuity of subsurface strata is found, spacing should be as indicated for the type of structure with at least one boring at the location of every safety-related or Seismic Category I 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 also be taken as the depth at which the shear wave velocity of the soil mass exceeds 3,000 ft/sec. It may be necessary to include in the investigation program several borings needed to complete information 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 soil stability problems at the site. Generally all borings should extend at least 30 feet 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 can affect foundations and should penetrate at least 20 ft into sound rock. For weathered shale or soft rock, depths should be as for soils.

[3]As determined by the final locations of safety-related structures and facilities.

[4]Includes shafts or other accessible excavations that meet depth requirements.

APPENDIX C

SPACING AND DEPTH OF SUBSURFACE EXPLORATIONS FOR SAFETY-RELATED[3] FOUNDATIONS

TYPE OF STRUCTURE	SPACING OF BORINGS[4] 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 sq ft (approximately 100 ft spacing) and, in addition, a number of borings along the periphery, at corners, and other selected locations. One boring per 100 linear ft for essentially linear structures.[5]	Principal borings: 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.[5]
Earth dams, dikes, levees, and embankments.	Principal borings: one per 100 linear ft along axis of structure and at critical locations perpendicular to the axis to establish geological sections and groundwater conditions for analysis.[5]	Principal borings: one per 200 linear ft to d_{max}. Others should penetrate all strata whose strength would affect stability. For water-impounding structures, to sufficient depth to define all aquifers and zones of underseepage that could affect performance of structure.[5]
Deep cuts,[6] canals	Principal borings: one per 200 linear ft along the alignment and at critical locations perpendicular to the alignment to establish geologic sections for analysis.[5]	Principal borings: one per 200 linear ft 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.[5] Borings should penetrate pervious strata below which groundwater may influence stability.

[5] Also supplementary borings or soundings which are design dependent or necessary to define anomalies, critical abutment conditions, etc.

[6] Includes temporary cuts, open during construction, where loss of strength due to excessive deformations would affect ultimate site safety.

APPENDIX C

SPACING AND DEPTH OF SUBSURFACE EXPLORATIONS FOR SAFETY-RELATED[3] FOUNDATIONS

TYPE OF STRUCTURE	SPACING OF BORINGS[4] OR SOUNDINGS	MINIMUM DEPTH OF PENETRATION
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 ft for buried pipelines; at least one boring for each footing for pipelines above ground.[7]	Principal borings: For buried pipelines, one per 200 linear ft 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.[7]
Tunnels	Principal borings: one per 100 linear ft.[5]	Principal borings: one per 200 linear ft to penetrate into sound rock or to d_{max}. Others to 5 times the tunnel diameter below the invert elevation.[7]
Reservoirs, impoundments	Principal borings: one per 50,000 ft^2 of interior area of the impoundment, in addition to borings at the locations of dams or dikes.[7]	Principal borings: at least one-fourth, but no fewer than one, of the principal borings to penetrate into sound rock or to d_{max}. Others to a depth of 25 ft below reservoir bottom elevation.[7]

[7] Supplementary borings or soundings as necessary to define anomalies.

APPENDIX D

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APPENDIX E

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