RS-002, "PROCESSING APPLICATIONS FOR EARLY SITE PERMITS"

ATTACHMENT 2

2.5.4 STABILITY OF SUBSURFACE MATERIALS AND FOUNDATIONS

REVIEW RESPONSIBILITIES

Primary - Mechanical and Civil Engineering Branch (EMEB)

Secondary - None

I. AREAS OF REVIEW

For this section of the site safety assessment for an early site permit (ESP) application, information should be presented by the applicant concerning the properties and stability of all soils and rock, which may affect the facilities for a nuclear power plant or plants of specified type (or falling within a plant parameter envelope [PPE]) that might be constructed on the proposed site, 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, should be demonstrated. 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.

    e. History of deposition and erosion, including glacial and other preloading 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 test data provided by the applicant.

3. The relationship of the planned 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 assessment 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. Excavation and backfill plans and engineered earthwork analysis 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. This information will be reviewed at the combined license (COL) stage.

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 a nuclear power plant or plants of specified type (or falling within a PPE) that might be constructed on the proposed site.

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 to ensure 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 site safe shutdown earthquake(SSE) vibratory ground motion (Subsection 2.5.4.9) is evaluated in detail in Section 2.5.2 of the safety assessment. This information is summarized and cross-referenced in this subsection. The SSE is evaluated 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 dynamic 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. These items will be reviewed at the COL stage.

The EMEB will perform the following reviews related to the Geotechnical Engineering aspects of the site as follows:

1. EMEB determines 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 Section 2.5.1 of NUREG-0800 (Ref. 1).

2. EMEB reviews the seismological and geological investigations carried out to establish the ground motion environment for seismic design of a nuclear power plant or plants of specified type (or falling within a PPE) that might be constructed on the proposed site, the procedures and analyses used by the applicant in establishing the SSE for the site, and the seismic design bases for foundations as part of its primary review responsibility for Section 2.5.2 of NUREG-0800 (Ref. 2).

3. EMEB 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 to ensure that the soil loads and structural deflections, including any reduction in support capability of subsurface materials, can safely be accommodated by structural components.

II. ACCEPTANCE CRITERIA

The applicable rules and basic acceptance criteria pertinent to the areas of this section of this review standard are:

1. 10 CFR Part 50, Appendix A, 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 accident conditions. (Ref. 3)

2. 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. 4)

3. 10 CFR Part 100.23, "Geologic and Seismic Siting Criteria." 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.

If a reactor design is not specified, the ESP applicant may (instead of providing information on safety-related facilities or systems, structures, and components as called for in this section of this review standard) provide a PPE to characterize a facility or facilities for comparison with the geological, geotechnical and seismological characteristics of the site. A PPE can be developed

for a single type of facility or a group of candidate facilities by selecting limiting values of parameters. Important PPE parameters for safety assessment Section 2.5 include, but are not limited to, SSE (e.g., peak ground acceleration, minimum soil shear wave velocity), site water level (e.g., maximum ground water level), and the soil properties design bases (e.g., minimum static bearing capacity and liquefaction).

Note: Though not required at the ESP stage, the COL applicant will need to demonstrate compliance with General Design Criterion 2 (Ref. 5) as it relates to structures, systems, and components important to safety being designed to withstand the effects of earthquakes, tornadoes, hurricanes, floods, tsunami, and seiches without loss of capability to perform their safety functions.

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, Appendix A, General Design Criterion 44; and 10 CFR Part 100.

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 Criterion 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. 6)

2. Regulatory Guide 1.198, “Procedures and Criteria for Assessing Seismic Soil Liquefaction at Nuclear Power Plant Sites.” This guide describes procedures and criteria acceptable to the staff for assessing the potential for earthquake-induced liquefaction of soils for the design of foundations and earthworks at nuclear power plant sites in accordance with 10 CFR Part 100. (Ref. 7)

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. 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. 8)

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. (Ref. 9)

A thorough evaluation of the geotechnical engineering aspects of the proposed site as described in the following subsections should be presented along with the basic data supporting all conclusions. Sufficient information should be provided (Ref. 10) to allow the staff and its advisors to conduct independent analyses. The site investigations should 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 Reference 4 and the regulatory positions of References 8 and 9 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 should be presented in this subsection or cross-referenced to the appropriate subsection in Section 2.5.1 of the safety assessment.

Subsection 2.5.4.2. In meeting the requirements of Reference 4 and the regulatory positions of References 8 and 9, 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. 11), applicable standards published by the American Society for Testing and Materials (Ref.12), publications of the Institution of Civil Engineers (Ref.13), and various research reports prepared by universities (Refs.14 and 15). The properties of foundation material should be supported by data from field investigations (Refs.16 and 17) and laboratory test records (Ref.18).

Normally, a complete field investigation and sampling program should be performed to define the occurrence and properties of underlying materials at a given site (Refs. 16 and 17). Summary tables should be provided which catalog the important test results; test results should be plotted when appropriate. Also, a detailed discussion of laboratory sample preparation should be given when applicable. For critical laboratory tests, full details should 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 soil samples were properly taken and tested in sufficient number to define all the 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 should also show that the consolidation behavior of the soils as well as their static and dynamic strength have been adequately defined. 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 Reference 4 and the regulatory positions of References 6 through 9, 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. When safety-related structure locations are not provided (e.g., if a PPE is referenced in the ESP application), a bounding footprint for such structures should be provided.

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 safety assessment. A supplemental report providing geologic maps and photographs of the excavations for the facilities of a nuclear power plant or plants that might be constructed on the proposed site should be provided at the COL stage.

Subsection 2.5.4.4. In meeting the requirements of Reference 4 and the regulatory positions of References 8 and 9, 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. 8, 11, 12, 16, and 17), and whether the applicant's interpretations are supported by adequate field records in the safety assessment. See also Subsection 2.5.2.3 of NUREG-0800.

Subsection 2.5.4.5. In meeting the requirements of References 3 and 4 and the regulatory positions of References 6 through 9, the presentation of the data concerning excavation, backfill, and earthwork analyses is acceptable at the COL stage 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. Compaction specifications and embankment and foundation designs are justified by field and laboratory tests and analyses to ensure stability and reliable performance.

3. Quality control methods are discussed.

4. 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 3 and 4 and the regulatory positions of References 6 through 9, 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 safety assessment:

1. Discussion of critical cases of groundwater conditions relative to the foundation stability of the safety-related facilities of a nuclear power plant or plants of specified type (or falling within a PPE) that might be constructed on the proposed site.

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 3 and 4 and the regulatory positions of References 7, 8, and 9, 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 of NUREG-0800.

The soil-structure interaction analysis should be described. In the soil-structure interaction analysis, the following parameters are reviewed:

1. 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.

2. 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.

3. The static and dynamic loads, and the stresses and strains induced in the soil surrounding and underlying the structure are adequately and realistically evaluated.

4. 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 3 and 4 and the regulatory positions of References 6 through 9, if the foundation materials at the site adjacent to and under expected or planned locations of 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 necessary. 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 necessary 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 Section 2.5.2 of NUREG-0800. 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 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 should include the effects of these strains in its 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 Reference 4, a brief summary of the derivation of the SSE is presented and references are included to Subsection 2.5.2.6 of NUREG-0800.

Subsection 2.5.4.10. In meeting the requirements of References 3 and 4 and the regulatory positions of References 6 through 9, the discussions of static analyses are acceptable if the stability of all planned safety-related facilities has been analyzed from a static stability standpoint including bearing capacity, rebound, settlement, and differential settlements under dead loads of fills and plant facilities, and lateral loading conditions. Field and laboratory test procedures and results should be included to document soil and rock properties used in the analyses. The applicant should 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 (applicable to the COL stage). In meeting the requirements of References 3 and 4 and the regulatory positions of References 6 through 9, the discussion of criteria and design methods is acceptable at the COL stage 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 (applicable to the COL stage). In meeting the requirements of References 3 and 4 and the regulatory positions of References 6 through 9, the discussion of techniques to improve subsurface conditions is acceptable at the COL stage 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).

The technical rationale for application of the above acceptance criteria to the stability of subsurface materials and foundations is discussed in the following paragraphs.

The Commission evaluates the suitability of proposed sites for nuclear power and test reactors to determine if the application complies with 10 CFR Part 100. Section 100.20(c) requires that physical characteristics (including seismology, meteorology, geology, and hydrology) be taken into account when determining each site's acceptability. Meeting this requirement provides

assurance (1) that a nuclear power plant or plants of specified type (or falling within a PPE) that might be constructed at the site could be designed to withstand anticipated geologic, geotechnical, and seismic phenomena and (2) that, during normal operations or seismic events, a nuclear power plant or plants of specified type (or falling within a PPE) that might be constructed on the proposed site would pose no undue risk to the public as a result of instability, deformation, or failure of structural foundations and earthworks.

Standards developed by the American Society for Testing and Materials (ASTM) are used to perform soil analyses and tests for determining the static and dynamic properties of the soils and rock that will underlie the structures, systems, and components of a nuclear power plant or plants of specified type (or falling within a PPE) that might be constructed on the proposed site. To satisfy the geotechnical engineering requirements of 10 CFR Part 100, the applicant's safety assessment should contain a description of subsurface soil and rock characteristics for the proposed site and include static and dynamic analyses of plant foundations. This information will permit the staff to assess the acceptability of the site and to determine the potential influence of these characteristics on the design of structures, systems, and components designated as important to safety. Meeting these requirements provides assurance that structures, systems, and components important to safety for a nuclear power plant or plants of specified type (or falling within a PPE) that might be constructed on the proposed site could be designed to withstand appropriately severe static and dynamic loads on the foundations.

Compliance with 10 CFR 100.23 requires that the geologic and seismic conditions at the proposed site be considered during the siting and design of a nuclear power plant or plants. It describes the investigations needed to obtain geologic and seismic data necessary to determine site suitability and to provide reasonable assurance that a nuclear power plant or plants of specified type (or falling within a PPE) could be constructed and operated at the proposed site without undue risk to the health and safety of the public with respect to those characteristics.

III. REVIEW PROCEDURES

Requirements and procedures governing issuance of ESPs for approval of proposed sites for nuclear power facilities are specified in 10 CFR Part 52 (Ref. 19). Information required for such a permit includes a description of the site's seismic characteristics. For this type of permit, the application is reviewed as outlined below.

The review process is conducted in a similar manner and concurrent with that described in Section 2.5.1 of NUREG-0800. The services of consultants are used on selected sites to aid the staff in evaluating the geotechnical engineering aspects of particular sites.

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 adequacy of the extent and content of the site investigations (such as borings, trench logs, seismic investigations, and laboratory test results) is reviewed at the COL stage to ascertain that they are within the present state-of-the-art.

Site subsurface investigations supporting the ESP application should be conducted to provide sufficient coverage of the site areas upon which all safety-related structures will be located, such that there is reasonable assurance that the actual site conditions, revealed during excavations or further soil borings, will be consistent with the site subsurface model developed to support the ESP application. The ESP will contain a license condition requiring the reporting of any information the ESP holder has identified as having a significant implication for public health and safety or for common defense and security. The Commission will evaluate any such information reported and will take appropriate action.

Generally, the staff is guided by the criteria in References 3 through 5 and by Regulatory Guides described in References 6 through 10 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 safety assessment. 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, alteration, 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 ensure 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 safety assessment, 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 necessary. The final conclusion is based on professional judgment, considering the complexity of the site subsurface conditions. As part of the review, the staff should 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. (If such locations are not known at the ESP stage, as would be the case if the applicant references a PPE, the bounding footprint of the facility should be specified.) 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 should be consistent or additional investigations are necessary, or the applicant should use the most conservative values.

Subsection 2.5.4.5. Excavations, backfill, and earthwork are evaluated by the staff at the COL stage 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. The records of laboratory static and dynamic 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 ensure that static and dynamic stability criteria 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 soils and rocks 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 (guidance in Section 2.5.2 of NUREG-0800) 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 Section 2.5.2 of NUREG-0800, or as needed 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 ensure 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. Estimates of the "safety factor" obtained from the applicant's analyses are 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, are 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 earthquake is contained in Section 2.5.2 of NUREG-0800. 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, is 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 (Refs. 11, 12, 13, and 17). 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 planned locations of plant facilities. The site investigation, sampling, and laboratory test programs should be adequate for this evaluation.

2. Determining whether or not the methods of analysis are appropriate for the planned earthworks, foundations, and soil conditions at the site.

3. Determining whether or not the bearing capacity, settlement, differential settlement, and tilt estimates indicate conservative and tolerable behavior of the planned 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.

Subsection 2.5.4.11. 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 Corps of Engineers, and U.S. Department of the Interior. Design safety features, the applicant's proposed confirmatory tests and measurements, and monitoring of performance for planned safety-related foundations and earthworks are reviewed and evaluated at the COL stage on a case-by-case basis.

Subsection 2.5.4.12 (applicable to the COL stage). Planned 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. This evaluation will be performed at the COL stage.

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 referenced in Section II above, the conclusion in the safety evaluation report (SER) will state that the investigations performed at the site are adequate to justify the soil and rock characteristics that may be used in the design. Staff reservations about any portion of the applicant's site investigations 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 +120 meters (+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. Ground-water at the site varies from +114 to 116 meters (+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:
>
> 1. 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 1200 m/sec (4000 ft/sec) and 500 m/sec (1800 ft/sec), respectively. Zone 1 ranges in thickness from less than 6 meters (20 feet) to more than 15 meters (50 feet).
>
> 2. Zone 2 consists of moderately weathered slate and varies from 5 to 18 meters (16 to 60 feet) thick. P and S wave velocities generally exceed 2000 m/sec (6500 ft/sec) and 800 m/sec (2500 ft/sec), respectively.
>
> 3. Zone 3 contains slightly weathered to unweathered slate and is encountered at depths of 18 to 27 meters (60 to 90 ft) below ground surface.
>
> 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 1-½ times the width of the foundation mat 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 materials 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 ensure the reliable performance of the ultimate heat sink water-retention facilities.

The applicant has shown that the appropriate acceleration level on sound rock is 0.12 g for the safe shutdown earthquake (SSE). 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 0.17 g 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 the information, including analysis and substantiation, presented by the applicant and discussed above, is sufficient to demonstrate that the properties and stability of all soils and rock, whose performance could adversely affect, directly or indirectly, the safety-related structures of a nuclear power plant of type specified by the applicant [or falling within the PPE submitted by the applicant] that might be constructed at the proposed site or pose a hazard to the public, meet the requirements of the pertinent Commission regulations (cite appropriate references).

The applicant has met the requirements of the pertinent Commission regulations (cite appropriate references) 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 needed, techniques and specifications to improve subsurface conditions, by meeting the regulatory position in Regulatory Guides (cite appropriate References) 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, the staff concludes that: (1) the site and plant foundations meet the geologic and seismic siting criteria of 10 CFR 100.23, (2) the stability of subsurface materials and foundations on the site is such that the site would be adequate to support a nuclear power plant of the type specified by the applicant [or falling within the PPE submitted by the applicant] that might be constructed on the proposed site, and (3) site characteristics are such that safety-related earthworks could be designed to perform their functions reliably.

V. IMPLEMENTATION

The following is intended to provide guidance to applicants and licensees regarding the NRC staff's plans for using this section of this review standard.

This section will be used by the staff when performing safety evaluations of ESP applications submitted by applicants pursuant to 10 CFR Part 52. Except in those cases in which the applicant proposes an acceptable alternative method for complying with specified portions of the Commission's regulations, the method described herein will be used by the staff in its evaluation of conformance with Commission regulations.

VI. REFERENCES

1. U.S. NRC Standard Review Plan, Section 2.5.1, "Basic Geologic and Seismic Information," NUREG-0800, Rev. 3, March 1997.

2. U.S. NRC Standard Review Plan, Section 2.5.2, "Vibratory Ground Motion," NUREG-0800, Rev. 3, March 1997.

3. 10 CFR Part 50, Appendix A, General Design Criterion 44, "Cooling Water."

4. 10 CFR Part 100, "Reactor Site Criteria."

5. 10 CFR Part 50, Appendix A, General Design Criterion 2, "Design Bases for Protection Against Natural Phenomena."

6. Regulatory Guide 1.27, "Ultimate Heat Sink for Nuclear Power Plants."

7. Regulatory Guide 1.198, "Procedures and Criteria for Assessing Seismic Soil Liquefaction at Nuclear Power Plants."

8 . Regulatory Guide 1.132, "Site Investigations for Foundations of Nuclear Power Plants."

9. Regulatory Guide 1.138, "Laboratory Investigations of Soils for Engineering Analysis and Design of Nuclear Power Plants."

10. Regulatory Guide 1.70, "Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants."

11. Journal of the Geotechnical Engineering Division, Proceedings of the American Society of Civil Engineers.

12. Book of ASTM Standards and Special Technical Publications, American Society for Testing and Materials.

13. Geotechnique, The Institution of Civil Engineers, London.

14. Earthquake Engineering Research Center, University of California, Berkeley.

15. Multi-disciplinary Center for Earthquake Engineering, State University of New York, Buffalo, NY.

16. Engineering Manual EM 1110-1-1804, "Geotechnical Investigations," U.S. Army Corps of Engineers, January 2001.

17. Engineering Manual EM 1110-2-1908, "Instrumentation of Earth and Rock Fill Dams," U.S. Army Corps of Engineers, June 1995.

18. Engineering Manual EM 1110-2-1906, "Laboratory Soil Testing," U.S. Army Corps of Engineers, August 1986.

19. 10 CFR Part 52,"Early Site Permits; Standard Design Certifications; and Combined Licenses for Nuclear Power Plants."