UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

PDR

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MEMORANDUM FOR: Robert B. Minogue, Director
Office of Standards Development

FROM: Saul Levine, Director
Office of Nuclear Regulatory Research

SUBJECT: RESEARCH INFORMATION LETTER NO. 41
LABORATORY TESTING PROCEDURES TO DETERMINE
THE CYCLIC STRENGTH OF SOILS

I. INTRODUCTION

Definition(1)

"In a few localities (water satured) fine sands have been encountered which are so loose that a slight disturbance such as a mild shock causes an important decrease in volume... and the sand flows like a viscous fluid. This phenomenon is known as spontaneous liquefaction." In this paper, spontaneous liquefaction, cyclic strength of soils, and liquefaction potential are synonomous. Appendix A, 10CFR Part 100 requires consideration of liquefaction potential in soil foundations.

Enclosed is NUREG-0031, "Laboratory Triaxial Testing Procedures to Determine the Cyclic Strength of Soil." The research program to produce this report was conducted by the Department of Materials Engineering, University of Chicago, under the direction of Prof. Marshall L. Silver. This program was initiated in response to a memorandum dated December 4, 1973, to T. A. Nemzek, Director, RRD, from L. Rogers, Director of Regulatory Standards.

Widely varying results were being obtained in testing soils for liquefaction potential (cyclic strength of soils) because standard test procedures did not exist. Hence, the subject study was conducted in response to the recognition of this fact, and because standard procedures are needed for nuclear power plant site investigations. The research program was conducted in conjunction with development of ASTM Performance Specifications.

The research results (NUREG-0031) were used in developing Regulatory Guide 1.138, "Laboratory Investigations of Soils for Engineering Analysis and Design of Nuclear Power Plants," and will be a basis for

(1) Soil Mechanics in Engineering Practice, K. Terzaghi and R. B. Peck. pp. 108.

a National Standard on cyclic triaxial testing. Thus, NUREG-0031 will probably be the principal reference for industry on cyclic triaxial testing. Additionally, it will help to expedite the licensing review of nuclear power plant applications.

The need for standard soil liquefaction test procedures has long been recognized by the geotechnical engineering profession, the U.S. Nuclear Regulatory Commission and the American Society for Testing Materials (ASTM). An NRC funded ASTM research group, directed by Prof. Silver, produced the results presented in NUREG-0031 which concluded that: "the cyclic strength characteristics of cohesionless soils may be evaluated by cyclic stress-controlled triaxial strength tests provided appropriate corrections are made for differences between the laboratory and field stress deformation conditions."

Additionally, the report (NUREG-0031) presents guidelines to ensure that:

1. test equipment has adequate dynamic characteristics,
2. soil specimens are properly prepared, and
3. testing techniques are compatible between various soil laboratories.

II. DISCUSSION

Major soil mechanics laboratories throughout the world were contacted to determine their testing methods and to evaluate the cyclic triaxial equipment in use. This information provided a basis to develop the test procedures for stress-controlled cyclic triaxial strength tests presented as a performance specification so that a geotechnical testing laboratory can:

1. Ensure that its test equipment and procedures meet required standards.
2. Check that results agree reasonably with results obtained by other laboratories.

Experienced private, university, and government soil mechanics laboratories conducted a series of controlled tests on a standard sand that provided data which can be used by any soil laboratory to verify that its test results are meaningful.

Behavior of soil deposits during earthquakes is described and compared to results simulated by laboratory soil test procedures. Specifications are presented to ensure that laboratory equipment meets the standards required for cyclic triaxial testing. Measurement and recording methods are specified. Methods of sample preparation and data reduction are also described, and finally, minimum standards for data presentation and interpretation are prescribed. Using the guidelines presented makes it possible for any laboratory to verify that its test results are meaningful.

III. RESULTS

Research results present recommended procedures for liquefaction potential testing by use of state-of-the-art testing techniques as a performance specification.

Equipment specifications developed ensure that a soil laboratory's equipment meets the standards required for dynamic soil testing. It was found that proper care avoids the effects of what are often considered to be minor details in specimen preparation and testing; the degree of agreement for the cyclic strength of the test sand was reasonable for several different failure criteria.

It was found that severe square wave forms and sinusoidal wave forms during load application gave cyclic strength values different by about 15% for the test sand. In general, the more abrupt the change in wave form and the longer the maximum load is applied to the specimen, the lower the measured cyclic strength of the soil. It is, therefore, recommended that a sine wave be used for cyclic strength testing of sands.

Great care must be taken when measuring the dimensions of the test specimen if accurate dry unit weights are to be calculated and reproducible results are to be achieved. In general, specimen dry unit weights must be held within plus or minus 8 kg/m^3 (0.5 lb/ft^3) to correlate with the test results presented in this report.

It was confirmed that specimen preparation techniques are critical when trying to reproduce cyclic strength test results and that it is necessary to closely follow the test procedure used in this research in order to obtain the values of cyclic soil strength reported in this report. For convenience, a wet tamping technique was chosen for use in this cooperative test program to ensure uniformity among the various laboratories participating in this research.

IV. RECOMMENDATIONS

It is recommended that NUREG-0031 be used as guidelines by the Office of Standards Development in development of applicable regulations and regulatory guides, by the Office of Nuclear Reactor Regulation to assist in the review of nuclear power plant operating applications, and by the applicant as a standard in the assessment of liquefaction potential of foundation soils at nuclear power plant sites.

Technical questions related to NUREG-0031 results may be directed to Dr. Jerry Harbour at 427-4370.

Original Signed by
Saul Levine

Saul Levine, Director
Office of Nuclear Regulatory Research

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