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REGULATORY GUIDE 1.138

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LABORATORY INVESTIGATIONS OF SOILS AND ROCKS FOR ENGINEERING ANALYSIS AND DESIGN OF NUCLEAR POWER PLANTS

A. INTRODUCTION

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 earthworks for nuclear power plants. The state of the art of laboratory testing practices of soils and rocks is reflected in existing standards, and, where appropriate, this guide discusses and references such standards.

In 1996, the Nuclear Regulatory Commission (NRC) issued new regulations concerning site evaluation factors and geologic and seismic siting criteria for nuclear power plants (10 CFR Part 100), “Reactor Site Criteria,” in Subpart B, “Evaluation Factors for Stationary Power Reactor Site Applications on or After January 10, 1997"). In particular, 10 CFR 100.20(c), 100.21(d), and 100.23 establish requirements for conducting site investigations for nuclear power plants for site applications submitted after January 10, 1997, to permit an evaluation of the site and provide information needed for seismic response analyses and engineering design. This evaluation should include the development of information relative to the static and dynamic engineering properties of soil and rock materials of the site.

Safety-related site characteristics are identified in detail in Regulatory Guide 1.70, “Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants.” Regulatory Guide 4.7, “General Site Suitability Criteria for Nuclear Power Stations,” discusses site characteristics that affect site suitability. Regulatory Guide 1.132, “Site Investigations for Foundations of Nuclear Power Plants,” discusses programs of field studies, exploratory borings, and sampling needed to provide geotechnical data for site evaluation and engineering analysis and design.

The technical basis for this regulatory guide is contained in NUREG/CR-5739 (1999). NUREG/CR-5739 was developed to reflect current and state-of-the-art techniques related to laboratory testing of soils and rock. It summarizes the processes required in a laboratory testing program ranging

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from storage, selection, and handling of test specimens to static and dynamic testing methods and equipment.

Regulatory guides are issued to describe to the public methods acceptable to the NRC staff for implementing specific parts of the NRC's regulations, to explain techniques used by the staff in evaluating specific problems or postulated accidents, and to provide guidance to applicants. Regulatory guides are not substitutes for regulations, and compliance with regulatory guides is not required. ~~Regulatory guides are issued in draft form for public comment to involve the public in developing the regulatory positions. Draft regulatory guides have not received complete staff review; they therefore do not represent official NRC staff positions.~~

The information collections contained in this ~~draft~~ regulatory guide are covered by the requirements of 10 CFR Parts 50 and 100, which were approved by the Office of Management and Budget, approval numbers 3150-0011 and 3150-0093. If a means used to impose an information collection does not display a currently valid OMB control number, the NRC may not conduct or sponsor, and a person is not required to respond to, the information collection.

B. DISCUSSION

~~1.~~ PURPOSE

In the course of site investigations and analyses for nuclear power plant facilities, the purpose of a laboratory testing program is to identify and classify soils and rocks and to evaluate their physical and engineering properties. The NRC staff reviews the information obtained from the site investigations and laboratory tests and considers the safety aspects of the application of the data to the design and construction of nuclear plants. Consideration of public safety imposes particularly stringent requirements on the design and construction of nuclear power plant facilities. Therefore, it is essential that all phases of a site investigation program and associated field and laboratory testing be carefully planned and carried out to ensure that soil and rock properties are realistically estimated.

The course of site and laboratory investigations will depend on actual site conditions, the nature of problems encountered or suspected at the site, and design requirements for foundations and earthworks. Therefore, a program should be made flexible and tailored to each site and plant design as the site and laboratory investigations proceed. The program should be under the direction of experienced engineers and geologists that have demonstrated competence in the field of soil and rock mechanics testing and are familiar with the site. Specific testing requirements and details of testing procedures will depend on the nature of the soils and rocks encountered. It is normally desirable to follow testing procedures that are generally known and accepted since they are easily reproduced. Also, the effects of standard procedures on test results are better understood. Depending on the nature of the soil and rock material, it may be more appropriate and desirable to modify existing standard procedures, however, it is important that such test procedures be fully described so that the test may be reproduced and the results verified. Laboratory procedures for some of the most common tests are shown in Appendix A with related references.

C. REGULATORY POSITION

1. LABORATORY TESTING PROGRAM

1.1 Laboratory Facilities

The basics for a laboratory facility for soil and rock testing include adequate test space, temperature controlled areas, adequate ventilation and air flow. Separate areas, and preferably separate rooms, are desirable for dust- and vibration-producing activities such as sieve analyses, compaction tests, and sample processing. Normally, samples should be tested on arrival from the field. If storage is required, consideration should be given to storing samples in a separate room with the relative humidity maintained at or near 100%.

The facility should be equipped with the proper equipment (from calipers and sieves to triaxial testing devices) necessary to perform the types of tests for which the facility was designed.

1.2. Laboratory Equipment

1.2.1 Apparatus

When standard laboratory testing procedures are used, the test apparatus should conform to the published specifications. When the testing apparatus does not satisfy published specifications, a complete description of the essential characteristics of the apparatus is needed, with appropriate references to published papers, reports, or monographs. To ensure that essential characteristics (such as dimensions, mating of parts, piston friction, and fluid seals) are not significantly altered by wear, handling, corrosion, dirt, or deterioration of materials, all testing apparatus should be inspected and maintained regularly.

Use and care of laboratory equipment are discussed in detail in EM 1110-2-1906, Das (1992) and Head (1992). Specifications for balances and scales are described in ASTM D 4753. EM 1110-2-1906 provides valuable discussions of common problems, precautionary measures, and control of errors when engaged in the testing of soils. Scholey et al. (1995) present a review of instruments for measuring small strain. Germaine and Ladd (1988) discuss problems associated with triaxial testing of saturated cohesive soils, including errors caused by the equipment or the procedures used.

1.2.2 Calibration

All test apparatus and instruments used for quantity measurement should be calibrated against certified calibration standards before being put into service. Calibrations can be verified at regular intervals thereafter. The necessary frequency for recalibration varies according to the susceptibility of the apparatus to change and the required precision of measurement. Physical length or volume measuring apparatus such as metallic tapes, rules, pycnometers, cylinders, or graduated cylinders need not be calibrated unless altered by visible wear or damage. Weights and other equipment used as standards to calibrate test instruments are normally recalibrated periodically by an external agency with equipment directly traceable to the National Institute of Standards and Technology. Instrument calibrations may be performed in-house using the specific laboratory’s own standards of references. EM 1110-2-1909 provides procedures recommended for the calibration of testing equipment. ASTM D 3740 and Sallfors (1989) provide information on equipment calibration and its importance, respectively.

1.2.3 Reagents and Water

Chemical testing in a soil laboratory is usually limited to routine tests. These tests determine such constituents as organic matter, chlorides, pH value, and sulfates. Head (1992) provides information on the most widely used clinical test for soils and groundwater.

2. HANDLING AND STORAGE OF SAMPLES

The identification markings of all samples are verified immediately upon their arrival at the laboratory, and an inventory should be maintained of all samples received.

2.1 Disturbed Samples

It is important that disturbed samples be examined and tested as soon as possible after arrival in the laboratory; however, for a large testing program, storage of the samples may be required for several days or weeks. Samples to be used for fluid content determinations, however, should be protected against change in water content.

2.2 Undisturbed Samples

Undisturbed samples should be protected from vibration, shock, significant temperature changes, and changes in water content. Moisture seals should be checked periodically and renewed as needed. Even the most careful sealing and storing of undisturbed samples cannot prevent physical and clinical changes. Therefore, the samples should not be retained for long periods, particularly if in contact with unprotected steel tubes. Storage for long periods of time may discredit any subsequent determination of their engineering properties. The duration of storage before testing should be recorded for each sample test. Samples that have been stored for long periods of time should not be considered to have the characteristics of undisturbed samples. Therefore, they should not be tested as undisturbed samples. For clay specimens, the delay between sampling and testing and the control kept over their volumes during storage are known to affect the strength and compressibilities measured in the laboratory. These measured properties will also be affected by the reconsolidated procedures (see Graham et al., 1990, and Brown and Chow, 1988). Further information on handling and storage of soil samples can be found in ASTM D4220.

2.3 Rocks

Rock samples should be transported as fragile material and protected from excessive changes in humidity and temperature. Like soil samples, rock samples should be examined and tested as soon as possible. For a large testing program, the rock specimens may be stored, but every effort should be made to protect the stored samples against damage.

3. INITIAL IDENTIFICATION AND EXAMINATION OF SAMPLES

The initial description of a sample should include but not be limited to what is seen, felt, and smelled.

ASTM D2488 describes procedures necessary for the description and identification of a soil sample based primarily on visual identification and manual test. ASTM D4452, on x-ray radiography of soil samples, describes procedures before testing for the detection of inherent abnormalities and disturbances; it is especially useful for undisturbed samples. ASTM D 2487 describes the various soil groups in detail and discusses the method of identification in order that a uniform classification procedure may be followed by those who use the system. RTH 102-93 describes procedures used in the petrographic examination of rock core samples. Petrographic examinations are made to determine the physical and chemical properties of a material, to describe and classify a sample, and to determine the amount of specific materials that may affect the specimen's intended use.

4. SELECTION AND PREPARATION OF TEST SPECIMENS

4.1 General

The selection of soil and rock specimens for laboratory testing requires careful examination of boring records and available samples. It is important that test specimens be representative of the soil or rock unit to be tested and be accurately described to permit establishment of the soil profile. Average test values of material properties need to be identified as well as the range of values identifying their variability. This requires the testing of not only the most representative samples, but also of those with extreme properties and those representative of critical zones. Guidelines for spacing of borings and frequency of sampling are given in Regulatory Guide 1.132. Additional boring and sampling may be required when laboratory examination of the samples reveals an inadequate number or distribution of suitable samples to meet testing requirements.

Undisturbed test samples should be prepared to preserve the natural structure and water content of the material. The sample should always be prepared in a humid room. Trimming instruments should be sharp and clean and the sample adequately supported.

4.2 Undisturbed Samples

Undisturbed tube samples of soils should be examined for evidence of disturbance. A serious source of damage to undisturbed soil samples is the extrusion of the samples from the sample tubes. One method that may minimize damage during the removal of samples from thin-wall tubes is to split the tube longitudinally by milling. An alternative may be to saw the tube transversely into segments of sufficient length to extrude a single test specimen from each and trim off the ends. The fact that milling may cause disturbance and changes in the void ratio in some soils, particularly in loose sand, is an important consideration in the assessment of the best way to remove samples from tubes. Dressing the cut tube edges before extruding samples from the tube sections reduces disturbance of the sample. Reuse of thin-walled sample tubes is not recommended if they have been damaged during retrieving or extruding samples.

Undisturbed tube samples should satisfy the following criteria:

(1) The specific recovery ratio should be between 90 and 100 percent; a tube with less recovery may be acceptable if it appears that the sample may have been broken off and otherwise appears undisturbed. The actual recovery obtained should be recorded and documented.

(2) On the surface of or in sliced sections of the sample, there should be no visible distortions, planes of failure, pitting, discoloration, or other signs of disturbance that can be attributed to the sampling operation or handling of the sample.

(3) The net length and weight of the sample and the results of other control tests should not have changed during shipment, storage, and handling of the sample.

In addition to the above, samples that have been subjected to violent mechanical shocks or to accidental freezing and thawing should not be considered to be undisturbed even if other evidence of disturbance is absent

Test specimens should be representative of each discrete soil or rock unit to be tested and should be accurately described on the basis of classification tests to permit establishment of the soil and geologic profiles. The best quality and most representative undisturbed samples available should be used in physical and engineering property tests of in situ soils, whether cohesive or cohesionless.

Trimming and shaping of test specimens of soils require great care to prevent disturbance and changes in water content. Frozen samples should be prepared under conditions that will prevent premature thawing. Details of procedures depend on the nature of the test and the specimen. EM 1110-2-1906 describes procedures for preparing soil samples for testing, while ASTM-D-4452 can be used to determine the quality of a sample before testing.

4.3 Reconstituted or Remolded Samples

High-quality undisturbed samples are preferred for all tests of strength and dynamic responses of in situ soils, whether cohesive or cohesionless. However, in some instances, reconstituted or remolded samples should be used when representative undisturbed samples cannot be obtained. Remolded samples are also used as representative of compacted fill or backfill material for new construction. Undisturbed samples of earth fill are taken for confirmatory testing during construction. Undisturbed samples are also taken in the testing and reevaluation of existing structures. Reconstituted specimens representative of in situ material should be molded to the in situ density and moisture content as determined from actual field measurements. Regulatory Guide 1.132 discusses methods of determining the in situ density of cohesionless soils. Samples representative of fill material should be molded to the range of densities and water contents expected or obtained under field conditions.

Laboratory personnel should record a complete detailed description of the specimen that should include but not be limited to identification of the material, color, consistency, brittleness of the material, and indication of disturbance of boring samples. Disturbed samples should not be used for any test other than classification, specific gravity, or water content (see EM 1110-2-1906).

4.4 Scalping of Large Particles

Standard-size laboratory testing equipment will not readily accommodate gravel and large particles. Such materials are typically scalped, or removed from the total sample, and the finer fraction tested. Fractional analysis of density for compaction control measures to account for scalped gradation are discussed by Torrey and Donaghe (1991), while Evans and

Zhou (1995) report the effects on cyclic strength caused by the inclusion of gravel size particles in various gradations of granular soils.

4.5 Laboratory Testing Program

The study of soil and rock mechanics covers the investigation, description, classification, testing, and analysis of soil and rock to determine their interaction with structures built in or upon them, or built with them. The physical properties of soils and rocks should be determined by carrying out tests on samples of soil in a laboratory. These tests can be divided into two main categories: classification tests and engineering properties tests. Classification tests indicate the general type of soil and the engineering category to which it belongs. Engineering properties are determined by specific tests that require careful considerations of field conditions, various design loading conditions, material properties, and possible problems at the site. The focus of laboratory investigations should depend on the design requirements and nature of problems encountered or suspected at the site.

In addition to the usual geotechnical engineering considerations, the investigation and evaluation of sites for nuclear power plants require an evaluation of the site response to earthquake loading as well as other dynamic loading conditions. Such analyses include the evaluation of wave propagation characteristics of subsurface materials with interaction effects of structures, analysis of the potential for soil liquefaction, settlement under dynamic loading, and analysis of the effects of earthquake loading on the stability of slope and embankments.

The basic parameters required as input for dynamic response analyses of soils include total mass density, relative density, Poisson’s ratio, static soil strength, initial stress conditions, shear and compressional wave velocities, and the dynamic shear modulus and damping ratio. The variation of strength, moduli, and damping with strain is also needed for such analyses.

5. TESTING PROCEDURES FOR DETERMINING STATIC SOIL PROPERTIES

5.1 General

Laboratory tests on soil and rock material should be thorough and of documented quality that permits a realistic estimate of soil and rock properties and subsurface conditions. Personnel experienced in laboratory practices for soil testing should be responsible for handling samples, preparing test specimens, specifying testing procedures and operations, with all related documentation.

5.2 Soil Testing

Classification tests and determination of engineering properties should be performed according to an accepted and published method. Laboratory procedures for some of the most common tests along with other related references, are shown in Appendix A. These include:

Water Content	Permeability
Unit Weights	Consolidation
Void Ratio	Direct Shear Test
Porosity	Triaxial Compression Tests
Saturation	Unconfined Compression Tests

Atterberg Limits	Relative Density
Specific Gravity	Grain Size Analysis
Erodibility Tests	Compaction

The number of tests required in a laboratory investigation program will depend on the type of material, the quality of samples, the purpose and relative importance of the test, and the scatter of test data. In general, all soils and rocks sampled at the site should first be identified and classified using appropriate index and classification tests. The Unified Soil Classification System (ASTM D 2487) should be used in describing soils and in preparing soil profiles, while ASTM D 5878 should be used for the classification of rock mass for specific engineering purposes. Further tests required to establish physical and engineering properties should be sufficient to define the range of values for material properties. A sufficient number of tests should be completed to cover the range of values expected under field conditions.

Standard test procedures that are followed without deviation and performed on standard equipment require documentation by reference only. For tests for which there are no standard procedures available or for which it is appropriate to use modified or alternative procedures, the details of the test procedures should be documented for evaluation and future referencing. The technical basis for deviating from standard testing procedures should be documented. Use of other than standard equipment, even if it is used with standard testing procedures, should also be documented.

5.3 Tests of Ground Water or Surface Waters

Testing of ground water and surface water depends on the nature of potential problems identified at the site. Acid water, for example, may cause the degradation of carbonate rocks and concrete foundations. Standard methods of testing water for physical, chemical, radioactive, and microbiological properties are described in Standard Methods for the Examination of Water and Wastewater (1998). This reference also describes methods of testing polluted water, wastewaters, effluents, bottom sediments, and sludges. Standard testing methods should be used unless special problems are encountered that require modifications or alternative methods.

6. TESTING PROCEDURES FOR DETERMINING DYNAMIC SOIL PROPERTIES

6.1 General

It is important that the laboratory tests represent field conditions as closely as practical to ensure a realistic assessment of soil properties. Before dynamic tests are performed, the initial state of stress in the soil should be determined, and a series of static consolidated-drained and consolidated-undrained triaxial compression tests should be made to determine static strength. The dynamic testing program should include tests to determine the soil parameters needed as input for reference analyses and soil structure interaction studies as well as testing to determine the dynamic strength characteristics and liquefaction potential of soils. Some laboratory investigations and testing procedures for determining dynamic soil properties and soil behavior are listed, with related references, in Appendix A. The dynamic soils property testing includes cyclic triaxial tests and resonant column tests.

6.2 Cyclic Triaxial Tests

Historically, the most common cyclic loading technique for investigating liquefaction resistance involves performance of the cyclic triaxial test, because of such factors as the availability of equipment and the relative ease of preparing undisturbed specimens. This is in spite of wide recognition of the inability of the test to accurately represent field earthquake stresses and boundary conditions (Seed and Idriss, 1982). Other research studies have demonstrated that laboratory-determined cyclic triaxial strengths (in fact, strengths determined from any unidrectional loading test) are higher than those expected to produce equivalent effects in the field (Seed, 1976). Research has also shown that estimation of field cyclic test results may not be possible by universal application of sample factors, e.g., gradation, density, and soil type (Koester, 1992).

As noted above, the cyclic triaxial test does not accurately model the stress conditions in situ. Caution should be exercised when using laboratory-obtained soil cyclic strengths. There should be appropriate downward adjustments of cyclic stress values obtained from triaxial tests as required. The rationale behind the adjustment and the data supporting its magnitude should be presented and referenced (see also Tatsuoka et al., 1994, on cyclic triaxial tests of sand and gravel, and Vucetic and Dobry, 1991, on cyclic triaxial tests in clays). Laboratory cyclic tests should be used only to establish parametric effects on cyclic strength behavior.

6.3 Resonant Column Tests

ASTM D4015, "Modulus and Damping of Soils by the Resonant-Column Method, describes testing procedures to determine the shear modulus, shear damping, rod modulus (Young's modulus), and rod damping for solid cylindrical specimens of soil in undisturbed and remolded conditions by vibration using the resonant column. Related references for these tests, which discuss their limitations and applicabilities, are included in Appendix A.

7. TESTING PROCEDURES FOR DETERMINING ENGINEERING PROPERTIES OF ROCK

Testing procedures and the determination of engineering properties of rock should be performed according to accepted and published methods. Common tests, along with other related references, are outlined in Appendix A. These include:

Porosity	Unconfined Compression
Permeability	Triaxial Compression
Seismic Velocity	Slate Durability
Direct Tensile Strength	Specific Gravity
Direct Shear	

D. Implementation

The purpose of this section is to provide guidance to applicants ~~and licensees~~ regarding the NRC staff's plans for using this regulatory guide. No backfitting is included or approved in connection with the issuance of this guide.

~~This proposed revision has been released to encourage public participation in its development.~~ Except in those cases in which the applicant proposes an acceptable alternative method for complying with specified portions of the NRC's regulations, the method to be described in the effective guide reflecting public comments will be used by the NRC staff in evaluating applications for construction permits, operating licenses, early site permits, or combined licenses submitted after January 10, 1997. This guide will not be used in the evaluation of an application for an operating license submitted after January 10, 1997, if the construction permit was issued before that date. This guide reflects current practice accepted by the NRC.

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ASTM D 2488-00, “Standard Practice for Description and Identification of Soils (Visual-Manual Procedure),” American Society for Testing and Materials, 2000.

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APPENDIX A

LABORATORY TESTING METHODS FOR SOIL AND ROCK

Name of Test	STANDARD OR PREFERRED METHOD	OTHER REFERENCES	PROPERTIES OR PARAMETERS DETERMINED	REMARKS/SPECIAL EQUIPMENT REQUIREMENTS
		SOILS --- INDEX AND CLASSIFICATION TESTS		
Gradation Analysis	ASTM D 421 D 422 D 2217 D 4221	Refs. 1, 2, 3, 4	Particle size distribution	Methods are applicable to some rocks, after disaggregation.
Percent fines	ASTM D 1140	Refs. 1, 4, 5	Percent of weight of material finer than No. 200 sieve.	
Atterberg Limits	ASTM D 427 D 4318 D 4943 Ref. 1	Refs. 2, 3, 5, 6, 7, 8	Liquid and plastic limit, plasticity index, shrinkage factor (limit)	
Specific Gravity	ASTM D 854 D 5550 Ref. 1	Refs. ~~1,~~ 2, 4	Specific gravity, apparent specific gravity, bulk unit weight sufficiently fine to eliminate internal voids in the intact rock.	Boiling should not be used for de-airing. Method can be used for rock, after grinding.
Radiography	ASTM D 4452	Ref. 12	Qualitative test of sample quality	
Description of Soil and Rock	ASTM D 2487 D 2488 D 4452 C 294 Ref. 9 Ref. 36		Description of soil from visual-manual examination	
		SOILS --- MOISTURE-DENSITY RELATIONS		
Bulk Unit Weight	Ref. 1		Bulk unit weight (bulk density)	Methods are applicable to some rocks, with some obvious modifications.
Water (Moisture) Content	ASTM D 425 D 1558 D 2216 D 2974 D 4643 D 4959 Ref. 1	Refs. 2, 10, 11~~, 12~~	Water content as a percent of dry weight	Method is applicable to rock.
Relative Density	Ref. 1		Maximum and minimum density of cohesionless soils	Requires vibration table. In vibration table testing, both amplitude and frequency should be adjusted to values that yield greatest density. However, treatment that produces breakage of grains should be avoided and mechanical analyses should be performed as a check on grain breakage.

Name of Test	STANDARD OR PREFERRED METHOD	OTHER REFERENCES	PROPERTIES OR PARAMETERS DETERMINED	REMARKS/SPECIAL EQUIPMENT REQUIREMENTS
Compaction	ASTM D 698 D 1557 D 4253 D 4254 D 5080 Ref. 1	Refs. 2, 4, 14	Maximum dry unit weight of soil	Method for earth-rock mixtures is given in Ref 37.
SOILS --- CONSOLIDATION AND PERMEABILITY				
Consolidation	ASTM D 2435 D 4186 Ref. 1	Refs. 2, 4, ~~5,~~ 14	One-dimensional compressibility, permeability of cohesive soil	
Permeability	ASTM D 2434 D 5084 Ref. 1	Refs. 2, 4, 18	Permeability	Suitable for remolded or compacted soils. For natural, In situ soils, field test should be used.
SOILS --- PHYSICAL AND CHEMICAL PROPERTIES				
Mineralogy		Refs. 16, 17, ~~18,~~ 19	Identification of minerals	Applicable to rock. Requires X-ray diffraction apparatus. Differential thermal analysis apparatus may also be used.
Organic Content	Ref. 16	ASTM D 2974 Ref. 20	Organic and inorganic carbon content as percent of dry weight.	Dry combustion methods (ASTM D 2974) are acceptable, but where organic matter content is critical, data so obtained should be verified by wet combustion tests.
Soluble Salts	ASTM D 4542	Ref. ~~21~~, 21		Concentration of soluble salts in soil pore water
Erodibility Tests Pinhole Test	ASTM D 4221 D 4647 Ref. 1	Refs.21, 37,		Significant in evaluation of potential erosion or piping.
Crumb Test	Ref. 1			
SCS Test	Ref. 1	Ref. 14		
Cylinder Dispersion	Ref. 1			
SOILS --- SHEAR STRENGTH AND DEFORMABILITY				
Unconfined Compression	ASTM D 2166	Ref. 1	Strength of cohesive soil in uniaxial compression.	
Direct Shear, Consolidated-drained	ASTM D 3080 Ref. 1	Ref. 4	Cohesion and angle of internal friction under drained conditions	
Triaxial Compression , Unconsolidated-Undrained	ASTM D 2850 Ref. 1	Refs. 2, 4, 23	Shear strength parameters; Cohesion and angle of internal friction for soils of low permeability.	
Triaxial Compression, Consolidated-Drained	Ref. 1	Refs. 2, 4, 23	Shear strength parameters; Cohesion and angle of internal friction. For long-term loading conditions.	Circumferential drains, if used, should be slit to avoid stiffening test specimen.

Name of Test	STANDARD OR PREFERRED METHOD	OTHER REFERENCES	PROPERTIES OR PARAMETERS DETERMINED	REMARKS/SPECIAL EQUIPMENT REQUIREMENTS
Triaxial Compression, Consolidated-Undrained	ASTM D 4767 Ref. 1	Refs. 2, 4, 23	Shear strength parameters; Cohesion and angle of internal friction for consolidated soil. With pressure measurements, cohesion and friction may be obtained.	Circumferential drains, if used, should be slit to avoid stiffening of test specimen.
Cyclic Triaxial	ASTM D 3999 D 5311 ~~Ref. 1~~	Refs. 8, 24, 25, 26, 28, 29, 30, 31, 32, 39, 41	Local strain, modulus and damping	
Cyclic Simple Shear		Refs. 21, 28, 33	Shear modulus and damping values and cyclic-strength of cohesive and cohesionless soils	Tests may be run with either stress control or strain control. Two different types of apparatus, NGI and Roscoe devices, are described in Refs. 15, 43, respectively.
Resonant Column	ASTM D 4015	Refs. 34, 35, 41	Shear modulus and damping in cohesive and cohesionless soils. Some devices can be used with deformations in longitudinal mode to determine Young's modulus. Some devices can be used to determine cyclic strength.	Requires resonant column device.
		ROCKS ---- ENGINEERING PROPERTIES		
Water Content	Ref. 9		Water Content	
Specific Gravity	ASTM C 127 C 128			
Porosity	ASTM D 4612 ASTM D 4404	Refs. 9, 13	Bulk unit weight, specific gravity, and total porosity (Melcher Method) or effective porosity (Simmons or Washburn-Bunting Method)	Soil testing methods generally applicable with minor modification.
Permeability	ASTM D 4525	Refs. 9, 13	Permeability of intact rock	Laboratory permeability values are not normally representative of in situ permeability of shallow jointed rock masses.
Degradation Resistance	ASTM C 535		Percent of weight of rock Greater than 3/4. In (19 mm)	
Seismic Velocity	ASTM D 2845		Compressional and shear wave velocities in intact rock	Requires signal generator, transducers, oscilloscope.
Direct Tensile Strength	ASTM D 2936		Uniaxial tensile strength of intact rock	
Splitting Tensile Strength ("Brazilian Test")	ASTM D 3967		Indirect measure of tensile strength of intact rock	

Name of Test	STANDARD OR PREFERRED METHOD	OTHER REFERENCES	PROPERTIES OR PARAMETERS DETERMINED	REMARKS/SPECIAL EQUIPMENT REQUIREMENTS
Modulus of Rupture	Ref. 37		Indirect measure of tensile strength of intact rock	
Unconfined Compression	ASTM D 2938		Young's moduli and unconfined compression strength of intact rock	
Uniaxial Compression	ASTM D 3148 D 4405		Young's moduli, Possion ratio	
Triaxial Compression Undrained	ASTM D 2664		Young's moduli, cohesion friction parameters of failure envelope	
Triaxial Compression Without Pore Pressure Measurements	ASTM D 5407	Ref. 42	Young's moduli, cohesion friction parameters	
Triaxial Compression With Pore Pressure Measurements		Ref. 42	Young's moduli, cohesion friction parameters of effective stress conditions	
Slake Durability	ASTM D 4644	Ref. 43	Index of resistance to slaking	
Direct Shear	ASTM D 5607		Shear strength	

APPENDIX A
REFERENCES

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REGULATORY ANALYSIS

1. STATEMENT OF THE PROBLEM

Regulatory Guide 1.138, "Laboratory Investigations of Soils for Engineering Analysis and Design of Nuclear Power Plants," was issued in 1978. It describes acceptable laboratory investigations and testing procedures for complying with the NRC's regulations for determining soil and rock properties and characteristics for engineering analysis and design of foundations and earthworks. In the intervening time, both the practice of geotechnical laboratory investigations and NRC regulations for plant siting have changed.

New regulations were issued under Subpart B, "Evaluation Factors for Stationary Power Reactor Site Applications on or After January 10, 1997," of 10 CFR Part 100. The new regulations have a major impact on seismic siting criteria, which necessitated issuing Regulatory Guide 1.165, "Identification and Characterization of Seismic Sources and Determination of Safe Shutdown Earthquake Ground Motion," in March 1997. While the impact on laboratory investigations for soils and rock is much smaller, it is still advisable to revise the related guidance in Regulatory Guide 1.138 because of the changes in practices in laboratory testing as reflected in newer ASTM, Corps of Engineers (COE), and other standards.

In the staff's view, a revision of Regulatory Guide 1.138 would promote the use of newer and more efficient methods of laboratory investigations, providing a better basis for evaluating site safety with respect to foundation design for critical structures.

2. OBJECTIVE

The objective of this regulatory action is to update NRC guidance on laboratory investigations for soils and rock for engineering analysis and design of foundations and earthworks to conform with new regulations and practices.

3. ALTERNATIVES

3.1 Alternative 1 - Do Not Revise Regulatory Guide 1.138

With this alternative, new license applications (after January 10, 1997) for nuclear power plants would continue to be based on practices of over 20 years ago, as far as laboratory investigations are concerned. Some future applicants may, on their own initiative, use more modern procedures, but would not be required to do so. This alternative is considered the baseline or no action alternative.

3.2 Alternative 2 - Revise Regulatory Guide 1.138

The staff has identified the following consequences related to Alternative 2:

3.2.1 Benefits

Conducting laboratory investigations with newer practices and specifications would be expedient because they represents the present practice in the industry. Other benefits to be derived from the new guidance would include better or less costly design and reduced risk from better designed plants.

3.2.2 Costs

Costs are expected to be approximately the same as under the previous version of the guide because no new and different types of laboratory investigations are specified. Additionally the laboratory investigations presented in an updated version of the guide would represent the present state of practice in that these methods are being used today in virtually any large site investigation of an engineering geological nature.

4. CONCLUSION

Based on the regulatory analysis, it is recommended that a proposed revision of Regulatory Guide 1.138 be issued ~~for public comment and then issued~~ as an effective revision. A revision of Regulatory Guide 1.138 would be beneficial because it may lead to safer plant designs, whereas the costs of the investigations should not materially increase. The staff sees no adverse effects associated with the revision.

BACKFIT ANALYSIS

This regulatory guide does not require a backfit analysis as described in 10 CFR 50.109(c) because it does not impose a new or amended provision in the NRC's rules or a regulatory staff position interpreting the NRC's rules that is either new or different from a previous staff position. In addition, this regulatory guide does not require the modification or addition to systems, structures, components, or design of a facility or the procedures or organization required to design, construct, or operate a facility. Rather, ~~a licensee or~~ an applicant can select a method for achieving compliance with a license or the rules or the orders of the Commission as described in 10 CFR 50.109(a)(7). This regulatory guide provides an opportunity to use industry-developed standards, if that is an ~~a licensee's or~~ applicant's preferred method.