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

SECTION 2.5.4 STABILITY OF SUBSURFACE MATERIALS AND FOUNDATIONS

REVIEW RESPONSIBILITIES

Primary - Site Analysis Branch (SAB)

Secondary - None

I. AREAS OF REVIEW

Information must be presented by the applicant concerning the stability of all soils and rock supporting the nuclear power plant foundations, 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. 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, uplift, or collapse.
   b. Zones of alteration or irregular weathering profiles, and zones of structural weakness.
   c. Unrelieved stresses in bedrock.
   d. Rocks or soils that might be unstable because of their minerology, 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.

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 and adequate representative laboratory test records.

6. Variable groundwater conditions (Subsection 2.5.4.6) as they affect the loading and stability of structural foundations and 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 to assure foundation stability and to confirm the validity of the soil profile model used in the analyses.

8. The liquefaction potential (Subsection 2.5.4.8) and consequences of liquefaction or partial 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.

9. The earthquake design bases (Subsection 2.5.4.9), as evaluated in detail in Section 2.5.2. These are summarized and cross-referenced in this subsection. The safe shutdown earthquake (SSE) and the operating basis earthquake (OBE) accelerograms and response spectra are evaluated in this subsection in combination with other hazards (floods, etc.) to assess the adequacy of the site materials and the foundation design of the nuclear power plant under dynamic conditions.

10. The results of investigations and analyses conducted to determine foundation stability 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, including an explanation of computer programs used in the analyses.

12. Techniques and specifications to improve subsurface conditions (Subsection 2.5.4.12), which are to be used at the site to provide adequate support for foundations.

II. ACCEPTANCE CRITERIA

A thorough evaluation of the foundation 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.

Subsection 2.5.4.1. 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.

Subsection 2.5.4.2. The description of properties of underlying materials are 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. 3), applicable standards published by the American Society for Testing and Materials (Ref. 4), publications of the Institution of Civil Engineers (Ref. 5), and various research reports prepared by universities (Ref. 6). The properties of foundation material must be supported by field and laboratory 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. 7). 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, and why the design envelope is conservative.

Subsection 2.5.4.3. 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. 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. 3, 4, 7), 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. 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 foundation properties are justified by tests and analyses to assure stability.

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. 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:

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 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. 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.

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 2.5.2.3.

The soil-structure interaction analysis should be described in and cross-referenced to this subsection. Soil-structure interaction is reviewed to ensure that:

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 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 in the soil-structure analysis.

4. The consequences of the induced soil stresses and strains, as they influence the support capability of the soil surrounding and underlying the structure, have been conservatively assessed.

5. The integrity of soil-supported or soil-imbedded safety-related facilities (such as Category I pipelines) have been investigated and analyzed to show they are not adversely influenced by the consequences of soil-structure interaction effects on soil supporting capacity.

Subsection 2.5.4.8. If the foundation materials at the site adjacent to and under Category I structures are soils and the water table is above bed rock, then an analysis of the liquefaction potential at the site is required. The need for a detailed analysis is determined by a study of the site stratigraphy, critical soil parameters, and the location of safety-related foundations. Undisturbed samples obtained at the site and appropriate laboratory tests show if the soils are likely to liquefy.

The analysis 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 Standard Review Plan (SRP) 2.5.2. The criterion that should be used to determine when the soil samples tested "liquefied" should be taken as the onset of (initial) liquefaction (defined as the cycle when the pore pressure first equals the confining pressure). If the behavior of the pore pressure is such that strains greater than a few percent occur before initial 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.

Non-seismic liquefaction (such as that induced by wind and wave action) should be analyzed using state-of-the-art soil mechanics principles.

Subsection 2.5.4.9. 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. The discussions of static analyses are acceptable if the stability of all safety-related facilities has been analyzed from a static stability standpoint including rebound, settlement, and differential settlements under deadloads of fills and plant facilities. 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.

Subsection 2.5.4.11. 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. 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, vibraflotation, 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 2.5.1. The services of the Corps of Engineers are used on selected sites to aid the staff in evaluating the foundation 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 design 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 foundation conditions, where marginal factors of safety have 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 Corps of Engineers. 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 foundation engineering area because actual site conditions may not be 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 Seismic and Geologic Siting Criteria (Ref. 1) and the Standard Format (Ref. 2) in reviewing Section 2.5.4.

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

Subsection 2.5.4.1. Geologic features are evaluated by conducting (the staff and the U.S. Geological Survey) 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 USGS 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 confidence?

3. Have all areas or zones of actual or potential surface or subsurface subsidence, uplift, or collapse; deformation, alternation 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 design analyses.

To determine whether sufficient investigations were performed, the staff carefully reviews the criteria developed and used by the applicant in laying out his boring, sampling and testing program and evaluates the effectiveness of the program in defining the specific foundation conditions at the site and assuring 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 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 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 the Corps of Engineers, 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. Expertise within the USGS regarding specific techniques is 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 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 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 boring logs and profiles to determine if any of the site soils could be susceptible to liquefaction. The results of standard penetration tests and undisturbed sampling performed in exploration borings are examined and, when appropriate, related to the liquefaction potential of in situ soils.

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

1. A careful review of the cyclic triaxial test data to insure that appropriate samples were obtained from critical, liquefiable zones.

2. 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.

3. An assessment of the liquefaction potential using a conservative envelope of the test data submitted.

4. 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 possible variations in the properties of the soil strata.

5. 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 that estimated by the staff. (The applicant's plans to "fix" the liquefaction condition, usually by excavation and backfill, vibraflotation, or chemical grouting is evaluated as discussed in Subsections 2.5.4.5 and 2.5.4.12.)

6. An assessment of past earthquake settlements due to partial liquefaction using state-of-the-art techniques.

7. An assessment of non-seismic 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 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. 8). 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. Determining 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. 8).

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, vibraflotation, 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 the foundation engineering aspects of the plant site, confirms that of the applicant, the conclusion in the SER states 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 are 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 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 schistocity, 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 thick, reinforced concrete mat on slightly weathered slate. The outer perimeter will also be on a reinforced concrete mat. The reactor service building between the reactors and the control building will be on mats at elevation +385 feet msl on slightly to moderately weathered rock. The turbine generators will be founded on 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 concrete footings or continuous footings (grade beams) at +385 feet msl, on moderately weathered slate. All piping will be entrenched and bedded in moderately to severely 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.

"Settlement and differential settlement of safety-related facilities will be less than one inch.

"The applicant states that severely weathered or soft zones will be excavated and replaced with lean concrete. This procedure will also be followed wherever severe weathering extends along joints, schistocity, 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.

"All backfill under structures will be concrete. Category I backfill around structures will either be concrete or compacted granular backfill. If granular soil is used, the applicant will place the backfill at 95 percent of maximum as determined by Modified Proctor. These backfill criteria are acceptable.

"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 estimated that the appropriate acceleration to use as input to Regulatory Guide 1.60 spectrum at foundation level 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 would amplify the motion. An acceleration level of 0.17g for the SSE will be used for those structures founded on weathered rock. The synthetic time history used for seismic design of Category I earth dams and for liquefaction assessment envelops the response spectra for the site and has a conservative duration.

"The seismic design of Category I buried piping is adequate to safely resist static soil pressures and displacements, dynamic soil pressures, strains induced by ground and structure movements, and pump shutdown pressures.

"Soil-structure interaction will be evaluated based on the Reissner solutions for a rigid foundation on an elastic half-space. Appropriate foundation moduli and damping values were determined by laboratory tests and field seismic investigations. This approach for interaction effects has been shown to be realistic and has staff concurrence. Peak foundation pressures during the SSE will be less than 20 percent of the allowable pressures on the weathered slate.

"Based on the results of the applicant's investigations, laboratory and field tests, analyses, and criteria for design and construction, we and our consultants 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. REFERENCES


1. 10 CFR Part 100, Appendix A, "Seismic and Geologic Siting Criteria for Nuclear Power Plants."

2. Regulatory Guide 1.70. "Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants," Revision 2.

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

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

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

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

7. M. Juul Hvorslev, "Subsurface Exploration and Sampling of Soils for Civil Engineering Purposes," Waterways Experiment Station, U. S. Army Corps of Engineers, November 1949.

8. GEODEX INTERNATIONAL, Soil Mechanics Information Service, Sonoma, California.

SRP 2.5.5