U.S. NUCLEAR REGULATORY COMMISSION

Revision 2
October 2003

REGULATORY GUIDE

OFFICE OF NUCLEAR REGULATORY RESEARCH

REGULATORY GUIDE 1.132

(Draft was issued as DG-1101)

SITE INVESTIGATIONS FOR FOUNDATIONS OF NUCLEAR POWER PLANTS

A. INTRODUCTION

This regulatory guide describes field investigations for determining the geological, engineering, and hydrogeological characteristics of a prospective plant site. It provides guidance for developing geologic information on stratigraphy, lithology, and structure of the site. The investigations recommended provide data defining the static and dynamic engineering properties of soil and rock materials at the site and their spatial distribution. Thus, the site investigations provide a basis for evaluating the safety of the site with respect to the performance of foundations and earthworks under anticipated loading conditions, including earthquakes.

In 1996, the Nuclear Regulatory Commission (NRC) issued new regulations concerning site evaluation factors and geologic and seismic siting criteria for nuclear power plants in Subpart B, “Evaluation Factors for Stationary Power Reactor Site Applications on or After January 10, 1997," of 10 CFR Part 100, “Reactor Site Criteria.” In particular, 10 CFR 100.20(c), 100.21(d), and 100.23 of Part 100 establish requirements for conducting site investigations for nuclear power plants for site applications submitted after January 10, 1997.

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.

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This guide was issued after consideration of comments received from the public. 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. Written comments may be submitted to the Rules and Directives Branch, ADM, U.S. Nuclear Regulatory Commission, Washington, DC 20555-0001.

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This regulatory guide describes methods acceptable to the NRC staff for conducting field investigations to acquire the data on geological and engineering characteristics of a site needed for a nuclear power plant site application. The guide includes recommendations for developing site-specific investigation programs and guidance for conducting subsurface investigations. The guide is being revised to incorporate newer practices and insights. A report written by the U.S. Army Corps of Engineers staff, NUREG/CR-5738, was used as a technical basis for this guide and may be consulted for details of procedures. The appendices to this guide are taken from that publication.

Laboratory tests and analyses for determining soil and rock properties are described in Regulatory Guide 1.138, “Laboratory Investigations of Soils for Engineering Analysis and Design of Nuclear Power Plants.” Regulatory Guide 1.165, “Identification and Characterization of Seismic Sources and Determination of Safe Shutdown Earthquake Ground Motion,” defines investigations related to seismicity, faults, and vibratory ground motion. This guide does not deal with volcanologic or hydrologic investigations, except for groundwater measurements at the site. Considerations for flooding are described in Regulatory Guide 1.59, “Design Basis Floods for Nuclear Power Plants.”

The information collections contained in this regulatory guide are covered by the requirements of 10 CFR Part 50, which were approved by the Office of Management and Budget, approval number 3150-0011. If a means used to impose an information collection does not display a currently valid OMB control number, the NRC may not conduct or sponsor, and a person is not required to respond to, the information collection.

B. DISCUSSION

PURPOSE

The purpose of the site investigations described in this guide is to acquire the geotechnical data needed to design nuclear power plant foundations for safety and performance. They should define the overall site geology to the degree necessary to understand subsurface conditions and to identify potential geologic hazards that may exist at the site. Local groundwater conditions must also be defined. Investigations for hazards such as fault offsets, landslides, cavernous rocks, ground subsidence, and soil liquefaction are especially important.

Investigations described here are closely related to those contained in Regulatory Guide 1.165. The main purpose of that guide is to define seismologic and related geologic aspects of the site for determining the safe shutdown earthquake ground motion (SSE), and it includes investigations over a broader area. This guide is more narrowly focused on the geologic and engineering characteristics of the specific site. Appendix D to Regulatory Guide 1.165 gives detailed instructions for investigating tectonic and nontectonic surface deformation. As these types of deformation are also part of the site engineering data, applicants are referred to that Appendix for appropriate guidance.

The aim of site investigations is to gain an understanding of the three-dimensional distribution of geological features (rocks, soils, extent of weathering, fractures, etc.) at the site, and to obtain the soil and rock properties that are needed for designing foundations for a nuclear power plant and associated critical structures. The density of data gathered varies over a plant site according to the variability of the soils and rocks and the importance assigned to structures planned for a particular location. Display and visualization of such data have traditionally been accomplished with maps and cross-sections. Given the computer resources and Geographic Information Systems (GIS) available today, it is advantageous to incorporate the data into a GIS database, which then permits plotting of appropriate maps, cross-sections, and three-dimensional displays. Employing a GIS also permits using different scales for effective viewing.

It is worthwhile to point out that good site investigations have the added benefit of saving time and money by reducing problems in licensing and construction. A case study report on geotechnical investigations, for example, concludes that additional geotechnical information would almost always save time and costs (National Research Council).

C. REGULATORY POSITION

1. GENERAL

A well-thought-out program of site exploration, progressing from literature search and reconnaissance investigations to detailed site investigation, construction mapping, and final as-built data compilation should be established to form a clear basis for the geotechnical work and foundation design. Because details of an actual site investigation program will be site dependent, such a program should be tailored to the specific conditions of the site using sound professional judgment. The program should be flexible and adjusted as the site investigation proceeds, with the advice of personnel experienced in site investigations. Also, this guide represents techniques available at the date of issuance. As the science advances, useful procedures and equipment should be included as they are developed and accepted by the profession.

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.

2. TYPES OF DATA TO BE ACQUIRED

2.1 Geological Conditions

Geological conditions comprise general geological conditions, the types and structure of soils and rocks at the surface and in the subsurface, the degree and extent of weathering, and petrological characteristics, such as structure, texture, and composition. The presence of potential hazards, such as faulting, landslides, erosion, or deposition by rivers or on shorelines; caverns formed by dissolution or mining activity; ground subsidence; and soil shrinking and swelling, is also to be determined. Data to evaluate the soil liquefaction potential and the orientation and characteristics of bedding, foliations, or jointing and faulting are also needed.

2.2 Engineering Properties of Soils and Rocks

These properties include density and seismic velocities and parameters of strength, elasticity, and plasticity. Some of these properties can be measured in situ, and those measurements together with sample collection are discussed in this guide. Detailed determination of these and other engineering properties also requires laboratory testing, which is described in Regulatory Guide 1.138.

2.3 Groundwater Conditions

Only conditions at the site, such as groundwater levels, thickness of aquifers and confining beds, groundwater flow patterns, and transmissivities and storage coefficients are to be determined.

2.4 Man-Induced Conditions

The existing infrastructure is to be located, together with dams or reservoirs whose locations may cause a flooding hazard or produce loading effects at the site. Past or ongoing activities, such as mining or oil and gas production, and other fluid extraction or injection also need to be documented. The presence of former industrial sites, underground storage tanks, or landfills should be determined and the potential for hazardous, toxic, or radioactive waste investigated.

2.5 Cultural and Environmental Considerations

Cultural resources, such as archaeological sites and artifacts, must be considered to comply with the Archaeological Resources Protection Act of 1979 and the Native American Graves Protection and Repatriation Act of 1990.

Aspects of the Clean Water Act (33 U.S.C. 1344) must also be taken into account. Placement of fill into wetlands is regulated at the national level. State and local wetland protection laws may also apply. Guidance on identifying and delineating wetlands is given in the Corps of Engineers Wetlands Delineation Manual. Information on applications for Section 404 permits for modifying wetlands can be obtained from District Offices of the Corps.

2.6 Related Considerations

Guidance on seismicity and related seismic data and historical records is in Regulatory Guide 1.165, together with guidance on vibratory ground motion resulting from earthquakes. Although this subject is not repeated here, many of the investigations listed in that guide could and should be coordinated with the site investigations described here and conducted at the same time for greater efficiency. Appendix D to Regulatory Guide 1.165 is to be used as guidance for investigating tectonic and nontectonic surface deformation.

3. LITERATURE SEARCH AND RECONNAISSANCE

3.1 General

Establishing the geological conditions and engineering properties of a site is an iterative process whereby successive phases of investigation lead to increasingly detailed data. Therefore, it is important to have a proper system for recording the data and gaining a three-dimensional understanding of site conditions. At the present time, a GIS is the most efficient way to record and present the data. A well-thought-out system of classifying and filing information is also important and is part of the quality assurance required for the project (see Regulatory Position 7.2). Appendix A to this guide lists some of the geologic features and conditions that may have to be considered in site investigations.

3.2 Existing Literature and Map Studies

The first step in the site investigation is to acquire existing knowledge of geological and other site conditions. An understanding of the regional geology must also be developed in order to interpret the rocks and soils of the site in their proper context. Published material and existing maps of topography, geology, hydrology, soils, etc., can reveal a wealth of information on site conditions. Study of aerial photographs and other remote sensing imagery complements this information. Regional strain rates of Global Positioning System (GPS), if available, should be collected to correlate with rates obtained from geology and other methods.

Possible sources of current and historical documentary information may include:

- Geology and engineering departments of State and local universities,
- County governments, many of which have GIS data of various kinds available,
- State government agencies such as the State Geological Survey,
- U.S. government agencies such as the U.S. Geological Survey, the Bureau of Reclamation, and the U.S. Army Corps of Engineers,
- Newspaper records of earthquakes, floods, landslides, and other events of significance,
- Interviews with local inhabitants and professionals.

Published maps such as topographic, geologic, and soils maps can be used to obtain information on the site, to aid in the field reconnaissance, and as a basis for further work. Aerial photographs and other remote-sensing imagery are also useful and complement this information. For additional sources, see Appendix B to this guide that contains a list of potential sources for maps, imagery, and other geologic data.

Some of the basic aspects that should be investigated include geologic conditions, previous land uses, and existing construction and infrastructure. Plans held by utilities should be consulted to locate services such as water, gas, electric, and communication lines. The locations of power lines, pipelines, and access routes should also be established. Mining records should be consulted for locations of abandoned adits, shafts, benches, and tailings embankments. Oil, gas, and water well records, as well as oil e/xploration data, can provide valuable subsurface information. Cultural resources such as historical and archaeological sites should be identified.

3.3 Field Reconnaissance

In addition to the study of published data, it is essential to perform a preliminary field reconnaissance of the site and its surrounding area. This will give a more realistic assessment of site conditions and regional geology and provide a basis for a detailed site investigation plan. Appendix A shows a list of special geologic features and conditions to be considered. In addition to the specific site, potential borrow areas, quarry sites, or water impoundment areas need to be investigated.

The team performing the reconnaissance should include, as a minimum, a geologist and a geotechnical engineer and may include other specialists such as an engineering geologist or geophysicist. An appropriate topographic or geologic map should be used during the field reconnaissance to note findings of interest. A GPS unit may be advantageous for recording locations in the field, as noted more in detail in Regulatory Position 7.1.

3.4 Site Suitability

After the reconnaissance investigations, sufficient information will be available to make a preliminary determination of site suitability and to formulate a plan for detailed site investigations. The presence of features that can cause permanent ground displacement such as fault displacement and settlement or subsidence, swelling soils and shales, or other hazards including underground cavities, landslides, or periodic flooding, may make proper engineering design difficult and usually will require extensive additional investigations. In such cases, it may be advantageous to abandon the site.

4. DETAILED SITE INVESTIGATIONS

4.1 General

Whereas the reconnaissance phase is oriented toward establishing the viability of the site, this phase is the task of acquiring all the geologic factors and engineering properties needed for design and construction of a plant, including its critical structures. The investigation should, therefore, be carried out in much greater detail, and a multidisciplinary team is needed to accomplish the varied tasks of this investigation.

Engineering properties of rocks and soils are determined through drilling and sampling, in situ testing, field geophysical measurements, and laboratory testing. This guide describes in situ testing and the field geophysical measurements, as well as drilling and sampling procedures used to gather samples for laboratory testing. For laboratory testing procedures, refer to Regulatory Guide 1.138.

Data sufficient to clearly justify all conclusions should be presented. Site information to be developed should include, as appropriate, (1) topographic and geologic maps, (2) plot plans showing locations of major structures and exploration, (3) boring logs and logs of exploratory trenches and excavations, (4) geologic profiles showing excavation limits for structures, and (5) geophysical data such as seismic survey time-distance plots, resistivity curves, seismic reflection cross-sections, maps, profiles, borehole logs, and surveys. Using techniques of investigation and sampling other than those indicated in this guide is acceptable when it can be shown that the alternative methods yield satisfactory results.

Locations of all boreholes, in situ tests, piezometers, observation wells, trenches, exploration pits, and geophysical measurements should be surveyed in both plan and elevation. This three-dimensional information should be entered into a GIS database, and suitable cross-sections, maps, and plans should be prepared to facilitate visualization of the geological information. Further details are given in Regulatory Position 7.1.

4.2 Surface Investigations

Detailed surface geological and geotechnical engineering investigations should be conducted over the site area to assess all the pertinent soil and rock characteristics. Some of the special geological features and conditions to be considered are listed in Appendix A.

The first steps in detailed site investigations are to prepare topographic maps at suitable scales to (1) plot geologic, structural, and engineering details at the site and (2) note conditions in the surrounding areas that are related, for instance, to borrow areas, quarries, or access roads. Aerial photographs and stereo pairs, together with other remote sensing imagery, may be of value for regional analysis, determination of fault and fracture patterns, and other features of interest.

Detailed mapping of topographic, hydrogeologic, and surface geologic features should be conducted, as appropriate for the particular site conditions, with scales and contour intervals suitable for site evaluation and engineering design (see also Regulatory Position 7.1). Rock outcrops, soil conditions, evidence of past landslides or soil liquefaction, faults, fracture patterns, geologic contacts, and lineaments should be identified and mapped. Details of local engineering geology and soil conditions should also be mapped and recorded, together with surface-water features such as rivers, streams, or lakes, as well as local surface drainage channels, ponds, springs, and sinks.

4.3 Subsurface Investigations

Subsurface explorations serve to expand the knowledge of the three-dimensional distribution of both geologic conditions (soils, rocks, structure) and engineering properties at the site and at borrow areas, as well as to gain further information on possible safety hazards such as underground cavities, hidden faults, or contacts. The investigations should be carried out using a variety of appropriate methods, including borings and excavations augmented by geophysical measurements. Methods of conducting subsurface investigations are tabulated in Appendix C to this guide.

The locations and depths of borings, excavations, and geophysical measurements should be chosen such that the site geology and foundation conditions are sufficiently defined in lateral extent and depth to permit designing all needed structures and excavations. The information acquired should also be such that engineering geologic cross-sections or subsurface profiles (including N-values, CPT values, etc.) can be constructed through foundations of safety-related structures and other important locations.

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

Boreholes are one of the most effective means of obtaining detailed information on geologic formations in the subsurface and their engineering properties. Cores and samples recovered, geophysical and other borehole surveys, and in situ tests all contribute to the range of information to be derived from boreholes. Excavations in the form of test pits, trenches, and exploratory shafts may be used to complement the borehole exploration; they permit acquiring more detailed and visual information on rock and soil conditions and conducting detailed fault studies, in situ density tests, and high-quality sampling.

4.3.1 Borings and Exploratory Excavations

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, including necessary calibrations, should be documented, as should all conditions encountered in various phases of the investigation. Personnel that are experienced and thoroughly familiar with sampling and testing procedures should inspect and document sampling results and transfer samples from the field to storage or laboratory facilities.

The complexity of geologic conditions and foundation requirements should be considered in choosing the actual distribution, number, and depth of borings and other excavations for a site. The investigative effort should be greatest at the locations of safety-related structures and may vary in density and scope in other areas according to their spatial and geological relations to the site. At least one continuously sampled boring should be used for each safety-related structure, and the boring should extend to a depth sufficient to define the geological and hydrogeological characteristics of the foundations.

NUREG/CR-5738 describes procedures for borings and exploratory excavations. A table from that report that shows widely used techniques for subsurface investigations and describes the applicability and limitations of these methods is reproduced in Appendix C. General guidelines for spacing and depth of borings are found in Appendix D.

4.3.1.1 Spacing. The spacing and depth of borings for safety-related structures should be chosen according to the foundation requirements and the complexity of anticipated subsurface conditions. Appendix D gives general guidelines concerning this subject. Uniform conditions permit the maximum spacing of borings in a regular grid for adequate definition of subsurface conditions. Subsurface conditions may be considered uniform if the geologic and stratigraphic features to be defined can be correlated from one boring 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.

If site conditions are non-uniform, a regular grid may not provide the most effective borehole distribution. 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 to define foundation properties. The goal is to define the thicknesses of the various material types, their degree of variability, and their range of material properties beneath the major structures.

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 at a spacing small enough to detect and delineate these features are needed. It is important that these borings penetrate all suspect zones or extend to depths below which their presence would not influence the safety of the structures. Geophysical investigations should be used to supplement the boring program.

4.3.1.2 Drilling Procedures. Drilling methods and procedures should be compatible with sampling requirements and the methods of sample recovery. Many of the methods are discussed in detail in EM 1110-0-1906 and *Principles of Geotechnical Engineering* (Das). 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. After use, each borehole should be grouted in accordance with State and local codes to prevent vertical movement of groundwater through the borehole.

Borehole elevation and depths into the borehole should be measured to the nearest 3 cm (0.1 ft) and should be correlatable to the elevation datum used for the site. Surveys of vertical deviation should be run in all boreholes that are used for crosshole seismic tests and other tests where deviation affects the use of data obtained. Boreholes with depths greater than about 30 m (100 ft) should also be surveyed for deviation. Details of information that should be presented on logs of subsurface investigations are given in Regulatory Position 4.5.

4.3.2 Sampling

Sampling of soils in boreholes should include, as a minimum, the recovery of samples at regular intervals and at changes in materials. Alternating split spoon and undisturbed samples with depth is recommended. Color photographs of all cores should be taken soon after removal from the borehole to document the condition of the soils at the time of drilling.

4.3.2.1 Sampling Rock. The engineering characteristics of rocks are related primarily to their composition, structure, bedding, jointing, fracturing, and weathering. Core samples are needed to observe and define these features. Suitable coring methods should be employed, 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 or low rock quality designation (RQD), zones requiring casing, and other zones where drilling difficulties are encountered should be investigated. The nature, geometry, and spacing of any discontinuities or anomalous zones should be determined by means of suitable logging or in situ observation methods. Areas with evidence of significant residual stresses should be evaluated on the basis of in situ stress or strain measurements. If it is necessary to determine dip and strike of bedding planes or discontinuities, oriented cores may be needed.

4.3.2.2 Sampling Coarse-Grained Soils. For coarse-grained soils, samples should be taken at depth intervals no greater than 1.5 m (5 ft). Beyond a depth of 15 m (50 ft) below foundation level, the depth interval for sampling may be increased to 3 m (10 ft). Also, one or more borings for each major structure should be continuously sampled. Requirements for undisturbed sampling of coarse-grained soils will depend on actual site conditions and planned laboratory testing. Some general guidelines for recovering undisturbed samples are given in Regulatory Position 4.3.2.4 of this guide. Experimentation with different sampling techniques may be necessary to determine the method best suited to local soil conditions.

Split spoon sampling and standard penetration tests should be used with sufficient coverage to define the soil profile and variations of soil conditions. Cone penetration tests may also be made to provide useful supplemental data if the cone test data are properly calibrated to site conditions.

Suitable samples should be obtained for soil identification and classification, mechanical analyses, and anticipated laboratory testing. For cyclic loading tests, it is important to obtain good quality undisturbed samples for testing. The need for, number, and distribution of samples will depend on testing requirements and the variability of the soil conditions. In general, however, samples should be included from at least one principal boring at the location of each safety-related structure. Samples should be obtained at regular intervals in depth and when changes in materials occur. Criteria for sampling are given in Regulatory Position 4.3.2.

Coarse-grained soils containing gravels and boulders are among the most difficult materials to sample. Obtaining good quality samples often requires the use of trenches, pits, or other accessible excavations into the zones of interest. Standard penetration test results from these materials may be misleading and must be interpreted very carefully. When sampling of 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.

4.3.2.3 Sampling 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 undisturbed samples should be obtained. Procedures for obtaining undisturbed samples are discussed in Regulatory Position 4.3.2.4 of this guide.

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, thin-wall tube samplers (see EM 1110-1-1906 for detailed procedures) or by methods that yield samples of equivalent quality. Borings used for undisturbed sampling of soils should be at least 7.6 cm (3 in.) in diameter.

4.3.2.4 Obtaining Undisturbed Samples. In a strict sense, it is physically impossible to obtain “undisturbed” samples in borings because of the adverse effects resulting from the sampling process itself (e.g., unloading caused by removal from confinement) and from shipping or handling. Undisturbed samples are normally obtained using one of two general methods: push samplers or rotary samplers. These methods permit obtaining satisfactory samples for shear strength, consolidation, permeability, and density tests, provided careful measurements are made to document volume changes that occur during each step in the sampling process. Undisturbed samples can be sliced to permit detailed study of subsoil stratification, joints, fissures, failure planes, and other details.

Push sampling involves pushing a thin-walled tube, using the hydraulic system of the drill rig, then enlarging the diameter of the sampled interval by some “clean out” method before beginning to sample again. Commonly used systems for push samples include the Hvorslev fixed-position sampler and the Osterberg hydraulic piston sampler. Rotary samplers are considered slightly more disruptive to soil structure and involve a double tube arrangement similar to a rock coring operation, except that the inner barrel shoe is adjustable and generally extends beyond the front of the rotating outer bit. This reduces the disturbance caused to the sample from the drill fluid and bit rotation. Commonly used rotational samplers include the Denison barrel and the Pitcher Sampler.

Undisturbed samples of clays and silts can be obtained, as well as nearly undisturbed samples of some sands. Care is necessary in transporting any undisturbed sample; sands and silts are particularly vulnerable to vibration disturbance. One method to prevent handling disturbance is to obtain 7.6 cm (3 in.) Shelby tube samples, drain them, and freeze them before transportation. There are no standard or generally accepted methods for undisturbed sampling of cohesionless soils. Such soils can be recovered by in situ freezing, followed by sampling with a rotary core barrel. For any freezing method, disturbance by cryogenic effects must be taken into account.

Chemical stabilization or impregnation can also be used as an option to sample and preserve the natural structure of cohesionless granular material. Agar has been used with positive results as an impregnation material for undisturbed sampling of sands below the water table as an alternative to freezing. Chemical impregnation can be used either in situ before sampling or after sampling to avoid further disturbance in transporting and handling the samples. This alternative to freezing is less expensive and produces samples that are easier to manage after collection. Removal of the impregnating material may be accomplished once the sample is in the laboratory.

Test pits, trenches, and shafts offer the only effective access to collect high quality block samples and to obtain detailed information on stratification, discontinuities, or preexisting shear surfaces in the ground. Cost increases with depth as the need for side wall support arises. Samples can be obtained by means of hand-carving oversized blocks of soil or hand-advancing of thin-walled tubes.

4.3.2.5 Borrow Materials. Exploration of borrow sources serves to determine the location and amount of available borrow materials. Borrow area investigations should use horizontal and vertical intervals sufficient to determine material variability and should include adequate sampling of representative materials for laboratory testing.

4.3.2.6 Materials Unsuitable for Foundations. Boundaries of unsuitable materials should be delineated by means of borings and representative sampling and testing. These boundaries should be used to define the required excavation limits.

4.3.3 Transportation and Storage of Samples

The handling, storage, and transportation of samples is as critical for sample quality as the collection procedures. Disturbance of samples after collection can happen in a variety of ways and transform samples from high quality, to slightly disturbed, to completely worthless. Soil samples can change dramatically because of moisture loss, moisture migration within the sample, freezing, vibration, shock, or chemical reactions.

Moisture loss may not be critical on representative samples, but it is preferable that it be kept to a minimum. Moisture migration within a sample causes differential residual pore pressures to equalize with time. Water can move from one formation to another, causing significant changes in the undrained strength and compressibility of the sample. Freezing of clay or silt samples can cause ice lenses to form and severely disturb the samples. Storage room temperatures for these kinds of samples should be kept above 4°C. Vibration or shock can provoke remolding and strength or density changes, especially in soft and sensitive clays or cohesionless samples. Transportation arrangements to avoid these effects need to be carefully designed. Chemical reactions between samples and their containers can occur during storage and can induce changes that affect soil plasticity, compressibility, or shear strength. Therefore, the correct selection of sample container material is important.

Cohesionless soil samples (unless stabilized chemically or by freezing) are particularly sensitive to disturbance from impact and vibration during removal from the borehole or sampler and subsequent handling. Samples should be kept at all times in the same orientation as that in which they were sampled (e.g., vertical position if sampled in a vertical borehole), well padded for isolation from vibration and impact, and transported with extreme care if undisturbed samples are required.

4.3.4 In Situ Testing

In situ testing of soil and rock materials should be conducted where necessary for definition of foundation properties, using boreholes, excavations, test pits, and trenches that are either available or have been prepared for the purpose of sampling and testing. Larger block samples for laboratory testing can also be obtained in such locations. Some of the applicable in situ testing methods are shown in Appendix F. For further description of procedures see NUREG/CR-5738.

In situ tests are often the best means to determine the engineering properties of subsurface materials and, in some cases, may be the only way to obtain meaningful results. Some materials are hard to sample and transport, while keeping them representative of field conditions, because of softness, lack of cohesion, or composition. In situ techniques offer an option for evaluating soils and rocks that cannot be sampled for laboratory analysis.

Interpretation of in situ test results in soils, clay shales, and moisture-sensitive rocks requires consideration of the drainage that may occur during the test. Consolidation during soil testing makes it difficult to determine whether the results relate to unconsolidated- undrained, consolidated-undrained, consolidated-drained, unconsolidated-drained conditions, or to intermediate conditions between these limiting states. Interpretation of in situ test results requires complete evaluation of the test conditions and limitations.

Rock formations are generally separated by natural joints and/or bedding planes, resulting in a system of irregularly shaped blocks that respond as a discontinuum to various loading conditions. Individual blocks have relatively high strengths, whereas the strength along discontinuities is reduced and highly anisotropic. Commonly, little or no tensile strength exists across discontinuities. Large-scale in situ tests tend to average out the effect of complex interactions. In situ tests in rock are used to determine in situ stresses and deformation properties, including the shear strength of the jointed rock mass. They also help to measure strength and residual stresses along discontinuities or weak seams in the rock mass. In situ testing performed in weak, near-surface rocks include penetration tests, plate loading tests, pressure-meter tests, and field geophysical techniques.

Table F-2 in Appendix F lists in situ tests that are useful for determining the shear strength of subsurface materials. Direct shear strength tests in rock measure peak and residual direct shear strength as a function of normal stress on the shear plane. Direct shear strength from intact rock can be measured in the laboratory if the specimen can be cut and transported without disturbance. In situ shear tests are discussed and compared in Nicholson and in Bowles. The suggested in situ method for determining direct shear strength of rocks is described in RTH 321-80. Although the standard penetration test (SPT) was used extensively in investigation of soil susceptibility, the usage of the cone penetration test (CPT) has increased significantly in recent years because CPT provides continuous penetration resistance profiles for soils and CPT results are more repeatable and consistent (Youd et al.). In both Appendix C and Appendix F, the applicability and limitations of the CPT and SPT are compared in parallel.

4.4 Geophysical Investigations

4.4.1 General

Geophysical methods include surface geophysics, borehole logging, and cross-borehole measurements. In all cases, these methods are a means of exploring the subsurface. Geophysical measurements should be used to fill in information between surface outcrops, trenches, and boreholes. Such measurements permit acquiring more continuous, and sometimes deeper, subsurface coverage, including data on geological and hydrogeological conditions and certain engineering properties of materials. They are of particular value in tying together information from various sources.

Available geophysical and borehole logging methods are listed in Appendix E to this guide and in EM-1110-1-1802. For boreholes that are deeper than 30 m (100 ft) or are used for crosshole measurements, borehole deviation should be measured. Geophysical measurements, borehole logging, and interpretation of geophysical measurements should be carried out by personnel that have the necessary background and experience in these techniques. Parameters of acquisition (spacings, instrument settings, etc.) and processing should be recorded to allow for proper interpretation of results.

At soil sites or rock sites with substantial weathering, crosshole shear wave measurements should be conducted in boreholes deep enough to allow determining the site amplification for seismic waves. These boreholes should also be sampled and logged as appropriate, including acoustic logging. Other geophysical measurements, such as seismic refraction and reflection and microseismic monitoring, may also be used for site amplification calculations.

4.4.2 Surface Geophysics

Recommended surface geophysical methods include seismic refraction and reflection surveys, as well as surface electromagnetic or electrical resistivity surveys. Other methods such as gravity, magnetics, and ground penetrating radar may also be used as appropriate. Spectral analysis of surface waves may be used to measure shear-wave velocity profiles. The method permits deriving elastic moduli and soil layer thicknesses (Gucunski and Woods, Stokoe and Nazarian, and Stokoe et al.). The surface geophysical measurements should be correlated with borehole geophysical and geological logs to derive maximum benefit from the measurements.

4.4.3 Borehole Geophysics

Boreholes should be logged with a suitable suite of geophysical logging methods. Borehole logs are useful for determining lithological, hydrological, and engineering properties of subsurface horizons. They are also very useful for the correlation of stratigraphic horizons between boreholes. Some of the applicable methods are shown in Appendix E to this guide, together with the engineering parameters they help to determine.

Crosshole geophysical measurements may be used to obtain detailed information on the region between two boreholes and to derive engineering and hydrogeologic properties, such as shear modulus, porosity, and permeability. Measurements of shear- and compressional-wave velocities are most common, but electrical resistivity and electromagnetic methods may also be employed. When very detailed information is desired, tomographic methods may be used that can provide a detailed picture of geophysical properties between boreholes.

Acoustic borehole logging and crosshole shear-wave measurements generally are low strain measurements. In rock, they provide a suitable approximation of shear modulus even under higher strain conditions. In soil, on the other hand, the modulus depends strongly on the strain level. However, so-called high strain shear-wave methods (crosshole) in soil are usually ineffective, because nonlinear effects may occur. Other in situ and laboratory tests are more promising for such measurements.

4.5 Logs of Subsurface Investigations

Boring logs should contain the date when the boring was made, the location of the boring, the depths of borings, and the elevations with respect to a permanent benchmark. The logs should also include the elevations of the top and bottom of borings and the elevations of the boundaries of soil or rock strata, as well as the level at which the water table was encountered. In addition, the classification and description of soil and rock layers, blow count values obtained from SPTs, percent recovery of rock core, quantity of core not recovered for each core interval or drill run, and rock quality designation (RQD) should be noted.

Results of field permeability tests and geophysical 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 incidents of settling or dropping of drill rods, abnormally low resistance to drilling or advance of samplers, core losses, or instability or heave of the side and bottom of boreholes. Influx of groundwater, depths and amounts of water or drilling mud losses, together with depths at which circulation is recovered, and any other special feature or occurrence should be recorded on boring logs and geological cross sections.

Incomplete or abandoned borings should be described with the same care as successfully completed borings. Logs of exploratory trenches and other excavations should be presented in a graphic format in which important components of the soil matrix and structural features in rock are shown in sufficient detail to permit independent evaluation. The location of all explorations should be recorded in the GIS and shown on geologic cross-sections, together with elevations and important data.

5. 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, such data should be supplemented by groundwater observations in properly installed wells or piezometers that are read at regular intervals from the time of their installation at least through the construction period.

Appendix G to this guide lists types of instruments for measuring groundwater pressure and their advantages and limitations. ASTM D 5092-95 provides guidance on the design and installation of groundwater monitoring wells. Types of piezometers, construction details, and sounding devices are described in EM 1110-2-1908.

Groundwater conditions should be observed during the course of the site investigation, and measurements should be made of the water level in exploratory borings. The groundwater or drilling mud level should be measured at the start of each workday for borings in progress, at the completion of drilling, and when the water levels in the borings have stabilized. In addition to the normal borehole groundwater measurements, piezometers or wells should be installed in as many locations as needed to adequately define the groundwater environment. Pumping tests are a preferred method for evaluating local permeability characteristics and assessing dewatering requirements for construction and operation of the plant. For major excavations where construction dewatering is required, piezometers or observation wells should be used during construction to monitor the groundwater surface and pore pressures beneath the excavation and in the adjacent ground. This guide does not cover groundwater monitoring during construction of plants that are designed with permanent dewatering systems.

When the possibility of perched groundwater tables or artesian pressures is indicated by borings or other evidence, piezometers should be installed such that each piezometric level can be measured 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 the artesian heads should be measured and logged.

6. CONSTRUCTION MAPPING

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. This work is usually performed after the excavation has been cleaned to grade and just before the placement of concrete or backfill, to permit recording of geologic details in the foundation. Particular attention should be given to the identification of features that may be important to foundation behavior but were undetected in the investigation program. Changes in foundation design should be noted on the appropriate plans, and newly discovered geologic features should be surveyed and entered into maps, cross-sections, and the database.

Features requiring excavation, such as structure foundations, cut slopes, tunnels, chambers, water inlets and outlets, should be mapped and investigated for geologic details that may be different from assumptions based on the pre-construction investigations. This work is usually performed after the excavation has been cleaned to grade and just before the placement of concrete or backfill. These maps should be prepared to show any feature installed to improve, modify, or control geologic conditions. Some examples are rock reinforcing systems, permanent dewatering systems, and special treatment areas. All features found or installed should be surveyed and entered into maps, cross-sections, and the database. Photographic or videographic records (or both) of foundation mapping and treatment should be made. Generally, the GIS and other databases should be continuously updated, up to and including the construction phase, resulting in as-built information.

Appendix A to NUREG/CR-5738 provides detailed guidance on technical procedures for mapping foundations. Mapping of tunnels and other underground openings must be planned differently from foundation mapping. Design requirements for support of openings may require installation of support before an adequate cleanup can be made for mapping purposes. Consequently, mapping should be performed as the heading or opening is advanced and during the installation of support features, which necessitates a well-trained geologist, engineering geologist, or geotechnical engineer at the excavation site. Specifications should be included in construction plans for periodic cleaning of exposed surfaces and to allow a reasonable length of time for mapping. Technical procedures for mapping tunnels are outlined in Appendix B to NUREG/CR-5738 and can be modified for large chambers.

The person in charge of foundation mapping should be familiar with the design and should consult with design personnel during excavation work whenever differences between the actual geology and the design base geological model are found. The same person should be involved in all decisions concerning changes in foundation design or additional foundation treatment that may be necessary based on observed conditions.

The previous requirement for a two-step licensing procedure for nuclear power plants, involving first a construction permit (CP), and then an operating license (OL), has been modified to allow for an alternative procedure. Requirements for applying for a combined license for a nuclear power facility are contained in Subpart C of 10 CFR Part 52. The combined licensing procedure may result in the award of a license before the start of construction. However, the need for construction mapping applies equally under the combined license procedure. In the past, previously unknown faults were often discovered in site excavations for nuclear power plants, demonstrating the importance of mapping such features while the excavations' walls and bases are exposed and the importance of assessing their potential to generate offsets or ground motion. Documents supporting the combined license application (Safety Analysis Reports) should, therefore, include plans to geologically map all excavations. Applicants must meet the requirements of 10 CFR 50.9 regarding notification to the NRC of information concerning a regulated activity with significant implications for public health and safety or common defense and security.

7. SUPPORT FUNCTIONS

7.1 Surveying/Mapping/GIS

Surveying is an important function that should accompany all essential site investigation activities from reconnaissance through construction mapping. There are many methods of surveying available today, from traditional triangulation or plane table work together with leveling to electronic distance and GPS measurements. For mapping small areas, plane table methods may still be among the fastest. In most cases, however, GPS or DGPS (differential GPS) together with automated recording and computing procedures is the most suitable method. Procedures for GPS surveying can be found in EM-1110-1-1003. The GPS measurements and other surveyed locations should be tied to National Geodetic Survey (NGS) markers in order to be compatible with topographic maps and digital maps of various kinds. The vertical component of GPS measurements is the least accurate component, but it is being improved with more accurate satellite orbits and other corrections. For greater accuracy, it may still be necessary to perform a certain amount of conventional leveling.

A suitable coordinate system for the site should be chosen. Three-dimensional coordinate systems include the World Geodetic System of 1984 (WGS 84), the International Terrestrial Reference Frame (ITRF), and the North American Datum of 1983 (NAD 83). Coordinates should be referred to NAD 83 to be legally recognized in most U.S. jurisdictions. Moreover, NGS provides software for converting the ellipsoid-based heights of NAD 83 to the sea-level-based heights that appear on topographic maps. NAD 83 coordinates are readily determined when measurements tie the site to an NGS marker.

All three-dimensional information should be entered into a GIS database. One of the advantages of a GIS is that data of various kinds, in the form of tables, can be associated with a coordinate system and then recalled to form graphical output of a desired type. The choice of the particular system used is up to the applicant. However, the data should be in a format that is readily readable.

In order to record the information gathered during site investigations, to place geological, geotechnical, and sampling/testing information into a spatial context, and to permit visual display in maps and cross sections, it is necessary to have a staff available that is experienced in surveying and in storing and displaying data in a GIS throughout all phases of site investigation and construction. These are essential activities that should be given proper emphasis and support by applicants.

7.2 Database/Sample Repository/Quality Assurance

All data acquired during the site investigation should be organized into suitable categories and preserved as a permanent record, 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. Much of the data will already be part of the GIS database but other data and records, such as logs of operations, photographs, test results, and engineering evaluations and calculations, should also be preserved for further reference.

Samples and rock cores from principal borings should also be retained. Regulatory Position 4.3.3 and Chapter 7 of NUREG/CR-5738 describe procedures for handling and storing samples. The need to retain samples and core beyond the recommended time is a matter of judgment and should be evaluated on a case-by-case basis. For example, soil samples in tubes will deteriorate with time and will not be suitable for undisturbed testing; however, they may be used as a visual record of what the foundation material is like. Similarly, cores of rock subject to slaking and rapid weathering such as shale will also deteriorate. It is recommended that photographs of soil samples and rock cores, together with field and final logs of all borings, be preserved for a permanent record.

The site investigations should be included in the overall Quality Assurance program for plant design and construction according to the guidance in Regulatory Guide 1.28 and the requirements of Appendix B to 10 CFR Part 50. Field operations and records preservation should, therefore, be conducted in accordance with quality assurance principles and procedures.

D. IMPLEMENTATION

The purpose of this section is to provide guidance to applicants regarding the NRC staff's plans for using this regulatory guide.

Except when an applicant proposes an acceptable alternative method for complying with the specified portions of the NRC's regulations, the methods described in this guide reflecting public comments will be used in the evaluation of applications for site approval of commercial nuclear power reactors submitted after January 10, 1997.

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[1] ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, phone (610)832-9500.

[2] Copies are available at current rates from the U.S. Government Printing Office, P.O. Box 37082, Washington, DC 20402-9328 (telephone (202)512-1800); or from the National Technical Information Service by writing NTIS at 5285 Port Royal Road, Springfield, VA 22161; <http://www.ntis.gov/ordernow>; telephone (703)487-4650. Copies are available for inspection or copying for a fee from the NRC Public Document Room at 11555 Rockville Pike, Rockville, MD; the PDR's mailing address is USNRC PDR, Washington, DC 20555; telephone (301)415-4737 or (800)397-4209; fax (301)415-3548; email is PDR@NRC.GOV.

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APPENDIX A Special Geologic Features and Conditions Considered in Office Studies and Field Observations (EM 1110-1-1804, Department of the Army, 1984)

Geologic Feature or Condition	Influence on Project	Office Studies	Field Observations	Questions to Answer
Landslides	Stability of natural and excavated slopes	Presence or age in project area or at construction sites should be determined. Compute shear strength at failure. Do failure strengths decrease with age of slopes--especially for clays and clay shales?	Estimate areal extent (length and width) and height of slope. Estimate ground slope before and after slide (may correspond to residual angle of friction). Check highway and railway cuts and deep excavations, quarries, and steep slopes.	Are landslides found off site in geologic formations of the same type that will be affected by project construction? What are probable previous and present groundwater levels? Do trees slope in an unnatural direction?
Faults and faulting; past seismic activity	Of decisive importance in seismic evaluations; age of most recent fault movement may determine seismic design earthquake magnitude, may be indicative of high state of stress that could result in foundation heave or overstress in underground works.	Determine existence of known faults and fault history from available information. Examine existing boring logs for evidence of faulting from offset of strata.	Verify presence at site, if possible, from surface evidence; check potential fault traces located from aerial imagery. Make field check of structures, cellars, chimneys, roads, fences, pipelines, known faults, caves, inclination of trees, offset in fence lines.	Are lineaments or possible fault traces apparent from regional aerial imagery?
Joints and fractures	High concentration of joints indicating weakness of bedrock and high strain.	Study aerial photos and define all available lineaments and their relationship if possible.	Investigate orientation and density of joints.	
Stress relief cracking and valley rebounding	Valley walls may have cracking parallel to valley. Valley floors may have horizontal cracking. In some clay shales stress relief from valley erosion or glacial action may not be complete.	Review pertinent geologic literature and reports for the valley area. Check existing piezometer data for abnormally low levels in valley sides and foundation; compare with normal groundwater levels outside valley.	Examine wells and piezometers in valleys to determine if levels are lower than normal groundwater regime (indicates valley rebound not complete).	

APPENDIX A, Cont'd.

Geologic Feature or Condition	Influence on Project	Office Studies	Field Observations	Questions to Answer
Sinkholes; karst topography	Major effect on location of structures and feasibility of potential site.	Examine aerial photos for evidence of undrained depressions.	Locate depressions in the field and measure size depth and slopes. Differences in elevation between center and edges may be almost negligible or many feet. From local residents, attempt to date appearance of sinkhole	Are potentially soluble rock formations present such as limestone, dolomite, or gypsum? Are undrained depressions present that cannot be explained by glaciation? Is surface topography rough and irregular without apparent cause?
Anhydrites or gypsum layers	Anhydrites in foundations beneath major structures may hydrate and cause expansion, upward thrust and buckling. Gypsum may cause settlement, subsidence, collapse or piping. Solution during life of structure may be damaging.	Determine possible existence from available geologic information and delineate possible outcrop locations.	Look for surface evidence of uplift; seek local information on existing structures. Check area carefully for caves or other evidence of solution features.	Are uplifts caused by possible anhydrite expansion or "explosion?"
Caves	Extent may affect project feasibility or cost. Can provide evidence regarding faulting that may relate to seismic design. Can result from unrecorded mining activity in the area.		Observe cave walls carefully for evidence of faults and recent faulting. Estimate age of any broken stalactites or stalagmites from column rings.	Are any stalactites or stalagmites broken from apparent ground displacement or shaking?
Erosion resistance	Determines need for total or partial channel slope protection.	Locate contacts of potentially erosive strata along drainage channels.	Note stability of channels and degree of erosion and stability of banks.	Are channels stable or have they shifted frequently? Are banks stable or easily eroded? Is there extensive bank sliding?

APPENDIX A, Cont'd.

Geologic Feature or Condition	Influence on Project	Office Studies	Field Observations	Questions to Answer
Internal erosion	Affects stability of foundations and dam abutments. Gravelly sands or sands with deficiency of intermediate particle sizes may be unstable and develop piping when subject to seepage flow.	Locate possible outcrop areas of sorted alluvial materials or terrace deposits.	Examine seepage outcrop areas of slopes and riverbanks for piping.	
Area subsidence	Area subsidence endangers long-term stability and performance of project	Locate areas of high groundwater withdrawal, oil and gas fields, and subsurface mineral extraction (coal, solution mining, and etc.) areas.	Check project area for new wells or new mining activity	Are there any plans for new or increased recovery of subsurface water or mineral resources?
Collapsing soils	Determines need for removal of shallow foundation materials that would collapse upon wetting	Determines how deposits were formed during geologic time and any collapse problems in area	Examine surface deposits for voids along eroded channels, especially in steep valleys eroded in fine-grained sedimentary formations	Were materials deposited by mud flows?
Locally lowered groundwater	May cause minor to large local and area settlements and result in flooding near rivers or open water and differential settlement of structures	Determine if heavy pumping from wells has occurred in project area; contact city and state agencies and USGS	Obtain groundwater levels in wells from owners and information on withdrawal rates and any planned increases. Observe condition of structures. Contact local water plant operators	
Abnormally low pore water pressures (lower than anticipated from groundwater levels)	May indicate effective stresses are still increasing and may cause future slope instability in valley sites	Compare normal groundwater levels with piezometric levels if data is available		Is a possible cause from past reduction in vertical stresses (e.g., deep glacial valley or canal excavations such as Panama Canal in clay shales where pore water pressures were reduced by stress relief)?

APPENDIX A, Cont'd.

Geologic Feature or Condition	Influence on Project	Office Studies	Field Observations	Questions to Answer
In situ shear strength from natural slopes	Provides early indication of stability of excavated slopes or abutment, and natural slopes around reservoir area.	Locate potential slide areas. Existing slope failures should be analyzed to determine minimum in situ shear strengths.	Estimate slope angles and heights, especially at river bends where undercutting erosion occurs. Determine if flat slopes are associated with mature slide or slump topography or with erosion features.	Are existing slopes consistently flat, indicating residual strengths have been developed?
Swelling soils and shales	Highly preconsolidated clays and clay shales may swell greatly in excavations or upon increase in moisture content..	Determine potential problem and location of possible preconsolidated strata from available information.	Examine roadways founded on geologic formations similar to those at site. Check condition of buildings and effects of rainfall and watering.	Do seasonal groundwater and rainfall or watering of shrubs or trees cause heave or settlement?
Varved clays	Pervious layers may cause more rapid settlement than anticipated. May appear to be unstable because of uncontrolled seepage flow through pervious layers between overconsolidated clay layers or may have weak clay layers. May be unstable in excavations unless well points are used to control groundwater.	Determine areas of possible varved clay deposits associated with prehistoric lakes. Determine settlement behavior of structures in the area.	Check natural slopes and cuts for varved clays; check settlement behavior of structures.	
Dispersive clays	A major factor in selecting soils for embankment dams and levees.	Check with Soil Conservation Service and other agencies regarding behavior of existing small dams.	Look for peculiar erosional features such as vertical or horizontal cavities in slopes or unusual erosion in cut slopes. Perform "crumb" test.	
Riverbank and other liquefaction areas	Major effect on riverbank stability and on foundation stability in seismic areas.	Locate potential areas of loose fine-grained alluvial or terrace sand; most likely along riverbanks where loose sands are present and erosion is occurring.	Check riverbanks for scallop-shaped failure with narrow neck (may be visible during low water). If present, determine shape, depth, average slope and slope of adjacent sections. Liquefaction in wooded areas may leave trees inclined at erratic angles. Look for evidence of sand boils in seismic areas.	

APPENDIX A, Cont'd.

Geologic Feature or Condition	Influence on Project	Office Studies	Field Observations	Questions to Answer
Filled areas	Relatively recent filled areas would cause large settlements. Such fill areas may be overgrown and not detected from surface or even subsurface evidence.	Check old topo maps if available for depressions or gullies not shown on more recent topo maps.		Obtain local history of site from area residents
Local overconsolidation from previous site usage	Local areas of a site may have been overconsolidated from past heavy loadings of lumber or material storage piles.			Obtain local history from residents of area

APPENDIX B Sources of Geologic Information (EM 1110-1-1804, Department of the Army, 1984)

Agency	Type of Information	Description	Remarks
USGS	Topographic maps	U.S. 7.5-minute series 1:24,000 (supersedes 1:31,680). Puerto Rico 7.5-minute series 1:20,000 (supersedes 1:30,000) Virgin Island 1:24,000 series. U.S. 15-minute series 1:62,500 (1:63,360 for Alaska) U.S. 1:100,000-scale series (quadrangle, county, or regional format) U.S. 1:50,000-scale county map series U.S. 1:250,000-scale series Digital elevation models are available for entire U.S. at 1:250,000, and for certain areas at 1:100,000 and 1:24,000 scales. Digital line graphs are available for some areas at 1:24,000 and 1:65,000 for: - Hydrography - Transportation - U.S. Publication Survey - Boundaries - Hypsography	Orthophotoquad monocolor maps also produced in 7.5-minute and 15-minute series. New index of maps for each state started in 1976. Status of current mapping from USGS regional offices and in monthly USGS bulletin, “New Publications of the U.S. Geological Survey.”
USGS	Geology maps and reports	1:24,000 (1:20,000 Puerto Rico), 1:62,500, 1:100,00, and 1:250,000 quadrangle series includes surficial bedrock and standard (surface and bedrock) maps with major landslide areas shown on later editions 1:500,000 and 1:2,500,000 (conterminous U.S., 1974).	New index of geologic maps for each state started in 1976. List of geologic maps and reports for each state published periodically.
USGS	Miscellaneous maps and reports	Landslide susceptibility rating, swelling soils, engineering geology, water resources, and groundwater.	Miscellaneous Investigation Series and Miscellaneous Field Studies Series, maps and reports, not well cataloged; many included as open file.
USGS	Special maps	1:7,500,000 and 1:1,000,000: Limestone Resources, Solution Mining Subsidence, Quaternary Dating Applications, Lithologic Map of U.S., Quaternary Geologic Maps.	
USGS	Hydrologic maps	Hydrologic Investigations Atlases with a principal map scale of 1:24,000; includes water availability, flood areas, surface drainage precipitation and climate, geology, availability of ground and surface water, water quality and use, and streamflow characteristics.	Some maps show groundwater contours and location of wells.

APPENDIX B, Cont'd.

Agency	Type of Information	Description	Remarks
USGS	Earthquake hazard	Seismic maps of each state (started in 1978 with Maine); field studies of fault zones; relocation of epicenters in eastern U.S.; hazards in the Mississippi Valley area; analyses of strong motion data; state-of-the-art workshops	Operates National Strong-Motion Network and National Earthquake Information Service publishes monthly listing of epicenters (worldwide).
USGS	Mineral resources	Bedrock and surface geologic mapping; engineering geologic investigations; map of power generating plants of U.S. (location of built, under construction, planned, and type); 7.5-minute quadrangle geologic maps and reports on surface effects of subsidence into underground mine openings of eastern Powder River Basin, Wyoming	
USGS	Bibliography	"Bibliography of North American Geology" North American, Hawaiian Islands, and Guam	Published until 1972
Geological Society of America (GSA)	Bibliography	"Bibliography and Index of Geology Exclusive of North America"	1934-1968
		"Bibliography and Index of Geology" Decade of North American Geology series	1969 to present, 12 monthly issues plus yearly cumulative index
NOAA	Earthquake hazards	National Geophysical Data Center in Colorado contains extensive earthquake hazard information	
NASA	Remote sensing data	Landsat, Skylab imagery	
NOAA	Remote sensing data		
Space Imaging	Remote sensing data	Multi-band satellite imagery with meter resolution	
USFWS	Wetlands	The National Wetlands Inventory maps at 1:24,000 for most of the contiguous U.S.	Available as maps or mylar overlays
USGS	Flood-prone area maps	1:24,000 series maps outlining floodplain areas not included in Corps of Engineers reports or protected by levees	Stage 2 of 1966 89th Congress House Document 465
US Army Engineer Waterways Experiment Station (USAEWES)	Earthquake hazard	"State-of-the-Art for Assessing Earthquake Hazards in the United States," Miscellaneous Paper S-73-1	Series of 19 reports, 1973 to present

APPENDIX B, Cont'd.

Agency	Type of Information	Description	Remarks
IUGS	Worldwide mapping	Commission for the Geological Map of the World publishes periodic reports on worldwide mapping in "Geological Newsletter"	
NRCS	Soil survey reports	1:15,840 or 1:20,000 maps of soil information on photomosaic background for each country. Recent reports include engineering test data for soils mapped, depth to water and bedrock, soil profiles grain-size distribution, engineering interpretation and special features. Recent aerial photo coverage of many areas. Soils maps at 1:7,500,000, 1:250,000, and 1:12,000 scale are available in digital format for some areas.	Reports since 1957 contain engineering uses of soils mapped, parent materials, geologic origin, climate, physiographic setting, and profiles.
FEMA	Earthquake hazard	NEHRP "Recommended provisions for Seismic Regulations for New Buildings and Older Structures," 1997, includes seismic maps.	
State Geologic Agencies	Geologic maps and reports	State and county geologic maps; mineral resource maps; special maps such as for swelling soils; bulletins and monographs; well logs; water resources, groundwater studies	List of maps and reports published annually, unpublished information by direct coordination with state geologist
DMA	Topographic Maps	Standard scales of 1:12,500, 1:50,000, 1:250,000 and 1:1,000,000 foreign and worldwide coverage including photomaps	Index of available maps from DMA
AAPG	Geological highway map series	Scale approximately 1 ~~in~~. Inch to 30 miles shows surface geology and includes generalized time and rock unit columns, physiographic map, tectonic map, geologic history summary, and sections	Published as 12 regional maps including Alaska and Hawaii
TVA	Topographic maps, geologic maps and reports	Standard 7.5-minute TVA-USGS topographic maps, project pool maps, large-scale topographic maps of reservoirs, geologic maps and reports in connection with construction projects	Coordinate with TVA for available specific information

APPENDIX C
METHODS OF SUBSURFACE EXPLORATION

METHOD	PROCEDURE	APPLICABILITY	LIMITATIONS
1. Methods of Access for Sampling, Test, or Observation			
Pits, trenches, shafts, tunnels	Excavation made by hadn, large auger, or digging machinery.	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. May need dewatering.
Auger boring	Boring advanced by hand auger or power auger.	Recovery of remolded samples and determining groundwater levels. Access for undisturbed sampling of cohesive soils.	Will not penetrate bounders or most rock.
Hollow stem auger boring	Boring advanced by means of continuous-flight helix auger with hollow-center stem.	Access to undisturbed or representative sampling through hollow stem with thin-wall tube sampler, core barrel, or split-barrel sampler.	Should not be used with coarse-grained soils. Not suitable for undisturbed sampling in loose sand or silt. Not recommended below the groundwater table in cohesionless soils.
Wash boring	Boring advanced by chopping with light bit and by jetting with upward deflected jet.	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.	Boring in soil or rock.	Drilling mud should be used in coarse-grained soils. Bottom discharge bits are not suitable for use with undisturbed sampling in soil unless combined with protruding core barrel, as in Denison sampler, or with upward deflected jets.
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 big; removal of cuttings by bailing.	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.	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 clearing of hole between sampling.

APPENDIX C, Continued

METHOD	PROCEDURE	APPLICABILITY	LIMITATIONS
2. Methods of Sampling Soil or Rock			
Hand cut or cylindrical sample	Sample is cut by hand from soil exposed in excavation.	Highest quality samples in all soils and in soft rock.	Requires accessible excavation and dewatering if below water table. Extreme care is required in sampling cohesionless soils.
Fixed-piston sampler	Thin-walled tube is pushed into soil with fixed piston in contact with top of sample during push.	Undisturbed samples in cohesive soils, silts, and sands above or below the water table.	Some types do not have a positive means to prevent piston movement.
Hydraulic piston sampler (Osterberg Sampler)	Thin-walled tube is pushed into soil by hydraulic pressure. Fixed piston in contact with top of sample during push.	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.	Undisturbed samples in stiff, cohesive soils. Representative samples in soft to medium cohesive soils and silts.	May not be suitable for sampling in cohesionless soils. Free piston provides no control of specific recovery ratio.
Open drive sampler	Thin-walled open tube is pushed into soil.	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.	Continuous undisturbed samples up to 20 m (66 ft) long in very soft to soft clays.	Not suitable for soils containing gravels, 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.	Undisturbed samples in stiff, hard, brittle, cohesive soils and sands with cementation, and in soft rock. Effective in sampling alternating hard and soft layers. Representative samples in soft-to-medium cohesive soils and silts. Disturbed samples may be obtained in cohesionless materials with variable success.	Frequently ineffective in cohesionless soils.
Split-barrel or split-spoon sampler	Split-barrel tube is driven into soil by blows of falling ram. Sampling is carried out in conjunction with Standard Penetration Test.	Representative samples in soils other than coarse-grained soils.	Samples are disturbed and not suitable for tests of physical properties.
Auger sampling	Auger drill used to advance hole is withdrawn at intervals for recovery of soil samples from auger flights.	Determine boundaries of soil layers and obtain samples of soil classification.	Samples not suitable for physical property or density tests. Large errors in locating strata boundaries may occur without close attention to details of procedure. In some soils, particle breakdown by auger or sorting effects may result in errors in determining gradation.

APPENDIX C, Continued

2. Methods of Sampling Soil or 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 drilling fluid.	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 rocks.
Denison sampler	Hole is advanced and reamed by core drill while sample is retained in non-rotating inner core barrel with corecatcher. Cuttings removed by circulating drilling fluid.	Undisturbed samples in stiff-to-hard cohesive soil, sand with cementation, and soft rocks. Disturbed sample may be obtained in cohesionless materials with variable success.	Not suitable for undisturbed sampling in loose, cohesionless soils or soft, cohesive soils. Difficulties may be experienced in sampling alternating hard and soft layers.
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	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.	Core samples in rock with preservation of joints and other zones of weakness.	Samples are not well suited to tests of physical properties.
Wash sampling or cuttings sampling	Cuttings are recovered from wash water or drilling fluid.	Samples useful in conjunction with other data for identification of major strata.	Sample quality is not adequate for site investigations for nuclear facilities.
Submersible vibratory (Vibracore) sampler	Core tube is driven into soil by vibrator.	Continuous representative samples in unconsolidated marine sediments.	Because of high area ratio and effects of vibration, samples may be disturbed.
Underwater piston corer	Core tube attached to drop weight is driven into soil by gravity after a free fall of controlled height.	Representative samples in unconsolidated marine sediments.	Samples may be seriously disturbed. Cable supported piston remains in contact with soil surface during drive.
Gravity corer	Open core tube attached to drop weight is driven into soil by gravity after free fall.	Representative samples at shallow depth in unconsolidated marine sediments.	No control of spedific recovery ratio. Samples are disturbed.

METHOD	PROCEDURE	APPLICABILITY	LIMITATIONS
3. Methods of In Situ Testing of Soil and Rock			
Standard Penetration Test (SPT)	Split-barrel sampler is driven into soil by blows of free-falling weight. Blow count for each 15 cm (6 in.) Of penetration is recorded.	Blow count may be used as an index of consistency or density of soil. May be used for detection of changes in consistency or density in clays 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 appratus and procedure. The technique should not be applied to soils containing large amounts of cobbles.
Cone Penetration Test (CPT)	Instrument steel cone is pushed continuously into the ground and measures resistance to penetration, skin friction, and other properties depending on devices incorporated in the cone.	Detection of changes in consistency, strength, and density in soils ranging from clays to finer gravel. Used to estimate static undrained shear strength of clays, liquefaction potential of cohesionless soils, and, if so instrumented, changes in pore water pressure in saturated soils. May also house accelerometer for use as downhole seismic receiver. Experimental cone penetrometers are under development to detect various contaminants.	Does not acquire soil samples, although similar tools are available to do so. Penetration depth may be limited due to push rig capacity in stiff soils, and the technique should not be applied to soils containing large amounts of cobbles.
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.	Used to estimate in situ undrained shear strength and sensitivity of clays.	Not suitable for use in silts, sands, 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	Expandable steel cone is driven into soil by falling weight. Blow count versus penetration is recorded.	Detection of gross changes in consistency or relative density. May be used in some coarse-grained soils.	Provides no quantitative information on soil properties.
Plate bearing test (soil)	Steel loading plate is placed on horizontal surface and is statically loaded, usually by hydraulic jack. Settlement versus time is recorded for each load increment.	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.
Plate bearing test or Plate jacking test (rock)	Bearing pad on rock surface is statically loaded by hydraulic jack. Deflection versus load is recorded.	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.	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 vicinity of borehole. Results may be misleading in testing materials whose properties may be anisotropic.

METHOD	PROCEDURE	APPLICABILITY	LIMITATIONS
3. Methods of In Situ Testing of Soil and Rock			
Field pumping test	Water is pumped from or into an aquifer at constant rate through penetrating well. Change in piezometric level is measured at well and at one or more observation wells. Pumping pressures and flow rates are recorded. Packers may be used for pump-in pressure tests.	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 the extent that the borehole intersects a sufficient number of joints to be representative of the joint system of the rock mass.
Borehole field permeability test	Water is added to an open-ended pipe casing sunk to desired depth. With constant head tests, constant rate of gravity flow into hole and casing pipe are measured. Variations include applied pressure tests and falling head tests.	Rough approximation of in situ permeability of soils and rock mass.	Pipe casing must be carefully cleaned out just to the bottom of the casing. Clear water must be used or tests may be grossly misleading. Measurement of local permeability only.
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.	Measurement of shearing resistance of rock mass in situ.	Tests are costly. Usually, variability of rock mass requires a sufficient number of tests to provide statistical control.
Pressure tunnel test	Hydraulic pressure is applied to sealed-off length of circular tunnel, and diametral deformations are measured.	Determination of elastic constants of the rock mass in situ.	Volume of rock tested is dependent on tunnel diameter. Cracking caused by 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.	Determination of elastic modulus of rock in situ. Capable of applying greater pressure than dilatometers.	Apparent stiffness may be affected by development of tension cracks.

APPENDIX C, Continued

3. Methods of In Situ Testing of Soil and Rock

METHOD	PROCEDURE	APPLICABILITY	LIMITATIONS
Borehole deformation meter	Device for measuring diameters is placed in borehole, and hole is overcored to relieve stresses on annular rock core with deformation meter. Diameters (usually 3) are measured before and after overcoring. Rock modulus is measured by laboratory tests on core; in situ stresses are computed by elastic theory.	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.
Inclusion stressmeter	Rigid stress-indicating device (stressmeter) is placed in borehole, and hole is overcored to relieve stresses on annular core with stress meter. In situ stresses are computed by elastic theory.	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 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.	Measurement of one component of normal stress in situ. Does not require knowledge of rock modulus.	Stress field affected by excavation or tunnel used. Interpretation of test results subject to assumption that loading and unloading moduli are equal. Questionable results in rock with strongly time-dependent properties.
Hydraulic fracturing test	Fluid is pumped into sealed-off portion of borehole with pressure increasing until fracture occurs.	Estimation of minor principal stress.	Affected by anisotropy of tensile strength in 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.	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.
Uphole/downhole seismic test	Seismic signal is transmitted between borehole and ground surface, and transit time is recorded.	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.

APPENDIX C, Continued

3. Methods of In Situ Testing of Soil and Rock

METHOD	PROCEDURE	APPLICABILITY	LIMITATIONS
Acoustic velocity log	Logging tool contains transmitting and two receiving transducers separated by fixed gauge length. Signal is transmitted through rock adjacent to borehole, and transit time over the gauge length is recorded as the difference in arrival times at the receivers.	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 the borehole fluid.
3-D velocity log	Logging tool contains transmitting and receiving transducer separated by fixed gauge length. Signal is transmitted through rock adjacent to borehole, and wave train at receiver is recorded.	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.	Appropriate combination 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 borehole. 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. A detector, isolated from the source, responds to either slow neutrons or secondary gamma rays. Response of detector is recorded.	Correlation of strata between boreholes and location of strata boundaries. Provides an approximation to water content and can be run in cased or uncased, fluid filled, or empty boreholes.	Because of very strong borehole effects, results are generally not of sufficient accuracy for quantitative engineering uses.
Gamma-gamma log (Density log)	Gamma rays are emitted into rock around the borehole by a source in the logging tool, and a detector isolated from the source responds to back-scattered gamma rays. Response of detector is recorded.	Estimation of bulk density in rock, qualitative indication of changes of density in 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.	Detection and mapping of joints, seams, cavities, or other visually observable features in rock. Can be used in empty uncased holes or in boreholes filled with clear water.	Results are affected by any condition that impairs visibility.
Borehole televiewer	A rotating acoustic signal illuminates the borehole wall, and reflected signals are recorded.	Detection and mapping of joints, seams, cavities, or other observable features in rock. Can be used in mud-filled boreholes.	Transparency of borehole fluid is not essential.

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

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 effective in situ 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 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 10 m (33 ft) 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 6 m (20 ft) into sound rock. For weathered shale or soft rock, depths should be as for soils.

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[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 D, Continued

STRUCTURE	SPACING OF BORINGS OR SOUNDINGS	MINIMUM DEPTH OF PENETRATION
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 900 m^2 (10,000 ft^2) (approximately 30 m (100 ft) spacing). In addition, a number of borings along the periphery, at corners, and other selected locations. One boring per 30 m (100 ft) for essentially linear structures.	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 width of the structure or to a depth equal to the foundation depth below the original ground surface, whichever is greater.[3]
Earth dams, dikes, levees, embankments	Principal borings: one per 30 m (100 ft) along axis of structure and at critical locations perpendicular to the axis to establish geological sections with groundwater conditions for analysis.[2]	Principal borings: one per 60 m (200 ft) 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.[2]
Deep cuts,[4] canals	Principal borings: one per 60 m (200 ft) along the alignment and at critical locations perpendicular to the alignment to establish geologic sections with groundwater conditions for analysis.[2]	Principal borings: One per 60 m (200 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.[2] Borings should penetrate pervious strata below which groundwater may influence stability.[2]

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[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.

Appendix D, Continued

STRUCTURE	SPACING OF BORINGS 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 30 m (100 ft) for buried pipelines; at least one boring for each footing for pipelines above ground.	Principal borings: For buried pipelines, one of every three to penetrate sound rock or to d_{max}. Others to 5 times the pipe diameters below the elevation. For pipelines above ground, depths as for foundation structures.[2]
Tunnels	Principal borings: one per 30 m (100 ft),[2] may vary for rock tunnels, depending on rock type and characteristics and planned exploratory shafts or adits.	Principal borings: one per 60 m (200 ft) to penetrate into sound rock or to d_{max}. Others to 5 times the tunnel diameter below the invert elevation.[2,3]
Reservoirs, impoundments	Principal borings: In addition to borings at the locations of dams or dikes, a number of borings should be used to investigate geologic conditions of the reservoir basin. The number and spacing of borings should vary, with the largest concentration near control structures and the coverage decreasing with distance upstream.	Principal borings: At least one-fourth to penetrate that portion of the saturation zone that may influence seepage conditions or stability. Others to a depth of 7.5 m (25 ft) below reservoir bottom elevation.[2]

Sounding = An exploratory penetration below the ground surface used to measure or observe an in situ property of subsurface materials, usually without recovery of samples or cuttings.

Principal boring = A borehole used as a primary source of subsurface information. It is used to explore and sample all soil or rock strata penetrated to define the site geology and the properties of 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 information obtained represents essentially a single location.

APPENDIX E
Applications of Selected Geophysical Methods for Determination of Engineering Parameters

Geophysical Method	Basic Measurement	Application	Advantages	Limitations
			Surface	
Refraction (seismic)	Travel time of compressional waves through subsurface layers	Velocity determination of compression wave through subsurface. Depths to contrasting interfaces and geologic correlation of horizontal layers	Rapid, accurate, and relatively economical technique. Interpretation theory generally straightforward and equipment readily available	In saturated soils, the compression wave velocity reflects mostly wave velocities in the water, and thus is not indicative of soil properties.
Reflection (seismic)	Travel time of compressional waves reflected from subsurface layers	Mapping of selected reflector horizons. Depth determinations, fault detection, discontinuities, and other anomalous features	Rapid, thorough coverage of given site area. Data displays highly effective.	In saturated soils, the compression wave velocity reflects mostly wave velocities in the water, and thus is not indicative of soil properties.
Rayleigh wave dispersion	Travel time and period of surface Rayleigh waves	Inference of shear wave velocity in near-surface materials	Rapid technique which uses conventional refraction seismographs	Coupling of energy to the ground may be inefficient, restricting extent of survey coverage. Data resolution and penetration capability are frequency-dependent; sediment layer thickness and/or depth interpretations must be considered approximate.
Vibratory (seismic)	Travel time or wavelength of surface Rayleigh waves	Inference of shear wave velocity in near-surface materials	Controlled vibratory source allows selection of frequency, hence wavelength and depth of penetration [up to 60 m (200 ft)]. Detects low-velocity zones underlying strata of higher velocity. Accepted method	Coupling of energy to the ground may be inefficient, restricting extent of survey coverage. Data resolution and penetration capability are frequency-dependent; sediment layer thickness and/or depth interpretations must be considered approximate.
Reflection profiling (seismic-acoustic)	Travel times of compressional waves through water and subsurface materials and amplitude of reflected signal.	Mapping of various lithologic horizons; detection of faults, buried stream channels, and salt domes, location of buried man-made objects; and depth determination of bedrock or other reflecting horizons.	Surveys of large areas at minimal time and cost; continuity of recorded data allows direct correlation of lithologic and geologic changes; correlative drilling and coring can be kept to a minimum.	Data resolution and penetration capability is frequency- dependent; sediment layer thickness and/or depth to reflection horizons must be considered approximate unless true velocities are known; some bottom conditions (e.g., organic sediments) prevent penetration; water depth should be at least 5 to 6 m (15 to 20 ft) for proper system operation.
Electrical resistivity	Electrical resistance of a volume of material between probes	Complementary to refraction (seismic). Quarry rock, groundwater, sand and gravel prospecting. River bottom studies and cavity detection.	Economical nondestructive technique. Can detect large bodies of "soft" materials.	Lateral changes in calculated resistance often interpreted incorrectly as depth related; hence, for this and other reasons, depth determinations can be grossly in error. Should be used in conjunction with other methods, i.e., seismic.

APPENDIX E, Cont'd.

Geophysical Method	Basic Measurement	Application	Advantages	Limitations
		Surface (Continued)		
Acoustic (resonance)	Amplitude of acoustically coupled sound waves originating in an air-filled cavity	Traces (on ground surface) lateral extent of cavities	Rapid and reliable method. Interpretation relatively straightforward. Equipment readily available	Must have access to some cavity opening. Still in experimental stage - limits not fully established
Ground penetrating radar(GPR)	Travel time and amplitude of a reflected electromagnetic wave	Rapidly profiles layering conditions. Stratification, dip, water table, and presence of many types of anomalies can be determined	Very rapid method for shallow site investigations. On line digital data processing can yield "on site" look. Variable density display highly effective	Transmitted signal rapidly attenuated by water. Severely limits depth of penetration. Multiple reflections can complicate data interpretation. Generally performs poorly in clay-rich sediments.
Gravity	Variations in gravitational field	Detects anticlinal structures, buried ridges, salt domes, faults, and cavities	Provided extreme care is exercised in establishing gravitational references, reasonably accurate results can be obtained	Requires specialized personnel. Anything having mass can influence data (buildings, automobiles, etc). Data reduction and interpretation are complex. Topography and strata density influence data.
Magnetic	Variations of earth's magnetic field	Determines presence and location of magnetic or ferrous materials in the subsurface. Locates ore bodies	Minute quantities of magnetic materials are detectable	Only useful for locating magnetic materials. Interpretation highly specialized. Calibration on site extremely critical. Presence of any ferrous objects near the magnetometer influences data.
Uphole/downhole (seismic)	Vertical travel time of compressional and/or shear waves	Velocity determination of vertical P- and/or S-waves. Identification of low-velocity zones	Rapid technique useful to define low- velocity strata. Interpretation straightforward	Care must be exercised to prevent undesirable influence of grouting or casing.
Crosshole (seismic)	Horizontal travel time of compressional and/or shear waves	Velocity determination of horizontal P- and/or S-waves. Elastic characteristics of sub-surface strata can be calculated.	Generally accepted as producing reliable results. Detects low-velocity zones provided borehole spacing not excessive.	Careful planning with regard to borehole spacing based upon geologic and other seismic data an absolute necessity. Snell's law of refraction must be applied to establish zoning. A borehole deviation survey must be run. Requires highly experienced personnel. Repeatable source required.
Borehole spontaneous potential	Natural earth potential	Correlates deposits, locates water resources, studies rock deformation, assesses permeability, and determines groundwater salinity.	Widely used, economical tool. Particularly useful in the identification of highly porous strata (sand, etc.).	Log must be run in a fluid filled, uncased boring. Not all influences on potentials are known.

APPENDIX E, Cont'd.

Geophysical Method	Basic Measurement	Application	Advantages	Limitations
		Borehole (Continued)		
Single-point resistivity	Strata electrical resistance adjacent to a single electrode	In conjunction with spontaneous potential, correlates strata and locates porous materials	Widely used, economical tool. Log obtained simultaneous with spontaneous potential	Strata resistivity difficult to obtain. Log must be run in a fluid filled, uncased boring. Influenced by drill fluid.
Long and short-normal resistivity	Near-hole electrical resistance	Measures resistivity within a radius of 40 to 165 cm (16 to 64 in.)	Widely used, economical tool	Influenced by drill fluid invasion. Log must be run in a fluid filled, uncased boring.
Lateral resistivity	Far-hole electrical resistance	Measures resistivity within a radius of 6 m (20 ft)	Less drill fluid invasion influence	Log must be run in a fluid filled, uncased boring. Investigation radius limited in low moisture strata.
Induction resistivity	Far-hole electrical resistance	Measures resistivity in air- or oil-filled holes	Log can be run in a nonconductive casing	Large, heavy tool.
Borehole imagery (acoustic)	Sonic image of borehole wall	Detects cavities, joints, fractures in borehole wall. Determines attitude (strike and dip) of structures.	Useful in examining casing interior. Graphic display of images. Fluid clarity immaterial.	Highly experienced operator required. Slow log to obtain. Probe awkward and delicate.
Continuous sonic (3-D) velocity	Time of arrival of P- and S-waves in high-velocity materials	Determines velocity of P- and S-waves in near vicinity of borehole. Potentially useful for cavity and fracture detection. Modulus determinations. Sometimes S-wave velocities are inferred from P-wave velocity .	Widely used method. Rapid and relatively economical. Variable density display generally impressive. Discontinuities in strata detectable	Shear wave velocity definition questionable in unconsolidated materials and soft sedimentary rocks. Only P-wave velocities greater than 1500 m/s (5,000 ft/s) can be determined.
Natural gamma radiation	Natural radioactivity	Lithology, correlation of strata, may be used to infer permeability. Locates clay strata and radioactive minerals.	Widely used, technically simple to operate and interpret.	Borehole effects, slow logging speed, cannot directly identify fluid, rock type, or porosity. Assumes clay minerals contain potassium-40 isotope.

APPENDIX E, Cont'd.

Geophysical Method	Basic Measurement	Application	Advantages	Limitations
		Borehole (Continued)		
Gamma-gamma density	Electron density	Determines rock density of subsurface strata.	Widely used. Can be applied to quantitative analyses of engineering properties. Can provide porosity.	Borehole effects, calibration, source intensity, chemical variation in strata affect measurement precision. Radioactive source hazard.
Neutron porosity	Hydrogen content	Moisture content (above water table), total porosity (below water table)	Continuous measurement of porosity. Useful in hydrology and engineering property determinations. Widely used	Borehole effects, calibration, source intensity, bound water, all affect measurement precision. Radioactive source hazard.
Neutron activation	Neutron capture	Concentration of selected radioactive materials in strata	Detects elements such as U, Na, Mn. Used to determine oil-water contact (oil industry) and in prospecting for minerals (Al, Cu)	Source intensity, presence of two or more elements having similar radiation energy affect data.
Borehole magnetic	Nuclear precession	Deposition, sequence, and age of strata	Distinguishes ages of lithologically identical strata	Earth field reversal intervals under study. Still subject of research.
Mechanical caliper	Diameter of borehole	Measures borehole diameter	Useful in a wet or dry hole	Must be recalibrated for each run. Averages 3 diameters.

APPENDIX E, Cont'd.

Geophysical Method	Basic Measurement	Application	Advantages	Limitations
Borehole (Continued)				
Acoustic caliper	Sonic ranging	Measures borehole diameter.	Large range. Useful with highly irregular shapes	Requires fluid filled hole and accurate positioning.
Temperature	Temperature	Measures temperature of fluids and borehole sidewalls. Detects zones of inflow or fluid loss .	Rapid, economical, and generally accurate	None of importance.
Fluid resistivity	Fluid electrical resistance	Water-quality determinations and auxiliary log for rock resistivity.	Economical tool	Borehole fluid must be same as groundwater.
Tracers	Direction of fluid flow	Determines direction of fluid flow.	Economical	Environmental considerations often preclude use of radioactive tracers.
Flowmeter	Fluid velocity and quantity	Determines velocity of subsurface fluid flow and, in most cases, quantity of flow.	Interpretation is simple.	Impeller flowmeters usually cannot measure flows less than 1 to 1.7 cm/s (2 - 3 ft/min).
Borehole dipmeter	Sidewall resistivity	Provides strike and dip of bedding planes. Also used for fracture detection.	Useful in determining information on the location and orientation of primary sedimentary structures over a wide variety of hole conditions.	Expensive log to make. Computer analysis of information needed for maximum benefit.
Downhole flow meter	Flow across the borehole	Determines the rate and direction of groundwater flow	A reliable, cost effective method to determine lateral foundation leakage under concrete structures	Assumes flow not influenced by emplacement of borehole.

APPENDIX F
IN SITU TESTING METHODS

Table F-1

In Situ Tests for Rock and Soil
(adapted from EM 1110-1-1804, Department of the Army, 1984)

Purpose of Test	Type of Test	Applicability to Soil	Applicability to Rock
Shear strength	Standard penetration test (SPT)	X	
	Field vane shear	X	
	Cone penetrometer test (CPT)	X	
	Direct shear	X	
	Plate bearing or jacking	X	X[a]
	Borehole direct shear[b]	X	
	Pressuremeter[b]		X
	Uniaxial compressive[b]		X
	Borehole jacking[b]		X
Bearing capacity	Plate bearing	X	X[a]
	Standard penetration	X	
Stress conditions	Hydraulic fracturing	X	X
	Pressuremeter	X	X[a]
	Overcoring		X
	Flatjack		X
	Uniaxial (tunnel) jacking	X	X
	Borehole jacking[b]		X
	Chamber (gallery) pressure[b]		X
Mass deformability	Geophysical (refraction)	X	X
	Pressuremeter or dilatometer	X	X[a]
	Plate bearing	X	X
	Standard penetration	X	
	Uniaxial (tunnel) jacking	X	X
	Borehole jacking[b]		X
	Chamber (gallery) pressure[b]		X
Relative density	Standard penetration	X	
	In situ sampling	X	
Liquefaction susceptibility	Standard penetration	X	
	Cone penetration test (CPT)	X	
	Shear wave velocity (v_s)	X	

[a] Primarily for clay shales, badly decomposed, or moderately soft rocks, and rock with soft seams.
[b] Less frequently used.

APPENDIX F, Cont'd.

Table F-2 In Situ Tests to Determine Shear Strength (adapted from EM 1110-1-1804, Department of the Army, 1984)

	For		
Test	Soils	Rocks	Remarks
Standard penetration	X		Use as index test only for strength. Develop local correlations. Unconfined compressive strength in tsf is often 1/6 to 1/8 of N-value
Direct shear	X	X	Expensive; use when representative undisturbed samples cannot be obtained
Field vane shear	X		Use strength reduction factor
Plate bearing	X	X	Evaluate consolidation effects that may occur during test
Uniaxial compression		X	Primarily for weak rock; expensive since several sizes of specimens must be tested
Cone penetration test (CPT)	X		Consolidated undrained strength of clays; requires estimate of bearing factor, N_c

Table F-3 In Situ Tests to Determine Stress Conditions (adapted from EM 1110-1-1804, Department of the Army, 1984)

Test	Soils	Rocks	Remarks
Hydraulic fracturing	X		Only for normally consolidated or slightly consolidated soils
Hydraulic fracturing		X	Stress measurements in deep holes for tunnels
Vane shear	X		Only for recently compacted clays, silts and fine sands (see Blight, 1974, for details and limitations)
Overcoring techniques		X	Usually limited to shallow depth in rock
Flatjacks	X		
Uniaxial (tunnel) jacking	X	X	May be useful for measuring lateral stresses in clay shales and rocks, also in soils

Blight , G.E. " Indirect Determination of in Situ Stress Ratios in Particulate Materials, " *Proceedings of a Speciality Conference, Subsurface Explorations for Underground Excavation and Heavy Construction*. American Society of Civil Engineers, New York, 1974.

Table F-4 In Situ Tests to Determine Deformation Characteristics (adapted from EM 1110-1-1804, Department of the Army, 1984)

	For		
Test	Soils	Rocks	Remarks
Geophysical refraction, Cross-hole and downhole	X	X	For determining dynamic Young's Modulus, E, at the small strain induced by test procedure. Test values for E must be reduced to values corresponding to strain levels induced by structure or seismic loads.
Pressuremeter	X	X	Consider test as possibly useful but not fully evaluated. For soils and soft rocks, shales, etc.
Chamber test	X	X	
Uniaxial (tunnel) jacking	X	X	
Flatjacking		X	
Borehole jack or dilatometer		X	
Plate bearing		X	
Plate bearing	X		
Standard penetration	X		Used in empirical correlations to estimate settlement of footings; a number of relationships are published in the literature to relate penetration test blow counts to settlement potential.

APPENDIX G
Instruments for Measuring Groundwater Pressure

Instrument Type	Advantages	Limitations[1a]
Observation well	Can be installed by drillers without participation of geotechnical personnel.	Provides undesirable vertical connection between strata and is therefore often misleading; should rarely be used.
Open standpipe piezometer	Reliable. Long successful performance record. Self-de-airing if inside diameter of standpipe is adequate. Integrity of seal can be checked after installation. Can be converted to diaphragm piezometer. Can be used for sampling groundwater. Can be used to measure permeability.	Long time lag. Subject to damage by construction equipment and by vertical compression of soil around standpipe. Extension of standpipe through embankment fill interrupts construction and causes inferior compaction. Porous filter can plug owing to repeated water inflow and outflow. Push-in versions subject to several potential errors.
Twin-tube hydraulic piezometer	Inaccessible components have no moving parts. Reliable. Long successful performance record. When installed in fill, integrity can be checked after installation. Piezometer cavity can be flushed. Can be used to measure permeability.	Application generally limited to long-term monitoring of pore water pressure in embankment dams. Elaborate terminal arrangements needed. Tubing must not be significantly above minimum piezometric elevation. periodic flushing may be required. Attention to many details is necessary.
Pneumatic piezometer	Short time lag. Calibrated part of system accessible. Minimum interference to construction: level of tubes and readout independent of level of tip. No freezing problems.	Attention must be paid to many details when making selection. Push-in versions subject to several potential errors.
Vibrating wire piezometer	Easy to read. Short time lag. Minimum interference to construction: level of lead wires and readout independent of level of tip. Lead wire effects minimal. Can be used to read negative pore water pressures. No freezing problems.	Special manufacturing techniques required to minimize zero drift. Need for lightning protection should be evaluated. Push-in version subject to several potential errors.
Unbonded electrical resistance piezometer	Easy to read. Short time lag. Minimum interference to construction: level of lead wires and readout independent of level of tip. Can be used to read negative pore water pressures. No freezing problems. Provides temperature measurement. Some types suitable for dynamic measurements.	Low electrical output. Lead wire effects. Errors caused by moisture and electrical connections are possible. Need for lightning protection should be evaluated.

[a] Diaphragm piezometer readings indicate the head above the piezometer, and the elevation of the piezometer must be measured or estimated if piezometric elevation is required. All diaphragm piezometers, except those provided with a vent to the atmosphere, are sensitive to barometric pressure changes.

APPENDIX G, Cont'd.

Instrument Type	Advantages	Limitations[a]
Bonded electrical resistance piezometer	Easy to read. Short time lag. Minimum interference to construction: level of lead wires and readout independent of level of tip. Suitable for dynamic measurements. Can be used to read negative pore water pressures. No freezing problems.	Low electrical output. Lead wire effects. Errors caused by moisture, temperature, and electrical connections are possible. Long-term stability uncertain. Need for lightning protection should be evaluated. Push-in version subject to several potential errors.
Multipoint piezometer, with packers	Provides detailed pressure-depth measurements. Can be installed in horizontal or upward boreholes. Other advantages depend on type of piezometer: see above in table.	Limited number of measurement points. Other limitations depend on type of piezometer: see above in table.
Multipoint piezometer, surrounded with grout	Provides detailed pressure-depth measurements. Simple installation procedure. Other advantages depend on type of piezometer: See above in table.	Limited number of measurement points. Applicable only in uniform clay of known properties. Difficult to ensure in-place grout of known properties. Other limitations depend on type of piezometer: see above in table.
Multipoint push-in piezometer	Provides detailed pressure-depth measurements. Simple installation procedure. Other advantages depend on type of piezometer: See above in table.	Limited number of measurement points. Subject to several potential errors. Other limitations depend on type of piezometer: see above in table.
Multipoint piezometer, with movable probe	Provides detailed pressure-depth measurements. Unlimited number of measurement points. Allows determination of permeability. Calibrated part of system accessible. Great depth capability. Westbay Instruments system can be used for sampling groundwater and can be combined with inclinometer casing.	Complex installation procedure. Periodic manual readings only.

REGULATORY ANALYSIS

A separate regulatory analysis was not prepared for this regulatory guide. The regulatory analysis prepared for Draft Regulatory Guide DG-1101, “Site Investigations for Foundations of Nuclear Power Plants” (February 2001), provides the regulatory basis for this regulatory guide as well. DG-1101 was issued for public comment as the draft of this present regulatory guide. A copy of the regulatory analysis is available for inspection and copying for a fee at the U.S. Nuclear Regulatory Commission Public Document Room, 11555 Rockville Pike, Rockville, MD; the PDR’s mailing address is USNRC PDR, Washington, DC 20555; telephone (301)415-4737 or 1-(800)397-4209; fax (301)415-3548; e-mail <PDR@NRC.GOV>.