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U.S. NUCLEAR REGULATORY COMMISSION

REGULATORY GUIDE

OFFICE OF STANDARDS DEVELOPMENT

REGULATORY GUIDE 1.132

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.

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

*Lines indicate substantive changes from previous issue.

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Comments and suggestions for improvements in these guides are encouraged at all times, and guides will be revised, as appropriate, to accommodate comments and to reflect new information or experience. This guide was revised as a result of substantive comments received from the public and additional staff review.

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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 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.

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.