



U.S. NUCLEAR REGULATORY COMMISSION
STANDARD REVIEW PLAN
OFFICE OF NUCLEAR REACTOR REGULATION

2.5.4 STABILITY OF SUBSURFACE MATERIALS AND FOUNDATIONS

REVIEW RESPONSIBILITIES

Primary - Hydrologic and Geotechnical Engineering Branch (HGEB)

Secondary - None

I. AREAS OF REVIEW

Information must be presented by the applicant concerning the properties and stability of all soils and rock which may affect the nuclear power plant facilities, under both static and dynamic conditions including the vibratory ground motions associated with the safe shutdown earthquake. Stability of these materials, as they influence the safety of seismic Category I facilities, must be demonstrated. In addition an assessment of the properties and stability of these materials should be consistent with SRP Sections 3.7 and 3.8. Much of the information discussed in this section may be presented in other sections, in which case it may be cross-referenced rather than repeated here.

The staff review covers the following specific areas:

1. Geologic features (Subsection 2.5.4.1) in the vicinity of the site:
 - a. Areas of actual or potential surface or subsurface subsidence, solution activity, uplift, or collapse.
 - b. Zones of alteration or irregular weathering profiles, and zones of structural weakness.
 - c. Unrelieved stresses in bedrock and their potential for creep and rebound effects.
 - d. Rocks or soils that might be unstable because of their mineralogy, lack of consolidation, water content, or potentially undesirable response to seismic or other events.

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USNRC STANDARD REVIEW PLAN

Standard review plans are prepared for the guidance of the Office of Nuclear Reactor Regulation staff responsible for the review of applications to construct and operate nuclear power plants. These documents are made available to the public as part of the Commission's policy to inform the nuclear industry and the general public of regulatory procedures and policies. Standard review plans are not substitutes for regulatory guides or the Commission's regulations and compliance with them is not required. The standard review plan sections are keyed to the Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants. Not all sections of the Standard Format have a corresponding review plan.

Published standard review plans will be revised periodically, as appropriate, to accommodate comments and to reflect new information and experience.

Comments and suggestions for improvement will be considered and should be sent to the U.S. Nuclear Regulatory Commission, Office of Nuclear Reactor Regulation, Washington, D.C. 20555.

- e. History of deposition and erosion, including glacial and other pre-loading influence on soil deposits.
 - f. Estimates of consolidation and preconsolidation pressures and methods used to estimate these values.
2. The static and dynamic engineering properties of soil and rock strata underlying the site (Subsection 2.5.4.2) as supported by representative field and laboratory data provided by the applicant.
 3. The relationship of the foundations for safety-related facilities and the engineering properties of underlying materials as illustrated on plot plans and profiles (Subsection 2.5.4.3) provided by the applicant.
 4. The results of seismic refraction and reflection surveys, including in-hole and cross-hole explorations, as presented in the safety analysis report (SAR) by discussions, plot plans, boring logs, tables, and profiles to support the assumed dynamic soil or rock characteristics (Subsection 2.5.4.4) and stratigraphy.
 5. Safety-related excavation and backfill plans and engineered earthwork analyses and criteria (Subsection 2.5.4.5) as illustrated on plot plans and profiles, discussed in the text, and supported by explorations for borrow material, test fills and adequate representative laboratory test records.
 6. Groundwater conditions and piezometric pressure in all critical strata (Subsection 2.5.4.6) as they affect the loading and stability of foundation materials. This part of the staff review also includes an evaluation of the applicant's plans for dewatering during construction as well as groundwater control throughout the life of the plant.
 7. The responses of site soils or rocks to dynamic loading (Subsection 2.5.4.7), including appropriate laboratory and field test records in sufficient number and detail adequate to support conclusions derived from the analyses. Soil-structure interaction analyses are reviewed in coordination with Structural Engineering Branch (SEB) to assure soil properties data for the soil profile model are representative of the in situ soils.
 8. The liquefaction potential (Subsection 2.5.4.8) and consequences of liquefaction of all subsurface soils, including the settlement of foundations. These analyses are based on soil properties obtained by state-of-the-art laboratory and field tests and involve application of both deterministic and probabilistic procedures.
 9. The earthquake design bases (Subsection 2.5.4.9) are evaluated in detail in Section 2.5.2 of the SAR. These are summarized and cross-referenced in this subsection. The safe shutdown earthquake (SSE) and the operating basis earthquake (OBE) are evaluated in this subsection in combination with other hazards (floods, etc.) to assess the adequacy of the site materials under dynamic conditions.
 10. The results of investigations and analyses conducted to determine foundation material stability, deformation and settlement under static conditions (Subsection 2.5.4.10).

11. Criteria, references, and design methods (Subsection 2.5.4.11) used in static and seismic analyses of foundation materials, including an explanation of computer programs used in the analyses and soil loads on subsurface facilities.
12. Techniques and specifications to improve subsurface conditions (Subsection 2.5.4.12), which are to be used at the site to provide suitable foundation conditions.
13. Additional information on foundations is covered in SRP Section 3.8.5 and should be cross-referenced to this section.

The HGEB will coordinate other branch evaluations that interface with the Geotechnical Engineering aspects of the site as follows: Geosciences Branch (GB) will determine the adequacy of the geologic and seismic information cited in support of the applicant's conclusions concerning the suitability of the plant site as part of its primary review responsibility for SRP Section 2.5.1. GB also reviews the seismological and geological investigations carried out to establish the ground motion environment for seismic design of the plant, the procedures and analyses used by the applicant in establishing the SSE and OBE for the site, and the seismic design bases for foundations as part of its primary review responsibility for SRP Section 2.5.2. HGEB reviews the geotechnical parameters and methods employed in the analysis of soil and foundation response to the ground motion environment. The results of the stability evaluations of subsurface materials and foundations are reviewed by SEB to assure that the soil loads and structural deflections, including any reduction in support capability of subsurface materials, can safely be accommodated by structural components as part of its primary review responsibilities for SRP Sections 3.7 and 3.8. Licensing Guidance Branch (LGB) will coordinate the review of technical specifications to insure that Geotechnical Engineering Design features related to materials of construction and geometric arrangement of subsurface materials, foundations, cut slopes, and embankments, which if degraded or altered would have a significant effect on safety, are included in conjunction with its primary review responsibility for SRP Section 16.0. Quality Assurance Branch (QAB) will coordinate the review of Geotechnical Engineering aspects of the QA program pertaining to safety-related structures, systems, and components in conjunction with its primary review responsibilities for SRP Section 17.1.

For those areas of review identified above as being reviewed as part of the primary review responsibility of other branches, the acceptance criteria necessary for the review and their methods of application are contained in the referenced SRP section of the corresponding primary branch.

II. ACCEPTANCE CRITERIA

The applicable rules and basic acceptance criteria pertinent to the areas of this section of the Standard Review Plan are:

1. 10 CFR Part 50, §50.55a - Codes and Standards. This rule requires that structures, systems, and components shall be designed, fabricated, erected, constructed, tested and inspected in accordance with the requirement of applicable codes and standards commensurate with the importance of the safety function to be performed. (Ref. 1).

2. 10 CFR Part 50, Appendix A:

- (a) General Design Criterion 1 - "Quality Standards and Records." This criterion requires that structures, systems and components important to safety shall be designed, fabricated, erected, and tested to quality standards commensurate with the importance of the safety functions to be performed. It also requires that appropriate records of the design, fabrication, erection, and testing of structures, systems, and components important to safety shall be maintained by or under the control of the nuclear power unit licensee throughout the life of the unit. (Ref. 2)
 - (b) General Design Criterion 2 - "Design Bases for Protection Against Natural Phenomena." This criterion requires that safety-related portions of the system shall be designed to withstand the effects of earthquakes, tornadoes, hurricanes, floods, tsunamis, and seiches without loss of capability to perform their safety functions. (Ref. 3)
 - (c) General Design Criterion 44 - "Cooling Water" - This criterion requires that a system shall be provided with the safety function of transferring the combined heat load from structures, systems, and components important to safety to an ultimate heat sink under normal operating and accidental conditions. (Ref. 4)
- 3. 10 CFR Part 50, Appendix B, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants." This appendix establishes quality assurance requirements for the design, construction, and operation of those structures, systems, and components of nuclear power plants that prevent or mitigate the consequences of postulated accidents that could cause undue risk to the health and safety of the public. (Ref. 5)
 - 4. 10 CFR Part 100, "Reactor Site Criteria." This part describes criteria which guide the evaluation of the suitability of proposed sites for nuclear power and testing reactors. (Ref. 6)
 - 5. 10 CFR Part 100, Appendix A, "Seismic and Geologic Siting Criteria for Nuclear Power Plants." These criteria describe the nature of the investigations required to obtain the geologic and seismic data necessary to determine site suitability and identify geologic and seismic factors required to be taken into account in the siting and design of nuclear power plants. (Ref. 7)

The following Regulatory Guides provide information, recommendations, and guidance and in general describe a basis acceptable to the staff that may be used to implement the requirements of 10 CFR Part 50, §50.55a; 10 CFR Part 50, Appendix A, General Design Criteria 1, 2 and 44; 10 CFR Part 50, Appendix B; 10 CFR Part 100; and 10 CFR Part 100, Appendix A.

- 1. Regulatory Guide 1.27, "Ultimate Heat Sink for Nuclear Power Plants." This guide describes a basis acceptable to the staff that may be used to implement General Design Criteria 2 and 44 with regard to the ultimate heat sink, including necessary retaining structures and the canals and conduits connecting the ultimate heat sink with the cooling water system intake structures. (Ref. 8)

2. Regulatory Guide 1.28, "Quality Assurance Program Requirements (Design and Construction)." This guide describes a method acceptable to the staff for complying with the Commission's regulations with regard to 10 CFR Part 50, Appendix B, overall quality assurance program requirements during design and construction of nuclear power plants. (Ref. 9)
3. Regulatory Guide 1.132, "Site Investigations for Foundations of Nuclear Power Plants." This guide describes programs of site investigations related to geotechnical engineering aspects that would normally meet the needs for evaluating the safety of the site from the standpoint of the performance of foundation and earthworks under anticipated loading conditions including earthquake in complying with 10 CFR Part 100 and 10 CFR Part 100, Appendix A. It provides general guidance and recommendations for developing site-specific investigation programs as well as specific guidance for conducting subsurface investigations, the spacing and depth of borings and sampling. (Ref. 10)
4. Regulatory Guide 1.138, "Laboratory Investigations of Soils for Engineering Analysis and Design of Nuclear Power Plants." This guide describes laboratory investigations and testing practices acceptable for determining soil and rock properties and characteristics needed for engineering analysis and design for foundations and earthwork for nuclear power plants in complying with 10 CFR Part 100 and 10 CFR Part 100, Appendix A. (Ref. 11)

A thorough evaluation of the geotechnical engineering aspects of the nuclear plant site as described in the following subsections must be presented along with the basic data supporting all conclusions. Sufficient information must be provided to allow the staff and its advisors to conduct independent analyses. The site investigations must be adequate in scope and in technique to provide the necessary data.

Specific criteria necessary to meet the relevant requirements of the Commission regulations identified above are as follows:

Subsection 2.5.4.1. In meeting the requirements of References 1, 6, and 7 and the regulatory positions of References 10 and 11, the section defining geologic features is acceptable if the discussions, maps, and profiles of the site stratigraphy, lithology, structural geology, geologic history, and engineering geology are complete and are supported by site investigations sufficiently detailed to obtain an unambiguous representation of the geology. The information must be presented in this subsection or cross-referenced to the appropriate subsection in Section 2.5.1 of the SAR.

Subsection 2.5.4.2. In meeting the requirements of References 1, 2, 3, 6, and 7 and the regulatory positions of References 10 and 11, the description of properties of underlying materials is considered acceptable if state-of-the-art methods are used to determine the static and dynamic engineering properties of all foundation soils and rocks in the site area. These methods are described, for example, in geotechnical journals published by the American Society of Civil Engineers (Ref. 13), applicable standards published by the American Society for Testing and Materials (Ref. 14), publications of the Institution of Civil Engineers (Ref. 15), and various research reports prepared by universities (Ref. 16). The properties of foundation material must be supported by field (Ref. 19 and 20) and laboratory (Ref. 21) test records.

Normally, a complete field investigation and sampling program must be performed to define the occurrence and properties of underlying materials at a given site (Ref. 17). Summary tables must be provided which catalog the important test results; test results should be plotted when appropriate. Also, a detailed discussion of laboratory sample preparation must be given when applicable. For critical laboratory tests, full details must be given, e.g., how saturation of the sample was determined and maintained during testing, how the pore pressures changed.

The applicant should provide a detailed and quantitative discussion of the criteria used to determine that the samples were properly taken and tested in sufficient number to define all the critical soil parameters for the site. For sites that are underlain by saturated soils and sensitive clays, it should be shown that all zones which could become unstable due to liquefaction or strain-softening phenomena have been adequately sampled and tested. The relative density of the soils at the site should be determined. The applicant must also show that he has adequately defined the consolidation behavior of the soils as well as their static and dynamic strength. The discussion should explain how the developed data is used in the safety analyses, how the test data is enveloped for design, why the design envelope is conservative and present a table indicating the value of the parameters used in the analyses.

Subsection 2.5.4.3. In meeting the requirements of References 2, 3, 6, and 7 and the regulatory positions of References 8, 10, and 11, the discussion of the relationship of foundations and underlying materials is acceptable if it includes:

1. A plot plan or plans showing the locations of all site explorations, such as borings, trenches, seismic lines, piezometers, geologic profiles, and excavations with the locations of the safety-related facilities superimposed thereon.
2. Profiles illustrating the detailed relationship of the foundations of all seismic Category I and other safety-related facilities to the subsurface materials.
3. Logs of core borings and test pits.
4. Logs and maps of exploratory trenches in the preliminary safety analysis report (PSAR), and geologic maps and photographs of the excavations for the facilities of the nuclear power plant in the final safety analysis report (FSAR).

Subsection 2.5.4.4. In meeting the requirements of References 1, 2, 6, and 7 and the regulatory positions of References 10 and 11, the presentation of the dynamic characteristics of soil or rock is acceptable if geophysical investigations have been performed at the site and the results obtained therefrom are presented in detail. Completeness of the presentation is judged by whether or not the exploratory techniques used by the applicant yield unambiguous and useful information, whether they represent state-of-the-art exploration methods (Refs. 10, 13, 14, and 17), and whether the applicant's interpretations are supported by adequate field records in the SAR. See also Subsection 2.5.2.3.

Subsection 2.5.4.5. In meeting the requirements of References 1 through 7 and the regulatory positions of References 8 through 11, the presentation of the data concerning excavation, backfill, and earthwork analyses is acceptable if:

1. The sources and quantities of backfill and borrow are identified and are shown to have been adequately investigated by borings, pits, and laboratory property and strength testing (dynamic and static) and these data are included, interpreted, and summarized.
2. The extent (horizontally and vertically) of all Category I excavations, fills, and slopes are clearly shown on plot plans and profiles.
3. Compaction specifications and embankment and foundation designs are justified by field and laboratory tests and analyses to assure stability and reliable performance.
4. Quality control methods are discussed and the quality assurance program described and referenced.
5. Control of groundwater during excavation to preclude degradation of foundation materials is described and referenced.

Subsection 2.5.4.6. In meeting the requirements of References 2, 3, 4, 6, and 7 and the regulatory positions of References 8, 10, and 11, the analysis of groundwater conditions is acceptable if the following are included in this subsection or cross-referenced to the appropriate subsections in Section 2.4 of the SAR:

1. Discussion of critical cases of groundwater conditions relative to the foundation stability of the safety-related facilities of the nuclear power plant.
2. Plans for dewatering during construction.
3. Analysis and interpretation of seepage and potential piping conditions during construction.
4. Records of field and laboratory permeability tests.
5. History of groundwater fluctuations as determined by periodic monitoring of local wells and piezometers. Flood conditions should also be considered.

Subsection 2.5.4.7. In meeting the requirements of References 2, 3, 4, 6, and 7 and the regulatory positions of References 10 and 11, descriptions of the response of soil and rock to dynamic loading are acceptable if:

1. An investigation has been conducted and discussed to determine the effects of prior earthquakes on the soils and rocks in the vicinity of the site. Evidence of liquefaction and sand cone formation should be included.
2. Field seismic surveys (surface refraction and reflection and in-hole and cross-hole seismic explorations) have been accomplished and the data presented and interpreted to develop P and S wave velocity profiles.
3. Dynamic tests have been performed in the laboratory on samples of the foundation soil and rock and the results included. The section should be cross-referenced with Subsection 2.5.2.5.

The soil-structure interaction analysis should be described in SRP Sections 3.7.1 and 3.7.2 and cross-referenced to this subsection. In the soil-structure interaction analysis, the following parameters are reviewed:

- a. The static and dynamic properties of the soil supporting the structure are properly determined and compatible with the characteristics of the analytical model used to evaluate soil-structure interaction effects.
- b. The soil profile has been properly modeled when a two-dimensional finite-element analysis is used, or if a half-space analysis method is used, when foundation moduli and damping are consistent with soil properties and soil profiles at the site.
- c. The static and dynamic loads, and the stresses and strains induced in the soil surrounding and underlying the structure are adequately and realistically evaluated.
- d. The consequences of the induced soil stresses and strains, as they influence the soil surrounding and underlying the structure, have been conservatively assessed.

Subsection 2.5.4.8. In meeting the requirements of References 2, 3, 4, 6, and 7 and the regulatory positions of References 8, 10, and 11, if the foundation materials at the site adjacent to and under Category I structures and facilities are saturated soils and the water table is above bedrock, then an analysis of the liquefaction potential at the site is required. The need for a detailed analysis is determined by a study on a case by case basis of the site stratigraphy, critical soil parameters, and the location of safety-related foundations. Undisturbed samples obtained at the site and appropriate laboratory tests are required to show if the soils are likely to liquefy. Liquefaction potential assessments using both deterministic and probabilistic approaches are desirable.

When the need for an in-depth analysis is indicated, it may be based on cyclic triaxial test data obtained from undisturbed soil samples taken from the critical zones in the site area. The shear stresses induced in the soil by the postulated earthquake should be determined in a manner that is consistent with SRP Section 2.5.2. The criterion that should be used to determine when the soil samples tested "liquefied" should be taken as the onset of liquefaction (defined as the cycle when the pore pressure first equals the confining pressure). Test data showing the rate of pore pressure increase with number of load cycles should be presented. If the behavior of the pore pressure is such that peak to peak axial strains greater than a few percent occur before liquefaction, then the applicant must include the effects of these strains in his assessment of the potential hazards that complete or partial liquefaction could have on the stability and settlement of any Category I structures.

Nonseismic liquefaction (such as that induced by erosion, floods, wind loads on structures and wave action) should be analyzed using state-of-the-art soil mechanics principles.

Subsection 2.5.4.9. In meeting the requirements of References 3, 6, and 7, the earthquake design basis analysis is acceptable if a brief summary of the derivation of the safe shutdown and operating basis earthquakes (SSE and OBE) is presented and references are included to Subsections 2.5.2.6 and 2.5.2.7.

Subsection 2.5.4.10. In meeting the requirements of References 1, 2, 3, 4, 6, and 7 and the regulatory positions of References 8, 10, and 11, the discussions of static analyses are acceptable if the stability of all safety-related facilities has been analyzed from a static stability standpoint including bearing capacity, rebound, settlement, and differential settlements under deadloads of fills and plant facilities, and lateral loading conditions. Field and laboratory test procedures and results must be included to document soil and rock properties used in the analyses. The applicant must show that the methods of analysis used are appropriate for the local soil conditions and the function of the facility.

Subsection 2.5.4.11. In meeting the requirements of References 1, 2, 3, 4, 6, and 7 and the regulatory positions of Reference 8, the discussion of criteria and design methods is acceptable if the criteria used for the design, the design methods employed, and the factors of safety obtained in the design analyses are described and a list of references presented. An explanation and verification of the computer analyses used and source references should be included.

Subsection 2.5.4.12. In meeting the requirements of References 1 through 7 and the regulatory positions of References 8 and 9, the discussion of techniques to improve subsurface conditions is acceptable if plans, summaries of specifications, and methods of quality control are described for all techniques to be used to improve foundation conditions (such as grouting, vibroflotation, dental work, rock bolting, or anchors).

III. REVIEW PROCEDURES

The review process is conducted in a similar manner and concurrent with that described in SRP Section 2.5.1. The services of consultants are used on selected sites to aid the staff in evaluating the geotechnical engineering aspects of particular sites.

After acceptance of the SAR, the results of site investigations (such as borings, geologic maps, logs of trenches and pits, permeability test records, results of seismic investigations, laboratory test results, profiles, and plot plans) are studied and cross-checked in considerable detail to determine whether or not the assumptions used in the evaluation are conservative. The design criteria are reviewed to ascertain that they are within the present state-of-the-art. Staff comments and questions at this phase of the review, concerning the information in the SAR, are sent to the applicant as first-round questions (Q-1). For those facilities that have complex subsurface conditions, where marginal safety has been achieved, or where the applicant proposes to construct a seismic Category I earth or rockfill dam, an independent analysis of the design is performed by the staff or its advisors. The evaluations conducted by the staff and its advisors may identify additional unresolved items, or reveal that the applicant's investigations and analyses are not complete or sufficiently conservative. Additional information is then requested in a second round of questions (Q-2), or a staff position is taken requiring adoption of a more conservative approach.

The data needed to satisfy the requirements of this section are not usually complete in the early stages. Detailed design investigations are usually still in progress and final conclusions have often not been made. Because of this, the question and answer exchange may not be complete at the Q-2 stage. Most of the open items of Section 2.5 remaining at the time that the safety evaluation

report (SER) input is required are in the geotechnical engineering area because actual site conditions may not be fully revealed until excavations are opened and construction has begun. Thus, a site visit, in addition to that noted in Section 2.5.1, "Basic Geologic and Seismic Information," is necessary during the post-CP period to examine the foundation materials exposed in excavations during construction. Information and final designs, including confirming tests and revised analyses, are to be submitted in the FSAR.

Generally, the staff is guided by the criteria in References 1 through 11 and the Standard Format (Ref. 12) in reviewing Section 2.5.4.

Following is a brief description of the review procedures conducted by the staff in evaluating the geotechnical engineering aspects of nuclear power plant sites.

Subsection 2.5.4.1. Geologic features are evaluated by conducting an independent literature search and comparing these results with the information included in the applicant's SAR. References used in reviewing this subsection include published or unpublished reports, maps, geophysical data, construction records, etc., by the USGS, other Federal agencies, State agencies, and private companies (such as oil corporations and architect engineering firms). In conjunction with the literature search, the staff and its advisors review the geological investigations conducted by the applicant. Using the references listed at the end of this section and other sources, the following questions are considered in detail:

1. Are the exploratory techniques used by the site investigator representative of the present state-of-the-art? Do the samples represent the in situ soil conditions?
2. Do the applicant's investigations provide adequate coverage of the site area and in sufficient detail to define the specific subsurface conditions with a high degree of confidence?
3. Have all areas or zones of actual or potential surface or subsurface subsidence, uplift or collapse, deformation, alternation, solution cavities or structural weakness, unrelieved stresses in bedrock, or rocks or soils that might be unstable because of their physical or chemical properties been identified and adequately evaluated?

Subsection 2.5.4.2. Properties of underlying materials are evaluated to determine whether or not the investigations performed (including laboratory and field testing) were sufficient to justify the soil and rock properties used in the foundation analyses.

To determine whether sufficient investigations were performed, the staff carefully reviews the criteria developed and used by the applicant in laying out the boring, sampling and testing program and evaluates the effectiveness of the program in defining the specific foundation conditions at the site to assure that all critical conditions have been adequately sampled and tested. If suitable criteria have not been developed and used by the applicant, the staff develops appropriate criteria, using Regulatory Guide 1.132 and the data given in the SAR, and determines if sufficient investigation and testing have been carried out. If criteria are given, the staff reviews them to determine if they are appropriate and have been implemented.

If it is the staff's judgment that the applicant's investigations or testing are inappropriate or insufficient, additional investigations will be required. The final conclusion is based on professional judgment, considering the complexity of the site subsurface conditions. As part of the review, the staff must ascertain, often with the help of consultants, that state-of-the-art laboratory and field techniques and equipment are employed in determining the material properties.

Subsection 2.5.4.3. Plot plans and profiles are reviewed by comparing the subsurface materials with the proposed locations (horizontal and vertical) of foundations and walls of all seismic Category I facilities. The profiles and plot plans are cross-checked in detail with the results of all subsurface investigations conducted at the site to ascertain that sufficient exploration has been carried out and to determine whether or not the interpretations made by the investigators are valid and the foundation design assumptions contain adequate margins of safety.

Subsection 2.5.4.4. Staff evaluation consists of a detailed review of all geophysical explorations conducted at the site, including seismic refraction, reflection, and in-hole surveys and magnetic and gravity surveys. Consultant expertise regarding specific techniques may be drawn upon in this review. Logs of core borings, trenches, and test pits are reviewed and compared with data from the seismic surveys and other geophysical explorations. Results must be consistent or additional investigations are required, or the applicant must use the most conservative values. Following the PSAR review and during the FSAR review the staff compares conditions as mapped in the open excavations with interpretations and assumptions derived during the investigation program.

Subsection 2.5.4.5. Excavations, backfill, and earthwork are evaluated by the staff as follows:

1. The investigations for borrow material, including boring and test pit logs, and compaction test data are reviewed and judged as to their adequacy.
2. Laboratory dynamic and static records of tests performed on samples compacted to the design specifications are reviewed to ascertain that state-of-the-art criteria are met.
3. Analyses and interpretations are reviewed to assure that static and dynamic stability requirements are met.
4. Excavation and compaction specifications and quality control procedures are reviewed to ascertain conformance to state-of-the-art conservative standards.

Subsection 2.5.4.6. Groundwater conditions as they affect foundation stability are evaluated by studying the applicant's records of the historic fluctuations of groundwater at the site as obtained by monitoring local wells and springs and by analysis of piezometer and permeability data from tests conducted at the site. The applicant's dewatering plans during and following construction are also reviewed. Adequacy of these plans is evaluated by comparing with the results of the groundwater investigations and by professional judgment of groundwater and soil conditions at the site.

Subsection 2.5.4.7. Response of soil and rock to dynamic loading and soil-structure interaction is evaluated by a detailed study of the results of the

investigations and analyses performed. Specifically, the effects of past earthquakes on site soils or rocks (a requirement in SRP Section 2.5.2) are determined. The data from core borings, from geophysical investigations, and from dynamic laboratory tests such as sonic and cyclic triaxial tests on undisturbed samples are evaluated. The object of the staff review is to ascertain that reasonably conservative dynamic soil and rock characteristics are used in the design and analyses and that all the significant soil and rock strata have been considered in the analyses. In some cases, independent analyses and interpretations are carried out as outlined in SRP Section 2.5.2, or as required to verify the liquefaction analysis discussed in Subsection 2.5.4.8.

Subsection 2.5.4.8. Liquefaction potential is reviewed by a study of the results of geotechnical investigations including boring logs, laboratory classification test data and soil profiles to determine if any of the site soils could be susceptible to liquefaction. The results of in-situ tests such as the standard penetration tests and the density and strength data obtained from undisturbed samples obtained in exploration borings are examined and, when appropriate, related to the liquefaction potential of in situ soils.

If it is determined that there may be liquefaction-susceptible soils beneath the site, the applicant's site exploration methods, laboratory test program, and analyses are reviewed for adequacy and reasonableness. The analysis submitted by the applicant is reviewed in detail and compared to an independent study performed by the staff employing both deterministic and probabilistic methods as appropriate. As a minimum, the staff study consists of:

1. A review of appropriate standard penetration test results, other in-situ test data and groundwater conditions to assess liquefaction potential.
2. A careful review of conventional laboratory and cyclic triaxial test data to insure that appropriate samples were obtained and tested from critical, liquefiable zones.
3. Confirmation that an adequate number of samples were properly tested and that the test results account for the natural variation in different samples as well as define the cyclic resistance to liquefaction of the soils.
4. An assessment of the liquefaction potential using a conservative envelope of the test data submitted.
5. A calculation of the stress induced by the earthquake that has been arrived at by an envelope of critical conditions calculated for the site based on variations in the properties of the soil strata.
6. Assurance that conservative ranges of relative density of the soils are estimated. The applicant's estimates of the "safety factor" obtained from his analysis is compared to the safety margins estimated by the staff. (The applicant's plans to "eliminate" the liquefaction condition, usually by excavation and backfill, vibroflotation, or chemical grouting is evaluated as discussed in Subsections 2.5.4.5 and 2.5.4.12.)
7. An assessment of post-earthquake stability and settlements due to partial liquefaction using state-of-the-art techniques.

8. An assessment of nonseismic liquefaction based on state-of-the-art techniques.

Subsection 2.5.4.9. The in-depth staff evaluation of the safe shutdown and operating basis earthquakes is contained in SRP Section 2.5.2. The staff's evaluation of the amplification characteristics of specific soils and rocks beneath the site as determined by procedures discussed in that section and in Subsections 2.5.4.2, 2.5.4.4, and 2.5.4.7 are summarized and cross-referenced herein.

The review of Subsection 2.5.4.9 concentrates on determining its consistency or inconsistency with other subsections. Cross-referencing with other sections is expected.

Subsection 2.5.4.10. Static analyses of the bearing capacity and settlement of the supporting soils under the loads of fills, embankments, and foundations are evaluated by conventional, state-of-the-art methods (Ref. 18). In general, the evaluation procedure includes:

1. Determining whether or not the soil and rock properties used in the analyses represent the actual site conditions beneath the plant facilities. The site investigation, sampling, and laboratory test programs must be adequate for this evaluation.
2. Determining whether or not the methods of analysis are appropriate for the earthworks, foundations, and soil conditions at the site.
3. Coordinating with SEB to determine whether or not the bearing capacity, settlement, differential settlement, and tilt estimates indicate conservative and tolerable behavior of the plant foundations when these values are compared to design criteria and quality assurance specifications.
4. Evaluation of particularly complex cases on the basis of accepted principles and techniques as supplemented by case histories and confirmatory measurement and analysis programs (Ref. 18).

Subsection 2.5.4.11. Criteria and design methods, including construction control and monitoring systems, are evaluated on the basis of conservative accepted practice for similar facilities. Site exploration, sampling, testing, and interpretation are judged with respect to completeness, care and technique, meaningful documentation, performance records for similar projects, published guidelines, and state-of-the-art practice. However, unconventional or research-oriented tests and interpretations are encouraged whenever such work aids or supplements conventional practices. Design criteria and methods are compared to similar standards published or utilized by public agencies such as the U.S. Navy Department, U.S. Army Engineers, and U.S. Department of the Interior. Design safety features, the applicant's proposed confirmatory tests and measurements, and monitoring of performance for safety-related foundations and earthworks are reviewed and evaluated on a case-by-case basis.

Subsection 2.5.4.12. Techniques to improve subsurface conditions are evaluated by reviewing the applicant's specifications and techniques for performance and quality control for such activities as grouting, excavation and backfill, vibroflotation, rock bolting, and anchoring. Confirmatory data should be contained in the FSAR.

IV. EVALUATION FINDINGS

If the evaluation by the staff, on completion of the review of geotechnical engineering aspects of the plant site, confirms that the applicant has met the requirements of References 1 through 7 and the regulatory positions of References 8 through 11, the conclusion in the SER will state that the investigations performed at the site are adequate to justify the soil and rock characteristics used in the design, and that the design analyses contain adequate margins of safety for construction and operation of the subject nuclear power plant. Staff reservations about any portion of the applicant's analyses will be stated in sufficient detail to make clear the precise nature of the staff concern.

A typical staff SER finding follows:

The site is located in the Piedmont at an average elevation of +395 feet mean sea level (msl). Exploratory borings have been made and refraction and reflection seismic surveys conducted to establish the stratigraphy of the site. Additionally, undisturbed samples of representative soils and core borings have been obtained to evaluate the characteristics of the foundation materials; close-centered cross-hole seismic tests have been conducted to determine the elastic properties of these materials. Groundwater at the site varies from +375 to +380 feet msl.

The area has been exposed to subaerial weathering and erosion since middle Mesozoic time, and a deep weathering profile has developed. The depth of weathering depends on the location and degree of jointing, orientation of schistosity, and composition of the parent rock.

The applicant has categorized the foundation material into three zones according to the degree of weathering:

- (a) Zone 1 contains residual soil derived from severely weathered slate. The soil is a sandy, silty clay containing slate and quartz fragments. Decomposed to severely weathered slate is also present. The slate still retains the original rock structure, although it is soft and partly friable. Quartz veins within the slate are extremely fractured. Seismic compression (P) and shear (S) wave velocities exceed 4000 ft/sec and 1800 ft/sec, respectively. Zone 1 ranges in thickness from less than 20 feet to more than 50 feet.
- (b) Zone 2 consists of moderately weathered slate and varies from 15 to 60 feet thick. P and S wave velocities generally exceed 6500 ft/sec and 2500 ft/sec, respectively.
- (c) Zone 3 contains slightly weathered to unweathered slate and is encountered at depths of 60 to 90 ft below ground surface.

The site area will be leveled to about elevation +390 feet msl, and containments will be founded on a 10 foot thick, reinforced concrete mat on slightly weathered slate or fill concrete over slightly weathered slate. The reactor service building between the reactors and the control building will be on mats at elevation +385 feet msl on compacted structural fill resting on slightly to moderately weathered rock. The turbine generators will be founded on compacted structural fill over moderately weathered rock at elevation +380 feet msl. The diesel generator building, reactor

plant component air-cooled heat exchanger enclosures, and the CACS air-cooled heat exchanger will be founded on either individual concrete footings or continuous footings (grade beams) at +385 feet msl, on compacted structural fill over moderately weathered slate. Allowable bearing capacities from laboratory tests and field plate tests for Zone 1, Zone 2, and Zone 3 materials are 4, 10, and 25 tons per square foot, respectively. All piping will be entrenched and bedded in moderately to severely weathered slate.

Settlement and differential settlement of safety-related facilities has been estimated to be less than one inch.

The applicant states that severely weathered or soft zones of rock will be excavated and replaced with lean concrete. This procedure will also be followed wherever severe weathering extends along joints, schistosity, etc., below the base of the foundations; this material will be excavated to a depth 1-1/2 times the width of the zone and backfilled with concrete.

Category I structural backfill under structures will either be concrete or compacted granular backfill. If granular backfill is used, it will be compacted to at least 85 percent relative density or to 95 percent of the maximum density determined by the Modified Proctor test. These backfill criteria are acceptable criteria for soil pressures on foundations and buried pipes and are suitable and conservative for both static and dynamic conditions.

Suitable borrow material for dikes, dams and impervious linings are available for the ultimate heat sink ponds. The applicant's tests on these materials and the construction criteria to be followed ensure that leakage, piping and cracking hazards of these vital earthworks are minimal. Filters, blanket drains, relief wells, piezometers and settlement monuments will assure the reliable performance of the ultimate heat sink water-retention facilities.

The applicant has shown that the appropriate acceleration level on sound rock is 0.12g for the safe shutdown earthquake (SSE). The operating bases earthquake (OBE) value is taken as 0.06g. The applicant has performed a site-dependent analysis to estimate the site amplification effects and found that the weathered rock or structural backfill would amplify the rock motion. An acceleration level of 0.17g for the SSE will be used for those structures founded on weathered rock or structural backfill over weathered rock. The time history used for seismic design of Category I earth dams and for liquefaction assessment envelopes the response spectra for the site and has a conservative duration.

The staff concludes that information, including analysis and substantiation, presented by the applicant is sufficient to demonstrate that the properties and stability of all soils and rock, whose performance could adversely affect directly or indirectly safety-related structures of the nuclear plant or pose a hazard to the public, meet the requirements of the pertinent Commission's regulations (cite appropriate References 1 through 7).

The applicant has met the requirements of the pertinent Commission's regulations (cite appropriate References 1 through 7) with respect to defining geologic features; demonstration of the static and dynamic

engineering properties of soil and rock strata underlying the site as supported by results of investigations including borings, shafts, pits, trenches, and field and laboratory tests; properties of borrow materials; compaction and excavation specifications; design criteria, methods, and analyses; groundwater conditions and control; response of site soil and rock to static and dynamic loading including evaluation of liquefaction potential; settlement analyses; and, where required, techniques and specifications to improve subsurface conditions, by meeting the regulatory position in Regulatory Guide (cite appropriate References 8 through 11) or by providing and meeting an alternative method to these regulatory positions that the staff has reviewed and found to be acceptable.

Based on the results of the applicant's investigations, laboratory and field tests, analyses, and criteria for design and construction, we conclude that the site and the plant foundations will be adequate to safely support the planned nuclear power plant and that safety-related earthworks will perform their functions reliably.

V. IMPLEMENTATION

Implement revisions to this SRP section immediately upon publication. Circumstances which prevent implementation or impose unusual conditions upon licensee or applicant may be brought to the attention of NRC for resolution. Alternative methods for licensee or applicant compliance with Commission regulations may be proposed for NRC review. See referenced Regulatory Guides, NUREGs and Rules for further specific details on implementation.

VI. REFERENCES

1. 10 CFR Part 50, §50.55a, "Codes and Standards."
2. 10 CFR Part 50, Appendix A, General Design Criterion 1, "Quality Standards and Records."
3. 10 CFR Part 50, Appendix A, General Design Criterion 2, "Design Bases for Protection Against Natural Phenomena."
4. 10 CFR Part 50, Appendix A, General Design Criterion 44, "Cooling Water."
5. 10 CFR Part 50, Appendix B, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants."
6. 10 CFR Part 100, "Reactor Site Criteria."
7. 10 CFR Part 100, Appendix A, "Seismic and Geologic Siting Criteria for Nuclear Power Plants."
8. Regulatory Guide 1.27, "Ultimate Heat Sink for Nuclear Power Plants."
9. Regulatory Guide 1.28, "Quality Assurance Program Requirements (Design and Construction)."
10. Regulatory Guide 1.132, "Site Investigations for Foundations of Nuclear Power Plants."

11. Regulatory Guide 1.138, "Laboratory Investigations of Soils for Engineering Analysis and Design of Nuclear Power Plants."
12. Regulatory Guide 1.70, "Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants."
13. Journal of the Geotechnical Engineering Division, Proceedings of the American Society of Civil Engineers.
14. Book of ASTM Standards and Special Technical Publications, American Society for Testing and Materials.
15. Geotechnique, The Institution of Civil Engineers, London.
16. Earthquake Engineering Research Center, University of California, Berkeley.
17. M. Juul Hvorslev, "Subsurface Exploration and Sampling of Soils for Civil Engineering Purposes," Waterways Experiment Station, U.S. Army Corps of Engineers, November 1949.
18. GEODEX INTERNATIONAL, Soil Mechanics Information Service, Sonoma, California.
19. Engineering Manual EM 1110-2-1907, "Soil Sampling," U.S. Army Corps of Engineers, March 1972.
20. Engineering Manual EM 1110-2-1908, "Instrumentation of Earth and Rock Fill Dams," U.S. Army Corps of Engineers, August 1971.
21. Engineering Manual EM 1110-2-1906, "Laboratory Soil Testing," U.S. Army Corps of Engineers, November 1970.