July 10, 1979

Note to: Accession Unit
Room 050
Phillips Building

From: Leon L. Beratan, Chief, Site Safety Standards, D/SHSS, SD

Please place the attached document in the PDR using the following file and file points:

PDR File
(Select one and enter number)

Proposed Rule (PR) ______
Reg. Guide 1.138
Petition (PRM) ______
Effective Rule (RM) ______
ANSI ______
IAEA ______

Additional Info
(Enter if appropriate)

ACRS Minutes No. ______
Relates to Proposed Rule (PR) ______
Relates to Reg. Guide ______
Relates to Petition (PRM) ______
Relates to Effective Rule (RM) ______
Federal Register Notice ______
SD Task No. ______
NUREG Report ______
Contract No. ______

Subject: Proposed Guidelines for Laboratory Testing of Geological Materials for Nuclear Power Facilities

cc:
Central File

538 037

7908090031

MISCELLANEOUS PAPER GL-79-9

PROPOSED GUIDELINES FOR LABORATORY TESTING OF GEOLOGICAL MATERIALS FOR NUCLEAR POWER FACILITIES

by

Arley G. Franklin and William F. Marcuson III

Geotechnical Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

April 1979

Final Report

Approved For Public Release; Distribution Unlimited

Prepared for U. S. Nuclear Regulatory Commission
Washington, D. C. 20555

Under Contract No. AT(49-24)-0126

538 038

POOR ORIGINAL

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Miscellaneous Paper GL-79-9	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) PROPOSED GUIDELINES FOR LABORATORY TESTING OF GEOLOGICAL MATERIALS FOR NUCLEAR POWER FACILITIES		5. TYPE OF REPORT & PERIOD COVERED Final Report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Arley G. Franklin William F. Marcuson III		8. CONTRACT OR GRANT NUMBER(s) Contract No. AT(49-24)-0126
9. PERFORMING ORGANIZATION NAME AND ADDRESS U. S. Army Engineer Waterways Experiment Station Geotechnical Laboratory P. O. Box 631, Vicksburg, Miss. 39180		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS U. S. Nuclear Regulatory Commission Washington, D. C. 20555		12. REPORT DATE April 1979
		13. NUMBER OF PAGES 36
14. MONITORING AGENCY NAME & ADDRESS(If different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

538 039

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Nuclear power plants
Soil mechanics
Rock mechanics
Laboratory tests

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report gives proposed guidelines for the laboratory testing of soil and rock materials for geotechnical analysis and design of nuclear power facilities. It discusses requirements for laboratory facilities and test apparatus, including calibration of test devices; the handling and storage of samples; the selection and preparation of test specimens; and procedures that should be followed in testing. It gives special emphasis to testing for dynamic response analysis of soils, and discusses a number of pitfalls and sources of error

(Continued)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

20. ABSTRACT (continued).

in performing and interpreting cyclic tests. A table is provided in which various test methods for soil and rock are listed, together with references to published standard or preferred methods of test and references to other important or useful publications.

538 040

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

PREFACE

This report was prepared by the U. S. Army Engineer Waterways Experiment Station (WES) for the U. S. Nuclear Regulatory Commission (NRC) under Contract No. AT(49-24)-0126, for use by the NRC in developing Regulatory Guide 1.138, "Laboratory Investigations of Soils for Engineering Analysis and Design of Nuclear Power Plants." Regulatory Guide 1.138 as published for comment by the NRC differs in some particulars from the guidelines proposed in this report.

This report was prepared during the period of April 1975 through June 1976 by Drs. A. G. Franklin and W. F. Marcuson III of the Earthquake Engineering and Geophysics Division (EE&GD), Geotechnical Laboratory (GL), WES. The work was done under the general supervision of Dr. F. G. McLean, former Chief, EE&GD, and Mr. James P. Sale, Chief, GL.

Directors of the WES during the preparation of this report were COL G. H. Hilt, CE, and COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

538 041

TABLE OF CONTENTS

538 042

TABLE OF CONTENTS (Continued)

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	25.4	millimetres
feet	0.3048	metres
miles (U. S. statute)	1.609344	kilometres
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
pounds (force) per square inch	6894.757	pascals
pounds (force) per square foot	47.88026	pascals
kips (force) per square foot	47.88026	kilopascals
inches per second	25.4	millimetres per second
feet per second	0.3048	metres per second

538 044

A. INTRODUCTION

Appendix A to 10 CFR Part 100 establishes requirements for site investigations for nuclear power plants that will permit evaluation of the site and provide information for seismic evaluation and engineering design. Included in the required investigations is the development of information relevant to the static and dynamic engineering properties of soil and rock materials of the site.

Safety-related site characteristics are identified in detail in Section 2.5 of Regulatory Guide 1.70, "Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants." Proposed Regulatory Guide 4.7, "General Site Suitability Criteria for Nuclear Power Stations," discusses major site characteristics, including those related to geology and seismology, that should be considered in determining the suitability of a site. Sections 2.5.1 through 2.5.5 of the Standard Review Plan of the Office of Nuclear Reactor Regulation, NRC, provides acceptance criteria for geologic, seismic, and foundation-related information to be provided in Safety Analysis Reports. Proposed Regulatory Guide 0.00, "Site Investigations for Foundations of Nuclear Power Facilities," discusses programs of field studies, drilling, and sampling reeded to provide field data and material samples for site evaluations and engineering design.

The present guide describes acceptable laboratory testing practices for the study of geologic materials from sites of nuclear power facilities in order to provide information on material properties and characteristics that is needed to cary out evaluations or analyses to assure the safety of the facilities against geologic, seismic, or foundations-related hazards.

B. DISCUSSION

In the course of site investigations and analyses for nuclear power facilities, laboratory testing is performed on geologic materials to identify and classify site materials and to evaluate material properties for site safety analyses, foundation analyses, and engineering design. Considerations of public safety impose particularly stringent requirements on engineering design and construction of nuclear power facilities, so that all phases of the site investigations and associated testing and analyses must be carried out in such a way as to assure a high degree of confidence in the results. In addition, it is necessary that information obtained from the investigations be reported in such a manner and with sufficient completeness to allow verification by independent analysis and evaluation on the part of the regulatory staff and its consultants.

Conditions at sites of nuclear power facilities vary to a high degree, and the course of a site investigation depends on the nature of the problems, or potential problems, encountered. Appropriate types of laboratory tests depend on the parameters required as input for analyses or evaluation of potential geotechnical problems. In many cases, the nature of the soil or rock dictates the type of test and the details of test procedure, so that modifications in established procedures are sometimes required. Because the significance of test results is dependent on minor details, verifiability of the results makes it desirable that testing procedures follow, where possible, practices that are generally known and accepted. Where departures from these practices are required, they should be fully described.

Acceptance criteria given in the Standard Review Plan require that state-of-the-art methods be used to determine the static and dynamic properties of foundation soils and rocks in the site area. For most purposes, the state of the art is reflected in established standard methods, such as those adopted by the American Society for Testing and Materials (ASTM), procedures established by agencies such as the Corps of Engineers, the Bureau of Reclamation, or the Soil Conservation Service, or practices described in generally accepted texts on laboratory testing.

For some geotechnical problems, in particular those involving dynamic response of soils, the state of the art is changing relatively rapidly. This guide describes programs, methods of testing, and laboratory procedures that are acceptable for these cases, and reflect the state of the art at the time of its preparation. Cognizance should be taken, however, of continuing research and advances in the state of the art.

C. REGULATORY POSITION

1. Laboratory Apparatus and Facilities

1.1 Apparatus. When laboratory test procedures follow published standards, such as those of the ASTM, or manuals, such as the Corps of Engineers Engineer Manual on Laboratory Soils Testing, the test apparatus should conform to published specifications. Where modifications are used because of special needs, they should be reported with the test results. Where test methods do not follow standards or manuals, complete descriptions of the essential characteristics of test apparatus should be given. This may be done by reference to published papers, reports, monographs, or the like, where appropriate. All laboratory apparatus should be regularly inspected and maintained to assure that essential characteristics (such as dimensions, mating of parts, piston friction, or fluid seals) are not significantly altered by wear, handling, corrosion, dirt, or deterioration of materials.

1.2 Calibration. All test apparatus and instruments should be calibrated against certified calibration standards before being put into service, and calibrations should be verified at regular intervals thereafter. Necessary frequency of calibration or checking of calibration varies according to the susceptibility of the apparatus to change and the required precision of measurement. Sealed glass thermometers and hydrometers are not normally susceptible to change. Physical length or volume measuring apparatus, such as metallic tapes, scales, pycnometers, or graduates, are not normally subject to calibration change unless altered by visible wear or damage. Standards of mass, such as metallic weights, may be subject to significant alteration by wear or corrosion over long periods, with hard use, or where great precision is required. Balances or scales should be recalibrated at least annually, and should be checked against known weights during the course of each day's work. Balances or scales used in the field should also be checked against known weights in each field location. In general, instruments for measuring forces, pressures, temperatures, and electrical quantities, and length measuring instruments with moving parts, should be calibrated against certified calibration standards at least annually, and more frequently in cases of instruments that are subject to change by drift or wear. All laboratory apparatus should be inspected for signs of damage, wear, deterioration, or drift on a continuing basis. Apparatus used for critical tests should be inspected and subjected to calibration checks at the time of each test. Records of calibration and inspection should be maintained. Calibration procedures for laboratory equipment for soils testing are described in Reference 36 (EM 1110-2-1909).

1.3 Reagents and Water. Guidelines for suitable chemical reagents, distilled water, and apparatus for chemical analyses can be found in Reference 2 (APHA, et al, 1971). Water for use in soil or rock testing may be distilled or demineralized by ion-exchange processes. Since ordinary distillation does not remove ammonia or carbon dioxide, and ion-exchange demineralization does not remove organic colloids, special precautions are required where these substances may be present and may interfere with tests. Tap water may be used where specified by standard methods or where chemical analysis show that it does not contain impurities in sufficient amounts to interfere with tests. De-aired water should be provided, since dissolved gases or air can make it impossible to obtain full saturation in test specimens. A procedure for de-airing water is described in Reference 35 (US Army EM 1110-2-1906). Suitable commercial de-airing devices may be used.

1.4 Laboratory Facilities. A laboratory for soil or rock testing should have a firm, solid floor and be free of traffic and machinery vibrations. Temperature control of the entire laboratory is preferred, and is essential for areas in which triaxial, simple shear, resonant column, consolidation, or permeability tests are conducted. Temperatures should be maintained within a range of approximately 5°C during tests of these types. Separate areas, and preferably separate rooms, should be used for dust-producing activities such as sieve analyses and sample processing. A room with relative humidity maintained at or near 100% (a "humid room") and large enough to permit storage of samples and preparation of test specimens should be provided.

2. Sample Handling and Storage

Handling and storage of soil and rock samples should not produce damage or alteration that could affect the results of laboratory tests. Undisturbed* soil samples, whether in blocks or tubes, are the most vulnerable to damage, and thus require the most stringent protective measures. Undisturbed samples should be transported and handled so as to avoid damage to the soil structure by impacts or vibration, and undisturbed samples of granular soils in tubes, unless frozen, should be transported and stored vertically if they are to be tested in an undisturbed condition. Padded containers or racks should always be used for transportation and are highly recommended for storage. Samples to be stored

---

* Defined in Appendix B.

prior to testing must be protected against changes in water content; they should be closely inspected upon receipt at the laboratory to assure that moisture seals are intact, and the seals should be renewed if needed. Storage should be in a humid room. Even the most careful treatment, however, can not prevent slow structural and chemical changes with time, which usually result in decrease of shear strength and the measured value of preconsolidation stress. Samples should be tested as soon as possible after receipt, and preferably should not be stored for more than two weeks prior to testing. Samples that have been stored for long periods may be suitable for visual inspection, but should not be considered to have the characteristics of undisturbed samples. A discussion of the effects of storage and extrusion on undisturbed samples is given in Reference 6 (Arman and McManis, 1976).

Undisturbed samples of sand may be drained and frozen at the sampling site to make them less susceptible to disturbance during transportation and handling. Such treatment affords some protection from mechanical disturbance, but does not obviate the need for careful handling. Frozen samples should be protected from thawing and from wide fluctuations of temperature below the freezing point. Sand samples should be well-drained, but not dry, before they are frozen, since freezing of saturated or near-saturated samples produces disturbance from expansion of freezing water. Soils that are not free-draining can not be frozen without disturbance.

Remolded or bulk samples of soil do not require storage in a humid room nor protection from mechanical disturbance, but should be stored indoors and protected against contamination. Rock samples normally can be stored in core boxes, except that samples to be used for fluid content determinations and shale samples to be used for tests of mechanical properties should be protected from change in fluid content. Rock samples should be stored indoors to provide protection from weathering. Rocks with soil-like properties, such as soft shales or weakly indurated sandstones, should be treated as soils.

3. Selection and Preparation of Test Specimens

The selection of soil and rock specimens for laboratory testing requires careful examination of all samples, in order that test specimens accurately represent the characteristics of each discrete soil or rock unit, and that the soil profile be accurately described. Specimens should be selected so that test results define average values of material properties as well as the range of values and their degree of variability. This requires the testing not only of the most representative samples, but also those with extremes of properties and those representative of critical zones. Guidelines for spacing of borings and frequency of sampling are given in Regulatory Guide 0.00, "Site Investigations for Foundations of Nuclear Power Plants." In some instances, additional boring and sampling may be required, when laboratory examination of the samples reveals that they are not adequate in freedom from disturbance, number, or distribution to meet testing requirements.

Undisturbed tube samples of soils should be examined for evidence of disturbance. Requirements that should be satisfied by undisturbed samples are stated by Hvorslev (Reference 18) as:

a. The specific recovery ratio* shall not be greater than 1.00 nor smaller than $(1-2C_i)$, where C_i is the inside clearance ratio* at the cutting edge. When thin-wall drive samplers, samplers with stationary piston, or core barrels are used, it is generally sufficient that the total recovery ratio be equal to or slightly smaller than unity.

b. On the surface of or in sliced sections of the sample there must be no visible distortions, planes of failure, pitting, discoloration, or

---

* Defined in Appendix B.

other signs of disturbance which can be attributed to the sampling operation or handling of the sampler.

c. The net length and weight of the sample and the results of other control tests must not change during shipment, storage, and handling of the sample.

All of the above requirements should be satisfied, and, in addition, 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.

Hvorslev describes procedures for examining cut surfaces of soil samples. Portions of tube samples may be examined by these procedures while other portions are used for testing. A desirable alternative is the use of X-radiographs, which can be used to examine samples for distortion of strata, gaps, voids, and shear zones, and which leaves the samples intact. It is also useful for delineating the boundaries of soil zones with different properties, and thus aids in subdividing samples and selecting test specimens. Procedures for examination by X-radiography are given in Reference 19 (Krinitzsky, 1970).

A serious source of damage to undisturbed soil samples is extrusion from sample tubes. The preferred method of removal of samples from thin-wall tubes is to split the tube longitudinally by milling. An acceptable alternative is to saw the tube transversely into segments of sufficient length to extrude a single test specimen from each and to permit penetrometer or vane shear testing (where applicable) and trimming of the ends. Before extrusion of samples from the tube sections, the cut tube edges should be dressed. Reuse of thin-wall sample tubes should not be attempted.

Trimming and shaping of test specimens of soils require great care to prevent disturbance and changes in moisture content. Normally, preparation should be done in a humid room. Frozen samples should be prepared under conditions that will prevent premature thawing. Details of procedure depend on the nature of the test and the specimen. For a number of tests of soils, procedures are described in Reference 35 (EM 1110-2-1906, 1970). Preparation of rock specimens for testing is described in Reference 22 (Obert and Duvall, 1967).

4. Testing Requirements

4.1 General. The evaluation of a site requires the development of subsurface soil and rock profiles. All soils and rocks sampled at the site require appropriate examination and testing for identification and classification. This requires index and classification tests and moisture and density determinations, and may also require mechanical analyses, mineralogical analyses, organic content determinations, or other types of testing, as appropriate to the soil and rock types and water conditions encountered.

Test requirements beyond those for identification and classification are determined by consideration of soil and rock types present and their relations to structures or systems belonging or related to the facility. Depending on the nature of potential problems, such as settlement, slope stability, or bearing capacity, various laboratory tests such as tests of compressibility, consolidation behavior, or shear strength are required. Most tests of this nature are well-known; common ones are included in Appendix A, together with tests for more special applications and references to applicable standards and other selected literature.

Laboratory procedures, particularly those of a routine nature, should normally be carried out according to generally accepted and published procedures, where they are available. Such published procedures include the standards of the American Society for Testing and Materials (ASTM), some of which are listed in Appendix A, and the American Association of State Highway Officials (AASHO); the Laboratory Manuals of the U. S. Army Corps of Engineers and the U. S. Bureau of Reclamation; widely known and accepted monographs and journal papers describing test procedures; and other publications of similar character and standing. The U. S. Army Engineer Manual EM 1110-2-1906 (Reference 35) gives detailed procedures for many tests of engineering properties of soils. The two-volume monograph, Methods of Soil Analysis, (Reference 5) sponsored jointly by the American Society of Agronomy and the American Society for Testing and Materials, provides procedures for some engineering properties tests and a wide variety of tests for physical, chemical, and microbiological properties of soils. Both of these references provide valuable discussions of pitfalls, precautionary measures, calibration procedures, and control of errors. Where standard procedures are not available, or where special problems make others preferable, alternative procedures or modifications of standard procedures may be used. For purposes of review, published procedures that are followed without deviation require documentation only by reference, but other procedures or modifications of standard procedures should be described and documented.

4.2 Testing for Dynamic Response Analyses. Dynamic response analyses may be required for evaluation of site and structural behavior under earthquake loads, as well as dynamic loading from other sources, such as machine vibrations or explosive events. Such analyses include the analysis of wave propagation through site materials, including interaction effects with structures; the analysis of the potential for liquefaction or loss of strength of cohesionless soils under dynamic loading, and analysis of the effects of earthquake loading on the stability of slopes and embankments. Appropriate test methods, together with references for procedures, are listed in Appendix A. An extensive and detailed discussion of test methods and analyses relevant to dynamic response of soils is given in Reference 25 (Shannon and Wilson and Agbabian-Jacobsen Associates, 1972).

538 054

4.2.1 Development of Soil Profile. Dynamic analyses require as input the parameters describing the soil profile, and must therefore be preceded by exploration and testing to obtain those parameters.

4.2.2 Static Stress Analysis. An analysis is generally required to provide the initial state of stress on which dynamic stresses are superimposed. Parameters required as input include the static stress-strain parameters, and where seepage is involved, in situ permeability values. A test program including both consolidated-drained and consolidated-undrained, monotonically-loaded, strain-controlled, triaxial shear tests would be an acceptable means of obtaining the stress-strain parameters. The test program should include all soils involved in the analysis. Consolidation should cover a range of consolidation stress ratios appropriate to the range expected in the field; values of 1.0, 1.5, and 2.0 are usually satisfactory. Confining pressures should also cover a range of values appropriate to those expected in the field. Pore pressures should be measured in undrained tests. Sufficient data should be obtained to permit nonlinearity of the stress-strain relations to be well defined, as well as the peak and residual shear strengths. For determination of permeability, in situ testing methods should be used wherever possible.

4.2.3 Wave Propagation Analyses. The basic soil parameters required for a dynamic stress analysis are the total mass density, Poisson's Ratio, shear modulus, and damping ratio. The shear modulus and damping values are, in soils, functions of strain level, and it is important that they be determined over a range of strains that are appropriate to the problem. Because of limitations inherent in available test equipment, it is necessary to perform tests by various methods to evaluate response at different strain levels. Useful tests would include the resonant column test, strain-controlled, undrained, cyclic triaxial tests, and the cyclic simple shear test (undrained), supplemented by field tests which yield stress-strain relations for small strain levels. Figure 1 shows approximate ranges of strains applicable to these test methods.

Values of Poisson's Ratio may be obtained by (a) monitoring both axial and radial strains in the cyclic triaxial shear test, (b) comparing data from cyclic triaxial and cyclic simple shear tests, (c) comparing response in the axial mode with that in the torsional mode in the resonant column test, or (d) comparing shear wave and compression wave velocities. Care should be taken that data compared are from tests with approximately equal strain levels. Under dynamic or undrained conditions Poisson's Ratio for saturated soils normally will have a value approaching 0.5, and such a value may be assumed as an alternative to determination from test data.

Laboratory tests should be performed with specimens consolidated both isotropically and anisotropically, with a range of consolidation stress ratios and confining pressures appropriate to the field condition.

The analysis of test data to evaluate modulus and damping values is discussed in Reference 25 (Shannon and Wilson and Agbabian-Jacobsen Associates, 1972). It is preferable, where possible, that the methods of analysis of test data do not require assumptions of idealized models of material behavior, such as linear elasticity or linear viscoelasticity.

4.2.4 Shear Resistance of Soils Under Dynamic Loading

4.2.4.1 General. The shear and deformation behavior of soils subjected to seismic or other dynamic loads should be determined by a testing program including both monotonic (static) and cyclic load tests. Appropriate static tests would include stress- or strain-controlled, consolidated-undrained, triaxial tests, with pore pressure measurements. These tests should include isotropically and anisotropically consolidated specimens, with a range of con-

538 056

fining pressures and consolidation stress ratios appropriate to the field conditions. The effects of cyclic loading should be evaluated by a program of stress- or strain-controlled cyclic loading tests, which may be triaxial, simple shear, or torsional shear, of adequate scope to determine the degree to which shearing resistance is affected by cyclic loading.

4.2.4.2 Liquefaction Potential. Saturated cohesionless soils are susceptible under some conditions to liquefaction and/or loss of shear strength under earthquake loading. Where laboratory determination of liquefaction potential is required, stress-controlled, undrained, cyclic triaxial tests should be performed on each material that might be susceptible. Tests should be performed with test specimens consolidated both isotropically and anisotropically, with a range of confining pressures and consolidation stress ratios appropriate to the field conditions, and with a range of stress amplitudes such that 5% and 10% (peak-to-peak) strain amplitudes are obtained over the range of 3 to 50 cycles. Stress-controlled cyclic simple shear tests may be used as an alternative or to supplement cyclic triaxial tests.

In the present state of the art, the cyclic triaxial test is the only one generally available for engineering application in liquefaction analyses. This test possesses severe shortcomings, and requires the application of empirical correction factors, which have been developed from a limited data base, to test results to compensate for effects of nonideal conditions in loading or in configuration of test specimens. Alternative methods, such as shake table tests, cyclic simple shear tests, and cyclic torsional tests, are essentially research tools at the present time. Where available these tests may be used, but they should be supplemented by cyclic triaxial tests unless sufficient data are available to demonstrate a correlation of results of the test method used with either field performance or conventional tests.

4.2.5 Special Considerations and Potential Pitfalls. The following points should be given careful attention in planning, performing, and interpreting dynamic laboratory tests:

4.2.5.1 Preparation of Test Specimens. For all dynamic laboratory tests, the test specimens should be prepared and treated so as to represent as nearly as possible the material whose field behavior is to be analyzed. For fill materials, the preferred procedure is to perform tests on specimens obtained from undisturbed samples of test fills. Alternatively, tests may be performed on test specimens compacted to field density and water content, with the degree of saturation adjusted prior to testing, if necessary, to correspond to the condition to be analyzed. For analysis of in situ materials, whether cohesive or non-cohesive, the preferred test specimen for all tests of strength and dynamic response is an undisturbed sample of high quality. Where reconstituted specimens must be used to represent in situ materials, they should be reconstituted at in situ dry density as determined from actual density measurements. The use of relative density as interpreted from SPT tests is not sufficiently accurate for this purpose. The method of reconstitution has a strong effect on the test results, and this effect should be considered in the interpretation of test data as well as in planning the test program. See Reference 21 (Mulilis, Chan, and Seed, 1975) for a discussion of the effects of method of sample preparation. Care should be taken to avoid mixing granular soils of different gradation. Such a mixture may exhibit behavior that is entirely different from that of its separate components, even though the in situ density is closely reproduced.

4.2.5.2 Effects of Scalping. Where large particles are present in the material to be tested, the diameter of the test specimen should be at least 6 times the diameter of the largest particle. Scalping (the removal of a coarse fraction of the sample) is known to influence the results of dynamic tests, but the nature of the influence is not well understood, and scalping should be avoided wherever possible. In instances where scalping can not be avoided, the test specimens should be prepared at a density corresponding to the matrix* density of the in situ material, which is normally lower than the total bulk density. Scalping procedures should be explained together with reasons for expecting that test results are valid. Materials having parallel grain size distribution curves can not be assumed to be equivalent materials for purposes of dynamic testing.

4.2.5.3 Degree of Saturation. The dynamic behavior of soils is profoundly influenced by the degree of saturation, and tests of soils that will be below the water table should be performed only on specimens that are essentially 100% saturated, as indicated by Skempton's B value. The minimum acceptable B value is considered to be 0.95.

4.2.5.4 Determination of In Situ Density. The in situ density of cohesionless soil is of critical importance in dynamic behavior, and extreme care should be given to its determination. The proposed Regulatory Guide 0.00, "Site Investigations for Foundations of Nuclear Power Facilities," discusses methods of determination of in situ density in cohesionless soils and provides references.

4.2.5.5 Necking of Test Specimens. Test specimens in cyclic triaxial tests sometimes neck during extension. When necking begins, the test should be considered invalid from that point on.

4.2.5.6 Form of Loading Function. The preferred loading function for cyclic tests is sinusoidal. Square-wave or triangular-wave loading functions may also be used. Whatever the form of loading function used, the first half-cycle of loading in a cyclic triaxial test should be compressional. Square-

* Defined in Appendix B.

wave loading produces more severe conditions than sinusoidal loading, and consequently may produce an apparently lower dynamic shear strength or greater susceptibility to liquefaction. However, in the absence of experimentally developed site-specific correlation, the results of tests with square-wave loading as well as triangular-wave loading should be used without upward adjustment of apparent strength or resistance values.

4.2.5.7 Comparison of Response to Different Tests. In cyclic tests for dynamic modulus and damping values of soils, care should be taken to use tests that impose levels of strain that are appropriate to the analyses for which they are intended, as illustrated in Figure 1. In addition, where test programs include tests by different methods to study behavior over an extended range of strain levels, tests should be performed by the different methods in the regions of overlap. The redundancy so obtained will provide a means of comparing response under different test conditions, and will thus aid in verifying the consistency of the data obtained.

4.2.5.8 Frequency of Cyclic Loading. Information available at the present time indicates that the mechanical behavior of soils is relatively insensitive to frequency in the frequency range of primary interest in earthquake response problems. It is common practice to carry out laboratory cyclic tests at a frequency in the neighborhood of 1 Hz. If tests are performed at frequencies outside the range of 0.5 to 2 Hz, additional investigations should be made to verify that test results are comparable to those done at 1 Hz.

4.2.5.9 Number of Tests Required. In general, where the form of a relation between dependent and independent variables (such as cyclic shear stress and number of cycles to failure) is known or suspected to be non-linear, the definition of the curve expressing the relation requires at least three data points, and these should represent a range of values that is consistent with

538 060

that anticipated in the field. In some instances, it is possible to reduce the number of tests required when the scatter is small and the form of a curve has been established by other curves in the family. In other instances, the data may show a degree of scatter such that more than three tests are required to define the curve.

4.3 Dispersive Characteristics of Cohesive Soils. Where cohesive soils are used in water-retaining structures, or are otherwise used to control water movement, the dispersive characteristics or erodability should be evaluated by suitable tests of the materials at the same density and water contents used for design. Acceptable methods of test are described in References 26 (Sherard, et al, 1976) and 23 (Perry, 1975).

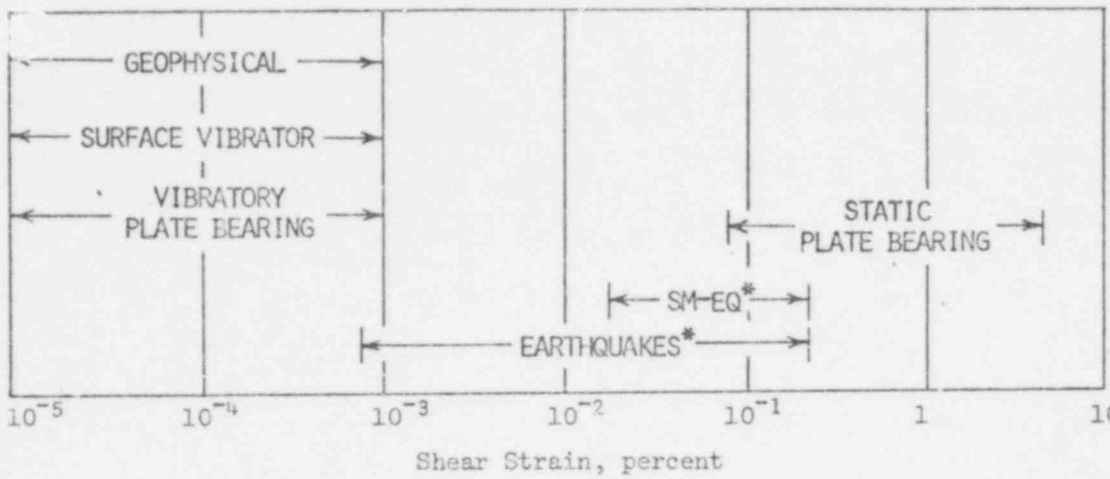
4.4 Tests of Groundwater or Surface Waters. The requirements for testing of groundwater or surface water depend on the nature of potential problems identified at the site. Standard methods of testing water for physical, chemical, radioactive, and microbiological properties are given in Reference 2 (APHA, AWWA, and WPCF, 1971). Also described are methods of testing polluted water, wastewaters, effluents, bottom sediments, and sludges. Standard methods of test should be used unless special problems are encountered which require modifications or alternative methods, in which case any departure from standard methods should be documented.

5. Presentation of Test Results

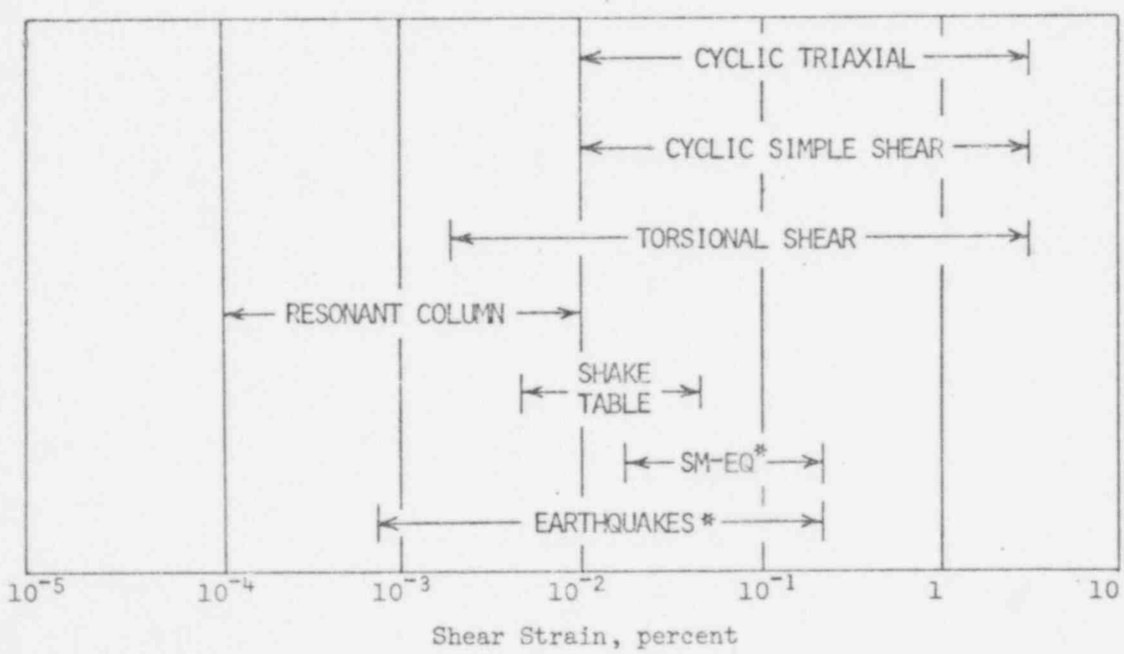
The results of laboratory tests should be reported in sufficient detail, and in suitable form, to permit independent verification and analysis during review. All test parameters that are needed to analyze or evaluate the test data, or to judge its validity, should be reported. In plots showing the results of tests or experiments, all data points should be shown. The construction and labelling of plots showing test results, and symbols used in figures and text, should conform to accepted engineering and scientific practice unless there are specific reasons for deviation. In such cases, the usages followed should be explained in accompanying discussions. A listing of standard terms and symbols for soil and rock mechanics is given in ASTM Standard D653 (Reference 3). The use of dual units (English and SI) is recommended.

In the presentation of test data, care should be taken to show clearly the degree of variability in the data and the range of extreme values, so that the degree of conservatism in the choice of design values can be assessed.

538 062



a. FIELD TESTS



b. LABORATORY TESTS

* Note: Range of shear strain denoted as "Earthquakes" represents an extreme range for most earthquakes. "SM-EQ" denotes strains induced by strong motion earthquakes.

558 063

Figure 1. FIELD AND LABORATORY TESTS SHOWING APPROXIMATE STRAIN RANGES (Adapted from Reference 25)

POOR ORIGINAL

APPENDIX A

LABORATORY TEST METHODS FOR SOIL AND ROCK

NAME OF TEST	STANDARD OR PREFERRED METHOD[1]	OTHER REFERENCES	PROPERTIES OR PARAMETERS DETERMINED	REMARKS/SPECIAL EQUIPMENT REQUIREMENTS
		SOILS - INDEX AND CLASSIFICATION TESTS		
Gradation Analysis	ASTM D421 D422 D2217	Ref 20 (Lambe, 1951), Ch IV; Ref 35 (EM 1110-2-1906), App. V	Particle size distribution	Methods are applicable to some rocks, after disaggregation.
Percent Fines	ASTM D1140	Ref 20 (Lambe, 1951). Ch IV; Ref 35 (EM-1110-2-1906), App V	Percent by weight of material finer than No. 200 sieve	
Atterberg Limits	ASTM D423 D424 D427	Ref 20 (Lambe, 1951), Ch III; Ref 35 (EM-1110-2-1906), App III	Plastic limit, liquid limit, plasticity index, shrinkage factors	
Specific Gravity	ASTM D854	Ref 20 (Lambe, 1951), Ch II; Ref 35 (EM 1110-2-1906), App IV	Specific gravity or apparent specific gravity of soil solids	Boiling should not be used for de-airing. Method can be used for rock, after grinding sufficiently fine to eliminate blind pore space.
Soil Description	ASTM D2488		Description of soil from visual-manual examination	

NAME OF TEST	STANDARD OR PREFERRED METHOD[1]	OTHER REFERENCES	PROPERTIES OR PARAMETERS DETERMINED	REMARKS/SPECIAL EQUIPMENT REQUIREMENTS
Soil Classification	ASTM D2487		Unified soil classification	
X-ray		Ref 19 (Krinitzsky, 1970)	Comparative density, macrostructure	Very useful for detection of disturbance due to sampling, and for delineation of soil strata in tube samples. Requires X-ray apparatus.
SOILS - MOISTURE-DENSITY RELATIONS				
Bulk Unit Weight	Ref 35 (EM 1110-2-1906) App. II		Bulk unit weight (bulk density)	Methods are applicable to rocks, with some obvious modifications.
Water Content	ASTM D2216 D29[illegible]	Ref 35 (EM 1110-2-1906), App I	Water content as percent of dry weight	Method is applicable to rock.
Relative Density	Ref 35 (EM 1110-2-1906) App. XII	ASTM D2049	Maximum and minimum density of cohesionless soils	Requires vibration table. In vibration table testing, both amplitude and frequency should be adjusted to values which 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.
Compaction	ASTM D698 D1557	Ref 35 (EM 1110-2-1906), App VI and App VI A.	Optimum moisture content-density relations	Method for earth and rock mixtures is given in Ref 35 (EM 1110-2-1906), App VI A.

NAME OF TEST	STANDARD OR PREFERRED METHOD[1]	OTHER REFERENCES	PROPERTIES OR PARAMETERS DETERMINED	REMARKS/SPECIAL EQUIPMENT REQUIREMENTS
		SOILS - CONSOLIDATION AND PERMEABILITY		
Consolidation	ASTM D2435	Ref 20 (Lambe, 1951), Ch IX; Ref 35 (EM 1110-2-1906), App VIII	One-dimensional compressibility, permeability of cohesive soil	
Expansion		Ref 17 (Holtz, 1970b)	One-dimensional expansion vs. load relation	Method uses conventional consolidometer apparatus.
Permeability	ASTM D2434	Ref 35 (EM 1110-2-1906), App. VII; Ref 16 (Holtz, 1970a)	Permeability	Suitable for remolded or compacted soils. For natural, in situ soils, field test should be used.
		SOILS - PHYSICAL AND CHEMICAL PROPERTIES		
Mineralogical Analysis	Ref 37 (Warshaw and Roy, 1961)	Ref 12 (Gillott, 1968), Ch 10; Ref 5 (ASA-ASTM, 1965)	Identification of minerals	Applicable to rock. Requires X-ray diffraction apparatus. Differential thermal analysis apparatus may also be used.
Organic Content	Ref 1 (Allison, 1960)	ASTM D2974; Ref 24 (Schmidt, 1970)	Organic and inorganic carbon content as percent of dry weight	Dry combustion methods (ASTM D2974) are acceptable, but where organic matter content is critical, data so obtained should be verified by wet combustion tests (Refs 1 & 24).

NAME OF TEST	STANDARD OR PREFERRED METHOD[1]	OTHER REFERENCES	PROPERTIES OR PARAMETERS DETERMINED	REMARKS/SPECIAL EQUIPMENT REQUIREMENTS
Soluble Salts	Ref 33 (Soil Conservation Service, 1967)		Concentration of soluble salts in soil pore water	
Pinhole Test		Ref 26 (Sherard, et al, 1976); Ref 23 (Perry, 1975)	Dispersion tendency in cohesive soils	Significant in evaluation of potential erosion or piping. See Ref 27 (Sherard, et al, 1976); Ref 23 (Perry, 1975).
SOILS - SHEAR STRENGTH AND DEFORMABILITY				
Unconfined Compression	ASTM D2166	Ref 35 (EM 1110-2-1906), App. XI	Strength of cohesive soil in uniaxial compression	
Direct Shear, Consolidated-Dr[illegible]	ASTM D3080	Ref 35 (EM 1110-2-1906), App IX, IX A.	Cohesion, c', and angle of internal friction, ϕ', under drained conditions	
Triaxial Shear, Unconsolidated-Undrained	ASTM D2850	Ref 7 (Bishop and Henkel, 1962); Ref 35 (EM 1110-2-1906), App X	Cohesion, c, and angle of internal friction, ϕ, for soils of low permeability	
Triaxial Shear, Consolidated-Undrained		Ref 35 (EM 1110-2-1906), App. X; Ref 7 (Bishop and Henkel, 1962)	Cohesion, c, and angle of internal friction, ϕ, for consolidated soil. With pore pressure measurements, c' and ϕ' may be obtained.	Circumferential drains, i[illegible] used, should be slit [illegible] avoid stiffening [illegible] test specimen.

NAME OF TEST	STANDARD OR PREFERRED METHOD[1]	OTHER REFERENCE	PROPERTIES OR PARAMETERS DETERMINED	REMARKS/SPECIAL EQUIPMENT REQUIREMENTS
Triaxial Shear, Consolidated-Drained		Ref 35 (EM 1110-2-1906), App. X; Ref 7 (Bishop and Henkel, 1962)	Cohesion, c', and angle of internal friction, ϕ', for long-term loading conditions	Circumferential drains, if used, should be slit to avoid stiffening test specimen.
Cyclic Triaxial, Strain-Controlled[2]		Ref 30 (Silver and Park, 1975); Ref 25 (Shannon & Wilson, Inc., and Agbabian-Jacobsen Associates, 1972)	Young's modulus, damping, and pore pressure response of cohesionless soils. Modulus and damping of cohesive soils	See text, Subsection 4.2.5.
Cyclic Triaxial, Stress Controlled	Ref 28 (Silver, 1976)	Ref 25 (Shannon & Wilson, Inc., and Agbabian-Jacobsen Associates, 1972); Ref 29 (Silver, et al, 1976)	Cyclic strength of cohesive and cohesionless soils	See text, Subsection 4.2.5.
Cyclic Simple Shear[2]		Ref 34 (Thiers and Seed, 1968); Ref 32 (Silver and Seed, 1971); Ref 10 (Finn, et al, 1971); Ref 25 (Shannon and Wilson, Inc. and Agbabian-Jacobsen Associates, 1972); Ref 31 (Silver and Seed, 1969)	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 34 and 10, respectively.

538 068

NAME OF TEST	STANDARD OR PREFERRED METHOD[1]	OTHER REFERENCES	PROPERTIES OR PARAMETERS DETERMINED	REMARKS/SPECIAL EQUIPMENT REQUIREMENTS
Resonant Column		Ref 14 (Hardin, 1970)	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[3]		
Porosity		Ref 8 (Buell, 1949); Ref 9 (Fancher, 1950)	Bulk unit weight, specific gravity, and total porosity (Melcher Method) or effective porosity (Simmons or Washburn-Bunting Method)	Soil testing methods are generally applicable, with minor modifications.
Permeability		Ref 8 (Buell, 1949); Ref 9 (Fancher, 1950)	Permeability of intact rock.	Laboratory permeability values are not normally representative of in situ permeability of shallow, jointed rock masses.
Seismic Velocity	ASTM D2845	Ref 22 (Obert and Duvall, 1967), pp 344-346; Ref 13 (Gregory, 1963)	Compressional and shear wave velocities in intact rock.	Requires signal generator, transducers, oscilloscope.

NAME OF TEST	STANDARD OR PREFERRED METHOD[1]	OTHER REFERENCES	PROPERTIES OR PARAMETERS DETERMINED	REMARKS/SPECIAL EQUIPMENT REQUIREMENTS
Direct Tensile Strength	ASTM D2936	Ref 22 (Obert and Duvall, 1967), pp 327-329	Uniaxial tensile strength of intact rock.	
"Brazilian Test"		Ref 22 (Obert and Duvall, 1967), pp 329-330	Indirect measure of tensile strength of intact rock.	
Modulus of Rupture		Ref 22 (Obert and Duvall, 1967), pp 333-334.	Indirect measure of tensile strength of intact rock.	
Unconfined Compression	ASTM D2938	Ref 22 (Obert and Duvall, 1967), pp 330-333, pp 339-344.	Elastic moduli and unconfined compressive strength of intact rock.	
Triaxial Compression (Undrained)	ASTM D2664	Ref 22 (Obert and Duvall, 1967), pp 336-344	Elastic moduli, c and ϕ parameters of failure envelope.	
Triaxial Compression with Pore Pressure Measurements		Ref 15 (Heck, 1972)	Elastic moduli, c and ϕ parameters under effective stress conditions.	
Slake-Durability		Ref 11 (Franklin and Chandra, 1972)	Index of resistance to slaking.	

NOTES: 1. ASTM standard methods are given in Reference 3.

2. Comprehensive single references are not available for most dynamic test procedures. A literature survey is recommended to any laboratory performing such tests.

3. Many methods of test for soils are also applicable to rock. See under listings for soils.

APPENDIX B

DEFINITIONS

For the purposes of this guide, the following words and terms are used with intended meanings as indicated below.

B Parameter, or B value means the pore pressure coefficient B in the equation

$$\Delta u = B \left[\Delta\sigma_3 + A (\Delta\sigma_1 - \Delta\sigma_3) \right]$$

in which Δu is the change in pore pressure resulting from stress changes $\Delta\sigma_1$ and $\Delta\sigma_3$ in a triaxial test.

Consolidation stress ratio means the ratio of the major principal stress to the minor principal stress during consolidation. If the ratio is unity, consolidation is isotropic.

Cyclic strength means the amplitude of cyclic stress, in extension, compression, or both, that produces failure by liquefaction or by excessive shear deformation in the test specimen, in a given number of cycles.

Damping means the dissipation of strain energy during cyclic loading. The energy dissipated is proportional to the area of the hysteresis loop.

Dispersion (of soils) means a change in soil structure with loss of bonding forces between particles, so that particles tend to assume wider spacing and are relatively easily eroded.

Dispersive (of soils) means having a tendency or susceptibility to dispersion.

Disturbed sample means a sample whose internal structure has been damaged to such a degree that it does not reasonably approximate that of the material in situ. Such a sample may be completely remolded, or it may bear a resemblance to an undisturbed sample in having preserved the gross shape given it by a sampling device.

Humid room means a room or chamber in which the relative humidity is maintained at or near 100%, and which is used for storage of samples and/or preparation of test specimens.

Hysteresis loop means a closed curve formed by a plot of stress versus strain during a cyclic test.

Inside clearance ratio, C_i of a sampling device, is defined as:

$$C_i = \frac{D_s - D_e}{D_e}$$

where D_s is the inside diameter of the body of the sample tube or liner and D_e is the diameter of the cutting edge.

Liquefaction means a sudden, large loss of shearing resistance in a cohesionless soil, associated with an increase in pore pressure. It may be caused by cyclic or monotonic loading.

Matrix, in soil or rock, is the assemblage of finer grains in which grains of distinctively larger size are embedded.

Remolded sample means a sample which has been disturbed to such an extent that its structure is determined by the stresses and strains undergone during and after sampling, and the effects of in situ conditions are obscured.

Representative sample means a sample that contains all of the mineral constituents of the stratum from which it is taken, in the same proportions, with the same grain size distribution, and is uncontaminated by foreign materials or by chemical alteration.

Specific recovery ratio, in the advance of a sample tube, is defined as:

$$R_s = \frac{\Delta L}{\Delta H}$$

where ΔL is the increment of length of sample in the tube corresponding to an increment ΔH of sampler advance.

Strain-controlled test means a test in which strains are imposed on a specimen with controlled rate and/or magnitude.

338 072

Stress-controlled test means a test in which stresses are applied to a specimen with controlled rate and/or magnitude.

Structure, in soil or rock, means a complex physical-mechanical property, components of which are the sizes, shapes, and arrangements of the constituent grains and intergranular matter, and the forces acting among the constituents.

Undisturbed sample means a sample obtained and treated in such a way that disturbance of its original structure is insignificant, so that the sample is suitable for laboratory tests of material properties that depend on structure.

538 073

APPENDIX C

REFERENCES

1) Allison, L. E., "Wet Combustion Apparatus and Procedure for Organic and Inorganic Carbon in Soil," Proceedings, Soil Science Society of America, Vol. 24, pp. 36-40, 1960.

2) American Public Health Association, American Water Works Association, and Water Pollution Control Federation, Standard Methods for the Examination of Water and Wastewater, 13th ed, New York, 1971.

3) American Society for Testing and Materials, Annual Book of ASTM Standards: Part 19, American Society for Testing and Materials, Philadelphia, PA., Issued Annually.

4) American Society for Testing and Materials, Special Procedures for Testing Soil and Rock for Engineering Purposes, ASTM STP 479, American Society for Testing and Materials, Philadelphia, PA., 1970.

5) American Society of Agronomy and American Society for Testing and Materials, Methods of Soil Analysis, Parts 1 and 2, Published by American Society of Agronomy, Inc., Madison, WI., 1965.

6) Arman, A. R. A., and McManis, Kenneth, L., "Effects of Storage and Extrusion on Sample Properties," Soil Specimen Preparation for Laboratory Testing, ASTM STP 599, American Society for Testing and Materials, 1976, (in press).

7) Bishop, A. W., and Henkel, D. J., The Measurement of Soil Properties in the Triaxial Test, 2d Edition, Edward Arnolds, Ltd., London, 1962.

8) Buell, Arthur W., "Porosity and Permeability Analysis," in Subsurface Geologic Methods (A Symposium), 1st ed, L. W. LeRoy and Harry M. Crain, Eds., Colorado School of Mines, Golden, CO., 1949, pp. 168-175.

9) Fancher, George H., "The Porosity and Permeability of Elastic Sediments and Rocks," in Subsurface Geologic Methods (A Symposium), 2d ed, L. W. LeRoy, Ed., Colorado School of Mines, Golden, CO., 1950, pp. 685-712.

10) Finn, W. D. Liam, Pickering, Dennison J., and Bransby, Peter L., "Sand Liquefaction in Triaxial and Simple Shear Tests," Journal of the Soil Mechanics and Foundations Division, ASCE, Vol. 97, No. SM4, 1971, pp. 639-659.

11) Franklin, J. A., and Chandra, R., "The Slake-Durability Test," International Journal of Rock Mechanics and Mineral Science, Volume 9, Pergamon Press, 1972, pp. 325-341.

12) Gillott, Jack E., Clay in Engineering Geology, Elsevier, New York, 1968.

538 074

13) Gregory, A. R., "Shear Wave Velocity Measurements of Sedimentary Rock Samples Under Compression," Proceedings, 5th Symposium on Rock Mechanics, University of Minnesota, The McMillan Company, New York, 1963, pp. 439-471.

14) Hardin, B. O., "Suggested Method of Test for Shear Modulus and Damping of Soils by the Resonant Column," Special Procedures for Testing Soil and Rock for Engineering Purposes, ASTM STP 479, American Society for Testing and Materials, Philadelphia, PA., 1970.

15) Heck, W. J., "Development of Equipment for Studying Pore Pressure Effects in Rock," Proceedings, Tenth Symposium on Rock Mechanics, University of Texas at Austin, American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York, 1972, pp. 243-266.

16) Holtz, W. G., "Suggested Method of Test for Permeability of Undisturbed Soil or Rock Specimens," Special Procedures for Testing Soil and Rock for Engineering Purposes, ASTM STP 479, American Society for Testing and Materials, Philadelphia, PA., 1970a, pp. 150-156.

17) Holtz, W. G., "Suggested Method of Test for One-Dimensional Expansion and Uplift Pressure of Clay Soils," Special Procedures for Testing Soil and Rock for Engineering Purposes, ASTM STP 479, American Society for Testing and Materials, Philadelphia, PA., 1970b, pp. 198-205.

18) Hvorslev, M. Juul, Subsurface Exploration and Sampling of Soils for Civil Engineering Purposes, U. S. Army Waterways Experiment Station, Vicksburg, MS., 1949. (Available from the Engineering Foundation, New York).

19) Krinitzsky, E. L., Radiography in the Earth Sciences and Soil Mechanics, Plenum Press, New York, 1970.

20) Lambe, T. W., Soil Testing for Engineers, John Wiley & Sons, Inc., New York, NY., 1951.

21) Mulilis, J. Paul, Chan, C. K., and Seed, H. B., "The Effects of Method of Sample Preparation on the Cyclic Stress Strain Behavior of Sands," Earthquake Engineering Research Center, Report No. EERC 75-18, University of California, Berkeley, CA., Jul 1975.

22) Obert, Leonard, and Duvall, Wilbur, I., Rock Mechanics and the Design of Structures in Rock, John Wiley & Sons Inc., New York, 1967.

23) Perry, E. B., "Piping in Earth Dams Constructed of Dispersive Clay; Literature Review and Design of Laboratory Tests," Technical Report S-75-15, U. S. Army Waterways Experiment Station, Vicksburg, MS., 1975.

24) Schmidt, N. O., "Suggested Method of Test for Organic Carbon Content of Soil by Wet Combustion," Special Procedures for Testing Soil and Rock for Engineering Purposes, American Society for Testing and Materials, STP 479, Philadelphia, 1970.

25) Shannon & Wilson Inc., and Agbabian-Jacobsen Associates, Soil Behavior Under Earthquake Loading Conditions; State-of-the-Art Evaluation of Soil Characteristics for Seismic Response Analyses, Report for U. S. Atomic Energy Commission, 1972.

533 075

26) Sherard, J. L., Dunnigan, L. P., Decker, R. S., and Steele, E. F., "Pinhole Test for Identifying Dispersive Soils," Journal of the Geotechnical Engineering Division, American Society of Civil Engineers, Vol. 102, No. GT 1, 1976, pp. 69-85.

27) Sherard, James L., Dunnigan, Lorn, P., and Decker, Rey, S., "Identification and Nature of Dispersive Soils," Journal of the Geotechnical Engineering Division, ASCE, Vol. 102, No. GT 4, 1976, pp. 287-301.

28) Silver, M. L., "Laboratory Triaxial Testing Procedures to Determine the Cyclic Strength of Soils," Report No. NUREG-31, U. S. Nuclear Regulatory Commission, 1976.

29) Silver, M. L., Chan, C. K., Ladd, R. S., Lee, K. L., Tiedemann, D. A., Townsend, F. C., Valera, J. E., and Wilson, J. H., "Cyclic Triaxial Strength of Standard Test Sand," Journal of the Geotechnical Engineering Division, ASCE, Vol. 102, No. GT 5, 1976, pp. 511-523.

30) Silver, M. L., and Park, T. K., "Testing Procedure Effects on Dynamic Soil Behavior," Journal of the Geotechnical Engineering Division, ASCE, Vol. 101, No. GT 10, 1975, pp. 1061-1083.

31) Silver, M. L. and Seed, H. B., "The Behavior of Sand Under Seismic Loading Conditions," Report No. EERC 69-16, Earthquake Engineering Research Center Berkeley, CA, December 1969.

32) Silver, M. L., and Seed, H. B., "Deformation Characteristics of Sand Under Cyclic Loading," Journal of the Soil Mechanics and Foundations Division, ASCE, Vol. 97, No. SM 8, 1971, pp. 1081-1098.

33) Soil Conservation Service, Soil Survey Laboratory Methods and Procedures for Collecting Soil Samples, Soil Survey Investigations Report No. 1, U. S. Soil Conservation Service, Washington, D. C., 1967.

34) Thiers, G. R., and Seed, H. B., "Cyclic Stress-Strain Characteristics of Clay," Journal of the Soil Mechanics and Foundations Division, ASCE, Vol. 94, No. SM 2, 1968, pp. 555-569.

35) U. S. Army Engineer Manual EM 1110-2-1906, Laboratory Soils Testing, Headquarters, Department of the Army, Office, Chief of Engineers, Washington, D. C., 30 Nov 1970.

36) U. S. Army Engineer Manual EM 1110-2-1909, Calibration of Laboratory Soils Testing Equipment, Headquarters, Department of the Army, Office, Chief of Engineers, Washington, D. C., 1 Dec 1970.

37) Warshaw, C. M., and Roy, R., "Classification and a Scheme for the Identification of Layer Silicates," Bulletin of the Geological Society of America, Vol. 72, pp. 1455-1492, 1961.

538 076

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Franklin, Arley G

Proposed guidelines for laboratory testing of geological materials for nuclear power facilities / by Arley G. Franklin and William F. Marcuson III. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1979.

23, [13] p. : ill. ; 27 cm. (Miscellaneous paper - U. S. Army Engineer Waterways Experiment Station ; GL-79-9)

Prepared for U. S. Nuclear Regulatory Commission, Washington, D. C., under Contract No. AT(49-24)-0126.

Appendix C: References.

1. Nuclear power plants. 2. Soil mechanics. 3. Rock mechanics. 4. Laboratory tests. I. Marcuson, William Frederick, joint author. II. United States. Nuclear Regulatory Commission. III. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Miscellaneous paper ; GL-79-9.

TA7.W34m no.GL-79-9