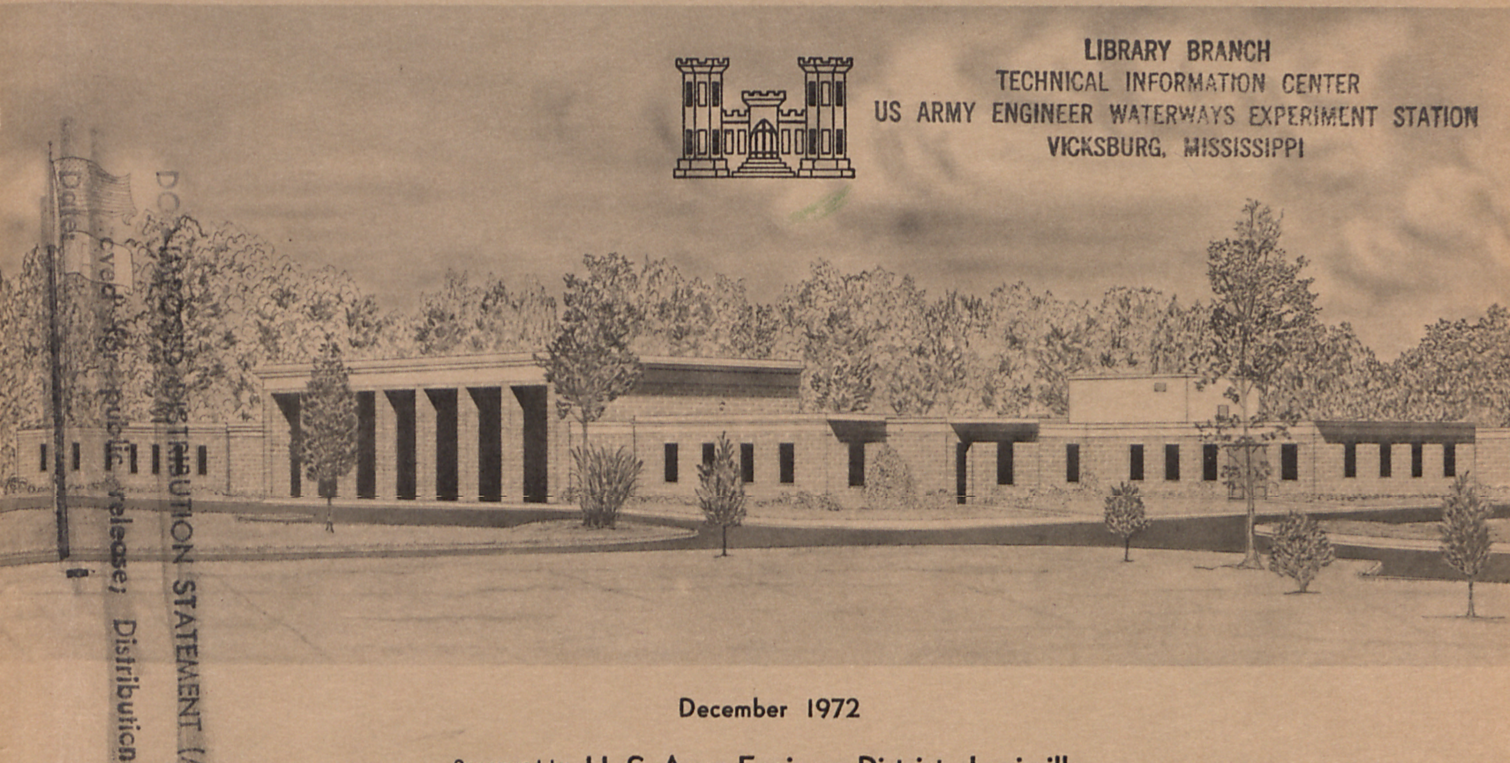
AD 921 576

MISCELLANEOUS PAPER S-72-42

EARTHQUAKE LIQUEFACTION POTENTIAL AT PATOKA DAM, INDIANA

by

W. F. Marcuson III, P. A. Gilbert



December 1972

Sponsored by U. S. Army Engineer District, Louisville

Conducted by U. S. Army Engineer Waterways Experiment Station
Soils and Pavements Laboratory
Vicksburg, Mississippi

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

WES Miscellaneous Paper No. S-72-42

Earthquake Liquefaction Potential at Patoka Dam, Indiana, by
W.F. Marcuson III, and P.A. Gilbert

This publication originally was Statement B.

It has been changed to Statement A. This is in accordance with a telephone conversation between Marie Spivey and Bill Marcuson. Mr. Marcuson stated that the distribution statement had been changed, the authority being Chief/ Earthquake Engineering and Vibration Division in accordance with concurrence of Chief/Foundations and Materials Branch, Louisville District, CE.

Marie Spivey
17 Oct 1974

"Approved for Public Release; Distribution Unlimited" in Dec 1972

MISCELLANEOUS PAPER S-72-42

EARTHQUAKE LIQUEFACTION POTENTIAL AT PATOKA DAM, INDIANA

by

W. F. Marcuson III, P. A. Gilbert

December 1972

Sponsored by U. S. Army Engineer District, Louisville

Conducted by U. S. Army Engineer Waterways Experiment Station
Soils and Pavements Laboratory
Vicksburg, Mississippi

ARMY-MRC VICKSBURG, MISS.

FOREWORD

The study reported herein was performed by the U. S. Army Engineer Waterways Experiment Station (WES) at the request of the U. S. Army Corps of Engineers District, Louisville, and was authorized in Intra-Army Order No. DC-B-72-105 dated 10 March 1972.

The engineers of the WES who were actively engaged in this study were Drs. F. C. Townsend and W. F. Marcuson III and Mr. P. A. Gilbert. The work was conducted under the general supervision of Messrs. R. W. Cunny, Chief, Soil Dynamics Branch, and R. G. Ahlvin and J. P. Sale, Assistant Chief and Chief, respectively, Soils and Pavements Laboratory. This report was reviewed by Mr. S. J. Johnson, Special Assistant, Soils and Pavements Laboratory.

During the time this study was conducted, COL Ernest D. Peixotto, CE, and Mr. F. R. Brown were Director and Technical Director, respectively, of the WES.

CONTENTS

CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
inches	2.54	centimeters
feet	0.3048	meters
miles (U. S. statute)	1.609344	kilometers
pounds	0.45359237	kilograms
pounds per square inch	0.689476	newtons per square centimeter
pounds per cubic inch	27679.91	kilograms per cubic meter
pounds per cubic foot	16.01846	kilograms per cubic meter
acre-feet	1233.482	cubic meters

SUMMARY

A preliminary exploration of the damsite revealed foundation materials with extremely low penetration resistance. The site is in a seismic Zone 2 (Algermissen) and near the border of a seismic Zone 3. Consequently, a laboratory study was conducted to evaluate the liquefaction potential of the foundation materials when subjected to an earthquake.

To evaluate the liquefaction potential, undisturbed samples of the foundation soils were obtained using a fixed-piston sampler and drilling mud. The materials were found to be fine clayey sands, fine silty sands, fine sandy clays, and silty clays. The in situ dry density was determined to range from 88 to 104 pcf in the depths considered to be critical in regard to liquefaction potential.

Cyclic triaxial tests were conducted on material representative of the five depths that were anticipated to be subject to liquefaction. Based on the results of these tests, the foundation is expected to liquefy if subjected to an earthquake of magnitude 6.5 with a peak acceleration of 0.17 g or greater.

Logs of borings are given in Appendix A. A simplified procedure for evaluating liquefaction potential is given in Appendix B.

EARTHQUAKE LIQUEFACTION POTENTIAL AT PATOKA DAM, INDIANA

PART I: INTRODUCTION

Background

1. The U. S. Army Engineer District, Louisville, is designing a dam on Patoka River in south-central Indiana, which will form Patoka Lake (see fig. 1). The damsite is 13 miles* northeast of Jasper, Indiana, and about 55 miles northwest of Louisville, Kentucky. The purposes of the dam are to furnish flood protection in the Patoka and Wabash River valleys and to reduce Wabash River flood stages downstream where it joins the Ohio River.

2. The reservoir is designed to store 301,640 acre-ft of water with a pool elevation of 548.** The proposed dam is to be constructed of earth and rock fill with a crest elevation of 566, a maximum height of 86 ft, and a length of 1500 ft.

3. The dam will be founded on fairly weak alluvial and lacustrine clays, silts, and sands. Brown sandy clay to sandy silt comprises the top 10 to 15 ft of overburden in the Patoka River valley. Gray silty sand and sandy silts occur immediately below this layer and range in thickness from 5 to 40 ft. Below the silty sand is an 11- to 21-ft layer of gray silty clay to clayey sandy silt. With the exception of the top 4 to 10 ft, all of the underlying material is saturated, due to a high groundwater table in the valley. Bedrock (highly weathered to friable sandstone) is buried beneath at least 60 ft of overburden at the damsite.

Purpose and Scope

4. A preliminary exploration of the damsite indicated foundation

---

* A table of factors for converting British units of measurement to metric units is presented on page vii.

** All elevations (el) cited herein are in feet referred to mean sea level.

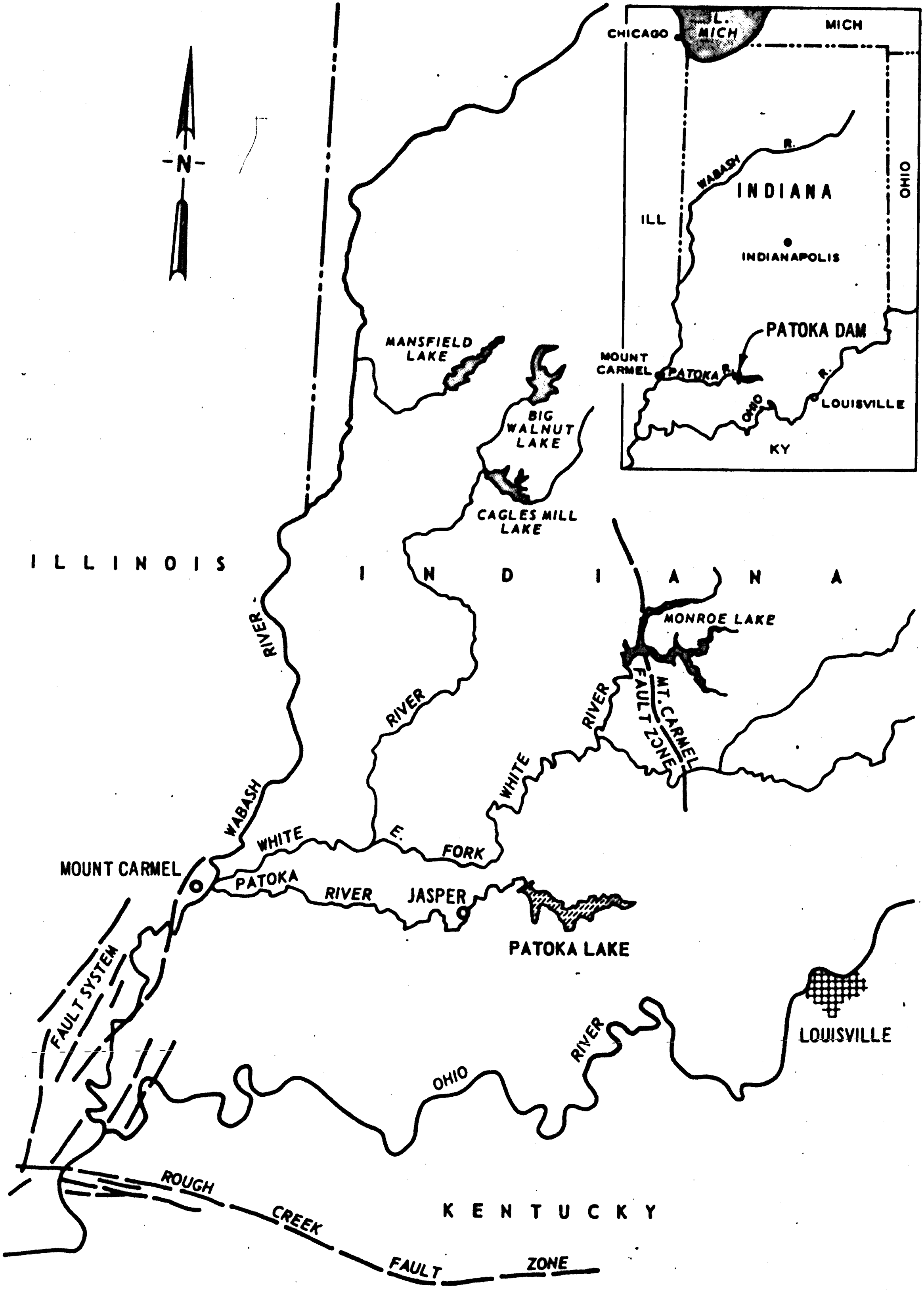


Fig. 1. Location of Patoka damsite

materials of remarkably low penetration resistance values. Since the damsite is located in an area classified by Algermissen[1] as seismic Zone 2 and is fairly close to a Zone 3 border, the U. S. Army Engineer Waterways Experiment Station (WES) was asked to evaluate the liquefaction potential of the foundation materials should they be subjected to earthquake excitation. A limited number of undisturbed samples were obtained from the foundation material at the site, and various laboratory tests, including mechanical analysis, classification indexes, density, and cyclic triaxial tests were conducted on the samples to evaluate the liquefaction potential of the Patoka damsite foundation materials under earthquake loadings.

PART II: SOIL SAMPLING

Initial Boring Program

Field investigation

5. The Louisville District engaged a contractor to drill two borings, S-1001 and SD-1002, on the downstream side of the proposed dam, and two borings, D-1003 and S-1004, on the upstream side of the proposed dam to obtain the samples for investigating the liquefaction potential of the foundation material. These borings were drilled at sta 9+00 (fig. 2). Undisturbed samples were taken using a piston (not fixed) sampler, and both ends of each sample were sealed with wax. These samples were to be used by WES for laboratory testing. Logs of the borings are presented in Appendix A.

6. Boring S-1001. This boring was drilled to refusal at an elevation of 424, which corresponds to a depth of 67.5 ft. The elevation of the top of the hole was 491.5 and the groundwater table was at el 488.4 on 11 Jan 1972. Shelby tube samples 36 in. in length and 3 in. in diameter were taken continuously when possible.

7. Boring SD-1002. This boring was drilled to refusal at an elevation of 427, which corresponds to a depth of 64.4 ft. The elevation of the top of the hole was 491.4. The groundwater table was at an approximate elevation of 488 at the time of this investigation. Standard penetration tests were conducted continuously to a depth of 50 ft. Below a depth of 50 ft, Shelby tube samples 36 in. in length and 3 in. in diameter were taken when possible. The N-values determined by the standard penetration tests* were extremely low, with values of 2 occasionally reported. These values are shown in fig. 3; other data shown in this figure will be discussed subsequently. The low N-values suggest that the in situ material has a low relative density.

8. Boring D-1003. This boring was drilled to refusal at an

---

* An N-value is the number of blows of a 140-lb hammer falling 30 in. required to drive a split-spoon sampler the last 12 in. of an 18-in. drive.

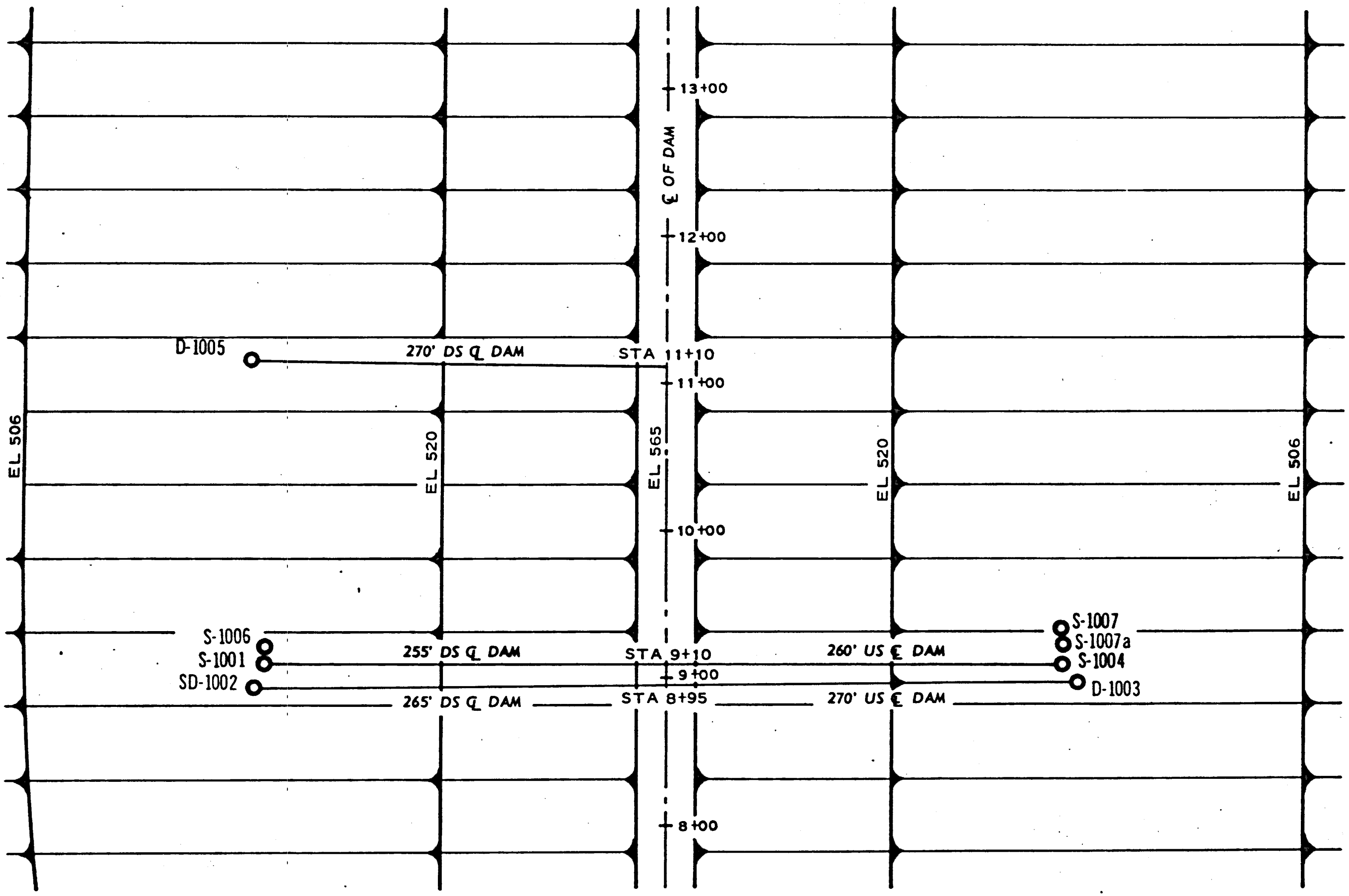


Fig. 2. Locations of borings

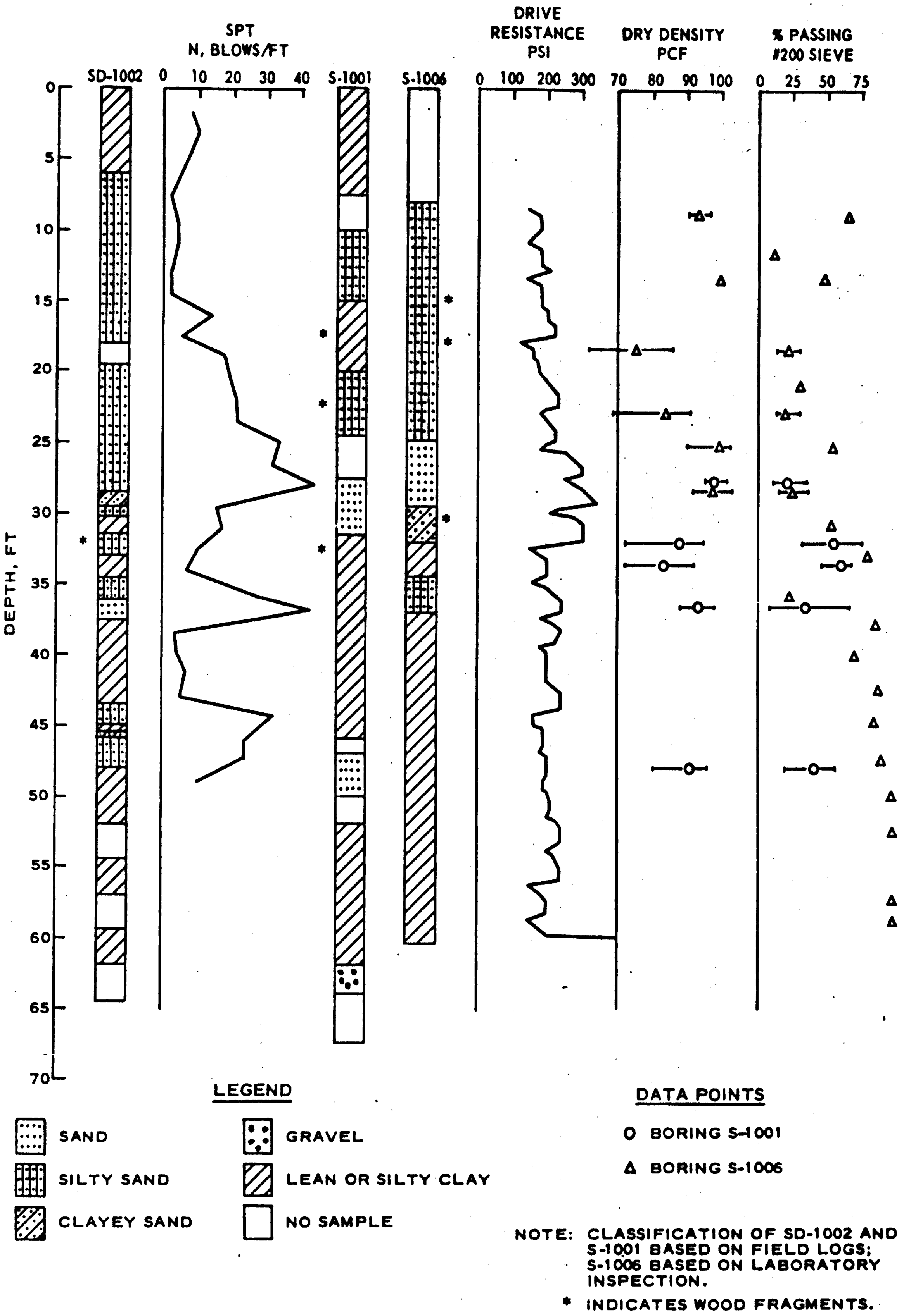


Fig. 3. Soil classification, penetration resistance, density, and percent passing No. 200 sieve for borings SD-1002, S-1001, and S-1006

elevation of 426, which corresponds to a depth of 63 ft. The elevation of the top of the hole was 489. Standard penetration tests were conducted continuously for the depth of the hole. The N-values were extremely low, varying from 2 to 19 blows per ft. These low N-values suggest that the in situ soil has a low relative density. The N-values versus depth for boring D-1003 are presented in fig. 4. Also shown in this figure are other data which will be discussed later.

9. Boring S-1004. This boring was drilled to refusal at an elevation of 425, which corresponds to a depth of 64 ft. The elevation at the top of the hole was 489 and the groundwater table was at el 456 on 22 Mar 1972. Shelby tube samples 36 in. in length and 3 in. in diameter were taken continuously when possible.

Laboratory examination

10. Based upon the N-values obtained from borings SD-1002 and D-1003 and upon the driller's descriptions of the samples, the following samples were determined to be composed predominantly of sand with little or no fines and were believed to have low relative densities.

Boring No.	Sample No.	Boring No.	Sample No.
S-1001	11	S-1004	4
	12		5
	13		6
	14		
	18		

11. These samples were X-rayed to determine sample disturbance and variation of density of material within the sample. If one assumes a uniform thickness of homogeneous material, then any variation in film density (darkness of X-ray) is proportional to the variation in material density. If the material is layered and if these layers show up distinctly across the sample as well as at the sample edge, it can be concluded that little sampling disturbance has occurred. The converse of this principle is also true.

12. Fig. 5 is a radiograph of sample 13 from boring S-1001 and is considered typical. The bottom 2 ft of the sample were lost when the

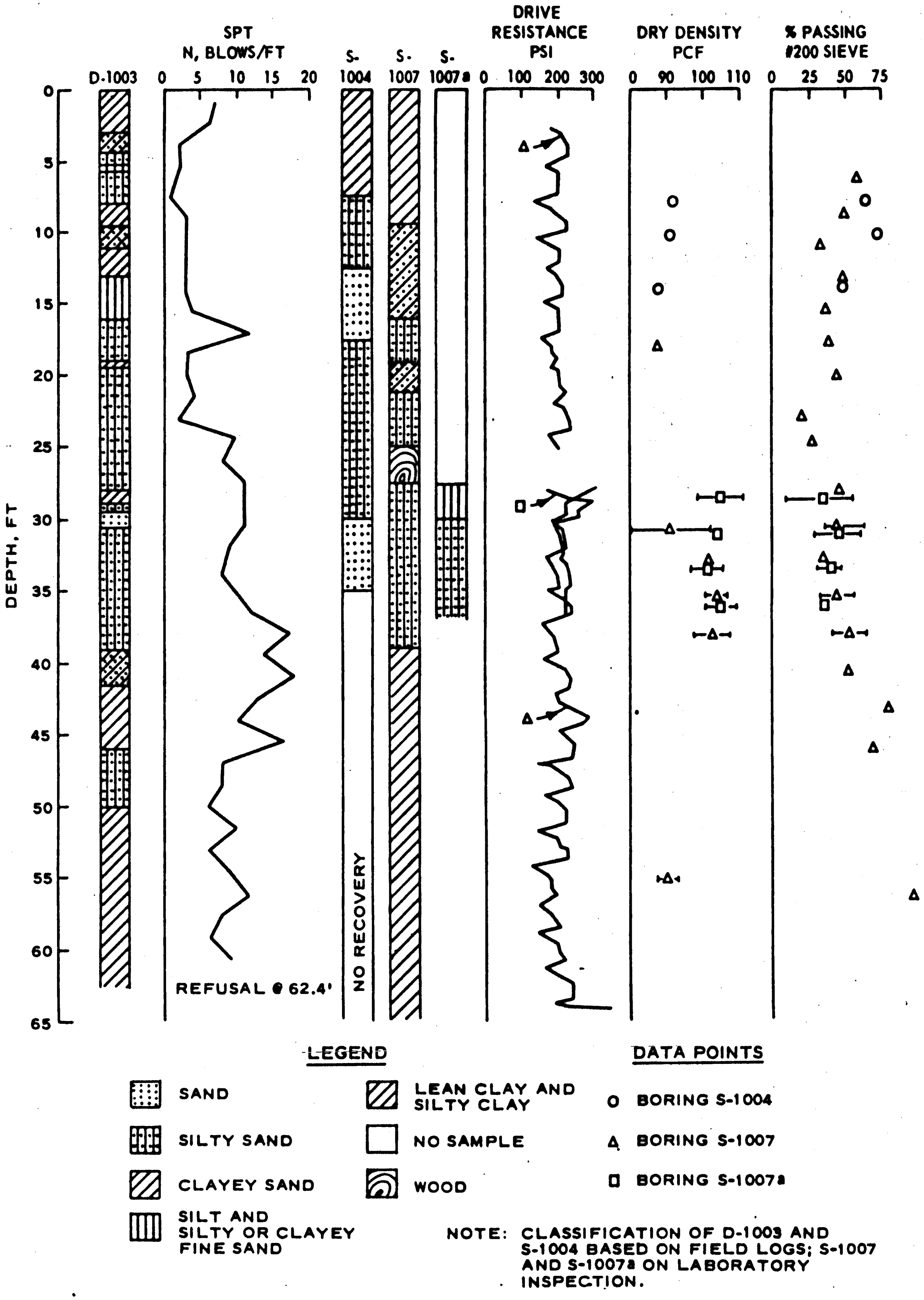


Fig. 4. Soil classification, penetration resistance, density, and percent passing No. 200 sieve for borings D-1003, S-1004, S-1007, and S-1007a

Fig. 5. Radiograph of sample 13, boring S-1001

tube was removed from the hole; the light area in the top two-thirds of the tube shows the evidence of the void. The top of the sample was obviously disturbed, as indicated by the swirls in the radiograph. The remaining portions of the specimen appear undisturbed. Based on the radiograph, the sample was cut into three segments, 13-1, -2, and -3, as shown on the side of the radiograph.

13. Even though examination of the radiographs indicated that all samples appeared to be considerably disturbed, the samples were cut into various segments as dictated by the radiographs, and density and gradation tests were conducted on each segment. The dry density and percent (by weight) passing the No. 200 sieve for samples 11, 12, 13, 14, and 18 of boring S-1001 and samples 4, 5, and 6 of boring S-1004 are shown in figs. 3 and 4, respectively. Fig. 3 shows that organic matter (wood) was encountered in boring S-1001 at approximately 32 ft. The dry density varies from about 100 pcf at 29 ft to 80 pcf at 48 ft, with a large portion of the foundation area at a dry density of around 95 pcf. The data in fig. 4 show less scatter than in fig. 3, and show a lower density in the upper 15 ft than in boring S-1001. These samples would indicate an in situ dry density of approximately 90 pcf for the upper layers of material.

14. Fig. 6 shows the range of the gradation curves from samples 11, 12, 13, 14, and 18 from boring S-1001 and samples 4, 5, and 6 from boring S-1004. These plots indicate that the percent (by weight) finer than the No. 200 sieve varied from 7% to 76%. The majority of these specimens had more than 20 percent fines. Two segments were determined to be fine sand (SP-SM). These were samples 11-3 and 14-4 of boring S-1001, which had D_{50} of 0.16 and 0.25 mm, respectively. All other segments were either sandy clay (CL), sandy silt (ML), silty sand (SM), or clayey sand (SC).

Additional Boring Program

Field investigation

15. Because the first borings had extremely low N-values and

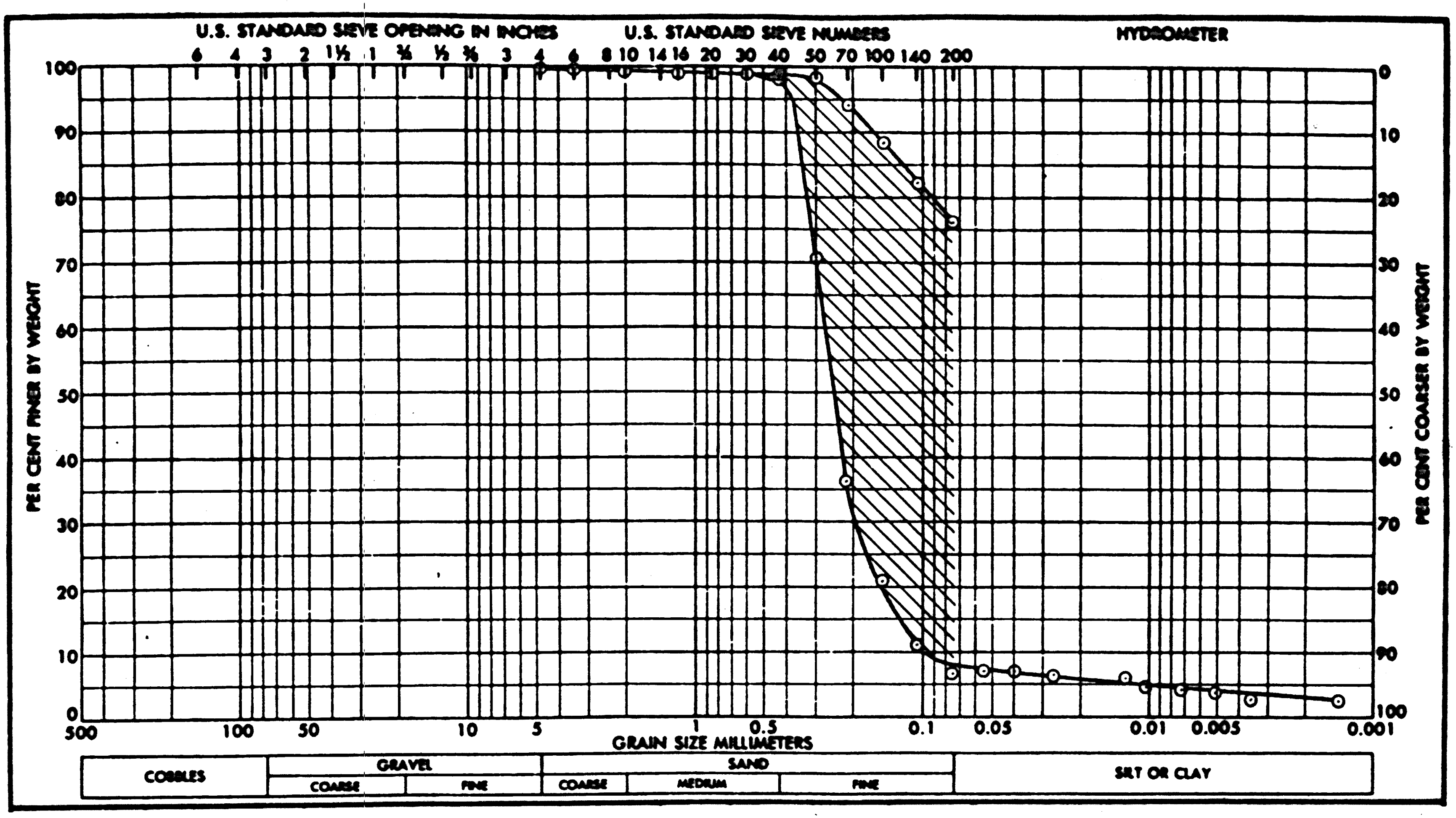


Fig. 6. Range of gradation curves for borings S-1001 and S-1004

because sample disturbance was suspected, three more borings were drilled by personnel of the Louisville District. At the request of the Louisville District, Mr. Kearney Waites, an experienced WES driller, assisted in the sampling operations. Boring S-1006 was drilled in the same area as borings S-1001 and SD-1002; borings S-1007 and S-1007a were near boring locations S-1004 and SD-1003. Boring logs are presented in Appendix A, figs. A5-A7.

16. Sampling techniques. The 3-in.-diam undisturbed samples were taken using the technique and procedures described in reference 2. A fixed-piston sampler and drilling mud are used in the technique. Hydraulic pressure was used to push the sampler and was recorded as average drive pressure for each 6-in. increment. A perforated, expanding packer was inserted at the bottom of the sample immediately after the tube was lifted clear of the drilling mud in the borehole. The sampler head and piston were removed, and the sample was placed in a rack, pinned to prevent rotation, and held in a vertical position until it was properly drained. Then an expanding packer was inserted on the top of the sample. The sample and the rack were next rotated 90 deg and held in a horizontal position. With the sample in this position, the top side was then struck approximately 50 light blows with a hammer. This consolidated the sand and thus prevented possible movement of loose samples of sand in the tube during transportation. Once in the laboratory, the tubes were X-rayed, cut into segments, and the density of each segment was determined. This procedure assumed that the volume of the tube segment was the in situ volume of the sand which was inside the tube segment.

17. Boring S-1006. This boring was drilled to refusal at a depth of 60 ft. Continuous Shelby tube samples 36 in. in length and 3 in. in diameter were taken when possible. Average drive pressure versus depth for boring S-1006 is shown in fig. 3. This plot can be compared with the penetration resistances from boring SD-1002 which is also shown in fig. 3. Both borings exhibited a drop in penetration resistance at depths of approximately 18, 33, and 44 ft and an increase in resistance at a depth of about 30 ft.

18. Borings S-1007 and S-1007a. Boring S-1007 was drilled to refusal at a depth of 64 ft. When possible, Shelby tube samples 36 in. in length and 3 in. in diameter were taken using the fixed-piston sampler. Fig. A6, the boring log, shows that it was not possible to obtain 36-in.-long samples from depths of 27 to 40 ft using the standard Shelby tube sampler. Therefore, core catchers consisting of six or eight spring steel fingers were fashioned in the field and boring S-1007a was drilled adjacent S-1007 (see fig. 2). Samples were obtained between depths of 27 and 37 ft, by using the modified Shelby tube. Fig. A7 is the boring log for this hole. Average drive pressure versus depth for borings S-1007 and S-1007a are shown in fig. 4. This plot can be compared with the penetration resistances from boring D-1003 which is also shown in fig. 4.

Laboratory examination

19. Based on the driller's description of the soil and on the pressure required to push the sampler (obtained from boring logs), samples 5-7, 9-23, 25, and 26 of boring S-1006; samples 2-10, 12-24, 26, and 27 of boring S-1007; and samples 1-4 of boring S-1007a were opened. A sample of the soil was removed from each and the packers were replaced in the 36-in.-long, 3-in.-diam tubes after the sample was removed. Each sample was subdivided so that a number of laboratory tests could be performed. The sample was first visually classified. This information is presented in table 1. Sieve analyses were also conducted on these samples and percent (by weight) finer than the No. 200 sieve is also given in table 1.

20. Available information, such as visual classification, grain-size curves, and drive pressure values, was studied and it was decided to conduct Atterberg limit tests on samples 5, 6, 7, and 20 of boring S-1006 and samples 7, 8, 23, and 24 of boring S-1007. Plasticity index data are also presented in table 1. After reviewing the additional plasticity index information, it was decided to determine the in situ dry density of the following samples: 5, 7, 9, 11, 12, and 13 from boring S-1006; 7, 13, 14, 15, 16, and 23 from boring S-1007; and 1, 2, 3, and 4 from boring S-1007a.

21. Several of these samples were X-rayed prior to cutting open the tubes to determine if the samples were disturbed or stratified. Stratified samples were cut according to the stratifications indicated by the radiographs. Fig. 7 is the radiograph of sample 16 from boring S-1007 and is considered to be typical. Based on the radiographs, the samples were cut in approximately 3-in. segments and density tests and sieve analyses were conducted. In situ dry density was determined in this manner for samples 9, 11, 12, and 13 from boring S-1006; samples 12, 13, 14, 15, and 16 from boring S-1007; and samples 1, 2, 3, and 4 from boring S-1007a. Fig. 8 presents density versus depth data for borings S-1006, S-1007, and S-1007a. The incremental density data are also shown in table 2. The in situ dry density was also determined for samples 5 and 7 from boring S-1006 and samples 7 and 23 from boring S-1007. These dry density values are listed in table 1. Because sample 5 from boring S-1006 and samples 7 and 23 from boring S-1007 exhibited low density values (see table 1), these tubes were cut into 6-in. increments and dry density was determined. These data are also given in table 2.

Selection of Potential Liquefaction-Susceptible Zones

22. With this portion of the investigation completed, five zones in the foundation were selected as probably the most susceptible to liquefaction. The five zones are described below.

a. A 9-ft-deep layer represented by sample 5 from boring S-1006. The in situ dry density of this material was estimated to be 92 pcf. This material was selected because it was nonplastic; it had a fairly low density; and the drive pressure in the sample area was low.

b. A 17.5-ft-deep layer represented by sample 7 from boring S-1007. The in situ dry density of this material was estimated to be 88 pcf. This material was chosen because it was nonplastic; it had a very low density; and the drive pressure in the sample area was low.

c. A 28-ft-deep layer represented by sample 13 from boring S-1006. The in situ dry density of this material was estimated to be 98 pcf. This material was chosen because it appeared to be a fine sand similar in grain size to sands that have liquefied in the past.

d. A nominal 33-ft-deep layer composed of various increments of samples obtained from borings S-1007 and S-1007a. To obtain this material, a plot of unit dry weight versus percent passing No. 200 sieve (fig. 9) was made for the segments of samples from this approximate depth. Material from every sample plotting inside and on the perimeter of the polygon in the upper right in fig. 9 was combined to form the 33-ft sample. The dry density of this material was estimated to be 104 pcf. This material was picked because it was extremely difficult to obtain an undisturbed sample; the WES driller said that this was the softest material he had seen in 25 years of drilling.

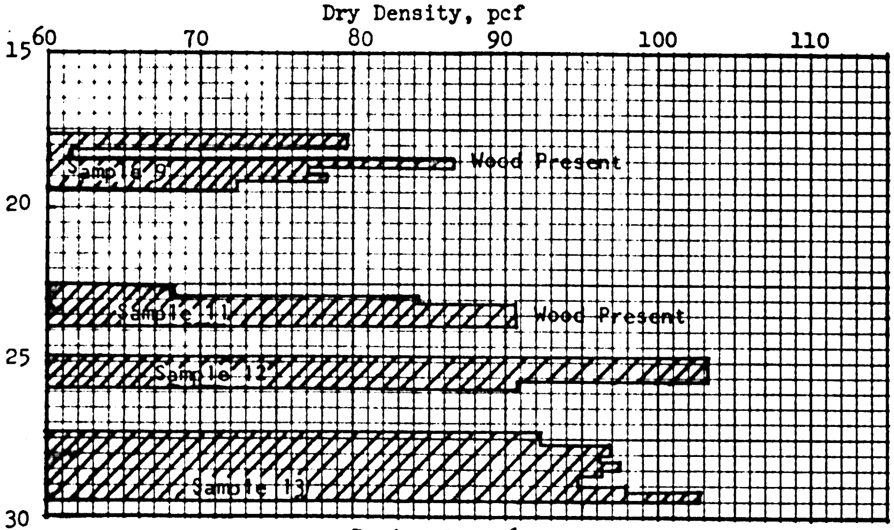
e. A 55-ft-deep layer represented by sample 23 from boring S-1007. The in situ dry density of this material was estimated to be 90 pcf. This material was chosen because of the extremely low drive pressure required to obtain the sample and the low N-values obtained in the sampling area. It is interesting to note that the soil at this depth in boring S-1001 poured from the tube as it came out of the drill hole. However, boring S-1006, which was drilled beside boring S-1001, did not show this soft material.

23. Grain-size curves for each of these five materials are shown in fig. 10. From the field and laboratory data, a soil profile at sta 9+00 was prepared (fig. 11). The locations of the five materials that were determined to be most susceptible to liquefaction are shown in this plot.

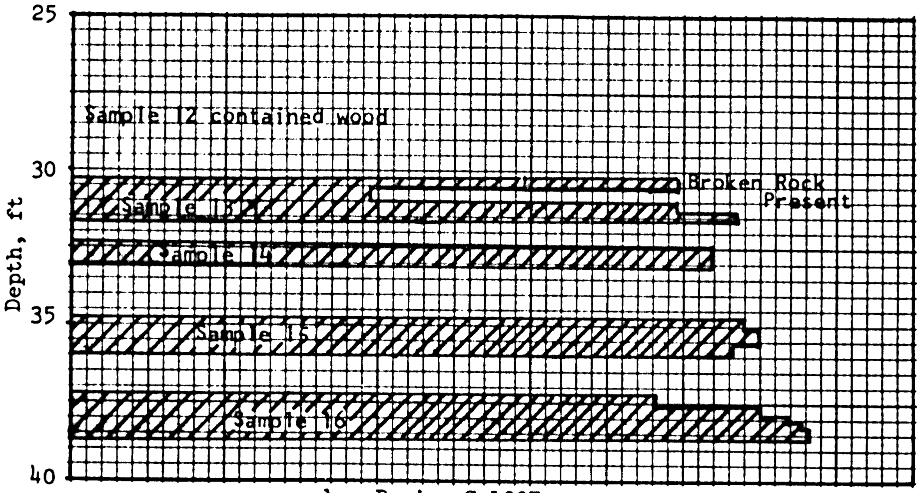
24. For this study relative density was not used because absolute in situ dry density was determined directly. However, the maximum and minimum densities were determined for some of the samples from the depths considered to be susceptible to liquefaction. The tests were performed using a vibratory table to determine maximum dry density ($\gamma_{d\ max}$) with the following results:

Material Depth ft	Dry Density, pcf	
	$\gamma_{d\ min}$	$\gamma_{d\ max}$
17.5	79	---
28	82.4	--
33	81	112

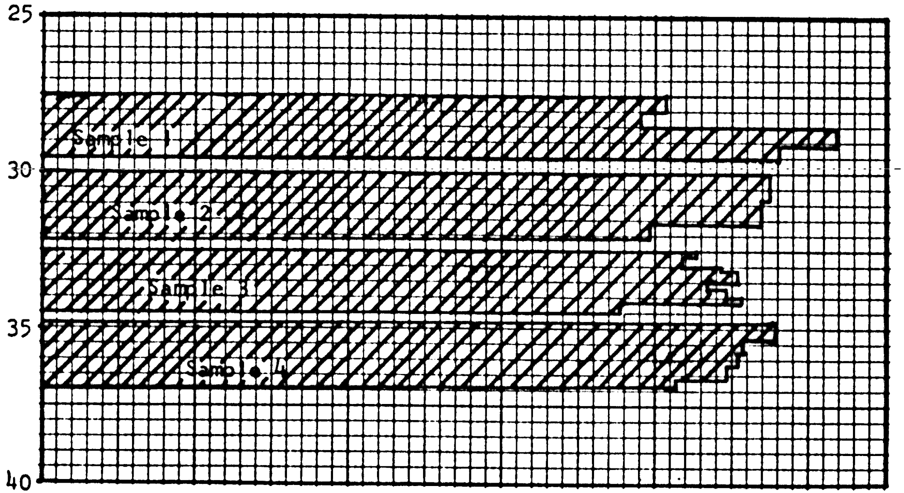
Fig. 7. Radiograph of sample 16, boring S-1007



a. Boring S-1006



b. Boring S-1007



c. Boring S-1007a

Fig. 8. In situ dry density versus depth for borings S-1006, S-1007, and S-1007a

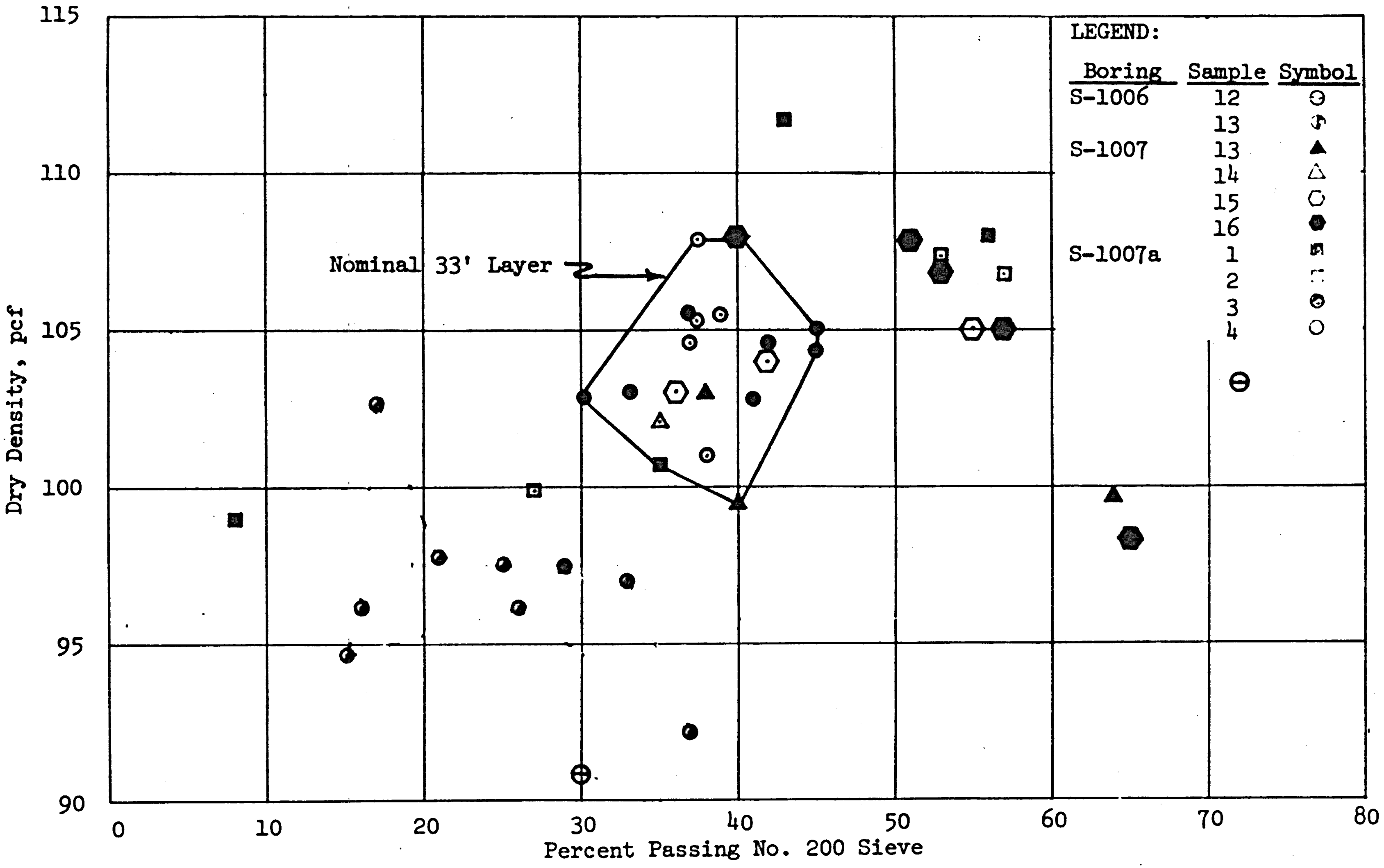
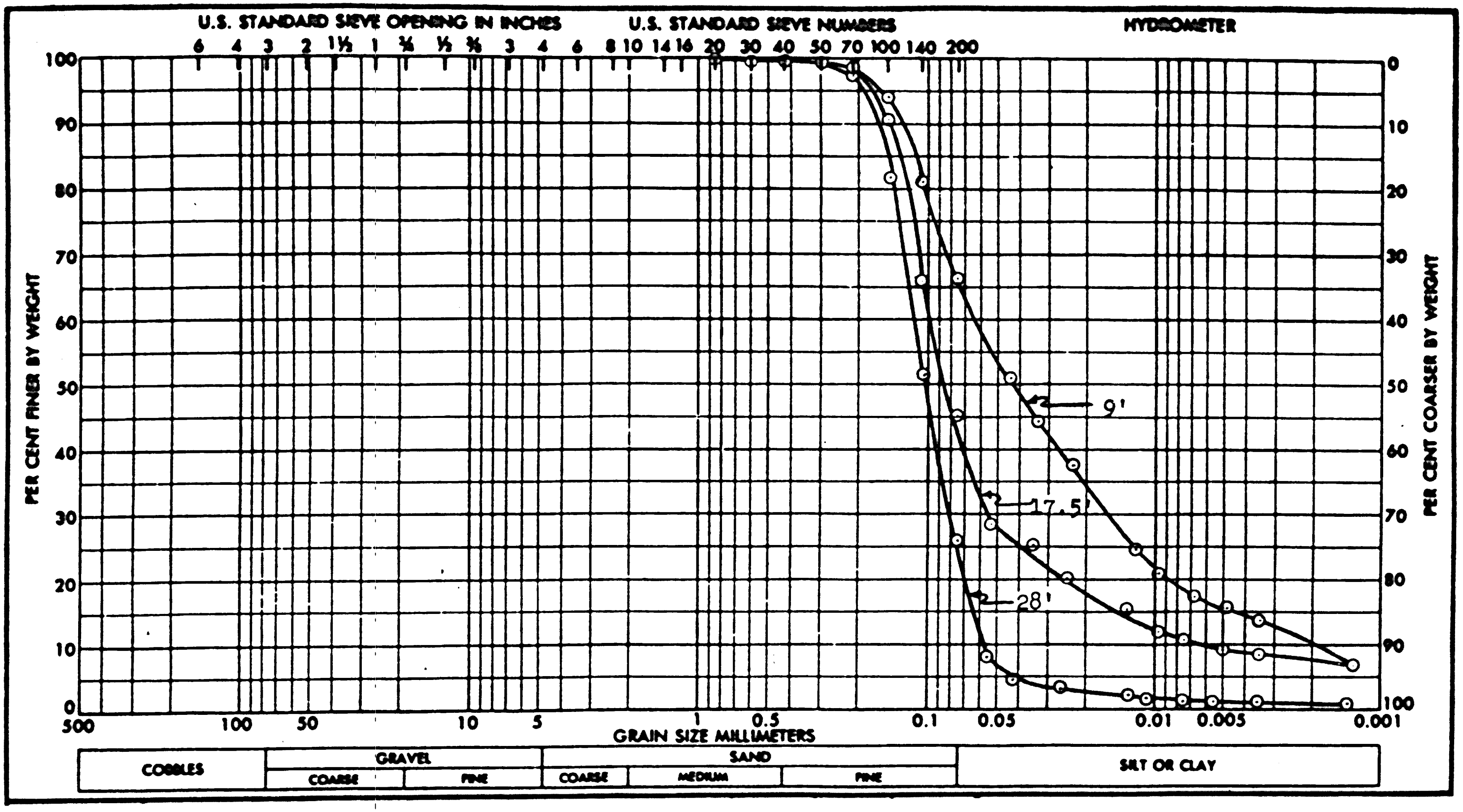
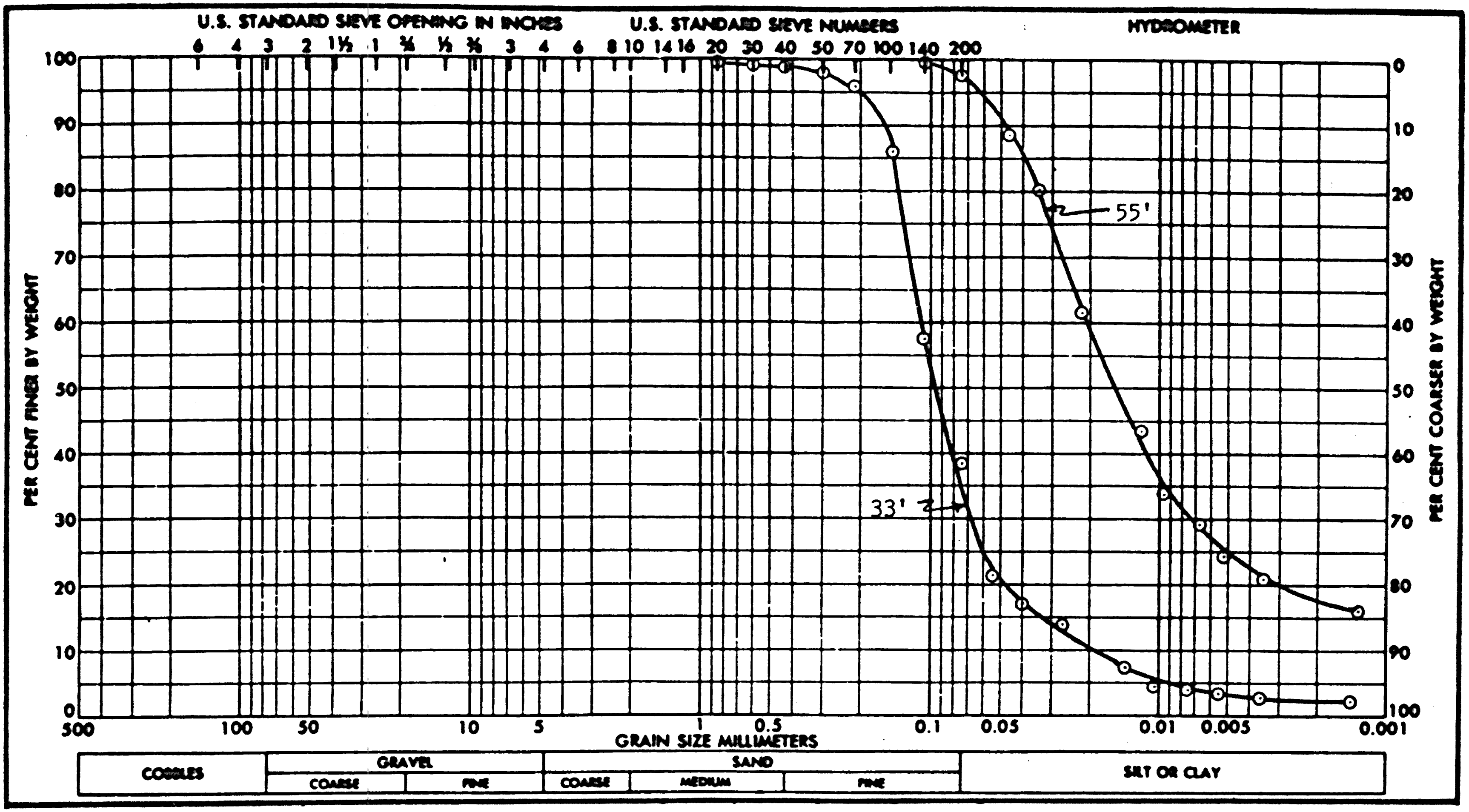


Fig. 9. Dry density versus percent passing No. 200 sieve



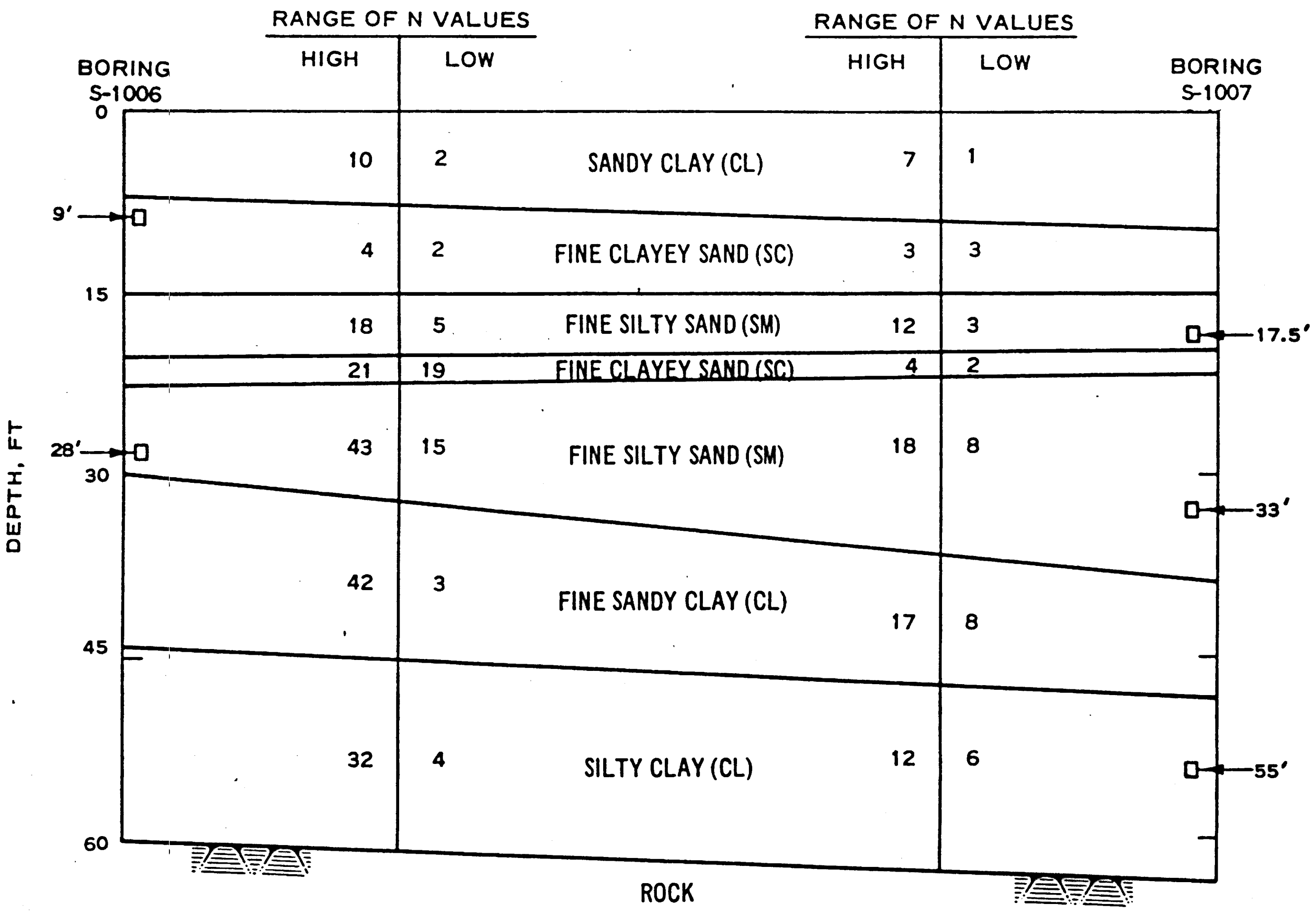
a. 9-, 17.5-, and 28-ft depths

Fig. 10. Grain-size curves for foundation materials selected as probably susceptible to liquefaction (sheet 1 of 2)



b. 33- and 55-ft depths

Fig. 10. (sheet 2 of 2)



BLOW COUNTS OBTAINED FROM ADJACENT BORINGS

Fig. 11. Soil profile at sta 9+00

Compaction tests were performed on the 17.5- 28-, and 33-ft material. For these tests, the samples were compacted inside a 2-in.-diam, 4-in.-high mold in four layers, with 25 blows of a 4-lb hammer falling 12 in. per layer. The results of these tests are:

Material Depth ft	Dry Density γ_d max	Water Content %
17.5	108.9	0
28	112	17.5
33	116	13

Using the data above, in situ relative densities of the 17.5-, 28-, and 33-ft materials were calculated to be 37%, 59%, and 73%, respectively.

Petrographic Analysis

25. Following selection of the depths at which materials might be susceptible to liquefaction, samples of materials from these depths were furnished to the WES Geology Branch for determination of rock type and particle shape.

26. Petrographic examinations were conducted on the samples representative of the materials at 9-, 17.5-, 33-, and 55-ft depths. The procedure used for this examination was as follows:

a. Approximately 250 g of each material was weighed.

b. Each sample was sized over the Nos. 60, 120, and 200 sieves. The individual plus No. 200 size fractions were then examined under the binocular and petrographic microscopes for determination of rock type and particle shape. The minus No. 200 size material was examined for rock type, and particle shape was estimated under the petrographic microscope.

27. Tables 3-5 show the percentages of each rock type and particle shape present in each of the samples and also show the distribution of rock types and particle shapes within each size of each sample. The samples consisted principally of angular to subrounded fragments and crystals of quartz with minor amounts of chert, feldspar, organic matter, or calcite. The minus No. 200 sizes contained a considerable amount of silt and clay-size fragments of quartz.

PART III: CYCLIC TRIAXIAL TEST EQUIPMENT AND PROCEDURES

Equipment

Triaxial device

28. In cyclic triaxial tests the deviator stress is uniformly increased and decreased while maintaining a constant chamber pressure. The test equipment utilized by the WES is shown schematically in fig. 12. The pneumatic control unit consists of regulators and solenoid valves that are actuated by a cam-operated microswitch. These valves provide alternating air pulses to a double-acting air cylinder (loading piston) such that a cyclic load is transmitted from the air cylinder through the piston to the sample. Obviously, to regulate the pulsating air pressures so that desired loads are imposed on the specimen requires extremely careful calibrations, considering friction in the system and uplift pressures generated by the chamber pressure.

Instrumentation

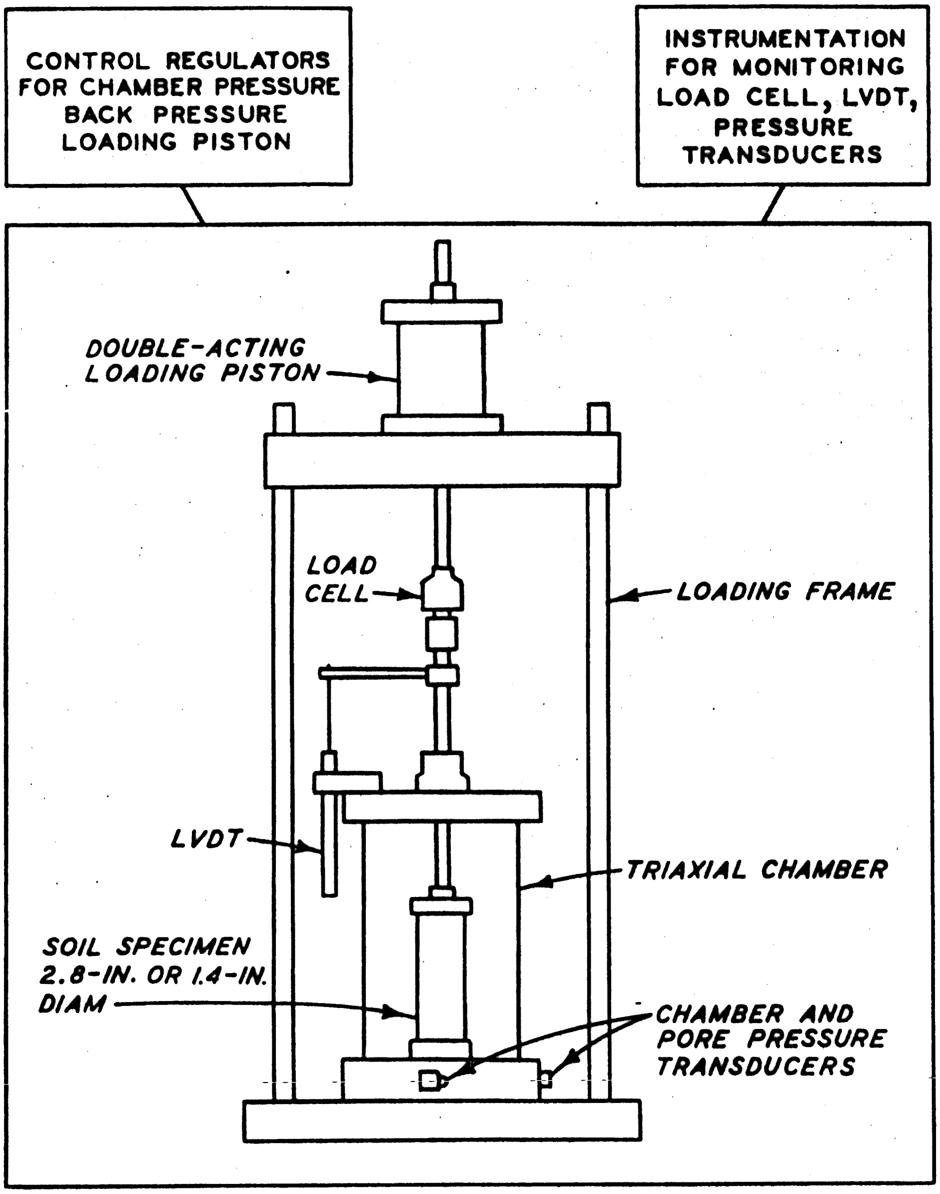
29. Electrical pressure transducers, a deformation transformer, and a load cell are used to measure pore pressure and chamber pressure, axial deformation, and axial load, respectively, because of the rapid change in sample behavior at liquefaction. A high-speed recorder is required to provide a continuous record of events during the test. Extra care is required to calibrate these sensors such that accurate measurements are maintained over the range of data created by the tests.

Procedures

30. The tests performed were consolidated-undrained. Four variables were recorded continually during the test: axial load, axial deformation, pore water pressure, and chamber pressure. Each test consisted of four stages: molding, saturation, consolidation, and cyclic loading. Each stage is described in detail below.

Molding

31. The forming jacket was measured to determine its exact



NOTE: LVDT IS A LINEAR VARIABLE DIFFERENTIAL TRANSFORMER.

Fig. 12. Cyclic triaxial test equipment

volume. Sufficient dry soil to give the desired density of the specimen to be built was then weighed and placed in a container. Distilled deaired water was added to the container to cover the soil completely and the soil and water were stirred gently to release entrapped air. The mixture was then boiled over a low flame for about 10 min. The rubber membranes used in this testing were 0.023 in. thick. A few inches of vacuum was applied to the space between the membrane and forming jacket to hold the membrane flat against the jacket. With the membrane and forming jacket in place on the triaxial base, the boiled soil (which had been allowed to cool) was spooned into the membrane. Two testing densities were sometimes desired, a medium density and a high density. The medium density was obtained by spooning the wet soil into the mold gently. To obtain the higher density, the wet soil was spooned into the mold then rodded gently with a 1/2-in.-diam steel rod. When the volume of the forming jacket had been filled with soil and the top soil surface smoothed off, a cap was put in place on top of the soil specimen and the membrane was pulled up around the cap. A rubber O-ring was used to hold the membrane tightly to the cap, and 10 in. of vacuum was applied to the soil specimen through the top cap. The forming jacket was removed and the specimen was measured at the top, bottom, and midheight under 10 in. of vacuum to determine its area and volume.

Saturation

32. The process of saturation consisted of two stages: seepage saturation and back-pressure saturation. As was mentioned above, a vacuum of 10 in. was applied to the specimen at the end of molding. After measurements of the specimen were made, the vacuum was increased to at least 20 in. A chamber pressure of 2 psi was applied to the sample and a line containing deaired distilled water was introduced to the bottom of the specimen. This line allowed water to seep into the specimen while air, which was entrapped inside the soil, percolated up through the top porous stone and out of the specimen. This operation was continued until air bubbles were no longer seen coming through the line from the top of the sample. At this point the vacuum was released and water allowed to enter the specimen from the top as well as the

bottom. When enough water had entered the specimen to dissipate the vacuum that was left in the soil from the seepage operation, pressure was slowly added to the chamber fluid while maintaining the pressure in the pore water of the soil at a constant 5.0 psi below the pressure in the chamber. Thus, the volume of air remaining in the specimen was decreased and, with time, was forced to dissolve in the pore water. Experience with the soils tested in this program showed that about 65.0 psi of back pressure acting for a period of 16 hr was sufficient to produce the desired saturation. Saturation for this testing program was given in terms of Skempton's B-parameter. The B-parameter is determined by the ratio of the change in pore water pressure to an induced change in chamber pressure. The value was checked in this testing by closing the drainage line and increasing the chamber pressure 5.0 psi and observing the increase in pore water pressure. The minimum acceptable B-value for this testing was 0.96; however, typical values were greater than 0.98. During saturation, the change in height of the specimen was measured with a dial indicator that could be read to the nearest 0.0001 in.

Consolidation

33. When saturation had been completed, the specimen was consolidated to the effective confining pressure under which it would be tested. This was done by closing the drainage line and increasing the chamber pressure such that the difference between the back pressure and chamber pressure was the desired effective confining pressure. The drainage line was then opened and the specimen began to consolidate. The volume and height change of the specimen were observed with time during consolidation, and the process was considered to be complete when the volume and height of the specimen reached a constant value. Typically, for the materials tested in this program, no more than 30 min was required for complete consolidation.

Cyclic loading

34. Cyclic loading consisted of the cyclic application and reduction of axial stress. The specimen was loaded in this manner through a double-acting air cell driven by the loading unit described previously at a frequency of 2 Hz. Depending upon the material tested, effective

confining pressure, density, and magnitude of cyclic load, the soil specimen would withstand a number of cycles of load and then would liquefy. Liquefaction consisted of deformation and a partial-to-total loss of strength. At the start of cyclic loading, little deformation occurred; but as the cyclic loading progressed, the pore pressure increased, consequently reducing the effective stress. Initial liquefaction is defined as the stage when pore pressure first becomes equal to the chamber pressure, giving an effective stress of zero. When this happened with a loose specimen, large deformation would soon occur accompanied by a total loss of strength. In dense specimens, liquefaction consisted of smaller deformations (typically about 5%) and loss of the ability to support a load under this amount of deformation.

PART IV: CYCLIC TRIAXIAL TESTS

35. As discussed in Part II, materials at five depths at the damsite were identified as possibly being susceptible to liquefaction under earthquake loading. Remolded samples of material from each of the five depths were subjected to cyclic triaxial loading under isotropic and anisotropic stress conditions. The sequence of testing was determined by the anticipated degree of susceptibility of each material to liquefaction, beginning with the one expected to be most susceptible. Results of these tests are discussed in the following paragraphs and are summarized in table 6.

Isotropic Loading

Material from 28-ft depth

36. Tests 1-4 and 20 were conducted on material representative of the 28-ft depth. The in situ dry density was estimated to be 98 pcf. The dry density of the remolded samples ranged from 97.0 to 99.8 pcf. For these tests, the B-values were 0.96 or more. These tests were conducted at a normal stress (σ_1) computed from overburden conditions to be 17.4 psi. The cyclic deviator stress (σ_{dc}) was varied between 3.96 and 10.34 psi. Initial liquefaction was obtained over a range of 1 to 134 cycles of loading, depending upon the magnitude of axial load. After these samples reached initial liquefaction, they developed a peak-to-peak strain of about 9% to 12% within one or two additional cycles of stress. The same samples reached about 20% strain in just a few more cycles (see table 6).

37. Fig. 13 is the actual trace (raw data) for cycles 1-3 and 11-13 for test 2. This sample behavior is considered typical. The top line is the chamber pressure, which for this test was 72.9 psi. The second line from the top is the axial load that started at an initial value of 27.3 lb, which gave an isotropic state of stress. The third line down is the axial deformation as measured by the LVDT. The bottom line is the pore water pressure, which had an initial value of 55.5 psi.

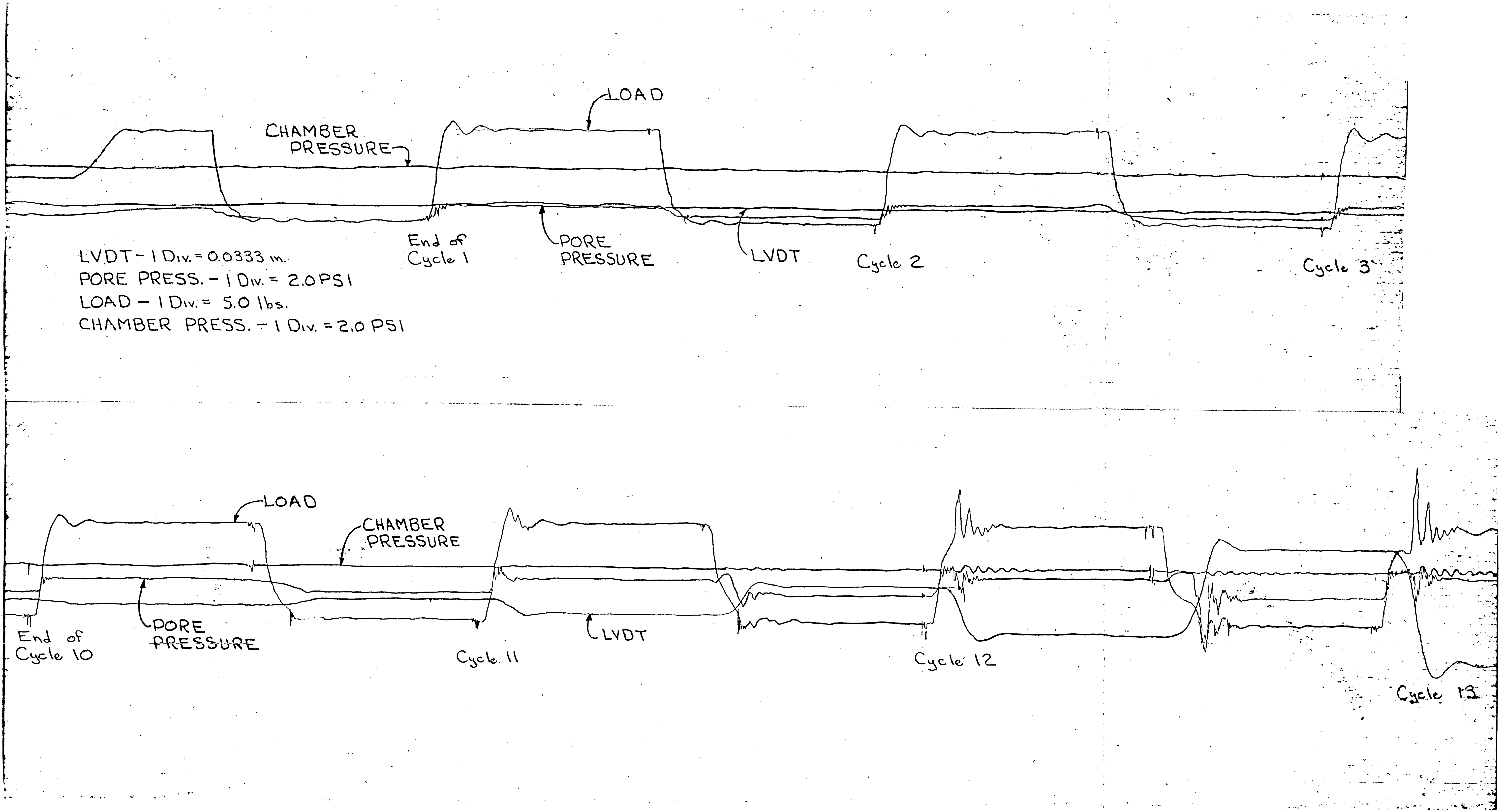


Fig. 13. Oscillograph record for cyclic triaxial test 2 of material from the 28-ft depth

The cyclic deviator stress for this test is 6 psi, which corresponds to an axial force of 38 lb. This figure shows that with each cycle of load, the pore pressure increases; however, at first the actual deformation is small. By the eleventh cycle, the pore pressure approached the chamber pressure and the actual deformation was still relatively small. On the twelfth cycle of loading, the pore pressure actually equaled the chamber pressure (initial liquefaction) and the axial deformation was approximately 0.65 in. peak to peak. The deformation can be subdivided, compression being about 40% and extension about 60% of the total peak-to-peak values. This is typical.

38. Fig. 14 is a plot of the triaxial data expressed as stress ratio versus the number of cycles of loading. The stress ratio[3] is expressed as

$$\frac{\sigma_{dc}}{2\sigma_a}$$

where

σ_{dc} = cyclic deviator stress, psi

σ_a = ambient effective consolidation stress, psi

The curves in fig. 14 are for initial liquefaction and 10% and 20% strain. Along the right ordinate is plotted peak ground acceleration. The conversion from stress ratio to acceleration was made for an assumed relative density of about 50% according to Seed's simplified procedure.[3] A brief review of the simplified procedure is presented in Appendix B.

39. The remolded dry density of the specimen for test 5 was supposed to be 98 pcf; however, the actual remolded dry density was 101.2 pcf. The confining pressure for this test was calculated assuming that the embankment was on top of the foundation. This gave a σ_1 of 58 psi. The results of this test are plotted in fig. 14. It is seen that when the results were normalized with respect to σ_a, the effect of the dam on top of the foundation was negligible.

40. Tests 16-19 were also conducted on material representative of the 28-ft depth. The purpose of the tests was to determine the effect

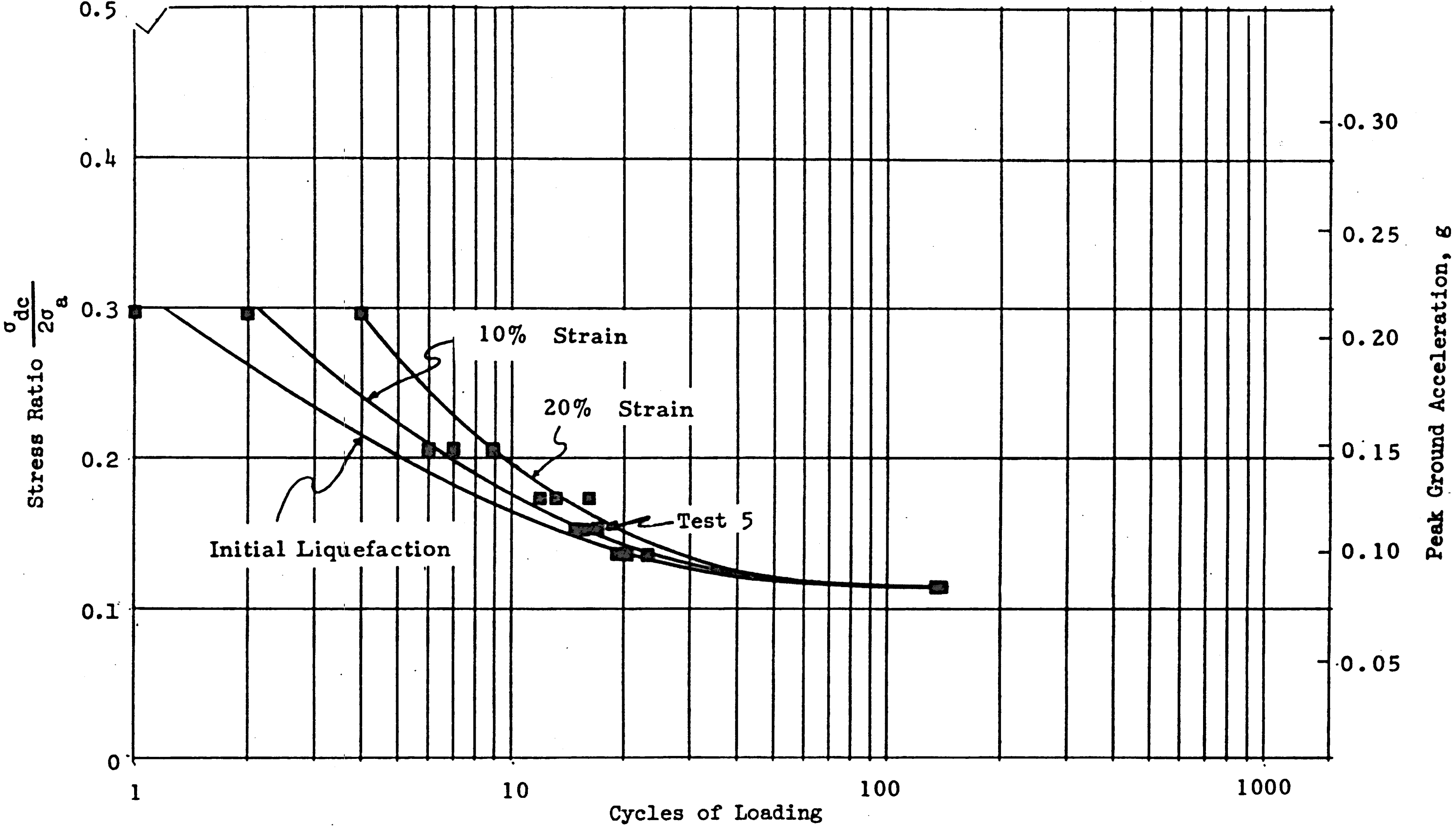


Fig. 14. Cyclic triaxial tests of material representative of the 28-ft depth at in situ density (98 pcf)

of field densification. For this series of tests, the dry density of the remolded specimens ranged from 107.4 to 109.1 pcf. Fig. 15 is a plot of stress ratio versus number of cycles of loading to initial liquefaction and to 10% strain. Acceleration is plotted along the right vertical axis. To calculate the acceleration, the material was assumed to have a relative density of 70% to 80%. After this material, in a dense state, developed a state of initial liquefaction, a substantial number of additional cycles was required to develop 10% strain. This behavior is quite different from the 98-pcf material, which developed large strains at only one or two cycles more than was required to develop initial liquefaction.

41. Fig. 16 is a plot of stress ratio versus the number of cycles of loading to initial liquefaction for the 28-ft-depth material for both the 98- and 109-pcf densities. If this plot is entered at a stress ratio of 0.2, the 98-pcf material is shown to liquefy after five cycles, while the 109-pcf material will liquefy after 100 cycles. Thus, it is seen that densification of this material from 98 to 109 pcf substantially increased the stability of the material. The benefits are even greater, however, since the dense material did not develop large deformations in the tests.

Material from 33-ft depth

42. Tests 6-9 and 11 were conducted on material representative of the 33-ft depth. The in situ dry density of this material is believed to be 104 pcf. The effective vertical stress, based on overburden conditions, was calculated to be 19.5 psi. The cyclic deviator stresses ranged from 3.06 to 5.65 psi, which gave a range of 5 to 287 cycles to initial liquefaction. The results of these tests are presented in fig. 17, which is a plot of stress ratio (acceleration) versus number of cycles of loading to initial liquefaction and to 10% and 20% strain.

43. Test 10 was also conducted on the material from the 33-ft depth at a confining pressure of 60.4 psi, which was computed for the condition that the dam was constructed on top of the layer. Data from this test are also plotted in fig. 17. The data points fall on the

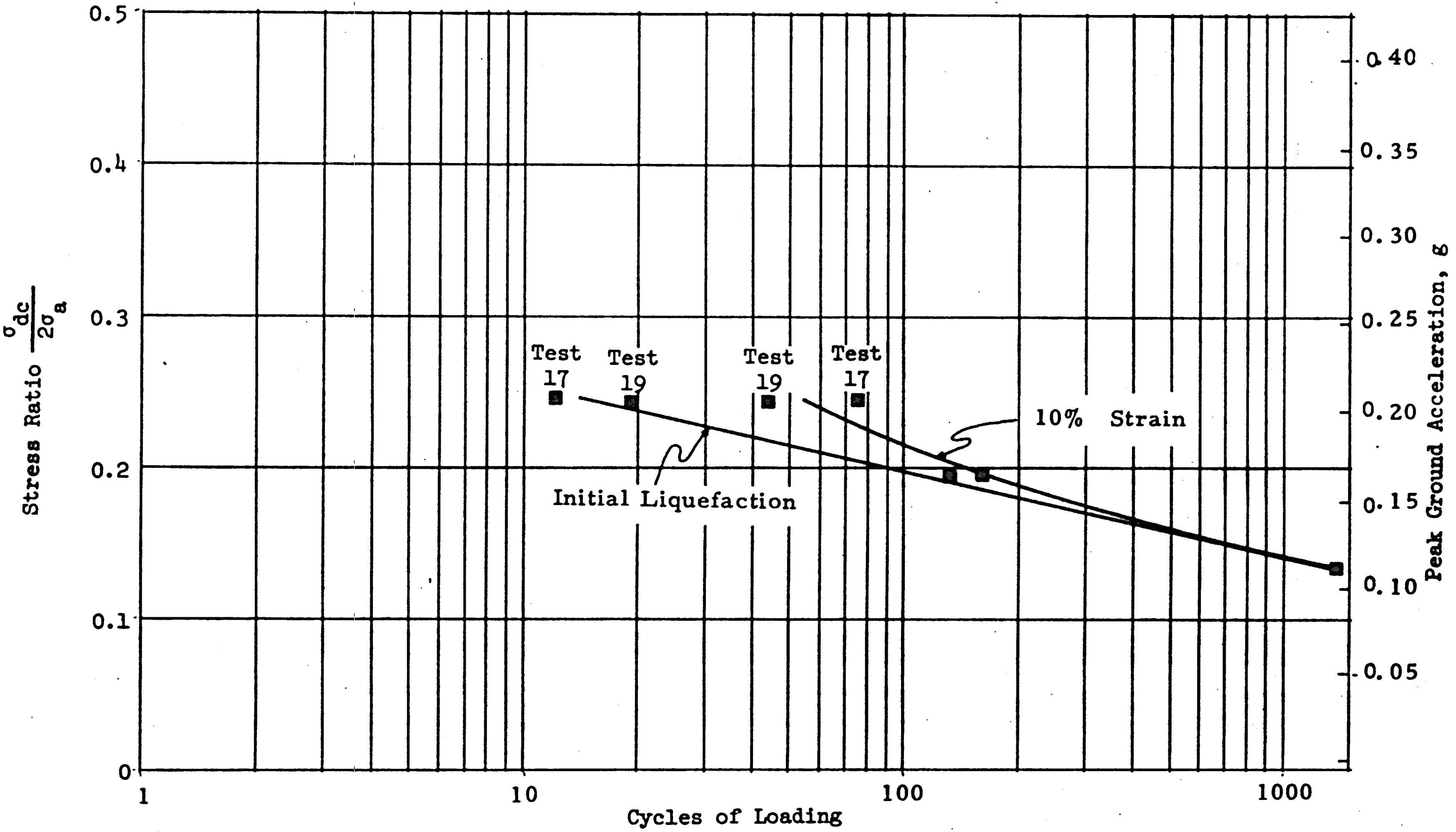


Fig. 15. Cyclic triaxial tests of material representative of the 28-ft depth at modified density (109 pcf)

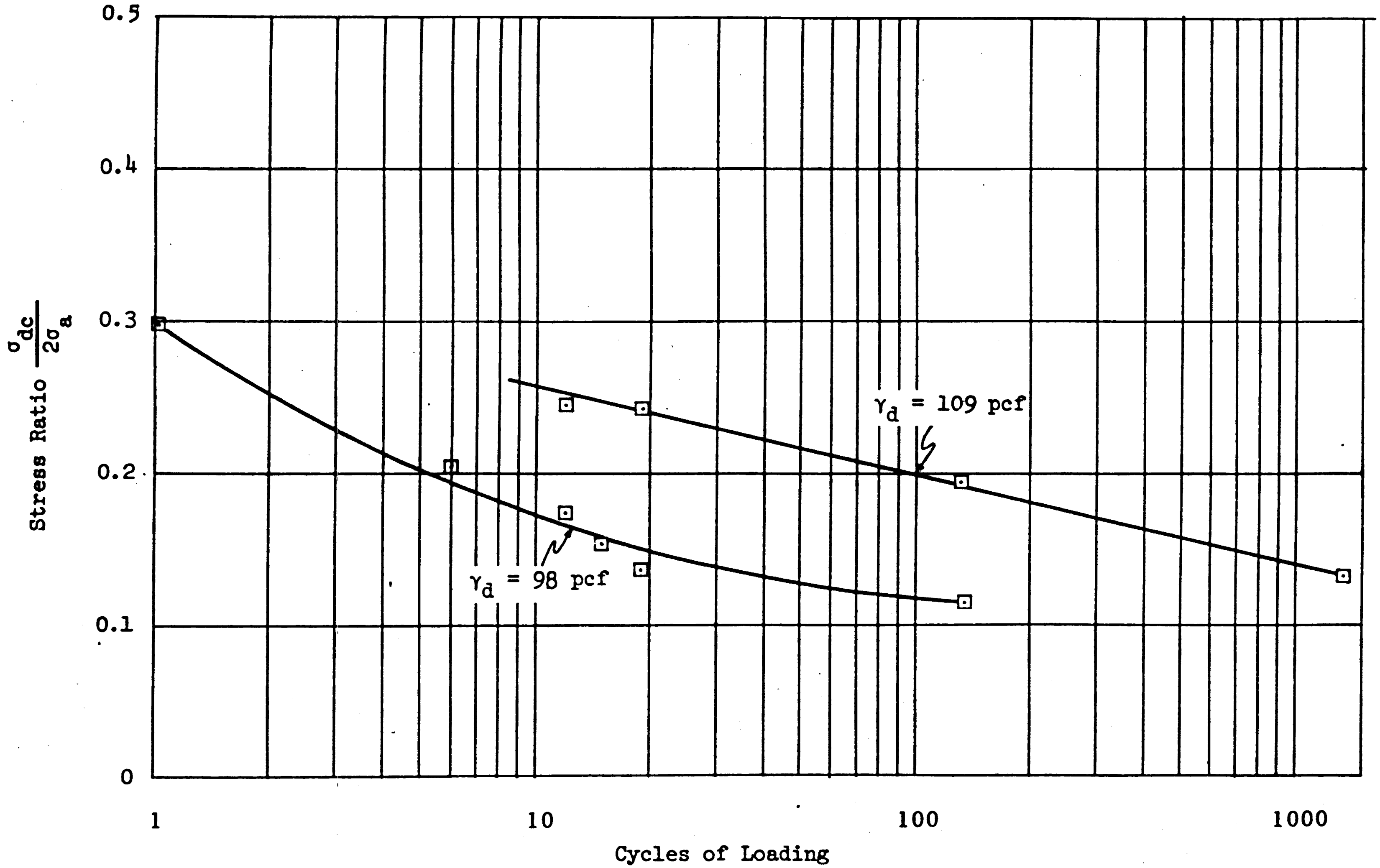


Fig. 16. Cycles of loading to initial liquefaction, material representative of the 28-ft depth at 98 and 109 pcf dry density

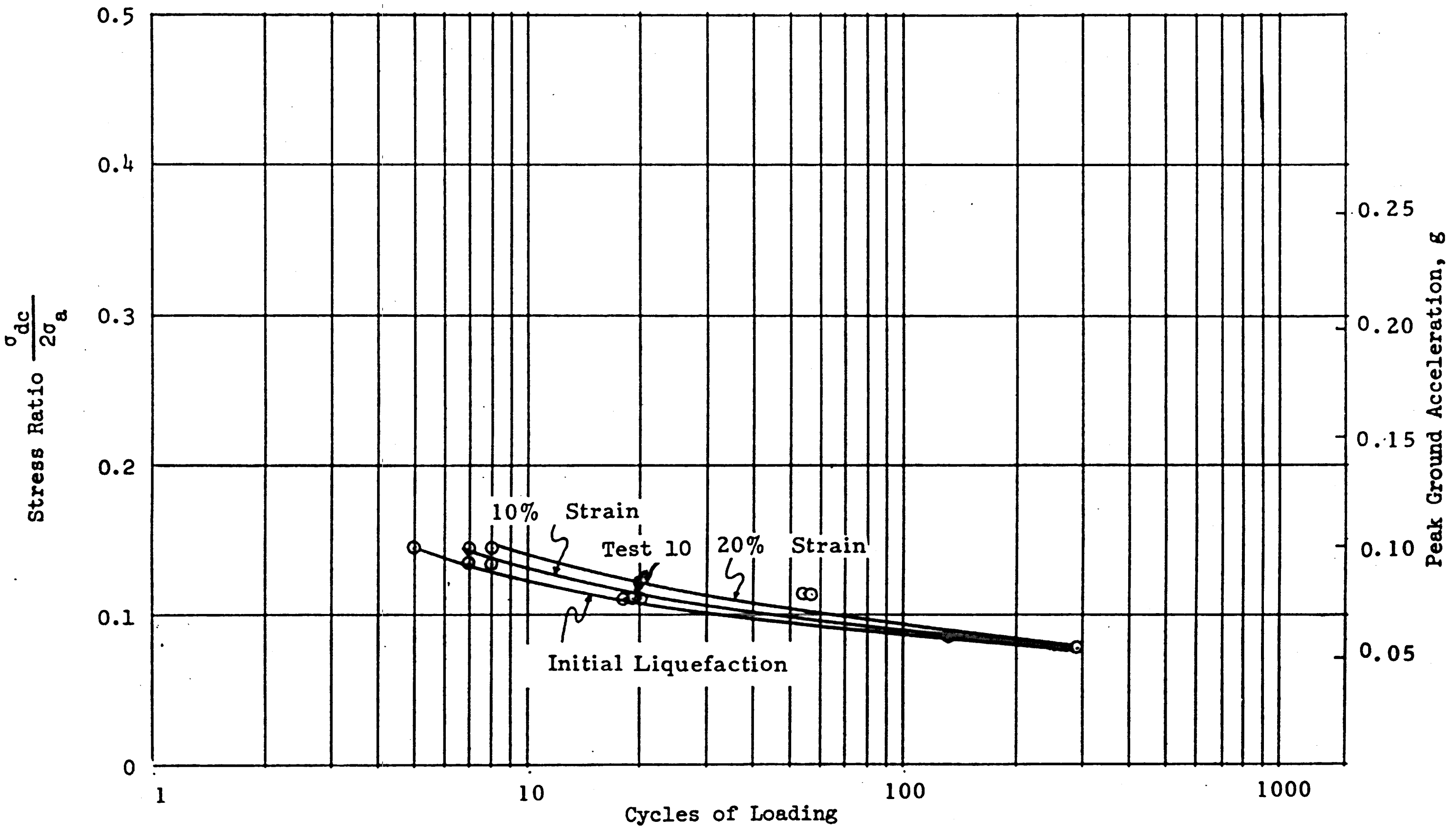


Fig. 17. Cyclic triaxial tests of material representative of the 33-ft depth at in situ density (104 pcf)

previous curve, which indicates that the additional overburden pressure had no significant effect.

44. Tests 12-15 were conducted on the material from a depth of 33 ft. For this series of tests, the samples were remolded at a dry density of approximately 113 pcf. The results of these tests, which were performed to determine the effect of in situ densification, are presented in fig. 18. Fig. 18 is a plot of stress ratio (acceleration) versus the number of cycles of loading to initial liquefaction and to 10% strain. The results of test 12 were suspect, so test 14 was conducted to check test 12. The results of test 14 are believed to be valid and test 12 is, therefore, ignored.

45. Fig. 19 is a plot of stress ratio versus the number of cycles of loading to initial liquefaction for the material at dry densities of 104 and 113 pcf. If this figure is entered at a stress ratio of 0.13, the numbers of cycles to initial liquefaction are 10 and 120 cycles for the 104 and the 113 pcf material, respectively. This is a significant increase in dry density and a significant increase in stability.

Material from 17.5-ft depth

46. Tests A-1, -2, -3, and -5 were conducted on material representative of the 17.5-ft depth. The in situ dry density was estimated to be 88 pcf. Sample consolidation occurred during saturation, and the dry density of the remolded specimens increased from its desired value of 88 pcf to 93.3 to 97.9 pcf. The B-values for these tests were 0.96 or higher. The overburden pressure was calculated to be 12.8 psi. The cyclic deviator stress ranged from 2.98 to 5.00 psi, which produced initial liquefaction in 1375 and 2 cycles, respectively. Fig. 20 is a plot of stress ratio (acceleration) versus number of cycles to initial liquefaction and to 10% and 20% strain.

Material from 9-ft depth

47. Tests A-4 and -7 were conducted on material representative of the 9-ft depth. The in situ dry density was estimated to be 92 pcf. The samples were prepared at a dry density of approximately 90 pcf, but saturation and consolidation caused the density to increase to 110.1 and 115.2 pcf for tests A-4 and -7, respectively. Thus, the test results

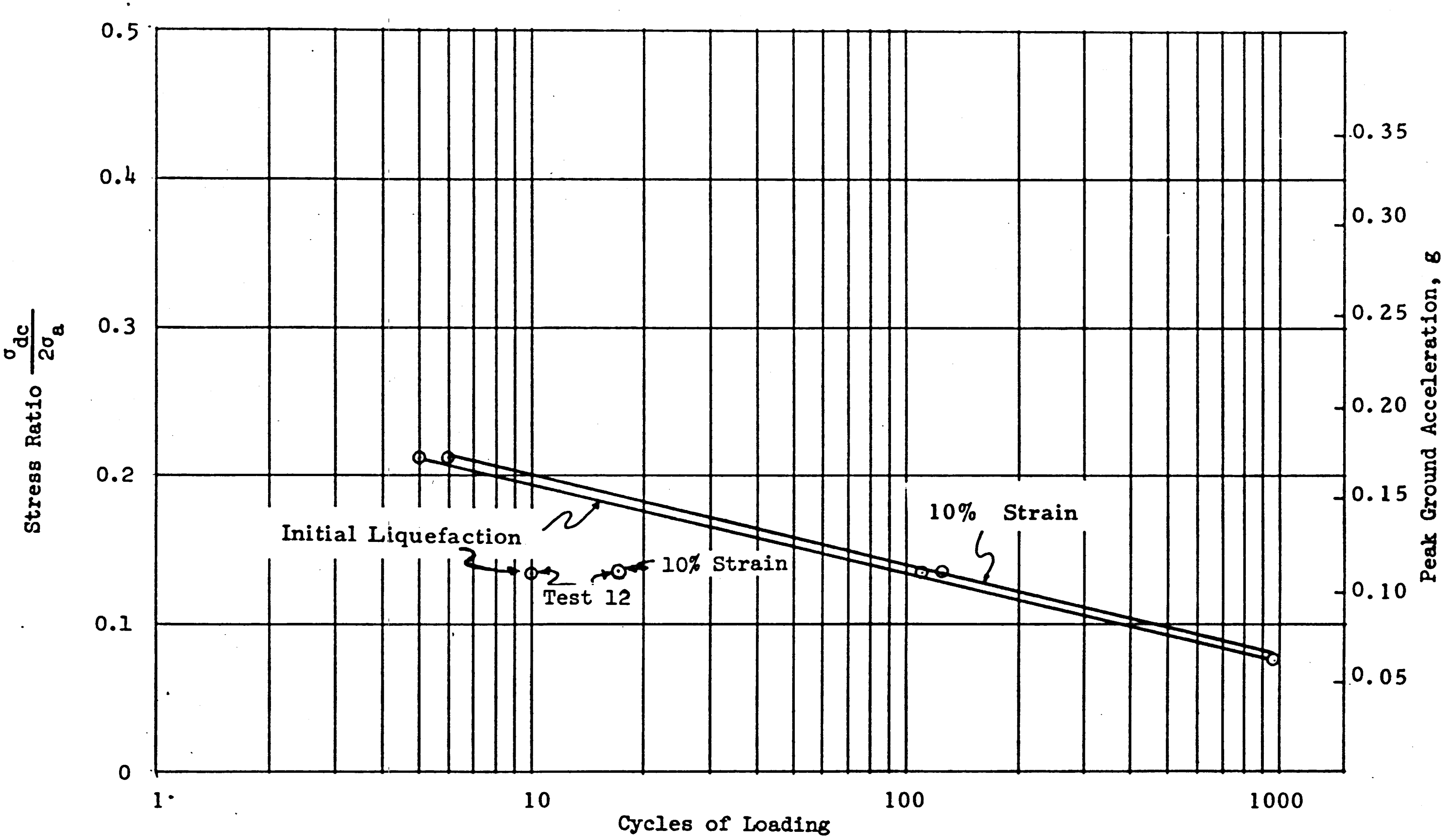


Fig. 18. Cyclic triaxial tests of material representative of the 33-ft depth at modified density (113 pcf)

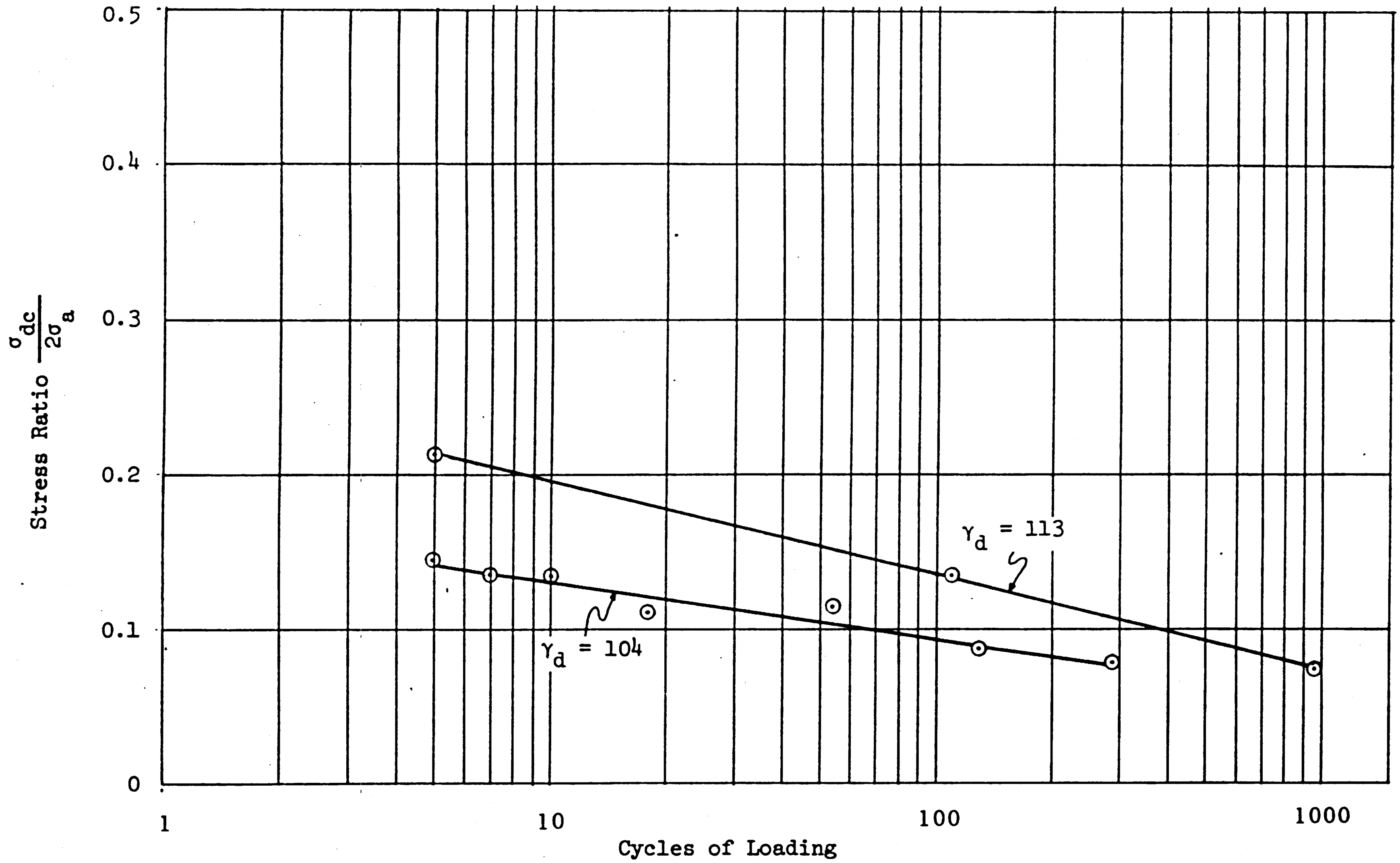


Fig. 19. Cycles of loading to initial liquefaction, material representative of the 33-ft depth at 104 and 113 pcf dry density

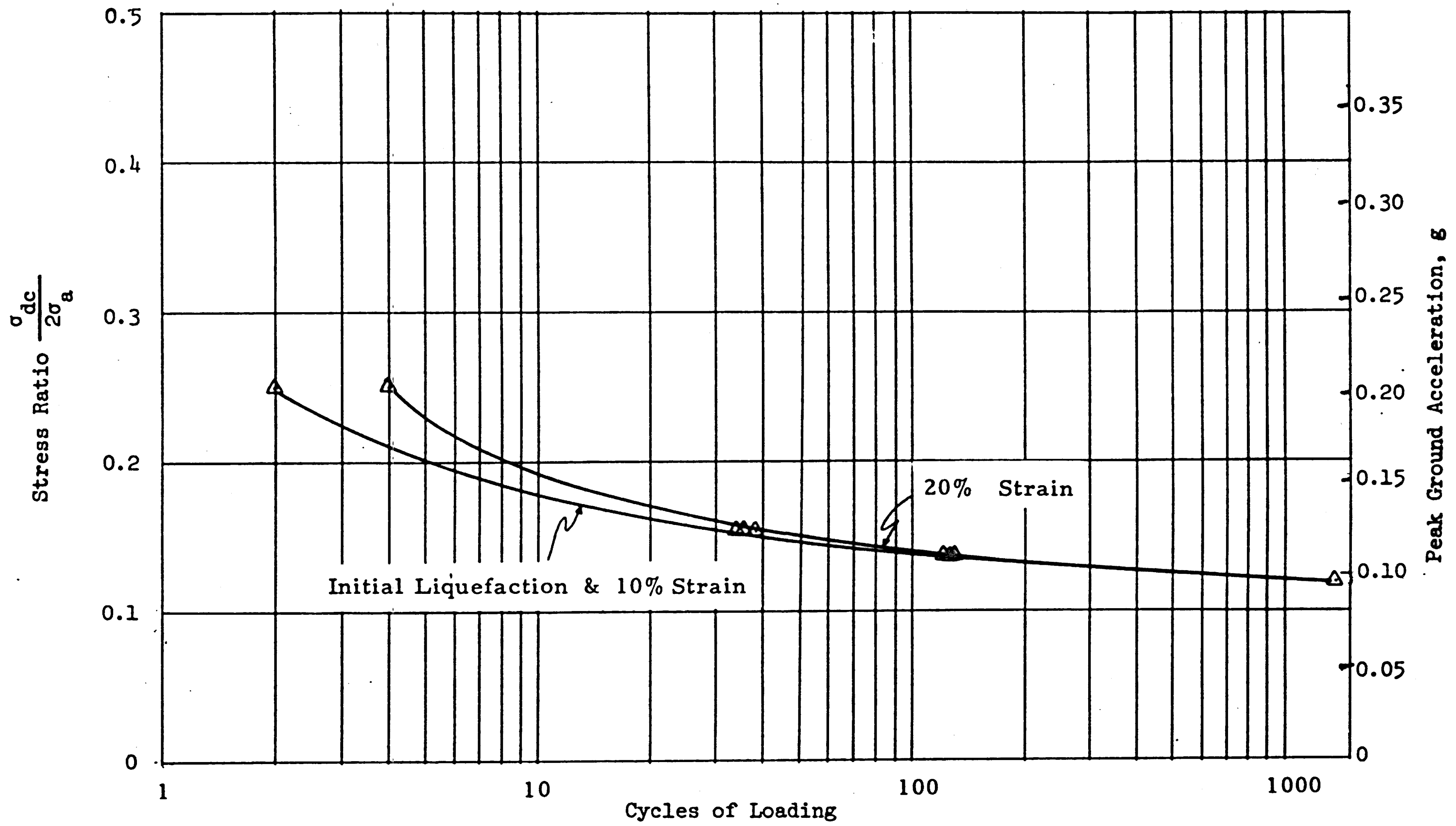


Fig. 20. Cyclic triaxial tests of material representative of the 17.5-ft depth

are for materials much denser than the in situ material. The B-values for these tests were 0.91 and 0.90. These B-values are below the 0.96 value that is considered to be the minimum acceptable B-value. During these tests the back pressure was increased to the approximate limit of the transducer. In the interest of time, testing was conducted with the low B-values. The applied vertical stress was calculated, based on overburden conditions, to be 7.8 psi. The cyclic deviator stress was varied from 3.6 to 5.2 psi, which yielded initial liquefaction in 109 and 10 cycles, respectively. The results of these tests are presented in fig. 21, which is a plot of stress ratio (acceleration) versus number of cycles of loading to initial liquefaction and to 10% strain.

Material from 55-ft depth

48. Tests A-6 and -8 were conducted on material representative of a depth of 55 ft. It should be noted that 98% of this material passed the No. 200 sieve. The meaning of tests on remolded samples of this material is questionable. The in situ dry density of this material was estimated to be 90 pcf. The samples were tested at dry densities of 96.7 and 93.0 pcf. The B-values were 0.96 for this material. The overburden pressure was calculated to be 29.1 psi. The cyclic deviator stresses ranged from 8.8 to 11.7 psi, which produced initial liquefaction in 217 and 17 cycles, respectively. Fig. 22 is a plot of stress ratio (acceleration) versus number of cycles of loading to initial liquefaction and to 10% and 20% strain.

Tests at in situ density

49. Fig. 23, a summary of all of the test results of isotropically loaded samples at in situ density, is a plot of stress ratio versus the number of cycles to initial liquefaction. From this figure it can be seen that the 33-ft material is the most susceptible to liquefaction. A stress ratio of 0.1 will cause initial liquefaction in 65 cycles of loading of this 33-ft material. All the other material will stand considerably more loading cycles at a stress ratio of 0.1.

Anisotropic Loading

50. All results discussed so far were for tests consolidated

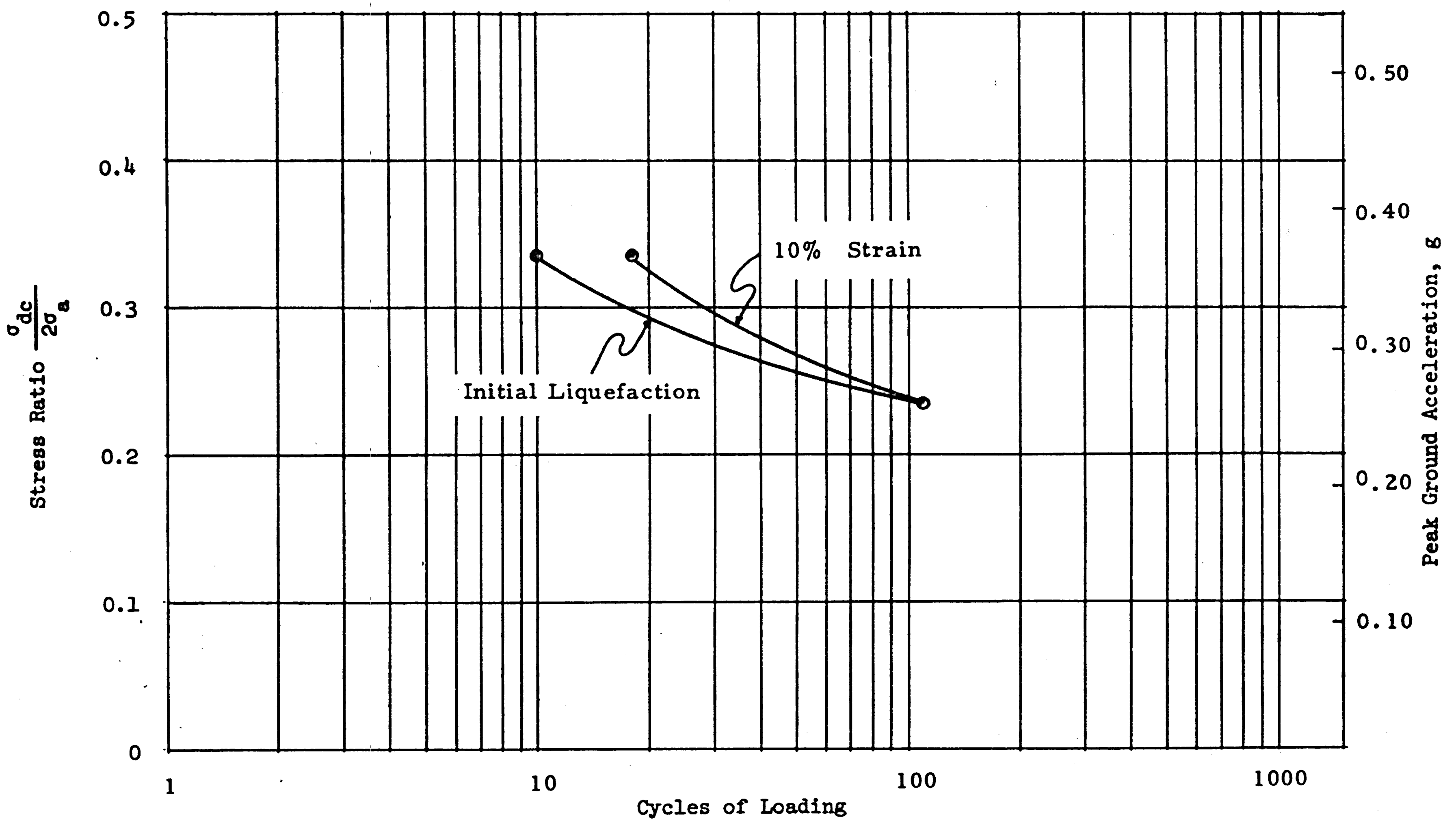


Fig. 21. Cyclic triaxial tests of material representative of the 9-ft depth

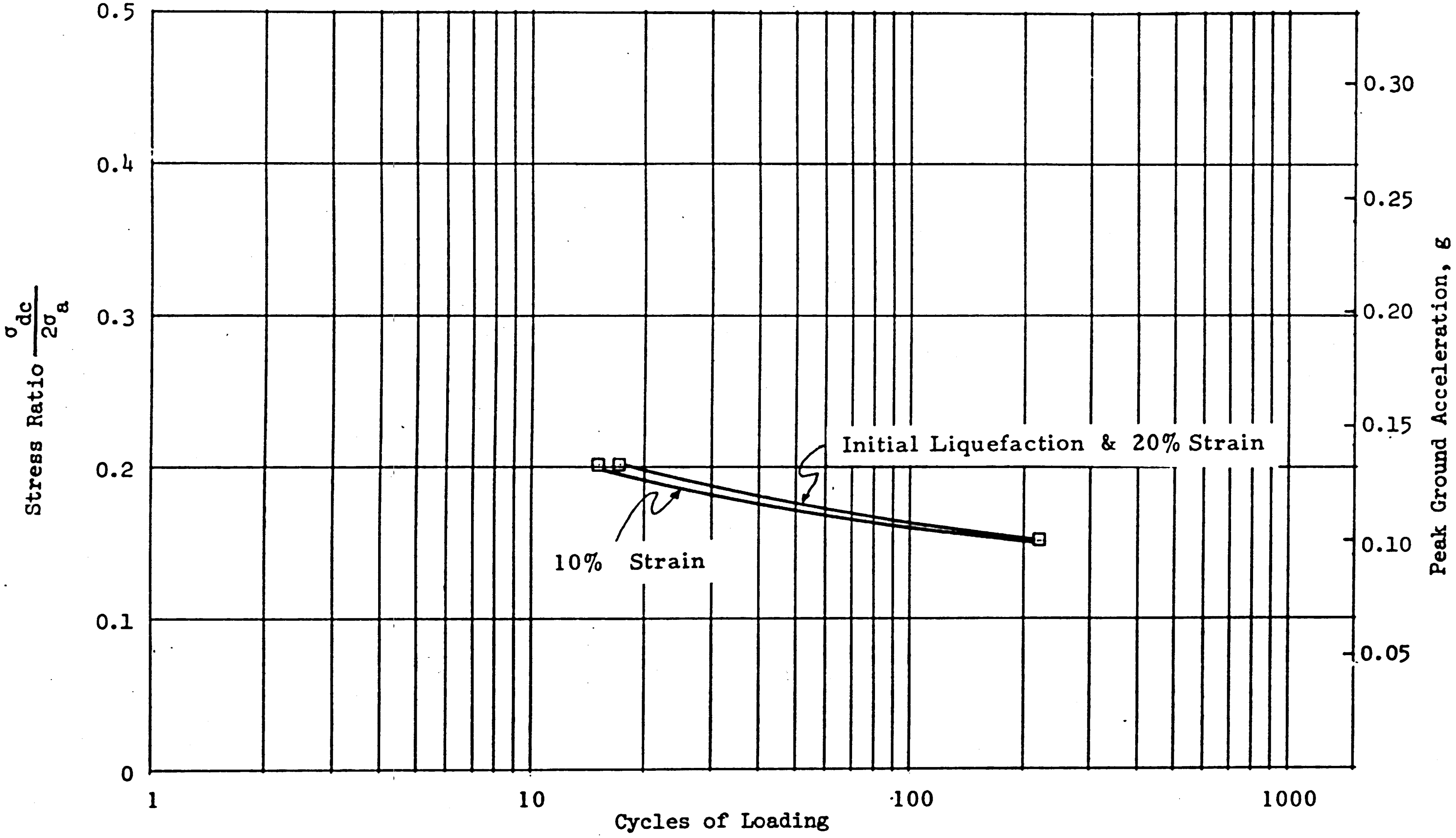


Fig. 22. Cyclic triaxial tests of material representative of the 55-ft layer

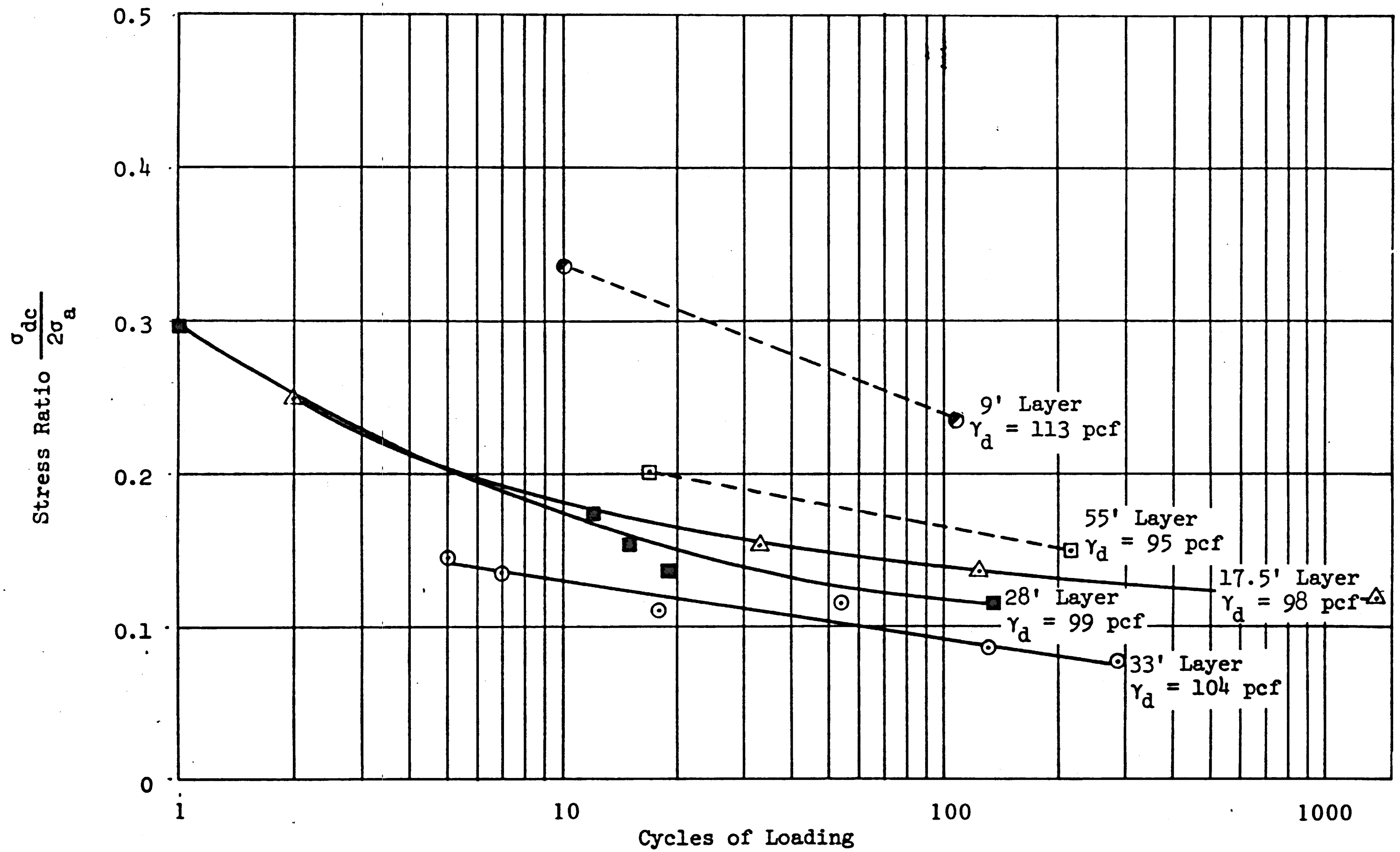


Fig. 23. Summary of cyclic triaxial tests at in situ density for isotropic loading to initial liquefaction

isotropically. In the field this is generally not the stress condition. To evaluate the effect of $\sigma_1 \neq \sigma_3$, tests were conducted at K values of 2.5 and 3.0. (These were considered to be the upper limits of the K values.) Tests A-9, -10, and -11 were conducted at a $K = \frac{\sigma_1}{\sigma_3} = 2.5$ and tests A-12, -13, and -14 were conducted at $K = 3.0$. These tests were conducted on the material representative of the 33-ft depth, since it was considered the most critical in regard to liquefaction. The tests were conducted at a remolded dry density of approximately 108 pcf, which was somewhat more than in situ dry density of 104 pcf. The results of these tests are not presented in terms of stress ratio $\frac{\sigma_{dc}}{2\sigma_a}$ because σ_a is defined as an ambient pressure. For $K \neq 1$, ambient pressure is not applicable.

51. The results of tests A-9, -10, and -11 are presented in fig. 24. This is a plot of pulsating deviator stress versus number of cycles of loading to 10% and 20% strain. (This strain is zero to peak and is in compression only.) These samples did not develop an initial liquefaction condition. Fig. 25 is a plot of pore pressure at 20% strain versus pulsating deviator stress for these tests. It can be seen that the pore pressure never equaled the chamber pressure.

52. The results of tests A-12, -13, and -14 are presented in fig. 26. This is a plot of pulsating deviator stress versus number of cycles of loading to 10% and 20% strain. Fig. 27 is a plot of pore pressure at 20% strain versus pulsating deviator stress. These samples did not reach initial liquefaction.

53. To compare the data for the material from the 33-ft depth at $K = 1.0$, 2.5, and 3.0 , fig. 28 was prepared. This is a plot of pulsating deviator stress versus number of cycles of loading to 10% (zero to peak) compression strain. If this plot is entered at 20 cycles, then a σ_{dc} of 5.0 psi causes failure if $K = 1.0$; a σ_{dc} of 8.7 psi causes failure if $K = 3.0$; and a σ_{dc} of 10.6 psi causes failure if $K = 2.5$.

54. The vertical consolidation stress is not a constant in this plot; it varied from 19.5 to 32.5 psi. To more clearly present the data, fig. 29 was prepared, which is a plot of vertical consolidation

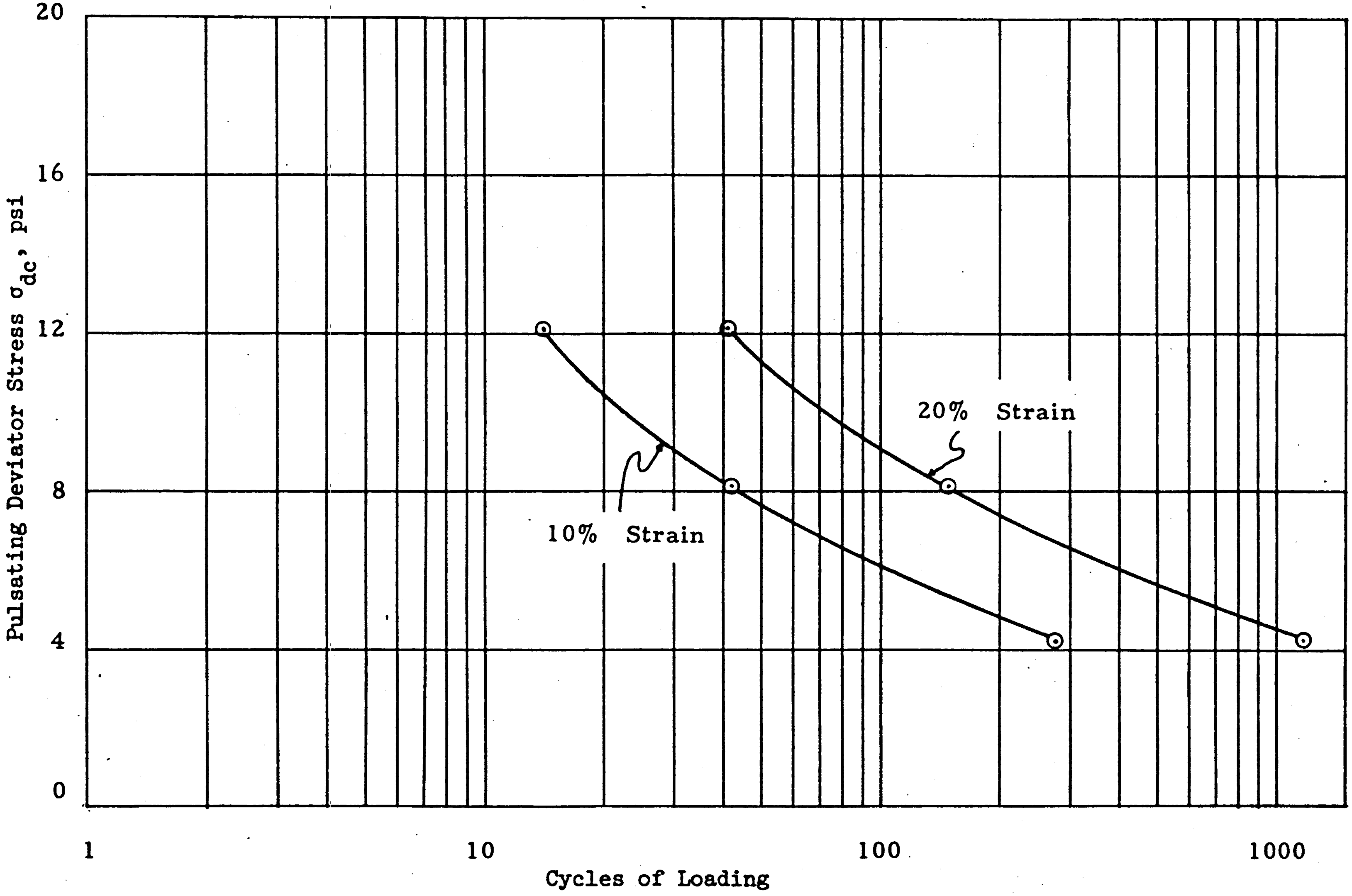


Fig. 24. Anisotropic (K = 2.5) cyclic triaxial loading of material representative of 33-ft depth--deviator stress versus cycles of loading (γ_d = 108 pcf, $\overline{\sigma}_3$ = 13.0 psi)

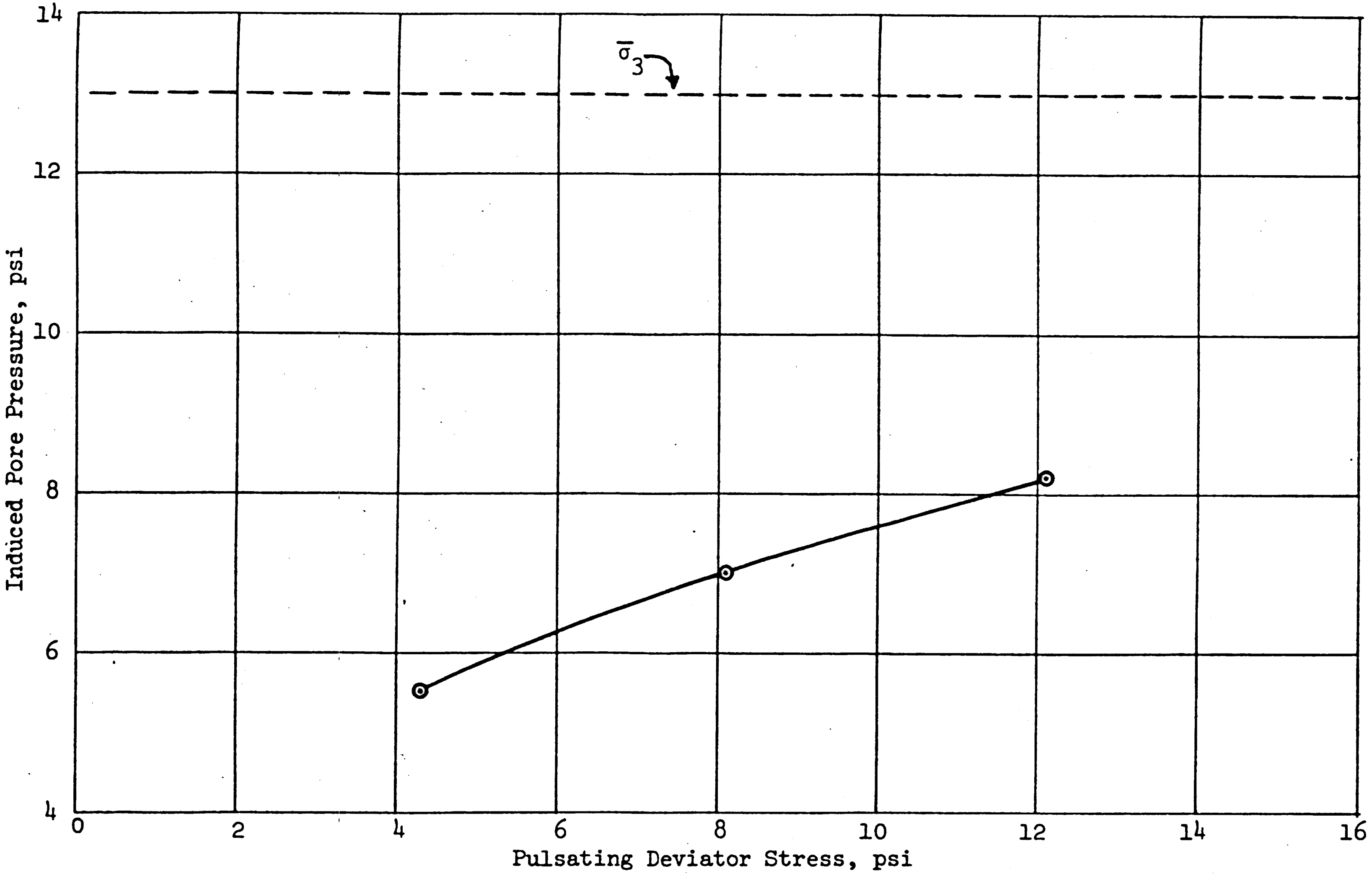


Fig. 25. Anisotropic (K = 2.5) cyclic triaxial loading of material representative of 33-ft depth--induced pore pressure versus pulsating deviator stress (γ_d = 108 psi, 20% strain)

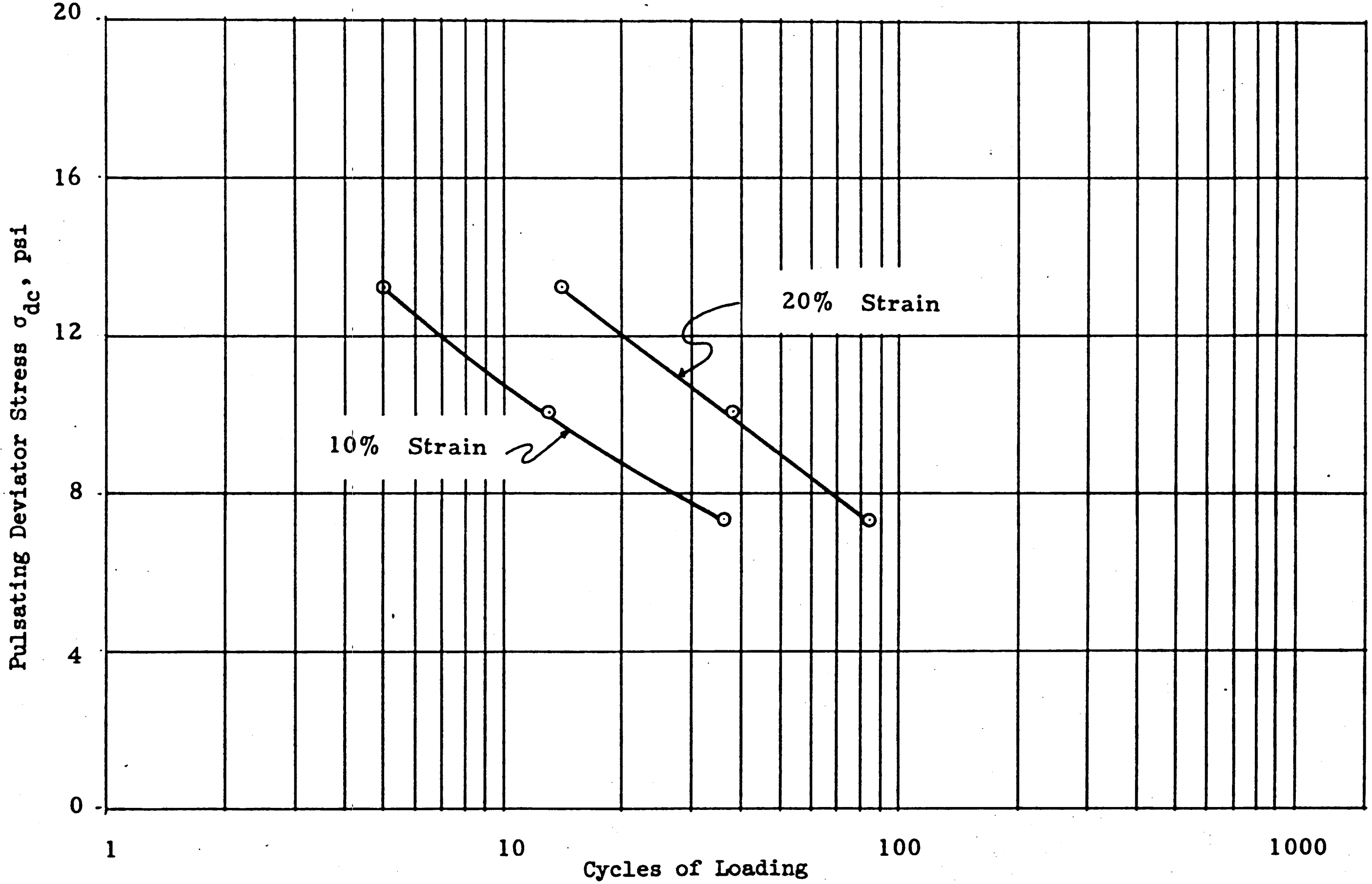


Fig. 26. Anisotropic (K = 3.0) cyclic triaxial loading of material representative of 33-ft depth--deviator stress versus cycles of loading (γ_d = 108 pcf, $\bar{\sigma}_3$ = 13.0 psi)

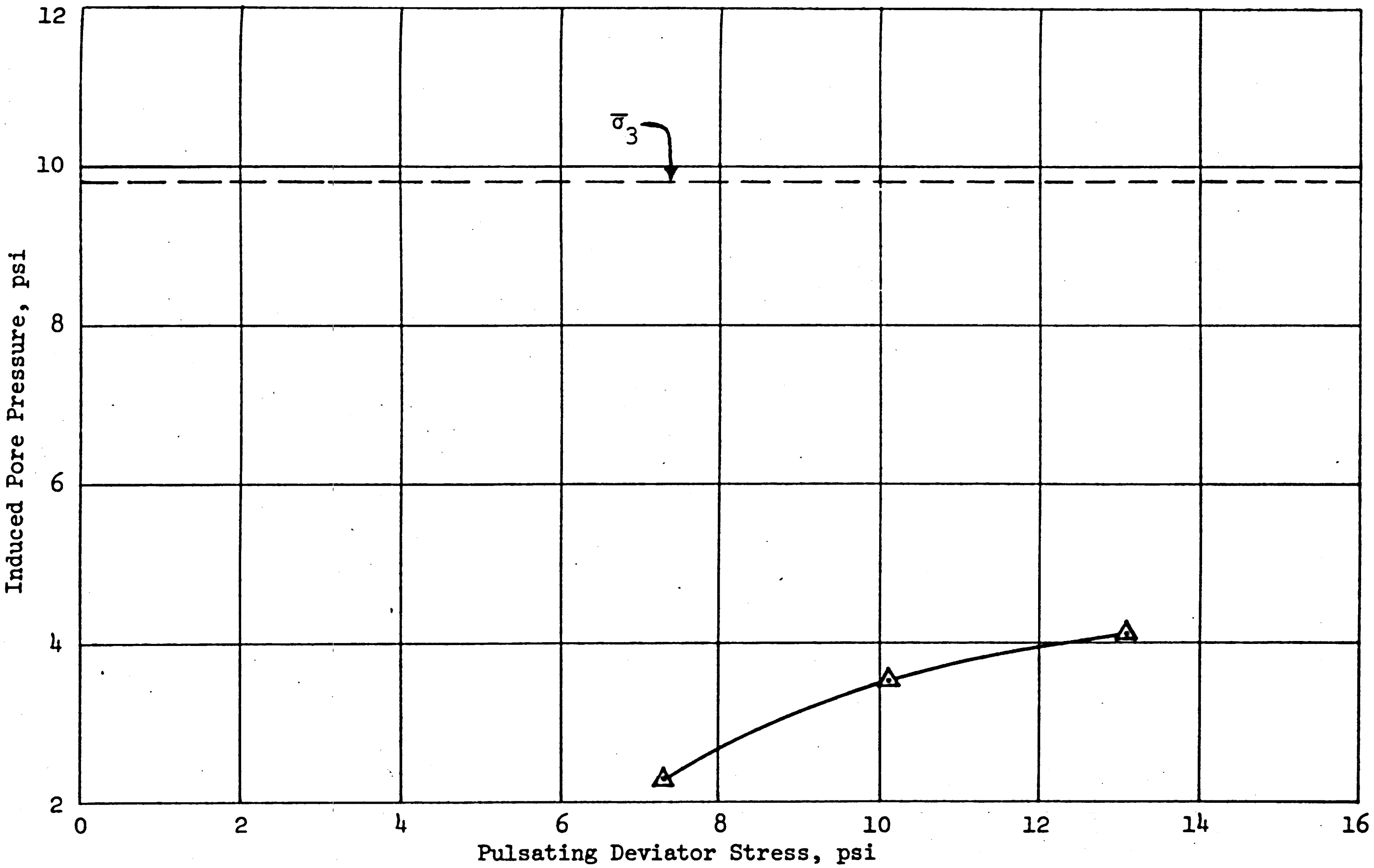


Fig. 27. Anisotropic (K = 3.0) cyclic triaxial loading of material representative of 33-ft depth--induced pore pressure versus pulsating deviator stress (γ_d = 107 pcf, 20% strain)

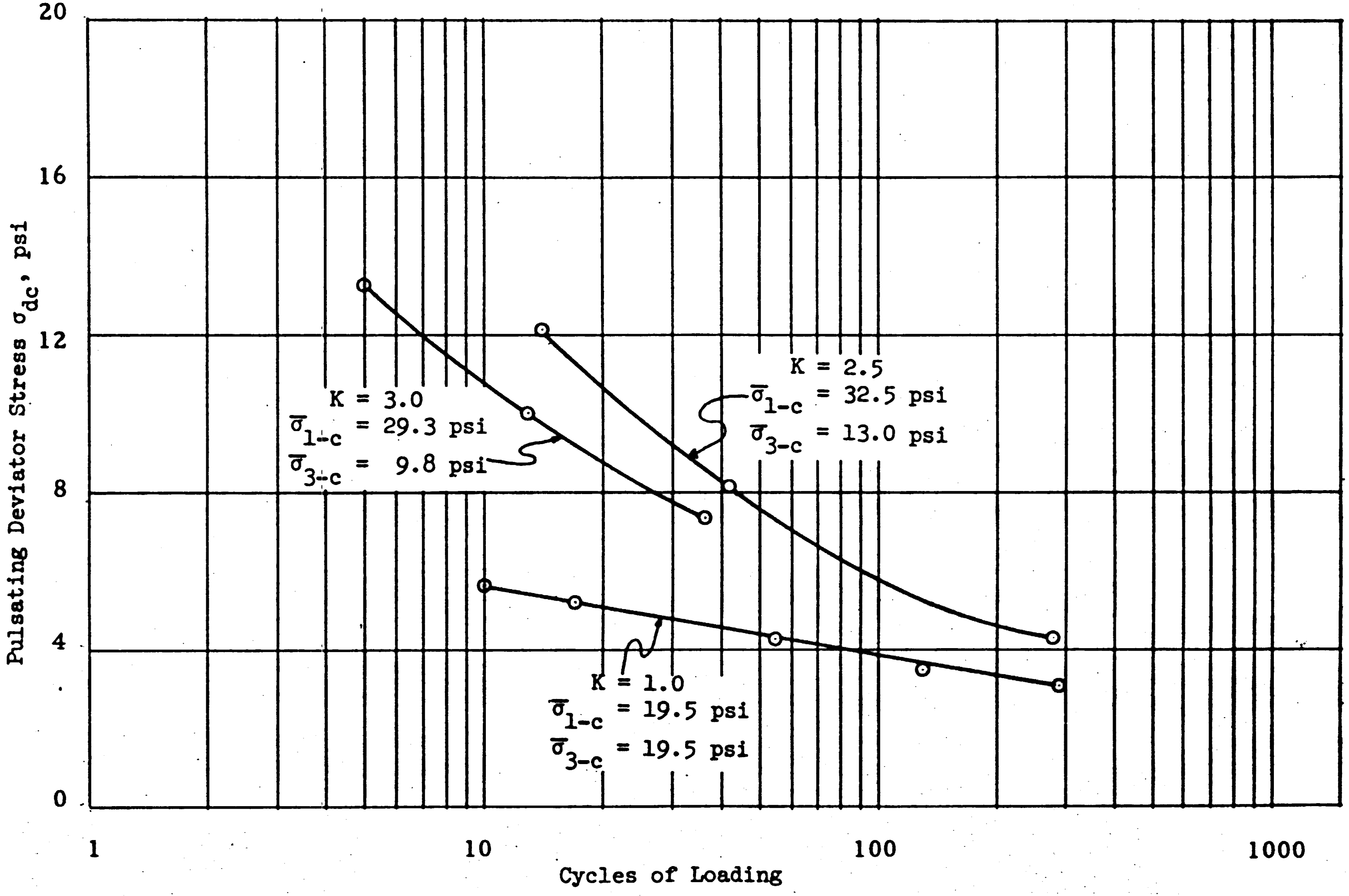


Fig. 28. Comparison of isotropic and anisotropic cyclic triaxial loading to 10% compression strain for material representative of 33-ft depth--deviator stress versus cycles of loading (K = 1.0, 2.5, and 3.0; γ_d = 106 pcf)

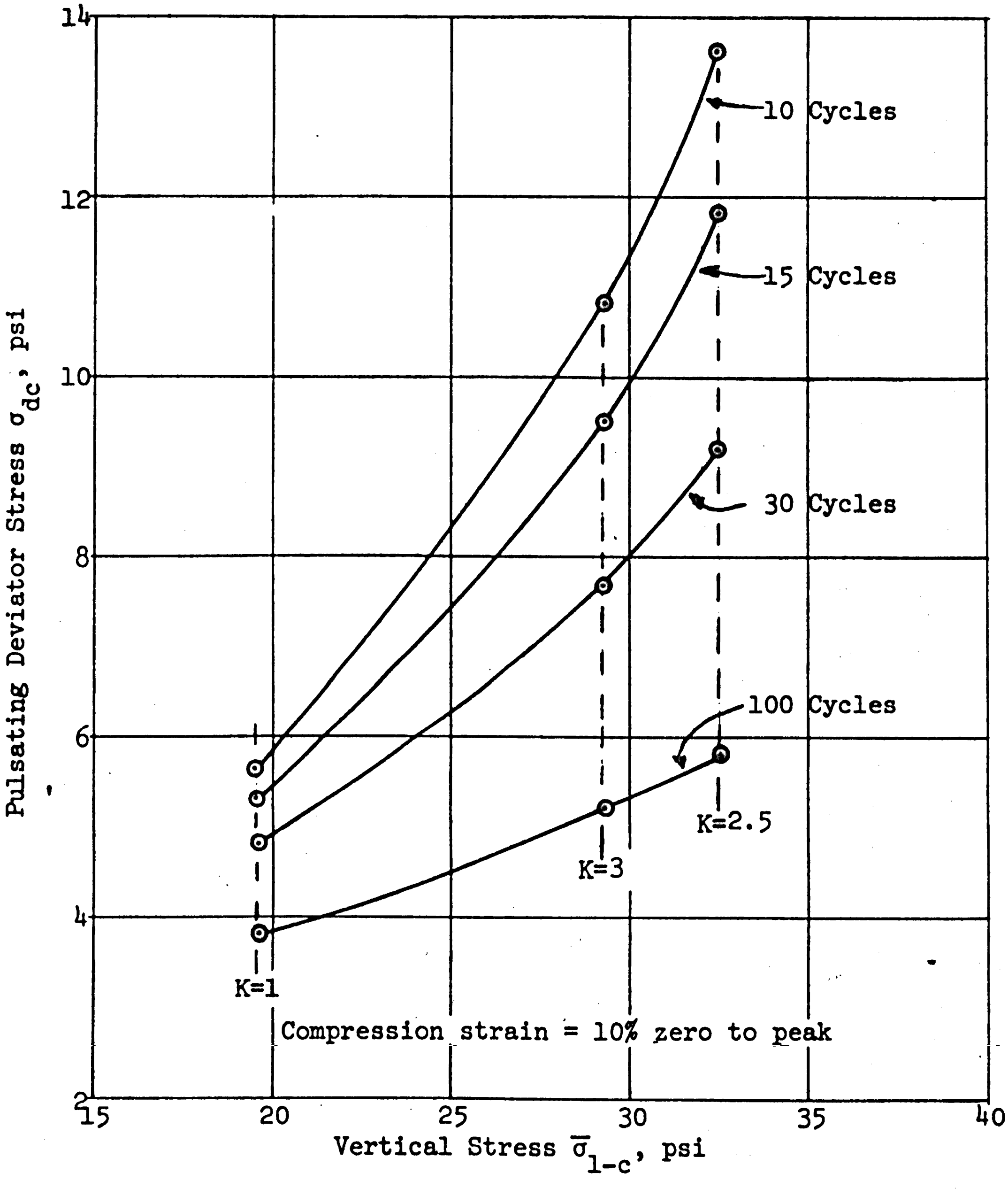


Fig. 29. Isotropic and anisotropic cyclic triaxial loading of materials representative of 33-ft depth--vertical stress versus deviator stress

stress ($\bar{\sigma}_{1-c}$) versus pulsating deviator stress, for the material from the 33-ft depth at a compression strain of 10%. This plot shows that $\bar{\sigma}_{1-c}$ (not K) is the parameter influencing the test results.

55. There are two different phenomena involved in comparing these three K values. For the K = 1.0 data, the samples remained fairly stable until the effective confining pressure became small. At this point the samples strained in extension and compression, an amount approximately 20%, in a few cycles. Comparatively, the $K \neq 1.0$ samples strained a proportional amount on each cycle of stress application. The samples strained only in compression and no catastrophic movements were observed.

PART V: ANALYSIS OF LIQUEFACTION POTENTIAL AT PATOKA DAMSITE

Predicted Ground Motions

56. A study was made at the WES to predict earthquake ground motions at Patoka damsite.[4] In the study several earthquakes at bedrock were considered. Among these earthquakes was a magnitude 7.5 earthquake occurring in the Mississippi Embayment, Nuttli's Zone 1, which is some 130 miles away. Such an earthquake would produce the following recurrent peak ground motions for 0.3 to 3.0 Hz at the damsite.

Acceleration, g	0.045
Velocity, cm/sec	17
Displacement, cm	7.5
Duration, sec*	160

57. The second earthquake considered in the study[4] is one that might occur anywhere in Nuttli's Zone 2, in which Patoka damsite is located. The epicenter of this earthquake would occur close to the damsite but not at it. The regional Zone 2 earthquake is a magnitude 6.5 event having at least the following peak recurrent ground motions for 0.3 to 3.0 Hz at the site.

Acceleration, g	0.11
Velocity, cm/sec	54
Displacement, cm	26
Duration, sec	68

58. The third and most severe earthquake considered is a local earthquake having its epicenter beneath the damsite. Such an earthquake might produce severe high-frequency acceleration pulses at the damsite according to California experiences at Parkfield, Pacoima Dam, and Melendy Ranch. Ambraseys also predicts severe acceleration pulses of high frequency in the epicentral area.** Data do not exist in the

---

* Duration is defined in this study as the total time duration of shaking greater than 0.05 g.

** N. N. Ambraseys, seminar "Selection of Design Earthquakes," U. S. Army Engineer Waterways Experiment Station, CE, 4 November 1970.

central United States to indicate if similar high accelerations at high frequencies can be expected at Patoka damsite. While geologic conditions at the site differ greatly from those in California, raising the possibility that California experiences do not apply, Ambraseys' views are based on a broad variety of geologic conditions. In the absence of observational data, it seems necessary to conclude that an earthquake having its epicenter at the damsite would result in some high acceleration pulses, having short periods at the damsite. Obviously, the likelihood of an earthquake occurring at the damsite is smaller than that of one occurring within a radius of 5 or 10 miles from the dam. An earthquake at the site might produce some accelerations as high as 0.7 g or higher but possibly would not affect maximum particle velocities and hence would have a somewhat limited significance.

Liquefaction Potential

59. The analysis of the liquefaction potential at Patoka damsite was made by a procedure[3] that involved the assumption of a horizontal acceleration and absence of shear forces on horizontal planes prior to the earthquake.* Therefore, this analysis is valid near and beyond the toe and beneath the center line of the dam.

60. The magnitude 7.5 earthquake occurring in the Mississippi Embayment is obviously not the most critical event; therefore, it is necessary to consider the regional or the local earthquake. No active faults were found in the immediate vicinity of the dam.[4] This would indicate that the possibility of experiencing the local earthquake is extremely remote. For this reason the regional earthquake will be considered first.

61. The lower limit of expected acceleration is the 0.11-g peak recurring acceleration, given in reference 4, and is assumed to be the average acceleration, or $0.65a_{max}$ as defined by Seed.[3] The maximum acceleration is computed to be $\frac{1}{0.65}$ (0.11 g) or 0.17 g . The following relationship between magnitude and average number of cycles having a magnitude of $0.65a_{max}$ has been proposed by Seed.

---

* The ratio of the acceleration at the soil surface to the acceleration at bedrock was assumed to be one.

Magnitude	N_{eq}*
8	30
7-1/2	20
7	10

* N_{eq} is the equivalent number of cycles as defined by Seed.

If one extrapolates these figures, a magnitude 6.5 earthquake would correspond to an N_{eq} of 5 cycles. If the duration of earthquake motion in the midcontinent area is taken to be four times that in the West Coast area, as proposed by Nuttli,[5] N_{eq} as defined by Seed would presumably become 120, 80, 40, and 20 cycles.

62. Following Seed's procedure, the following stress ratios ($\sigma_{dc}/2\sigma_a$) can be calculated.

Depth ft	$\left(\frac{a_{max}}{g}\right)$	$\left(\frac{0.65a_{max}}{g}\right)$	γ pcf	r_d	C_r	σ_a psi	$\left(\frac{\sigma_{dc}}{2\sigma_a}\right)$ psi
9	0.17	0.11	125	0.98	0.70	7.8	0.155
17.5	0.17	0.11	125	0.96	0.60	12.8	0.210
28	0.17	0.11	125	0.92	0.60	17.4	0.237
33	0.17	0.11	125	0.91	0.60	19.5	0.246
55	0.17	0.11	125	0.85	0.60	29.1	0.257

63. The stress ratios in the last column of the tabulation above are used in conjunction with figs. 21, 20, 14, 17, and 22. If the figures indicate more than 20 cycles of loading are required to fail the material, the foundation is considered safe according to the number of cycles proposed by Nuttli and by Seed. However, if less than 20 cycles caused failure, the material would fail according to Nuttli, but 5 cycles or less would have to cause failure according to Seed. The following tabulation presents the results of the analysis of the behavior of the foundation soils at in situ dry density under this regional earthquake.

Depth ft	Fig. No.	In Situ Dry Density pcf	$\left(\frac{\sigma_{dc}}{2\sigma_a}\right)$	Cycles to		
				Initial Liquefaction	10% Strain	20% Strain
9	21	92	0.155	1500*	1500*	1500*
17.5	20	88	0.210	4	4	7
28	14	98	0.237	3	4	6
33	17	104	0.246	1*	1*	2*
55	22	90	0.257	7*	5*	7*

* The data curves were extrapolated to obtain these values.

64. Thus, it is seen that the area around the dam and underneath the center line would undergo extensive liquefaction during a Nuttli's Zone 2 magnitude 6.5 earthquake according to Nuttli's criteria. However, it takes more than 5 cycles to cause 20% strain in all but the 33-ft material; therefore, only the 33-ft material fails according to Seed's criteria.

65. The 0.11-g peak recurring ground motion that gives a peak acceleration of 0.17 g assuming $a_{ave} = 0.65a_{max}$ can be assumed as a minimum value. California experience[6] would indicate that a peak acceleration of 0.44 g can be expected during a 6.5 magnitude earthquake. Using this value of peak acceleration, the stress ratios in the following tabulation can be calculated. If figs. 21, 20, 14, 17, and 22 are

Depth ft	Fig. No.	In Situ Dry Density pcf	$\left(\frac{\sigma_{dc}}{2\sigma_a}\right)$	Cycles to*		
				Initial Liquefaction	10% Strain	20% Strain
9	21	92	0.401	5	10	--
17.5	20	88	0.543	1	1	2
28	14	98	0.613	1	1	1
33	17	104	0.637	1	1	1
55	22	90	0.665	1	1	1

* The data curves were extrapolated to obtain these values.

then entered as indicated in the tabulation, it is seen that the foundation around the dam and underneath the center line would undergo extensive liquefaction according to any criteria proposed to date. The data for the 55-ft material should be accepted with some reservation since remolded samples were tested in lieu of undisturbed specimens.

66. Cyclic triaxial tests were conducted to determine the effects of densification on liquefaction potential. Materials representing the 28- and 33-ft depths were tested at dry densities of about 109 and 113 pcf, respectively. This corresponds to a relative density of 88% for the 28-ft material and 94% for the 33-ft material. These test results are presented in figs. 15 and 18. The calculation of stress ratio is identical with that discussed in paragraph 62 except that C_r is equal to 0.7. A maximum peak acceleration of 0.17 g will yield a stress ratio of 0.203 for the 28-ft material and 0.211 for the 33-ft material. These stress ratios and figs. 15 and 18 were used to predict the behavior of the compacted materials. The results are shown in the following tabulation giving the behavior of the compacted materials under the regional earthquake.

Depth ft	Dry Density, pcf		Fig. No.	$\left(\frac{\sigma_{dc}}{2\sigma_a}\right)$	Cycles to*	
	In Situ	Compacted			Initial Liquefaction	10% Strain
28	98	108	15	0.203	100	140
33	104	113	18	0.211	5	6

* The data curves were extrapolated to obtain these values.

67. Based on this analysis it is seen that the compacted materials would be safe if subjected to a magnitude 6.5 earthquake with a peak acceleration of 0.17 g. However, if the peak acceleration is increased to 0.44 g,[6] then stress ratios of 0.525 and 0.546 are computed for the 28- and 33-ft materials, respectively. If fig. 15 is extrapolated and entered at a stress ratio of 0.525, initial liquefaction is predicted in 1 cycle and 10% strain is predicted in 2 cycles. If fig. 18 is extrapolated and entered at a stress ratio of 0.546, initial liquefaction and 10% strain are predicted during the first cycle. Thus by using both Seed's and Nuttli's criteria, the compacted materials would experience a strain of 10% or greater if subjected to a magnitude 6.5 earthquake with a peak acceleration of 0.44 g.

68. It is doubtful that the materials could be compacted to these densities in situ without removing the material and replacing it. Certainly a field compaction would be required since the fines exceed the amount considered suitable for in situ compaction. (The maximum density obtained on the vibratory table was 112 pcf for the 33-ft material.) If the material is removed, it should be mixed with a cohesive material prior to replacement, as this would increase its resistance to liquefaction.

69. A similar analysis using the predicted ground motions for an earthquake occurring at the structure could be conducted. Because the foundation materials are predicted to fail when subjected to a Zone 2 regional earthquake, the use of an earthquake whose epicenter is located at the site is considered unnecessary. Obviously, extensive liquefaction of the foundation materials is predicted if the earthquake epicenter is located beneath the dam.

PART VI: CONCLUSIONS AND RECOMMENDATION

70. Based on the results of the study reported herein, it is concluded that if the Patoka damsite is subjected to a magnitude 6.5 Nuttli's Zone 2 earthquake, extensive liquefaction should be expected to occur in the foundation material around the dam. This liquefaction would occur throughout the foundation soil to rock.

71. If the consequences of foundation liquefaction require designing the dam for earthquake effects, it is recommended that consideration should be given to removing the foundation material to bedrock and replacing it with a compacted rolled-fill section of cohesive material. If in the cost analysis of this task, the cost of the removal of the bottom 15 ft of silty clay becomes prohibitive, it is recommended that a series of tests be conducted on undisturbed samples of the material to determine the liquefaction characteristics of such samples, since remolded samples were tested in this study.

LITERATURE CITED

1. Algermissen, S. T., "Seismic Risk Studies in the United States," Proceedings, Fourth World Conference on Earthquake Engineering, Santiago, Chile, 1969.

2. U. S. Army Engineer Waterways Experiment Station, CE, "Undisturbed Sand Sampling Below the Water Table," Bulletin 35, Jun 1950, Vicksburg, Miss.

3. Seed, H. B. and Idriss, I. M., "Simplified Procedure for Evaluating Soil Liquefaction Potential," Journal, Soil Mechanics and Foundation Engineering, American Society of Civil Engineers, Vol 97, No. SM9, Sep 1971, pp 1249-1273.

4. Krinitzsky, E. L., "Geological and Seismological Factors for Design Earthquakes, Patoka Damsite, Indiana," Miscellaneous Paper S-72-41, Dec 1972, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

5. Nuttli, O. W., "State-of-the-Art--Design Earthquake for the Central United States (in preparation), U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

6. Schnabel, P. B. and Seed, H. B., "Accelerations in Rock for Earthquakes in the Western United States" (in preparation).

7. Seed, H. B. and Peacock, W. H., "Test Procedures for Measuring Soil Liquefaction Characteristics," Journal, Soil Mechanics and Foundation Engineering, American Society of Civil Engineers, Vol 97, No. SM8, Aug 1971, pp 1099-1119.

Table 1

Soil Classification Data

Boring No.	Sample No.	Depth ft	Visual Classification	Plasticity Index	Percent Passing No. 200 Sieve	Range of In Situ Dry Density, pcf
S-1006	5	8.0-9.6	Fine silty sand (SM), gray	1	43	90-96
	6	10.4-12.8	Fine sand (SP-SM), light brown	NP	12	--
	7	12.8-13.8	Fine silty sand (SM), gray	NP	47	98-100
	9	17.6-19.5	Fine silty sand (SM)	--	28	61.5-86.6
	10	20.0-22.3	Fine clayey sand (SC), gray; organic matter (wood)	--	28	--
	11	22.4-23.8	Fine silty sand (SM)	--	28	68.2-90.7
	12	24.8-25.9	Clayey sand silt (ML)	--	53	90.7-103.2
	13	27.2-29.5	Fine silty sand (SM)	--	17	92.2-102.8
	14	29.6-31.9	Sandy clay (CL), gray; organic matter (wood)		52	--
	15	32.0-34.3	Fine sandy clay (CL), gray	--	78	--
	16	34.4-36.7	Fine clayey sand (SC), gray; organic matter (wood)	--	22	--
	17	36.8-39.1	Sandy clay (CL), gray; organic matter	--	84	--
	18	39.2-41.5	Fine sandy clay (CL), gray; organic matter	--	69	--
	19	41.6-43.9	Fine sandy clay (CL), gray; organic matter	--	87	--
	20	44.0-46.3	Silty clay (CL), gray; fine sand and organic matter	19	85	--
	21	46.4-48.7	Silty clay (CL), gray; fine sand and organic matter	--	89	--
	22	48.8-51.1	Silty clay (CL), gray; trace of iron oxide, fine sand, and organic matter	--	97	--
	23	51.2-53.5	Silty clay (CL), gray; trace of fine sand and organic matter	--	98	--
	25	56.0-58.3	Silty clay (CL), gray; trace of fine sand, iron oxide, and organic matter	--	99	--
	26	58.4-60.1	Silty clay (CL), gray; trace of iron oxide and organic matter	--	99	--
S-1007	2	4.9-7.1	Sandy clay (CL), brown	--	61	--
	3	7.2-9.3	Sandy clay (CL), gray	--	51	--
	4	9.6-11.7	Fine clayey sand (SC), brown	--	33	--
	5	12.0-14.2	Fine clayey sand (SC), gray; organic matter (wood)	--	47	--
	6	14.4-15.6	Fine clayey sand (SC), gray; organic matter (wood)	--	33	--
	7	16.8-19.1	Fine silty sand (SM), gray; organic matter (wood)	1	38	87-90
	8	19.2-21.1	Fine clayey sand (SC), gray; organic matter (wood)	6	44	--
	9	21.6-23.9	Fine silty sand (SM), light brown; organic matter (wood)	--	18	--

(Continued)

Table 1 (Concluded)

Boring No.	Sample No.	Depth ft	Visual Classification	Plasticity Index	Percent Passing No. 200 Sieve	Range of In Situ Dry Density, pcf
S-1007 (Cont'd)	10	24.0-25.1	Fine silty sand (SM), brown; organic matter (wood)	--	27	--
	12	27.5-28.5	Fine silty sand (SM)	--	45	--
	13	29.9-31.5	Fine silty sand (SM)	--	38	79.5-103.5
	14	32.3-33.4	Fine silty sand (SM)	--	35	101.9
	15	34.7-36.0	Fine silty sand (SM)	--	36	103.2-104.9
	16	37.1-38.6	Fine silty sand (SM)	--	41	98.2-108.2
	17	39.5-41.5	Fine sandy clay (CL), gray	--	52	--
	18	41.9-44.2	Silty clay (CL), gray; trace of fine sand and organic matter	--	81	--
	19	44.3-46.6	Fine sandy clay (CL), gray; organic matter	--	68	--
	20	46.7-49.0	Fine sandy clay (CL), gray; organic matter	--	98	--
	21	49.1-51.4	Silty clay (CL), gray; fine sand, iron oxide, and organic matter	--	99	--
	22	51.5-53.8	Silty clay (CL), gray; trace of fine sand and organic matter	--	99	--
	23	53.9-56.2	Silty clay (CL), gray; trace of fine sand and organic matter	23	99	88-92
	24	56.3-58.4	Silty clay (CL), gray; trace of fine sand, organic matter, and iron oxide	17	99	--
	26	61.1-63.4	Silty clay (CL), gray; trace of fine sand, iron oxide, and organic matter	--	99	--
	27	63.5-64.4	Silty clay (CL), gray; trace of fine sand, organic matter, and iron oxide	--	98	--
S-1007a	1	27.5-29.7	Clayey sandy silt (ML)	--	56	99-112
	2	29.9-32.1	Fine silty sand (SM)	--	27	99.7-107.5
	3	32.3-34.4	Fine silty sand (SM)	--	28	97.8-105.8
	4	34.7-36.9	Fine silty sand (SM)	--	37	101.3-108.0

Table 2

Dry Density of Sample Segments

Boring No.	Depth ft*	Sample No.	Dry Density, pcf, of Increment No. 1	2	3	4	5	6	7	8
S-1006	9.0	5	89.7	95.6	--	--	--	--	--	--
	17.6	9	79.7	61.6	86.6	77.0	78.3	72.5	--	--
	22.5	11	68.2	84.3	91.7	--	--	--	--	--
	24.8	12	103.3	90.9	--	--	--	--	--	--
	27.3	13	92.2	97.0	96.1	97.5	96.2	94.8	98.0	102.9
S-1007	17.5	7	86.6	88.0	90.4	--	--	--	--	--
	30.3	13	99.6	79.5	99.5	103.5	--	--	--	--
	32.4	14	102.0	--	--	--	--	--	--	--
	34.8	15	104.0	105.0	103.2	--	--	--	--	--
	37.2	16	97.1	105.0	106.9	107.8	108.2	--	--	--
	55.0	23	87.6	90.3	91.7	91.2	--	--	--	--
S-1007a	27.5	1	100.7	99.1	112.0	108.0	--	--	--	--
	30.0	2	107.5	107.0	99.8	--	--	--	--	--
	32.5	3	102.9	101.9	104.1	105.4	103.3	104.7	105.7	97.9
	34.8	4	108.0	105.8	105.4	104.7	101.3	--	--	--

* Depth to the top of the sample.

Table 3

Summary of Petrographic Analysis

Size Fraction	Mineral	Mineral Content, %, of Sample at Depth of 9 ft	17.5 ft	33 ft	55 ft
Plus No. 200 sieve	Quartz	54	58	62	2
	Limonite	1	--	Trace	--
	Chert	2	--	Trace	--
	Mica	--	Trace	--	--
	Feldspar	Trace	--	--	Trace
	Organic Matter	Trace	4	--	--
Minus No. 200 sieve	Calcite	--	--	--	5
	Silt and clay-size material*	26	25	27	69
	Clay	17	13	11	24
	Particle Shape	Shape, %, of Sample at Depth of 9 ft	17.5 ft	33 ft	55 ft
Plus No. 200 sieve	Round	2	1	8	Trace
	Subround	15	10	9	1
	Subangular	30	31	36	1
	Angular	10	20	9	Trace
Minus No. 200 sieve	Round	--	Trace	1	--
	Subround	12	2	2	4
	Subangular	14	7	22	54
	Angular	17	29	13	40

* Predominantly quartz fragments.

Table 4

Distribution of Minerals by Sieve Size

Depth of Material ft	Mineral	Mineral Content, % at Sieve Size +60	-60 +120	-120 +200	-200 +Pan
9	Quartz	49	99	95	--
	Limonite	49	--	--	--
	Organic matter	2	--	--	--
	Feldspar	--	1	1	--
	Chert	--	--	4	--
	Silt and clay-size material*	--	--	--	60
	Clay	--	--	--	40
17.5	Quartz	--	93	97	--
	Organic matter	100	7	3	--
	Mica	--	Trace	--	--
	Silt and clay-size material*	--	--	--	80
	Clay	--	--	--	20
33	Quartz	99	100	99	35
	Limonite	1	--	1	--
	Chert	--	--	Trace	--
	Silt and clay-size material*	--	--	--	30
	Clay	--	--	--	35
55	Quartz	--	--	96	--
	Feldspar	--	--	2	--
	Mica	--	--	2	--
	Calcite	--	--	--	5
	Silt and clay-silt material*	--	--	--	69
	Clay	--	--	--	24

---

* Predominantly quartz fragments.

Table 5

Distribution of Particle Shapes by Sieve Size

Depth of Material ft	Particle Shape	Particle Shape, %, at Sieve Size +60	-60 +120	-120 +200	-200 +Pan
9	Round	--	5	2	--
	Subround	10	25	28	28
	Subangular	40	55	53	33
	Angular	50	15	17	39
17.5	Round	--	--	--	--
	Subround	--	15	19	18
	Subangular	--	55	50	15
	Angular	100	30	30	75
33	Round	1	1	3	4
	Subround	19	21	12	6
	Subangular	60	51	61	60
	Angular	20	27	24	30
55	Round	--	--	5	--
	Subround	--	--	40	4
	Subangular	--	--	45	54
	Angular	--	--	10	40

Table 6

Summary of Test Results

										Initial Liquefaction*		10% Strain		20% Strain		
Boring No.	Sample No. (Representing Depth, ft)	Test No.	Dry Density γ_d pcf	Back Pressure psi	B	σ_a or $\bar{\sigma}_{3-c}$ psi	σ_{dc} psi	Acceleration g	Stress Ratio $\frac{\sigma_{dc}}{2\sigma_a}$	Cycles of Loading	Strain** %	Cycles of Loading	Actual Strain** %	Cycles of Loading	Actual Strain** %	K
								Isotropic Loading								
S-1006	13(28)	1	97.6	48.1	0.989	17.4	5.07	0.098	0.136	19	3.6	20	11.5	23	21.9	1.0
		2	99.4	55.5	0.960	17.4	6.01	0.124	0.173	12	3.8	13	9.4	16	18.8	1.0
		3	99.8	75.0	0.960	17.3	10.34	0.213	0.297	1	4.5	2	11.4	4	17.2	1.0
		4	98.8	54.8	0.984	17.4	3.96	0.083	0.114	134	2.2	136	12.4	140	21.5	1.0
		5	101.2	44.9	0.986	58.0	17.80	0.110	0.153	15	6.5	16	11.7	17	15.5	1.0
S-1007	(33)†	6	104.5	64.6	0.984	19.5	5.23	0.092	0.134	7	8.4	7	8.4	8	22.4	1.0
S-1007a		7	101.9	64.9	0.993	19.4	3.36	0.060	0.087	130	8.4	131	13.4	133	19.6	1.0
		8	104.1	64.7	0.987	19.5	4.16	0.078	0.114	54	3.7	55	13.2	57	21.1	1.0
		9	105.8	64.9	0.993	19.5	5.65	0.100	0.145	5	0.5	7	6.7	8	14.3	1.0
		10	103.9	47.4	0.992	60.4	13.26	0.076	0.110	18	7.4	19	13.2	20	20.6	1.0
		11	104.4	64.7	0.995	19.5	3.06	0.054	0.078	287	1.4	288	12.0	291	18.4	1.0
		12	112.8	64.8	0.976	19.4	5.20	0.108	0.134	10	9.2	10	9.2	17	16.3	1.0
		13	113.2	64.8	0.994	19.5	2.84	0.060	0.075	960	0.2	976	8.8	976	8.8	1.0
		14	114.0	64.8	0.996	19.5	5.22	0.108	0.134	110	0.9	125	7.0	127	7.2	1.0
		15	113.0	64.9	0.997	19.5	8.24	0.170	0.211	5	8.4	6	10.0	15	14.4	1.0
S-1006	13(28)	16	109.1	60.4	0.981	17.4	4.60	0.110	0.132	1360	1.0	1389	9.1	1389	9.1	1.0
		17	108.9	64.8	0.990	17.4	8.50	0.204	0.244	12	0.9	74	7.9	74	7.9	1.0
		18	108.7	64.8	0.990	17.4	6.73	0.162	0.193	131	1.2	157	7.6	157	7.6	1.0
		19	107.4	64.9	0.992	17.4	8.43	0.203	0.242	19	1.1	44	8.5	61	8.9	1.0
		20	97.0	70.0	0.989	17.4	7.12	0.147	0.205	6	4.5	7	10.7	9	19.5	1.0
S-1007	7(17.5)	A1	95.0	64.8	0.960	12.5	2.98	0.094	0.119	1375	1.9	1377	11.5	1385	17.0	1.0
		A2	97.0	75.3	0.960	10.0	5.00	0.158	0.250	2	14.4	2	14.4	4	22.5	1.0
		A3	93.3	69.7	0.980	12.8	3.49	0.110	0.136	123	4.3	124	10.0	130	18.2	1.0
S-1006	5(9)	A4	110.1	123.1	0.910	7.8	3.65	0.257	0.234	109	6.9	110	11.8	113	22.2	1.0
S-1007	7(17.5)	A5	97.9	64.7	0.980	12.9	3.92	0.124	0.152	33	1.1	35	10.8	38	17.1	1.0
S-1007	23(55)	A6	96.7	47.0	0.960	29.1	11.71	0.141	0.201	17	24.1	15	11.4	17	24.1	1.0
S-1006	5(9)	A7	115.2	82.5	0.900	7.7	5.17	0.364	0.336	10	1.7	18	10.8	20	11.0	1.0
S-1007	23(55)	A8	93.0	30.5	0.960	29.2	8.78	0.106	0.150	217	3.4	220	10.9	224	19.2	1.0
								Anisotropic Loading								
S-1007	(33)†	A9	108.5	64.7	0.970	13.0	4.27	--	--	--	--	275	10.0	1185	19.1	2.5
S-1007a		A10	108.3	65.0	0.990	13.0	8.10	--	--	--	--	42	10.0	149	20.4	2.5
		A11	107.4	65.0	0.960	13.0	12.08	--	--	--	--	14	10.0	41	19.6	2.5
		A12	106.6	65.0	0.970	9.8	7.27	--	--	--	--	36	10.0	84	18.7	3.0
		A13	107.0	65.0	0.970	9.8	10.07	--	--	--	--	13	10.0	38	18.0	3.0
		A14	107.2	65.0	0.970	9.8	13.20	--	--	--	--	5	10.0	14	17.8	3.0

---

* Defined as the stage when the pore pressure first equaled the chamber pressure.

** Strain values shown are peak-to-peak values (the sum of compression and extension strains) or zero-to-peak values, whichever was greater.

† Material obtained by combining boring S-1007 samples 13-1, 13-2, 14-1, 15-1, 15-3, 16-1 and boring S-1007a samples 1-4, 3-2, 3-3, 3-4, 3-5, 3-6, 3-7, 3-8, 4-1, 4-2, 4-3, 4-4, and 4-5.

APPENDIX A: BORING LOGS

DRILLING LOG

DIVISION Ohio River

INSTALLATION Louisville District

SHEET 1 OF 4 SHEETS

1. PROJECT Patoka Lake
2. LOCATION *(Coordinates or Station)* Sta 9+10, 255' D.S. ₵ Dam
3. DRILLING AGENCY Book 775, Page 4
4. HOLE NO *(As shown on drawing title and file number)* S-1001
5. NAME OF DRILLER Pittsburg Testing Laboratory
6. DIRECTION OF HOLE ☒ VERTICAL ☐ INCLINED ______ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN
8. DEPTH DRILLED INTO ROCK
9. TOTAL DEPTH OF HOLE
10. SIZE AND TYPE OF BIT 3" Diam Shelby Tube
11. DATUM FOR ELEVATION SHOWN *(TBM or MSL)* 36" length
12. MANUFACTURER'S DESIGNATION OF DRILL CME
13. TOTAL NO. OF OVERBURDEN SAMPLES TAKEN DISTURBED UNDISTURBED
14. TOTAL NUMBER CORE BOXES
15. ELEVATION GROUND WATER 488.4
16. DATE HOLE STARTED 11 Jan 1972 COMPLETED 24 Jan 1972
17. ELEVATION TOP OF HOLE 491.5
18. TOTAL CORE RECOVERY FOR BORING %
19. SIGNATURE OF INSPECTOR D.L.T.

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS *(Description)* d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS *(Drilling time, water loss, depth of weathering, etc., if significant)* g
	1 2		Brown sandy clay, medium moist	SS-1 Rec. 2'		
488.4 1-11-72	3 4 5			SS-2 Rec. 2.5'		
484.0 ±	6 7			SS-3 Rec. 1.7'		Tube leaked H_2O after sealing
481.5±	8 9 10			No Recovery		
479.0 ±	11 12		Brown silty sand, loose	SS-4 Rec. 2.0'		Sample disturbed in sealing
476.5±	13 14 15		Gray silty sand, loose	SS-5 Rec. 1.9'		Tube leaked H_2O after sealing
	16 17		Gray sandy clay, trace organic, wood particles	SS-6 Rec. 2.5'		
471.5±	18 19 20			SS-7 Rec. 2.4'		4

Fig. A1. Log of boring S-1001 (0 to 20 ft)

DRILLING LOG

DIVISION: Ohio River

INSTALLATION: Louisville District

SHEET 2 OF 4 SHEETS

1. PROJECT: Patoka Lake
2. LOCATION (Coordinates or Station):
3. DRILLING AGENCY:
4. HOLE NO. (As shown on drawing title and file number): S-1001
5. NAME OF DRILLER:
6. DIRECTION OF HOLE: ☐ VERTICAL ☐ INCLINED ______ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN:
8. DEPTH DRILLED INTO ROCK:
9. TOTAL DEPTH OF HOLE:
10. SIZE AND TYPE OF BIT:
11. DATUM FOR ELEVATION SHOWN (TBM or MSL):
12. MANUFACTURER'S DESIGNATION OF DRILL:
13. TOTAL NO. OF OVERBURDEN SAMPLES TAKEN: DISTURBED: UNDISTURBED:
14. TOTAL NUMBER CORE BOXES:
15. ELEVATION GROUND WATER:
16. DATE HOLE: STARTED: COMPLETED:
17. ELEVATION TOP OF HOLE:
18. TOTAL CORE RECOVERY FOR BORING: %
19. SIGNATURE OF INSPECTOR: D.L.T.

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
				SS-8		Pushed tube 1.8', hit wood
	21		Gray silty sand, trace clay			
				Rec. 2.1'		
	22			Fish-tailed		
	23			SS-9		Pushed tube 2.2', hit wood
	24		Gray silty sand, chunk of wood	Rec. 0.7'	Jar 1 @ 24.7'	Lost sample in sealing tube and took jar sample
	25			SS-10		1-10-72 Hole heaved to 23.0' Rock bit to 28.0'
	26			Rec. 0.0		
	27			Rock bit		
	28			SS-11		Gray, fine sand SP, loose sample disturbed
	29					
	30			Rec. 2.0'		
	31			SS-12		
	32			Rec. 2.5'		
	33			SS-13		Brown, sandy clay, w/wood
	34					
	35			Rec. 1.1'		
	36			SS-14		1-19-72 Gray sandy clay w/rock fragments and fine sand layers
	37			Rec. 1.8'		Bottom sl disturbed 38.0'
	38			SS-15		Light gray sandy clay to gray fat clay
	39					
	40					

Fig. A1 (Continued). Log of boring S-1001 (20 to 40 ft)

DRILLING LOG	DIVISION Ohio River	INSTALLATION Louisville District	SHEET 3 OF 4 SHEETS
1. PROJECT Patoka Lake		10. SIZE AND TYPE OF BIT 3" Diam Shelby Tube	
2. LOCATION (Coordinates or Station) Sta 9+10, 255' D. S. ℄ Dam		11. DATUM FOR ELEVATION SHOWN (TBM or MSL)	
3. DRILLING AGENCY Pittsburg Testing Laboratory		12. MANUFACTURER'S DESIGNATION OF DRILL CME	
4. HOLE NO. (As shown on drawing title and file number)	S-1001	13. TOTAL NO. OF OVERBURDEN SAMPLES TAKEN	DISTURBED / UNDISTURBED
5. NAME OF DRILLER Donahue		14. TOTAL NUMBER CORE BOXES	
6. DIRECTION OF HOLE ☒ VERTICAL ☐ INCLINED ______ DEG. FROM VERT.		15. ELEVATION GROUND WATER	
		16. DATE HOLE	STARTED 11 Jan 1972 COMPLETED 24 Jan 1972
7. THICKNESS OF OVERBURDEN		17. ELEVATION TOP OF HOLE 491.5	
8. DEPTH DRILLED INTO ROCK		18. TOTAL CORE RECOVERY FOR BORING %	
9. TOTAL DEPTH OF HOLE		19. SIGNATURE OF INSPECTOR J.V.	

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
				Rec. 2.3		40.5
	41					
	42			SS-16 Rec. 1.5'		Gray sandy to fat clay. Bottom 1.0' v. liquid, poured out of tube, not recovered
	43			Rock bit		43.0
	44					Very soft; sampler fell from 43.0' to 43.6'; no samples.
	45			SS-17		Reddish brown to gray sandy clay
	46			Rec. 2.3'		46.1
	47			No sample		Shelby tube & rods settled 46.1 to 47.2, no sample 47.2
	48			SS-18		Lt gray fine sand, loose, wet
	49			Rec. 2.0'		49.7 Shelby tube First try, plunger did not return. Second try, tube returned empty.
	50					
	51					
	52			Rec. 0.0		52.2
	53				Jar 2 54.7'	Gray, liquid; sample poured from tube as it came out of hole
	54	CL	Gray silty sandy clay, wet, very soft	Rec. 0.0		54.7
	55					No sample recovered. Tube pushed by hand without reaming hole.
	56					
	57			Rec. 0.0		57.2
	58				Jars 3 & 4	Gray, liquid, thickness of drill mud
	59			Rec. 0.0		59.7
	60					

Fig. A1 (Continued). Log of boring S-1001 (40 to 60 ft)

DRILLING LOG

DIVISION: Ohio River

INSTALLATION: Louisville District

SHEET 4 OF 4 SHEETS

1. PROJECT: Patoka Lake
2. LOCATION (Coordinates or Station):
3. DRILLING AGENCY: Pittsburg Testing Laboratory
4. HOLE NO. (As shown on drawing title and file number): S-1001
5. NAME OF DRILLER: Donahue
6. DIRECTION OF HOLE: ☒ VERTICAL ☐ INCLINED ______ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN:
8. DEPTH DRILLED INTO ROCK:
9. TOTAL DEPTH OF HOLE:
10. SIZE AND TYPE OF BIT:
11. DATUM FOR ELEVATION SHOWN (TBM or MSL):
12. MANUFACTURER'S DESIGNATION OF DRILL: CME
13. TOTAL NO. OF OVERBURDEN SAMPLES TAKEN: DISTURBED: UNDISTURBED:
14. TOTAL NUMBER CORE BOXES:
15. ELEVATION GROUND WATER:
16. DATE HOLE: STARTED 11 Jan 1972 COMPLETED 24 Jan 1972
17. ELEVATION TOP OF HOLE:
18. TOTAL CORE RECOVERY FOR BORING: %
19. SIGNATURE OF INSPECTOR: J.V.

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	61			SS-19		Gray, liquid w/0.2' soft clay at bottom of sample
	62			Rec. 2.4'		61.9 Refusal to Shelby
						Gravel, compact
	63			Rock bit		63.7 Tried to push
	64					Refusal, gravel
	65					
	66					
424.2+	67					
	68		Refusal			
	69					

Fig. A1 (Concluded). Log of boring S-1001 (60 ft to refusal)

DRILLING LOG | DIVISION: Ohio River | INSTALLATION: Louisville District | SHEET 1 OF 7 SHEETS

1. PROJECT: Patoka Lake
2. LOCATION (Coordinates or Station): Sta 8+95, 265' D. S. ℄ Dam
3. DRILLING AGENCY: Book 775, Page 6
4. HOLE NO. (As shown on drawing title and file number): SD-1002
5. NAME OF DRILLER: Pittsburg Testing Laboratory
6. DIRECTION OF HOLE: ☒ VERTICAL ☐ INCLINED ______ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN
8. DEPTH DRILLED INTO ROCK
9. TOTAL DEPTH OF HOLE
10. SIZE AND TYPE OF BIT
11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
12. MANUFACTURER'S DESIGNATION OF DRILL
13. TOTAL NO. OF OVERBURDEN SAMPLES TAKEN: DISTURBED | UNDISTURBED
14. TOTAL NUMBER CORE BOXES
15. ELEVATION GROUND WATER
16. DATE HOLE: STARTED 11 Feb 1972 | COMPLETED 25 Feb 1972
17. ELEVATION TOP OF HOLE: 491.4
18. TOTAL CORE RECOVERY FOR BORING: %
19. SIGNATURE OF INSPECTOR: E. G. P.

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
				8		
	1		Medium brown-tan silty clay, sl. sandy wet, soft	4		
		CL		4	Jar 1 @1.5'	Red brown damp silty clay, sandy W = 25.0
	2			2		
				5		
	3	CL		5	Jar 2 @3.0'	W = 25.0
				2		
	4			3		
		CL		5	Jar 3 @4.5'	W = 24.0
	5			1		
		CL		3	Jar 4 @5.5'	W = 24.0
	6	CL		2	Jar 5 @6.0'	W = 23.0
		SM	Brown w/tan silty sand, sl. clayey wet, comp.	1	Jar 6 @6.5'	Wet tan to reddish sandy clayey silt W = 20.0
	7	SM		1	Jar 7 @7.0'	W = 21.0
		SM		1	Jar 8 @7.5'	W = 19.0
	8	SM		2	Jar 9 @8.0'	W = 19.0 Reddish brown to tan wet silty sand
				2		
	9	SM		2	Jar 10 @9.0'	W = 17.2
				2		
481.4+	10			2		5

Fig. A2. Log of boring SD-1002 (0 to 10 ft)

DRILLING LOG

DIVISION Ohio River

INSTALLATION Louisville District

SHEET 2 OF 7 SHEETS

1. PROJECT Patoka Lake
2. LOCATION (Coordinates or Station) Sta 8+95, 265' D. S. ℄ Dam
3. DRILLING AGENCY Book 775, Page 6
4. HOLE NO (As shown on drawing title and file number) SD-1002
5. NAME OF DRILLER Pittsburg Testing Laboratory
6. DIRECTION OF HOLE ☒ VERTICAL ☐ INCLINED ______ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN
8. DEPTH DRILLED INTO ROCK
9. TOTAL DEPTH OF HOLE
10. SIZE AND TYPE OF BIT
11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
12. MANUFACTURER'S DESIGNATION OF DRILL
13. TOTAL NO. OF OVERBURDEN SAMPLES TAKEN DISTURBED UNDISTURBED
14. TOTAL NUMBER CORE BOXES
15. ELEVATION GROUND WATER
16. DATE HOLE STARTED 11 Feb 1972 COMPLETED 25 Feb 1972
17. ELEVATION TOP OF HOLE 491.4
18. TOTAL CORE RECOVERY FOR BORING %
19. SIGNATURE OF INSPECTOR E. G. P.

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
				2		
				2	Jar 11 @11'	Very soft brown silty sand W = 20.0
	11	SM	Light reddish brown silty sand, wet, comp.			
				2		
				0	Jar 12 @12'	W = 17.2
	12	SM				
				1		Brown silty sand
	13	SM		1	Jar 13 @13'	W = 13.6
				1		W = 18.1
			Same as above with some gray in color. Loose, sl comp.		Jar 14 @13.8'	Brown loose silty sand
	14		Gray with reddish brown silty sand, wet, comp.	1		
					Jar 15 @14.3'	W = 20.0
		SM		1		
					Jar 16 @15'	W = 19.0
	15	SM		1		
		SM		7	Jar 17 @15.5'	Gray loose silty sand W = 19.0
	16	SM		2	Jar 18 @16.0'	W = 21.0
		SM		12	Jar 19 @16.5'	W = 20.0
	17			2		Gray loose silty sand
		SM		2	Jar 20 @17.5'	W = 21.0
	18	SM	Gray silty sand, sl. org, wet, comp.	3	Jar 21 @18.0'	W = 24.0
				7	No recovery	
	19			10		No recovery
				8		
471.4±	20			4		

Fig. A2 (Continued). Log of boring SD-1002 (10 to 20 ft)

DRILLING LOG

DIVISION Ohio River

INSTALLATION Louisville District

SHEET 3 OF 7 SHEETS

1. PROJECT Patoka Lake
2. LOCATION (Coordinates or Station) Sta 8+95, 265' D. S. ₵ Dam
3. DRILLING AGENCY Book 775, Page 6
4. HOLE NO (As shown on drawing title and file number) SD-1002
5. NAME OF DRILLER Pittsburg Testing Laboratory
6. DIRECTION OF HOLE ☐ VERTICAL ☐ INCLINED ______ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN
8. DEPTH DRILLED INTO ROCK
9. TOTAL DEPTH OF HOLE
10. SIZE AND TYPE OF BIT
11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
12. MANUFACTURER'S DESIGNATION OF DRILL
13. TOTAL NO. OF OVERBURDEN SAMPLES TAKEN DISTURBED UNDISTURBED
14. TOTAL NUMBER CORE BOXES
15. ELEVATION GROUND WATER
16. DATE HOLE STARTED 11 Feb 1972 COMPLETED 25 Feb 1972
17. ELEVATION TOP OF HOLE 491.4
18. TOTAL CORE RECOVERY FOR BORING %
19. SIGNATURE OF INSPECTOR E. G. P.

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
		SM	Gray silty sand,wet, comp.	11	Jar 22 @20.5'	Gray medium silty sand W = 22.0
	21	SM	Gray silty sand,wet, comp. with occasional small rootlets	8	Jar 23 @21.0'	W = 23.0
		SM		4	Jar24 @21.5'	W = 20.0
	22	SM	Gray silty sand,wet,very comp	9	Jar 25 @22.C'	W = 21.0
				12	Jar 26 @22.5'	W = 23.0
	23	SM	Gray silty light gray sand, wet, comp.	4	Jar 27 @23.0'	W = 22.0
		SM	Gray silty sand with trace of clay	8	Jar 28 @23.5'	W = 22.0
	24			13	Jar 29 @24.0'	W = 15.4
		SM-SC	Light gray silty clayey sand, wet, comp.	18	Jar 30 @24.5'	Gray comp. silty sand W = 18.1
	25	SM	Light gray silty sand, wet, sl. comp.	18	Jar 31 @25.0'	W = 20.0
		SM		15	Jar 32 @25.5'	W = 21.0
	26	SM		10	Jar 33 @26.0'	W = 25.0
		SM		14	Jar 34 @26.5'	W = 23.5
	27	SM		17	Jar 35 @27.0'	W = 23.5
		SM		9	Jar 36 @27.5'	W = 22.0
	28	SM	Light gray-white silty sand, wet, sl. comp.	19	Jar 37 @28.0'	W = 22.0
		SM	Light gray with tan silty sand	24	Jar 38 @28.5'	W = 24.0
	29	SC	Gray with brown clayey silty sand, wet, soft	5	Jar 39 @29.0'	W = 25.0
		SC	Gray with brown clayey silty sand, organic, wet, soft	7	Jar 40 @29.5'	W = 26.1
	30	SM	Gray-black silty sand with light trace of clay and decayed weed, comp.	8	Jar 41 @30.0'	Gray comp. silty sand with black organic W = 37.6

Fig. A2 (Continued). Log of boring SD-1002 (20 to 30 ft)

DRILLING LOG

DIVISION Ohio River

INSTALLATION Louisville District

SHEET 4 OF 7 SHEETS

1. PROJECT Patoka Lake
2. LOCATION (Coordinates or Station) Sta 8+95, 265' D. S. ℄ Dam
3. DRILLING AGENCY Book 775, Page 7
4. HOLE NO. (As shown on drawing title and file number) SD-1002
5. NAME OF DRILLER Pittsburg Testing Laboratory
6. DIRECTION OF HOLE ☒ VERTICAL ☐ INCLINED ________ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN
8. DEPTH DRILLED INTO ROCK
9. TOTAL DEPTH OF HOLE
10. SIZE AND TYPE OF BIT
11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
12. MANUFACTURER'S DESIGNATION OF DRILL
13. TOTAL NO. OF OVERBURDEN SAMPLES TAKEN DISTURBED UNDISTURBED
14. TOTAL NUMBER CORE BOXES
15. ELEVATION GROUND WATER
16. DATE HOLE STARTED 11 Feb 1972 COMPLETED 25 Feb 1972
17. ELEVATION TOP OF HOLE 491.4
18. TOTAL CORE RECOVERY FOR BORING %
19. SIGNATURE OF INSPECTOR E. G. P.

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
			Gray silty sl. sandy clay with decayed wood, wet, soft		Jar 42 @30.0'	W = 40.2
		CL		4	Jar 43 @30.5'	Gray sandy clay with black organic. W = 32.7
	31	CL		6	Jar 44 @31.0'	W = 37.0
			Decayed wood (black)	11	Jar 45 @31.5'	
	32			2		
			Gray black silty sand with light trace of clay and wood fragments, wet, sl. comp.	3		
	33	SM		7	Jar 46 @33.0'	W = 26.6
		CL	Gray black sandy silty clay (org), wet, soft	2	Jar 47 @33.5'	W = 29.9 Gray sandy clay with black org.
	34	CL	Gray with some tan sandy silty clay	3	Jar 48 @34.0'	W = 38.9
		CL		4	Jar 49 @34.5'	W = 28.2
	35	CL	Brown sandy clay (org), wet, soft	4	Jar 50 @35.0'	W = 23.5
		SM-SC	Brownish gray silty clayey sand, wet, comp.	11	Jar 51 @35.5'	W = 22.0
	36	SM-SC		11	Jar 52 @36.0'	W = 25.0
		SP	Light gray with some brown silty sand, wet, sl, comp.	20	Jar 53 @36.5'	W = 22.0 Gray silty sand comp.
	37	SP	Light gray with some brown silty sand, wet, sl. comp.	22	Jar 54 @37.0'	W = 22.0
		SM-SP	Light gray with brown silty sand, wet, sl. comp.	20	Jar 55 @37.5'	W = 22.0
	38	CL	Brownish gray silty sandy clay, wet, soft	0	Jar 56 @38.0'	Gray sandy clay, soft W = 28.2
		CL		0	Jar 57 @38.5'	W = 28.2
	39	CL		3	Jar 58 @39.0'	W = 26.6
		CL		1	Jar 59 @39.5'	W = 23.0
451.4±	40	CL		2	Jar 60 @40.0'	W = 24.0

Fig. A2 (Continued). Log of boring SD-1002 (30 to 40 ft)

DRILLING LOG

DIVISION: Ohio River

INSTALLATION: Louisville District

SHEET 5 OF 7 SHEETS

1. PROJECT: Patoka Lake
2. LOCATION (Coordinates or Station): Sta 8+95, 265' D. S. ¢ Dam.
3. DRILLING AGENCY: Book 775 Page 7
4. HOLE NO. (As shown on drawing title and file number): SD-1002
5. NAME OF DRILLER: Pittsburg Testing Laboratory
6. DIRECTION OF HOLE: ☒ VERTICAL ☐ INCLINED ________ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN
8. DEPTH DRILLED INTO ROCK
9. TOTAL DEPTH OF HOLE
10. SIZE AND TYPE OF BIT
11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
12. MANUFACTURER'S DESIGNATION OF DRILL
13. TOTAL NO. OF OVERBURDEN SAMPLES TAKEN: DISTURBED . UNDISTURBED
14. TOTAL NUMBER CORE BOXES
15. ELEVATION GROUND WATER
16. DATE HOLE: STARTED 11 Feb 1972 COMPLETED 25 Feb 1972
17. ELEVATION TOP OF HOLE 491.4
18. TOTAL CORE RECOVERY FOR BORING %
19. SIGNATURE OF INSPECTOR: E. G. P.

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
		CL	Gray sandy silty clay, wet, soft-medium	2	Jar 61 @40.5'	Gray sandy clay, soft W = 24.0
	41	CL	Gray sandy silty clay with some brown, wet, soft-medium	2	Jar 62 @41.0'	W = 25.0
		CL		2	Jar 63 @41.5'	W = 26.1
	42	CL		5	Jar 64 @42.0'	W = 25.0
		CL	Gray sandy silty clay with black org., wet, soft-medium	2	Jar 65 @42.5'	W = 20.0
	43	CL		2	Jar 66 @43.0'	W = 23.5
				3	Jar 67 @43.5'	W = 29.9
	44	SM-SC	Gray with occasional brown silty clayey sand,wet, comp	4	Jar 68 @44.0'	Gray silty sand,comp. W = 22.0
		SM	Gray silty sand, wet, comp	10	Jar 69 @44.5'	W = 16.3
	45	SM		22	Jar 70 @45.0	W = 22.0
		CL	Gray sandy silty clay, wet, soft	4	Jar 71 @45.5'	W = 26.6
	46	SC	Gray brown clayey silty sand, wet, comp.	10	Jar 72 @46.0'	W = 23.5
		SM	Gray brown silty sand with light trace of clay, wet,comp.	14	Jar 73 @46.5'	W = 19.0
	47	SM-SC	Gray brown silty sl. clayey sand, wet, comp.	4	Jar 74 @47.0'	W = 23.5
		SM	Gray brown silty sand, wet, loose - sl. comp.	13	Jar 75 @47.5'	W = 19.0
	48	SM		10	Jar 76 @48.0'	W = 22.0
		SM	Gray brown silty sand with lt trace of clay	3	Jar 77 @48.5'	Gray sandy clay, soft W = 23.5
	49	CL	Gray silty sl. sandy clay, wet, soft	3	Jar 78 @49.0'	W = 30.4
		CL	Gray with some brown silty sl. sandy clay, wet, soft	6	Jar 79 @49.5'	W = 28.2
441.4±	50					

Fig. A2 (Continued). Log of boring SD-1002 (40 to 50 ft)

DRILLING LOG

DIVISION: Ohio River

INSTALLATION: Louisville District

SHEET 6 OF 7 SHEETS

1. PROJECT: Patoka Lake
2. LOCATION (Coordinates or Station): Sta 8+95, 265' D. S. ¢ Dam
3. DRILLING AGENCY: Book 775, Page 8
4. HOLE NO. (As shown on drawing title and file number): SD-1002
5. NAME OF DRILLER: Pittsburg Testing Laboratory
6. DIRECTION OF HOLE: ☐ VERTICAL ☐ INCLINED ________ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN
8. DEPTH DRILLED INTO ROCK
9. TOTAL DEPTH OF HOLE
10. SIZE AND TYPE OF BIT
11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
12. MANUFACTURER'S DESIGNATION OF DRILL
13. TOTAL NO. OF OVERBURDEN SAMPLES TAKEN | DISTURBED | UNDISTURBED
14. TOTAL NUMBER CORE BOXES
15. ELEVATION GROUND WATER
16. DATE HOLE | STARTED 11 Feb 1972 | COMPLETED 25 Feb 1972
17. ELEVATION TOP OF HOLE: 491.4
18. TOTAL CORE RECOVERY FOR BORING %
19. SIGNATURE OF INSPECTOR: E. G. P.

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
				SS-1		
	51					Gray sandy clay
				Rec. 2.5'		
	52					
	53			No recovery		
	54					
	55			SS-1		
						Gray sandy clay
	56					
				Rec. 0.2'		
	57					
	58			No recovery		
	59					
431.4+	60					

Fig. A2 (Continued). Log of boring SD-1002 (50 to 60 ft)

DRILLING LOG

DIVISION: Ohio River

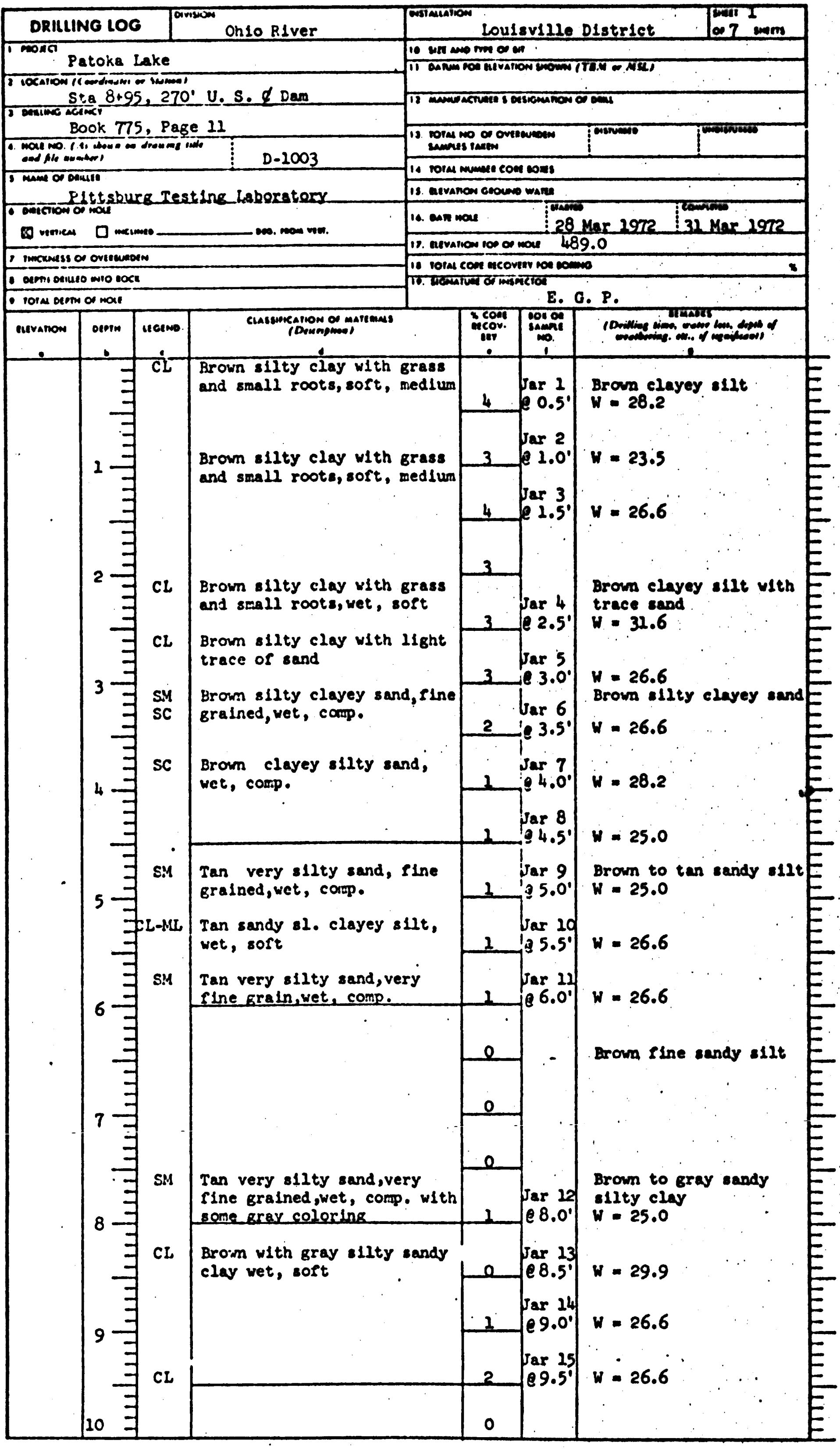
INSTALLATION: Louisville District

SHEET 7 OF 7 SHEETS

1. PROJECT: Patoka Lake
2. LOCATION (Coordinates or Station): Sta 8+95, 265' D. S. ℄ Dam
3. DRILLING AGENCY: Book 775, Page 8
4. HOLE NO. (As shown on drawing title and file number): SD-1002
5. NAME OF DRILLER: Pittsburg Testing Laboratory
6. DIRECTION OF HOLE: ☒ VERTICAL ☐ INCLINED ______ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN
8. DEPTH DRILLED INTO ROCK
9. TOTAL DEPTH OF HOLE
10. SIZE AND TYPE OF BIT
11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
12. MANUFACTURER'S DESIGNATION OF DRILL
13. TOTAL NO. OF OVERBURDEN SAMPLES TAKEN: DISTURBED UNDISTURBED
14. TOTAL NUMBER CORE BOXES
15. ELEVATION GROUND WATER
16. DATE HOLE: STARTED 11 Feb 1972 COMPLETED 25 Feb 1972
17. ELEVATION TOP OF HOLE: 491.4
18. TOTAL CORE RECOVERY FOR BORING %
19. SIGNATURE OF INSPECTOR: E. G. P.

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
				SS-3		
	61					Gray sandy clay
				Rec. 1.9'		
	62					
	63			Rock bit		Tried Shelby from 62.5, would not push
	64					
426.7±						
	65		Refusal			

Fig. A2 (Concluded). Log of boring SD-1002 (60 ft to refusal)



DRILLING LOG

DIVISION: Ohio River

INSTALLATION: Louisville District

SHEET 1 OF 7 SHEETS

1. PROJECT: Patoka Lake
2. LOCATION (Coordinates or Station): Sta 8+95, 270' U. S. ℄ Dam
3. DRILLING AGENCY: Book 775, Page 11
4. HOLE NO. (As shown on drawing title and file number): D-1003
5. NAME OF DRILLER: Pittsburg Testing Laboratory
6. DIRECTION OF HOLE: ☒ VERTICAL ☐ INCLINED ______ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN
8. DEPTH DRILLED INTO ROCK
9. TOTAL DEPTH OF HOLE
10. SIZE AND TYPE OF BIT
11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
12. MANUFACTURER'S DESIGNATION OF DRILL
13. TOTAL NO. OF OVERBURDEN SAMPLES TAKEN: DISTURBED ; UNDISTURBED
14. TOTAL NUMBER CORE BOXES
15. ELEVATION GROUND WATER
16. DATE HOLE: STARTED 28 Mar 1972 ; COMPLETED 31 Mar 1972
17. ELEVATION TOP OF HOLE: 489.0
18. TOTAL CORE RECOVERY FOR BORING %
19. SIGNATURE OF INSPECTOR: E. G. P.

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
		CL	Brown silty clay with grass and small roots, soft, medium	4	Jar 1 @ 0.5'	Brown clayey silt W = 28.2
	1		Brown silty clay with grass and small roots, soft, medium	3	Jar 2 @ 1.0'	W = 23.5
				4	Jar 3 @ 1.5'	W = 26.6
	2			3		
		CL	Brown silty clay with grass and small roots, wet, soft	3	Jar 4 @ 2.5'	Brown clayey silt with trace sand W = 31.6
	3	CL	Brown silty clay with light trace of sand	3	Jar 5 @ 3.0'	W = 26.6
		SM SC	Brown silty clayey sand, fine grained, wet, comp.	2	Jar 6 @ 3.5'	Brown silty clayey sand W = 26.6
	4	SC	Brown clayey silty sand, wet, comp.	1	Jar 7 @ 4.0'	W = 28.2
				1	Jar 8 @ 4.5'	W = 25.0
	5	SM	Tan very silty sand, fine grained, wet, comp.	1	Jar 9 @ 5.0'	Brown to tan sandy silt W = 25.0
		CL-ML	Tan sandy sl. clayey silt, wet, soft	1	Jar 10 @ 5.5'	W = 26.6
	6	SM	Tan very silty sand, very fine grain, wet, comp.	1	Jar 11 @ 6.0'	W = 26.6
				0		Brown fine sandy silt
	7			0		
				0		
	8	SM	Tan very silty sand, very fine grained, wet, comp. with some gray coloring	1	Jar 12 @ 8.0'	Brown to gray sandy silty clay W = 25.0
		CL	Brown with gray silty sandy clay wet, soft	0	Jar 13 @ 8.5'	W = 29.9
	9			1	Jar 14 @ 9.0'	W = 26.6
		CL		2	Jar 15 @ 9.5'	W = 26.6
	10			0		

Fig. A3. Log of boring D-1003 (0 to 10 ft)

DRILLING LOG	DIVISION Ohio River	INSTALLATION Louisville District	SHEET 2 OF 7 SHEETS

1. PROJECT Patoka Lake
2. LOCATION *(Coordinates or Station)* Sta 8+95, 270' U. S. ℄ Dam
3. DRILLING AGENCY Book 775, Page 11
4. HOLE NO. *(As shown on drawing title and file number)* D-1003
5. NAME OF DRILLER
6. DIRECTION OF HOLE ☒ VERTICAL ☐ INCLINED ______ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN
8. DEPTH DRILLED INTO ROCK
9. TOTAL DEPTH OF HOLE
10. SIZE AND TYPE OF BIT
11. DATUM FOR ELEVATION SHOWN *(TBM or MSL)*
12. MANUFACTURER'S DESIGNATION OF DRILL
13. TOTAL NO. OF OVERBURDEN SAMPLES TAKEN | DISTURBED | UNDISTURBED
14. TOTAL NUMBER CORE BOXES
15. ELEVATION GROUND WATER
16. DATE HOLE | STARTED 28 Mar 1972 | COMPLETED 31 Mar 1972
17. ELEVATION TOP OF HOLE 489.0
18. TOTAL CORE RECOVERY FOR BORING %
19. SIGNATURE OF INSPECTOR E. G. P.

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS *(Description)* d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS *(Drilling time, water loss, depth of weathering, etc., if significant)* g
	11	SM/SC	Gray silty sl. clayey sand, wet, comp	1 2	Jar 16 @ 11.0'	Gray silty sand W = 37,0
	12 13	CL	Gray with brown silty sandy clay, wet, soft	0 1 1 2	Jar 17 @ 13.0'	Gray silty sand, clay W = F.W.
	14 15 16	ML	Brownish gray sandy silt, wet, soft	0 1 2 1 1 3	Jar 18 @ 16.0'	Gray sandy silt W = 33.9
		SP/SM	Gray silty sand, wet, comp.	6 6	Jar 19 @ 17.0'	Gray sandy silt with organic W = 27.1
	17	SP/SM	Gray and tan silty sand, wet, comp.	6	Jar 20 @ 17.5'	W = 26.6
	18 19	SP/SM	Gray and tan silty sand with organic material, wet, comp.	2 1 2	Jar 21 @ 18.0' Jar 22 @ 18.5' Jar 23 @ 19.0'	W = 28.2 Gray sandy silt with organic W = 35.1 Gray silty sandy clay with organic W = 37.0
		CL	Brownish gray silty sandy clay, organic, wet, soft	1	Jar 24 @ 19.5'	W = 37.0
	20	SP/SM	Brownish gray, silty sand, organic, wet, comp.	1	Jar 25 @ 20.0'	Gray sandy silt trace clay W = 51.5

Fig. A3 (Continued). Log of boring D-1003 (10 to 20 ft)

DRILLING LOG

DIVISION: Ohio River

INSTALLATION: Louisville District

SHEET 3 OF 7 SHEETS

1. PROJECT: Patoka Lake
2. LOCATION (Coordinates or Station): Sta 8+95, 270' U. S. ℄ Dam
3. DRILLING AGENCY: Book 775, Page 11
4. HOLE NO. (As shown on drawing title and file number): D-1003
5. NAME OF DRILLER:
6. DIRECTION OF HOLE: ☒ VERTICAL ☐ INCLINED ________ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN:
8. DEPTH DRILLED INTO ROCK:
9. TOTAL DEPTH OF HOLE:
10. SIZE AND TYPE OF BIT:
11. DATUM FOR ELEVATION SHOWN (TBM or MSL):
12. MANUFACTURER'S DESIGNATION OF DRILL:
13. TOTAL NO. OF OVERBURDEN SAMPLES TAKEN: DISTURBED: UNDISTURBED:
14. TOTAL NUMBER CORE BOXES:
15. ELEVATION GROUND WATER:
16. DATE HOLE: STARTED 28 Mar 1972 COMPLETED 31 Mar 1972
17. ELEVATION TOP OF HOLE: 489.0
18. TOTAL CORE RECOVERY FOR BORING: %
19. SIGNATURE OF INSPECTOR: E. G. P.

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
		SP/SM	Brownish gray silty sand (organic), wet, comp.	2	Jar 26 @ 20.5'	W = 35.1
	21		Brownish gray silty sl. clayey sand, organic, wet, comp.	1		Brown to gray sandy silt with organic
		SM/SC		2	Jar 27 @ 21.5'	W = 33.9
	22	SM	Brownish gray silty sand, wet, comp.	2	Jar 28 @ 22.0'	W = 38.9
		SC	Gray brown clayey silty sand, wet, comp.	0	Jar 29 @ 22.5'	W = 37.0
	23	SM	Gray brown sl. clayey with decayed wood particles	1	Jar 30 @ 23.0'	Silty sand with organic. Very soft W = 36.4
		SM	Gray brown sl. clayey with decayed wood particles	1	Jar 31 @ 23.5'	W = 35.1
	24	SM		2	Jar 32 @ 24.0'	W = 35.1
		SM		3	Jar 33 @ 24.5'	Brown to gray silty sand with organic W = 38.9
	25	SM		7	Jar 34 @ 25.0'	W = 31.6
				2		
	26	SP/SM	Tan and gray silty sand, wet, comp.	3	Jar 35 @ 26.0'	Gray sand, wet W = 29.3
				5	Jar 36 @ 26.5'	W = 31.6
	27			3		Gray sand with organic
		SP/SM	Gray silty sand, wet, comp.	4	Jar 37 @ 27.5'	W = F.W.
	28	SP/SM	Gray silty sand, wet, comp. with decayed wood particles	7	Jar 38 @ 28.0'	Gray sand with organic W = 29.9
				2		
	29	SC	Gray clayey silty sand, wet, comp.	6	Jar 39 @ 20.0'	Gray sandy clay W = 63.9
		SM	Gray silty sand sl. clayey damp, comp.	5	Jar 40 @ 29.5'	W = 17.6
	30			8		Gray sandy clay with gravels

Fig. A3 (Continued). Log of boring D-1003 (20 to 30 ft)

DRILLING LOG

DIVISION: Ohio River

INSTALLATION: Louisville District

SHEET 4 OF 7 SHEETS

1. PROJECT: Patoka Lake
2. LOCATION (Coordinates or Station): Sta 8+95, 270' U. S. ℄ Dam
3. DRILLING AGENCY: Book 775, Page 11
4. HOLE NO. (As shown on drawing title and file number): D-1003
5. NAME OF DRILLER:
6. DIRECTION OF HOLE: ☒ VERTICAL ☐ INCLINED ________ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN:
8. DEPTH DRILLED INTO ROCK:
9. TOTAL DEPTH OF HOLE:
10. SIZE AND TYPE OF BIT:
11. DATUM FOR ELEVATION SHOWN (TBM or MSL):
12. MANUFACTURER'S DESIGNATION OF DRILL:
13. TOTAL NO. OF OVERBURDEN SAMPLES TAKEN: DISTURBED: UNDISTURBED:
14. TOTAL NUMBER CORE BOXES:
15. ELEVATION GROUND WATER:
16. DATE HOLE: STARTED 28 Mar 1972 COMPLETED 31 Mar 1972
17. ELEVATION TOP OF HOLE: 489.0
18. TOTAL CORE RECOVERY FOR BORING: %
19. SIGNATURE OF INSPECTOR: E. G. P.

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
		SP SM	Gray silty gravelly sand, wet, comp.	6	Jar 41 @ 30.5'	W = 17.6
	31	SM	Gray silty sand, wet, comp.	5	Jar 42 @ 31.0'	Gray sandy clay/gravels W = 20.5
		SM	Gray silty sand, wet, comp.	5	Jar 43 @ 31.5'	W = 22.0
	32	SM		4	Jar 44 @ 32.0'	Gray sand W = 22.0
		SM		5	Jar 45 @ 32.5'	W = 20.5
	33	SM		4	Jar 46 @ 33.0'	W = 19.0
		SM		3	Jar 47 @ 33.5'	Gray sand W = 19.0
	34	SM		5	Jar 48 @ 34.0'	W = 19.0
		SM		4		
	35	SM		4	Jar 49 @ 35.0'	Gray sandy silt wet W = 23.0
		SM		6	Jar 50 @ 35.5'	W = 22.0
	36	SM		4	Jar 51 @ 36.0'	No jar
		SM		6	Jar 52 @ 36.5'	Gray sandy silt W = 20.5
	37	SM		6	Jar 53 @ 37.0'	W = 20.5
		SM		7	Jar 54 @ 37.5	W = 19.0
	38	SM	Gray silty sand, sl. wet, comp.	8	Jar 55 @ 38.0'	Gray sandy silty clay W = 17.6
		SM		9	Jar 56 @ 38.5'	W = 17.6
	39	SM SC	Gray silty clayey sand, wet, comp.	10	Jar 57 @ 39.0'	W = 22.0
		SM SC	Gray silty clayey sand, wet, comp.	8	Jar 58 @ 39.5'	Gray sandy silty clay W = 19.0
	40	AL	Gray sandy silt, wet, comp.	6	Jar 59 @ 40.5	W = 20.5

Fig. A3 (Continued). Log of boring D-1003 (30 to 40 ft)

DRILLING LOG

DIVISION Ohio River

INSTALLATION Louisville District

SHEET 5 OF 7 SHEETS

1 PROJECT Patoka Lake

2 LOCATION (Coordinates or Station) Sta 8+95, 270' U. S. ₵ Dam

3 DRILLING AGENCY Book 775, page 12

4 HOLE NO (As shown on drawing title and file number) D-1003

5 NAME OF DRILLER

6 DIRECTION OF HOLE ☒ VERTICAL ☐ INCLINED ________ DEG. FROM VERT.

7 THICKNESS OF OVERBURDEN

8 DEPTH DRILLED INTO ROCK

9 TOTAL DEPTH OF HOLE

10 SIZE AND TYPE OF BIT

11 DATUM FOR ELEVATION SHOWN (TBM or MSL)

12 MANUFACTURER'S DESIGNATION OF DRILL

13 TOTAL NO. OF OVERBURDEN SAMPLES TAKEN DISTURBED UNDISTURBED

14 TOTAL NUMBER CORE BOXES

15 ELEVATION GROUND WATER

16 DATE HOLE STARTED 28 Mar 1972 COMPLETED 31 Mar 1972

17 ELEVATION TOP OF HOLE 489.0

18 TOTAL CORE RECOVERY FOR BORING %

19 SIGNATURE OF INSPECTOR E. G. P.

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
		SC	Gray clayey silty sand, sl. wet, comp.	4	Jar 60 @ 40.5'	Gray sandy silty clay W = 19.0
	41			9	Jar 61 @ 41.0'	W = 16.3
				9	Jar 62 @ 41.5'	W = 17.6
	42	CL	Gray with brown, silty sandy clay, damp, stiff	5	Jar 63 @ 42.0'	W = 20.5
		CL		6	Jar 64 @ 42.5'	Gray sandy silty clay W = 19.0
	43	CL		7	Jar 65 @ 43.0'	W = 19.0
		CL		4	Jar 66 @ 43.5'	W = 22.0
	44	SC	Gray silty sand, clayey, wet, comp.	5	Jar 67 @ 44.0'	Gray silty sandy clay W = 25.0
		CL	Gray sandy silty clay, wet, soft	5	Jar 68 @ 44.5'	W = 28.2
	45			5	Jar 69 @ 45.0'	W = 29.9
				8	Jar 70 @ 45.5'	Gray clayey sand W = 29.9
	46			9	Jar 71 @ 46.0'	W = 29.9
		SM	Gray silty sand, wet, comp.	6	Jar 72 @ 46.5'	Gray sandy clay W = 25.0
	47			4	Jar 73 @ 47.0'	W = 29.9
		SM		4	Jar 74 @ 47.5'	Gray sandy silty clay W = 29.9
	48			2	Jar 75 @ 48.0'	W = 29.9
				3	Jar 76 @ 48.5'	Gray clay trace sand W = 29.9
	49			5	Jar 77 @ 49.0'	W = 29.9
				2	Jar 78 @ 49.5'	W = 28.2
	50	SM		2	Jar 79 @ 50.0'	Gray silty sandy clay W = 29.9

Fig. A3 (Continued). Log of boring D-1003 (40 to 50 ft)

DRILLING LOG

DIVISION Ohio River

INSTALLATION Louisville District

SHEET 6 OF 7 SHEETS

1 PROJECT Patoka Lake

2 LOCATION (Coordinates or Station) Sta 8+95, 270' D. S. ℄ Dam

3 DRILLING AGENCY Book 775, page 12

4 HOLE NO (As shown on drawing title and file number) D-1003

5 NAME OF DRILLER

6 DIRECTION OF HOLE ☒ VERTICAL ☐ INCLINED ______ DEG. FROM VERT.

7 THICKNESS OF OVERBURDEN

8 DEPTH DRILLED INTO ROCK

9 TOTAL DEPTH OF HOLE

10 SIZE AND TYPE OF BIT

11 DATUM FOR ELEVATION SHOWN (TBM or MSL)

12 MANUFACTURER'S DESIGNATION OF DRILL

13 TOTAL NO. OF OVERBURDEN SAMPLES TAKEN DISTURBED UNDISTURBED

14 TOTAL NUMBER CORE BOXES

15 ELEVATION GROUND WATER

16 DATE HOLE STARTED 22 Mar 1972 COMPLETED 31 Mar 1972

17 ELEVATION TOP OF HOLE 489.0

18 TOTAL CORE RECOVERY FOR BORING %

19 SIGNATURE OF INSPECTOR E. G. P.

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
		CL	Gray silty clay, some sand (very silty),wet, soft	4	Jar 80 @50.5'	Gray silty sandy clay W = 29.9
	51			3	Jar 81 @51.0'	W = 29.9
				5	Jar 82 @51.5'	Gray clayey silt,wet W = 31.6
	52			5	Jar 83 @52.0'	W = 30.0
				3	Jar 84 @52.5'	W = 34.3
	53			3	Jar 85 @53.0'	Gray silty clay,wet W = 31.6
				3	Jar 86 @53.5'	W = 29.9
	54			3	Jar 87 @54.0'	W = 29.9
				4	Jar 88 @54.5'	Gray clayey silt W = 29.9
	55	CL	~~Gray silty clay, some sand~~	5	Jar 89 @55.0'	W = 31.6
				4	Jar 90 @55.5'	W = 35.1
	56	CL	Gray, silty clay,little sand and occasional small roots.	6	Jar 91 @56.0'	Gray clayey silt W = 31.6
				6	Jar 92 @56.5'	W = 29.9
	57			3	Jar 93 @57.0'	W = 30.0
				4	Jar 94 @57.5'	W = 29.9
	58			4	Jar 95 @58.0'	Gray clayey silt with a trace of sand W = 31.6
				3		
	59	CL	Brown silty sl. sandy clay, wet, soft	2	Jar 96 @59.0'	Gray clayey silt with trace of sand W = 30.0
		CL	Brown silty sl. sandy clay, wet, soft, little sand	4	Jar 97 @59.5'	Gray clayey silt W = 28.2
	60			3		

Fig. A3 (Continued). Log of boring D-1003 (50 to 60 ft)

DRILLING LOG

DIVISION Ohio River

INSTALLATION Louisville District

SHEET 7 OF 7 SHEETS

1 PROJECT Patoka Lake

2 LOCATION (Coordinates or Station) Sta 8+95, 270' D. S. ℄ Dam

3 DRILLING AGENCY Book 775, page 12

4 HOLE NO. (As shown on drawing title and file number) D-1003

5 NAME OF DRILLER

6 DIRECTION OF HOLE ☒ VERTICAL ☐ INCLINED ______ DEG. FROM VERT.

7 THICKNESS OF OVERBURDEN

8 DEPTH DRILLED INTO ROCK

9 TOTAL DEPTH OF HOLE

10 SIZE AND TYPE OF BIT

11 DATUM FOR ELEVATION SHOWN (TBM or MSL)

12 MANUFACTURER'S DESIGNATION OF DRILL

13 TOTAL NO. OF OVERBURDEN SAMPLES TAKEN DISTURBED UNDISTURBED

14 TOTAL NUMBER CORE BOXES

15 ELEVATION GROUND WATER

16 DATE HOLE STARTED 28 Mar 1972 COMPLETED 31 Mar 1972

17 ELEVATION TOP OF HOLE 489.0

18 TOTAL CORE RECOVERY FOR BORING %

19 SIGNATURE OF INSPECTOR E. G. P.

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
				4		Gray clayey silt
	61	CL	Gray with brown silty clay, wet, soft	5	Jar 98 @61.0'	W = 30.0
		CL	Gray with brown silty clay, wet, medium	4	Jar 99 @61.5'	Gray clayey silt W = 37.0
	62	CL	Gray brown silty clay, sl. gravelly with white silty sand damp, stiff-medium	4	Jar100 @62.0'	Gray clay W = 33.3
426.5±	62.5	CL		69	Jar101 @62.5'	Gray sand and gravel W = 22.0 Refusal at 62.9'

Fig. A3 (Concluded). Log of boring D-1003 (60 ft to refusal)

DRILLING LOG

DIVISION Ohio River

INSTALLATION Louisville District

SHEET 1 OF 4 SHEETS

1 PROJECT Patoka Lake

2 LOCATION (Coordinates or Station) Sta 9+10, 260' U. S. ℄ Dam

3 DRILLING AGENCY Book 775, Page 9

4 HOLE NO. (As shown on drawing title and file number) S-1004

5 NAME OF DRILLER Pittsburg Testing Laboratory

6 DIRECTION OF HOLE ☒ VERTICAL ☐ INCLINED ________ DEG. FROM VERT.

7 THICKNESS OF OVERBURDEN

8 DEPTH DRILLED INTO ROCK

9 TOTAL DEPTH OF HOLE

10 SIZE AND TYPE OF BIT

11 DATUM FOR ELEVATION SHOWN (TBM or MSL)

12 MANUFACTURER'S DESIGNATION OF DRILL

13 TOTAL NO. OF OVERBURDEN SAMPLES TAKEN DISTURBED UNDISTURBED

14 TOTAL NUMBER CORE BOXES

15 ELEVATION GROUND WATER

16 DATE HOLE STARTED 29 Feb 1972 COMPLETED 24 Mar 1972

17 ELEVATION TOP OF HOLE 489.1

18 TOTAL CORE RECOVERY FOR BORING %

19 SIGNATURE OF INSPECTOR E. G. P.

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
				SS-1		
	1		Brown sandy clay, medium, moist			
	2			Rec. 1.5'		
				SS-2		
	3					
			Brown sandy clay, medium, moist			
	4					
				Rec. 1.2'		
	5			SS-3		
	6		Brown sandy clay, moist			
	7			Rec. 1.6'		
				SS-4		
	8		Gray silty sand			
	9			Rec. 0.7'		
	10			SS-5		
	11		Gray silty sand			
	12			Rec. 0.9'		
	13			SS-6		
	14		Gray sand, medium, moist	Rec. 0.9'		
	15			SS-7		
	16		Gray sand			
	17			Rec. 1.5'		
	18			SS-8		
	19		Gray silty sand			
	20			Rec. 2.4'		

Fig. A4. Log of boring S-1004 (0 to 20 ft)

DRILLING LOG | DIVISION | INSTALLATION | SHEET 2 OF 4 SHEETS

1 PROJECT Patoka Lake

2 LOCATION (Coordinates or Station) Sta 9+10, 260' U. S. ℄ Dam

3 DRILLING AGENCY Book 775, Page 9

4 HOLE NO (As shown on drawing title and file number) S-1004

5 NAME OF DRILLER Pittsburg Testing Laboratory

6 DIRECTION OF HOLE ☒ VERTICAL ☐ INCLINED ______ DEG. FROM VERT.

7 THICKNESS OF OVERBURDEN

8 DEPTH DRILLED INTO ROCK

9 TOTAL DEPTH OF HOLE

10 SIZE AND TYPE OF BIT

11 DATUM FOR ELEVATION SHOWN (TBM or MSL)

12 MANUFACTURER'S DESIGNATION OF DRILL

13 TOTAL NO. OF OVERBURDEN SAMPLES TAKEN | DISTURBED | UNDISTURBED

14 TOTAL NUMBER CORE BOXES

15 ELEVATION GROUND WATER

16 DATE HOLE | STARTED 29 Feb 1972 | COMPLETED 24 Mar 1972

17 ELEVATION TOP OF HOLE 489.1

18 TOTAL CORE RECOVERY FOR BORING %

19 SIGNATURE OF INSPECTOR E. G. P.

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
				SS-9		
	21		Gray silty sand with organic			
	22			Rec. 2.5'		
	23			SS-10		
	24		Gray silty sand with some organic			
	25			Rec. 2.5'		
				SS-11		
	26		Gray silty sand			
	27			Rec. 2.5'		
	28			SS-12		
	29		Gray silty sand			
	30			Rec. 2.2'		
				SS-13		
	31		Gray sand			
	32			Rec. 0.8'		
El 456± 3-22-72	33			SS-14		
	34		Gray sand			
	35			Rec. 2.4'		
	36			No Rec.		
	37					
	38			No Rec.		
	39					
	40					

Fig. A4 (Continued). Log of boring S-1004 (20 to 40 ft)

DRILLING LOG | DIVISION | INSTALLATION | SHEET 3 OF 4 SHEETS

1 PROJECT Patoka Lake

2 LOCATION *(Coordinates or Station)* Sta 9+10, 260' U. S. ℄ Dam

3 DRILLING AGENCY Book 775, Page 10

4 HOLE NO *(As shown on drawing title and file number)* S-1004

5 NAME OF DRILLER Pittsburg Testing Laboratory

6 DIRECTION OF HOLE ☒ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.

7 THICKNESS OF OVERBURDEN

8 DEPTH DRILLED INTO ROCK

9 TOTAL DEPTH OF HOLE

10 SIZE AND TYPE OF BIT

11 DATUM FOR ELEVATION SHOWN *(TBM or MSL)*

12 MANUFACTURER'S DESIGNATION OF DRILL

13 TOTAL NO. OF OVERBURDEN SAMPLES TAKEN | DISTURBED | UNDISTURBED

14 TOTAL NUMBER CORE BOXES

15 ELEVATION GROUND WATER

16 DATE HOLE | STARTED 29 Feb 1972 | COMPLETED 24 Mar 1972

17 ELEVATION TOP OF HOLE 489.1

18 TOTAL CORE RECOVERY FOR BORING %

19 SIGNATURE OF INSPECTOR E. G. P.

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS *(Description)* d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS *(Drilling time, water loss, depth of weathering, etc., if significant)* g
	41			No Rec.		
	42					
	43					
	44			No Rec.		
	45					
	46			No Rec.		
	47					
	48					
	49			No Rec.		
	50					
	51			No Rec.		
	52					
	53					
	54			No Rec.		
	55					
	56			No Rec.		
	57					
	58					
	59			No Rec.		
	60					

Fig. A4 (Continued). Log of boring S-1004 (40 to 60 ft)

DRILLING LOG

DIVISION

INSTALLATION

SHEET 4 OF 4 SHEETS

1. PROJECT Patoka Lake
2. LOCATION (Coordinates or Station) Sta 9+10, 260' U. S. ℄ Dam
3. DRILLING AGENCY Book 775, Page 10
4. HOLE NO. (As shown on drawing title and file number) S-1004
5. NAME OF DRILLER Pittsburg Testing Laboratory
6. DIRECTION OF HOLE ☒ VERTICAL ☐ INCLINED ______ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN
8. DEPTH DRILLED INTO ROCK
9. TOTAL DEPTH OF HOLE
10. SIZE AND TYPE OF BIT
11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
12. MANUFACTURER'S DESIGNATION OF DRILL
13. TOTAL NO. OF OVERBURDEN SAMPLES TAKEN DISTURBED UNDISTURBED
14. TOTAL NUMBER CORE BOXES
15. ELEVATION GROUND WATER
16. DATE HOLE STARTED 29 Feb 1972 COMPLETED 24 Mar 1972
17. ELEVATION TOP OF HOLE 489.1
18. TOTAL CORE RECOVERY FOR BORING %
19. SIGNATURE OF INSPECTOR E. G. P.

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	61			No Rec.		
	62					
	63		Refusal Shelby	No Rec.		
	64					
424.1±	65		Rock bit 64.5'-65' gravel, compacted. Tried Shelby from 65'; would not push.			

Fig. A4 (Concluded). Log of boring S-1004 (60 ft to refusal)

BORING LOG
FIELD DATA

Project Patoka Dam **Location** **Date** 27 April 1972
Drill Rig CE-3772 **Inspector** K. Waites **Operator** P. Martin **Surface elev**
Levee District **Job No.** 441-S382.12SR41 **Boring No.** S-1006

SAMPLE NUMBER	DATE TAKEN 1972	STRATUM		DRIVE		SAMPLE		TYPE OF SAMPLER		Pressure psi	CLASSIFICATION AND REMARKS
		FROM	TO	FROM	TO	FROM	TO				
5	27 Apr			8.0	8.5	8.0	9.6	3" undist.	3" tube	140	Sand, silty, clayey, wet, tan
				8.5	9.0					170	
				9.0	9.5					180	
				9.5	10.0					180	
				10.0	10.4					160	
6	27 Apr			10.4	10.9	10.4	12.8	3" undist.	3" tube	140	Sand, fine, silty, wet, tan
				10.9	11.4					180	
				11.4	11.9					180	
				11.9	12.4					180	
				12.4	12.8					200	
7	27 Apr			12.8	13.3	12.8	13.8	3" undist.	3" tube	140	Sand, fine, silty, wet, tan
				13.3	13.8					180	
				13.8	14.3					180	
				14.3	14.8					180	
				14.8	15.2					180	(Sheet 1 of 8)

Fig. A5. Log of boring S-1006 (samples 5-7)

BORING LOG
FIELD DATA

Project Patoka Dam Location Date 27 Apr 1972

Drill Rig CE-3772 Inspector K. Waites Operator P. Martin Surface elev

Levee District Job No. 441-S382.12SR41 Boring No. S-1006

SAMPLE NUMBER	DATE TAKEN 1972	STRATUM		DRIVE		SAMPLE		TYPE OF SAMPLER		Pressure psi	CLASSIFICATION AND REMARKS
		FROM	TO	FROM	TO	FROM	TO				
8	27 Apr			15.2	15.7	15.2	17.6	3" undist.	3" tube	180	Sand, fine, silty, wet, wood, gray
				15.7	16.2					200	
				16.2	16.7					200	
				16.7	17.2					220	
				17.2	17.6					220	
9	28 Apr			17.6	18.1	17.6	19.5	3" undist.	3" tube	120	Sand, fine, silty, wet, wood, gray
				18.1	18.6					160	
				18.6	19.1					160	
				19.1	19.6					170	
				19.6	20.0					170	
10	28 Apr			20.0	20.5	20.0	22.3	3" undist.	3" tube	180	Sand, fine, silty, wet, gray
				20.5	21.0					200	
				21.0	21.5					220	
				21.5	22.0					230	
				22.0	22.4					230	(Sheet 2 of 8)

Fig. A5 (Continued). Log of boring S-1006 (samples 8-10)

BORING LOG
FIELD DATA

Project Patoka Dam
Location
Date 28 Apr 1972
Drill Rig CE-3772
Inspector K. Waites
Operator P. Martin
Surface elev
Levee District
Job No. 441-S382.12SR41
Boring No. S-1006

SAMPLE NUMBER	DATE TAKEN 1972	STRATUM		DRIVE		SAMPLE		TYPE OF SAMPLER		Pressure psi	CLASSIFICATION AND REMARKS
		FROM	TO	FROM	TO	FROM	TO				
11	28 Apr			22.4	22.9	22.4	23.8	3" undist.	3" tube	180	Sand, fine, silty, wet, gray
				22.9	23.4					200	
				23.4	23.9					210	
				23.9	24.4					220	
				24.4	24.8					220	
12	28 Apr			24.8	25.3	24.8	25.9	3 " undist.	3" tube	180	Sand, fine, wet, white
				25.3	25.8					260	
				25.8	26.3					280	
				26.3	26.8					300	
				26.8	27.2					300	
13	28 Apr			27.2	27.7	27.2	29.5	3" undist.	3" tube	240	Sand, fine, wet, white
13A	28 Apr			27.7	28.2	29.5	29.6		jar	280	Sand, fine, wet, white
				28.2	28.7					300	
				28.7	29.2					320	
				29.2	29.6					340	(Sheet 3 of 8)

Fig. A5 (Continued). Log of boring S-1006 (samples 11-13)

BORING LOG
FIELD DATA

Project Patoka Dam
Location
Date 28 Apr 1972
Drill Rig CE-3772
Inspector K. Waites
Operator P. Martin
Surface elev
Levee District
Job No. 441-S382.12SR41
Boring No. S-1006

SAMPLE NUMBER	DATE TAKEN 1972	STRATUM		DRIVE		SAMPLE		TYPE OF SAMPLER		Pressure psi	CLASSIFICATION AND REMARKS
		FROM	TO	FROM	TO	FROM	TO				
14	28 Apr			29.6	30.1	29.6	31.9	3" undist.	3" tube	200	Sand, clayey, wood, wet, silty, gray
14A	28 Apr			30.1	30.6	31.9	32.0		jar	280	Sand, clayey, wood, wet, silty, gray
				30.6	31.1					300	
				31.1	31.6					300	
				31.6	32.0					300	
15	2 May			32.0	32.5	32.0	34.3	3" undist.	3" tube	140	Clay, sandy, silty, soft, gray
15A	2 May			32.5	33.0	34.3	34.4		jar	180	Clay, sandy, silty, soft, gray
				33.0	33.5					200	
				33.5	34.0					200	
				34.0	34.4					200	
16	2 May			34.4	34.9	34.4	36.7	3" undist.	3" tube	160	Sand, fine, silty, wet, gray
16A	2 May			34.9	35.4	36.7	36.8		jar	200	Sand, fine, silty, clayey, wet, gray
				35.4	35.9					220	
				35.9	36.4					240	
				36.4	36.8					240	(Sheet 4 of 8)

Fig. A5 (Continued). Log of boring S-1006 (samples 14-16)

BORING LOG
FIELD DATA

Project Patoka Dam
Location
Date 2 May 72
Drill Rig CE-3772
Inspector K. Waites
Operator P. Martin
Surface elev
Levee District
Job No. 441-S382.12SR41
Boring No. S-1006

SAMPLE NUMBER	DATE TAKEN 1972	STRATUM		DRIVE		SAMPLE		TYPE OF SAMPLER		Pres-sure psi	CLASSIFICATION AND REMARKS
		FROM	TO	FROM	TO	FROM	TO				
17	2 May			36.8	37.3	36.9	39.1	3" undist.	3" tube	180	Clay, sandy, silty, soft, gray
17A	2 May			37.3	37.8	39.1	39.2		jar	220	Clay, sandy, silty, soft, gray
				37.8	38.3					240	
				38.3	38.8					230	
				38.8	39.2					220	
18	2 May			39.2	39.7	39.2	41.5	3" undist.	3" tube	180	Clay, sandy, silty, soft, gray
18A	2 May			39.7	40.2	41.5	41.6		jar	200	Clay, sandy, silty, soft, gray
				40.2	40.7					200	
				40.7	41.2					200	
				41.2	41.6					200	
19	2 May			41.6	42.1	41.6	43.9	3" undist.	3" tube	200	Clay, sandy, silty, soft, gray
19A	2 May			42.1	42.6	43.9	44.0		jar	220	Clay, sandy, silty, soft, gray
				42.6	43.1					240	
				43.1	43.6					240	
				43.6	44.0					240	(Sheet 5 of 8)

Fig. A5 (Continued). Log of boring S-1006 (samples 17-19)

BORING LOG
FIELD DATA

Project Patoka Dam
Location
Date 2 May 72
Drill Rig CE-3772
Inspector K. Waites
Operator P. Martin
Surface elev
Levee District
Job No. 441-S382.12SR41
Boring No. S-1006

SAMPLE NUMBER	DATE TAKEN 1972	STRATUM		DRIVE		SAMPLE		TYPE OF SAMPLER		Pressure psi	CLASSIFICATION AND REMARKS
		FROM	TO	FROM	TO	FROM	TO				
20	2 May			44.0	44.5	44.0	46.3	3" undist.	3" tube	160	Clay, sandy, silty, wet, soft, gray
20A	2 May			44.5	45.0	46.3	46.4		jar	180	Clay, sandy, silty, wet, soft, gray
				45.0	45.5					190	
				45.5	46.0					190	
				46.0	46.4					190	
21	2 May			46.4	46.9	46.4	48.7	3" undist.	3" tube	180	Clay, sandy, silty, wet, soft, gray
21A	2 May			46.9	47.4	48.7	48.8		jar	200	Clay, sandy, silty, wet, soft, gray
				47.4	47.9					200	
				47.9	48.4					200	
				48.4	48.8					190	
22	2 May			48.8	49.3	48.8	51.1	3" undist.	3" tube	190	Clay, silty, soft, wet, gray
22A	2 May			49.3	49.8	51.1	51.2		jar	200	Clay, silty, soft, wet, gray
				49.8	50.3					210	
				50.3	50.8					210	
				50.8	51.2					210	(Sheet 6 of 8)

Fig. A5 (Continued). Log of boring S-1006 (samples 20-22)

BORING LOG
FIELD DATA

Project Patoka Dam

Location

Date 2 May 1972

Drill Rig CE-3772

Inspector K. Waites

Operator P. Martin

Surface elev

Levee District

Job No. 441-S382.12SR41

Boring No. S-1006

SAMPLE NUMBER	DATE TAKEN 1972	STRATUM		DRIVE		SAMPLE		TYPE OF SAMPLER		Pres-sure psi	CLASSIFICATION AND REMARKS
		FROM	TO	FROM	TO	FROM	TO				
23	2 May			51.2	51.7	51.2	53.5	3" undist.	3" tube	200	Clay, silty, firm, gray
23A	2 May			51.7	52.2	53.5	53.6		jar	230	Clay, silty, firm, gray
				52.2	52.7					240	
				52.7	53.2					240	
				53.2	53.6					240	
24	2 May			53.6	54.1	53.6	55.9	3" undist.	3" tube	200	Clay, silty, firm, gray
24A	2 May			54.1	54.6	55.9	56.0		jar	220	Clay, silty, firm, gray
				54.6	55.1					230	
				55.1	55.6					240	
				55.6	56.0					240	
25	3 May			56.0	56.5	56.0	58.3	3" undist.	3" tube	150	Clay, silty, soft, gray
25A	3 May			56.5	57.0	58.3	58.4		jar	180	Clay, silty, soft, gray
				57.0	57.5					190	
				57.5	58.0					200	
				58.0	58.4					200	(Sheet 7 of 8)

Fig. A5 (Continued). Log of boring S-1006 (samples 23-25)

BORING LOG
FIELD DATA

Project Patoka Dam
Location
Date 3 May 1972
Drill Rig CE-3772
Inspector K. Waites
Operator P. Martin
Surface elev
Levee District
Job No. 441-S382.12SR41
Boring No. S-1006

SAMPLE NUMBER	DATE TAKEN 1972	STRATUM		DRIVE		SAMPLE		TYPE OF SAMPLER		Pressure psi	CLASSIFICATION AND REMARKS
		FROM	TO	FROM	TO	FROM	TO				
26	3 May			58.4	58.9	58.4	60.1	3" undist.	3" tube	150	Clay, firm, silty, trs.gravel, gray
26A	3 May			58.9	59.4	60.1	60.2		jar	180	Clay, firm, silty, trs.gravel, gray
				59.4	59.9					200	
				59.9	60.3					500	Refusal
							BORING COMPLETE				

(Sheet 8 of 8)

Fig. A5 (Concluded). Log of boring S-1006 (sample 26)

BORING LOG

FIELD DATA

Project Patoka Dam
Location
Date 3 May 1972
Drill Rig CE-3772
Inspector K. Waites
Operator P. Martin
Surface elev
Levee District
Job No. 441-S382.12SR41
Boring No. S-1007

SAMPLE NUMBER	DATE TAKEN 1972	STRATUM		DRIVE		SAMPLE		TYPE OF SAMPLER		Pressure psi	CLASSIFICATION AND REMARKS
		FROM	TO	FROM	TO	FROM	TO				
	3 May	0.0		0.0	2.4			Fish tail			Clay, silty, soft, tan; no samples
1	3 May			2.4	2.9	2.4	4.5	3" Undist.	3" tube	180	Clay, silty, soft, wet, tan
1A	3 May			2.9	3.4	4.5	4.6		jar	210	Clay, silty, soft, wet, tan
				3.4	3.9					220	
				3.9	4.4					230	
				4.4	4.8					230	
2	3 May			4.8	5.3	4.9	7.1	3" Undist.	3" tube	170	Silt, sandy, soft, wet, tan
2A	3 May			5.3	5.8	7.1	7.2		jar	200	Silt, sandy, soft, wet, tan
				5.8	6.3					200	
				6.3	6.8					200	
				6.8	7.2					200	
											(Sheet 1 of 10)

Fig. A6. Log of boring S-1007 (samples 1 and 2)

BORING LOG

FIELD DATA

Project Patoka Dam
Location
Date 4 May 1972
Drill Rig CE-3772
Inspector K. Waites
Operator P. Martin
Surface elev
Levee District
Job No. 441-S382.12SR41
Boring No. S-1007

SAMPLE NUMBER	DATE TAKEN 1972	STRATUM		DRIVE		SAMPLE		TYPE OF SAMPLER		Pres-ure psi	CLASSIFICATION AND REMARKS
		FROM	TO	FROM	TO	FROM	TO				
3	4 May			7.2	7.7	7.2	9.3	3" Undist.	3" tube	140	Silt, sandy, soft, wet, gray
3A	4 May			7.7	8.2	9.3	9.4		jar	180	Silt, sandy, soft, wet, gray
				8.2	8.7					200	
				8.7	9.2					220	
				9.2	9.6					220	
4	4 May			9.6	10.1	9.6	11.7	3" Undist.	3" tube	140	Sand, silty, soft, wet, gray
4A	4 May			10.1	10.6	11.7	11.8		jar	180	Sand, silty, soft, wet, gray
				10.6	11.1					200	
				11.1	11.6					200	
				11.6	12.0					200	
5	4 May			12.0	12.5	12.0	14.2	3" Undist.	3" tube	160	Sand,silty,clayey,soft,wet,gray
5A	4 May			12.5	13.0	14.2	14.3		jar	190	Sand,silty,clayey,soft,wet,gray
				13.0	13.5					200	
				13.5	14.0					210	
				14.0	14.4					210	(Sheet 2 of 10)

Fig. A6 (Continued). Log of boring S-1007 (samples 3-5)

BORING LOG

FIELD DATA

Project Patoka Dam
Location
Date 4 May 1972
Drill Rig CE-3772
Inspector K. Waites
Operator P. Martin
Surface elev
Levee District
Job No. 441-S382.12SR41
Boring No. S-1007

SAMPLE NUMBER	DATE TAKEN 1972	STRATUM		DRIVE		SAMPLE		TYPE OF SAMPLER		Pressure psi	CLASSIFICATION AND REMARKS
		FROM	TO	FROM	TO	FROM	TO				
6	4 May			14.4	14.9	14.4	16.6	3" Undist.	3" tube	160	Sand, fine, silty, wet, gray
6A	4 May			14.9	15.4	16.6	16.7		jar	200	Sand, fine, silty, wet, gray
				15.4	15.9					200	
				15.9	16.4					200	
				16.4	16.8					200	
7	4 May			16.8	17.3	16.8	19.1	3" Undist.	3" tube	150	Sand, silty, soft, wet, gray
7A	4 May			17.3	17.8	19.1	19.2		jar	180	Sand, silty, soft, wet, gray
				17.8	18.3					180	
				18.3	18.8					190	
				18.8	19.2					190	
8	4 May			19.2	19.7	19.2	21.1	3" Undist.	3" tube	180	Sand, silty, soft, wet, gray
8A	4 May			19.7	20.2	21.1	21.2		jar	200	Sand, silty, soft, wet, gray
				20.2	20.7					200	
				20.7	21.2					200	
				21.2	21.6					220	(Sheet 3 of 10)

Fig. A6 (Continued). Log of boring S-1007 (samples 6-8)

BORING LOG
FIELD DATA

Project Patoka Dam **Location** **Date** 4 May 1972
Drill Rig CE-3772 **Inspector** K. Waites **Operator** P. Martin **Surface elev**
Levee District **Job No.** 44-S382.12SR41 **Boring No.** S-1007

SAMPLE NUMBER	DATE TAKEN 1972	STRATUM		DRIVE		SAMPLE		TYPE OF SAMPLER		Pressure psi	CLASSIFICATION AND REMARKS
		FROM	TO	FROM	TO	FROM	TO				
9	4 May			21.6	22.1	21.6	23.9	3" undist.	3" tube	180	Sand, fine, soft, wood, gray
9A	4 May			22.1	22.6	23.9	24.0		jar	220	Sand, fine, soft, wood, gray
				22.6	23.1					230	
				23.1	23.6					230	
				23.6	24.0					230	
10	4 May			24.0	24.5	24.0	25.1	3" undist.	3" tube	180	Sand, fine, silty, wood, wet, gray
10A	4 May		25.2	24.5	25.0	25.1	25.2		jar	200	Sand, fine, silty, wood, wet, gray
		25.2		25.0	25.5					600	(Refusal)
				25.5	26.0			Fish tail			Log
11A	4 May			26.0	26.4	26.0	26.4	3" undist.	jar	640	Log
			27.8	26.4	27.5			Fish tail			Log
											(Sheet 4 of 10)

Fig. A6 (Continued). Log of boring S-1007 (samples 9-11)

BORING LOG
FIELD DATA

Project Patoka Dam
Location
Date 4 May 1972
Drill Rig CE-3772
Inspector K. Waites
Operator P. Martin
Surface elev
Levee District
Job No. 441-S382.12SR41
Boring No. S-1007

SAMPLE NUMBER	DATE TAKEN 1972	STRATUM		DRIVE		SAMPLE		TYPE OF SAMPLER		Pressure psi	CLASSIFICATION AND REMARKS
		FROM	TO	FROM	TO	FROM	TO				
12	4 May	27.8		27.5	28.0	27.5	28.5	3" undist.	3" tube	300	Sand, fine, soft, wet, gray
12A	4 May			28.0	28.5	28.5	28.6		jar	240	Sand, fine, soft, wet, gray
				28.5	29.0					220	
				29.0	29.5					220	
				29.5	29.9					220	
13	4 May			29.9	30.4	29.9	31.5	3" undist.	3" tube	180	Sand, fine, soft, wet, gray
				30.4	30.9					200	
				30.9	31.4					210	
				31.4	31.9					210	
				31.9	32.3					210	
14	4 May			32.3	32.8	32.3	33.9	3" undist.	3" tube	200	Sand, fine, silty, soft, wet, gray
14A	4 May			32.8	33.3	33.9	33.3		jar	220	Sand, fine, silty, soft, wet, gray
				33.3	33.8					230	
				33.8	34.3					230	
				34.3	34.7					230	(Sheet 5 of 10)

Fig. A6 (Continued). Log of boring S-1007 (samples 12-14)

BORING LOG

FIELD DATA

Project Patoka Dam

Location

Date 5 May 1972

Drill Rig CE-3772

Inspector K. Waites

Operator P. Martin

Surface elev

Levee District

Job No. 441-S382.12SR41

Boring No. S-1007

SAMPLE NUMBER	DATE TAKEN 1972	STRATUM		DRIVE		SAMPLE		TYPE OF SAMPLER		Pres-sure psi	CLASSIFICATION AND REMARKS
		FROM	TO	FROM	TO	FROM	TO				
15	5 May			34.7	35.2	34.7	36.0	3" undist.	3" tube	200	Sand, fine, silty, soft, wet, gray
				35.2	35.7					220	
				35.7	36.2					220	
				36.2	36.7					230	
				36.7	37.1					230	
16	5 May			37.1	37.6	37.1	38.6	3" undist.	3" tube	140	Sand, fine, silty, soft, wet, gray
				37.6	38.1					160	
				38.1	38.6					180	
				38.6	39.1					190	
				39.1	39.5					200	
17	5 May			39.5	40.0	39.5	41.5	3" undist.	3" tube	160	Sand, fine, silty, soft, wet, gray
17A	5 May			40.0	40.5	41.5	41.6		jar	200	Sand, fine, silty, soft, wet, gray
				40.5	41.0					220	
				41.0	41.5					230	
				41.5	41.9					230	(Sheet 6 of 10)

Fig. A6 (Continued). Log of boring S-1007 (samples 15-17)

BORING LOG
FIELD DATA

Project Patoka Dam
Location
Date 5 May 1972
Drill Rig CE-3772
Inspector K. Waites
Operator P. Martin
Surface elev
Levee District
Job No. 441-S382.12SR41
Boring No. S-1007

SAMPLE NUMBER	DATE TAKEN 1972	STRATUM		DRIVE		SAMPLE		TYPE OF SAMPLER		Pressure psi	CLASSIFICATION AND REMARKS
		FROM	TO	FROM	TO	FROM	TO				
18	5 May			41.9	42.4	41.9	44.2	3" undist.	3" tube	190	Clay, sandy, silty, soft, wet, gray
18A	5 May			42.4	42.9	44.2	44.3		jar	200	Clay, sandy, silty, soft, wet, gray
				42.9	43.4					240	
				43.4	43.9					280	
				43.9	44.3					260	
19	5 May			44.3	44.8	44.3	46.6	3" undist.	3" tube	200	Sand, silty, clayey, wet, gray
19A	5 May			44.8	45.3	46.6	46.7		jar	220	
				45.3	45.8					240	
				45.8	46.3					240	
				46.3	46.7					240	
20	9 May			46.7	47.2	46.7	49.0	3" undist.	3" tube	140	Clay, silty, firm, gray
20A	9 May			47.2	47.7	49.0	49.1		jar	180	Clay, silty, firm, gray
				47.7	48.2					200	
				48.2	48.7					220	
				48.7	49.1					230	(Sheet 7 of 10)

Fig. A6 (Continued). Log of boring S-1007 (samples 18-20)

BORING LOG
FIELD DATA

Project Patoka Dam
Location
Date 9 May 1972
Drill Rig CE-3772
Inspector K. Waites
Operator P. Martin
Surface elev
Levee District
Job No. 441-S382.12SR41
Boring No. S-1007

SAMPLE NUMBER	DATE TAKEN 1972	STRATUM		DRIVE		SAMPLE		TYPE OF SAMPLER		Pressure psi	CLASSIFICATION AND REMARKS
		FROM	TO	FROM	TO	FROM	TO				
21	9 May			49.1	49.6	49.1	51.4	3" undist.	3" tube	160	Clay, silty, firm, gray
21A	9 May			49.6	50.1	51.4	51.5		jar	200	Clay, silty, firm, gray
				50.1	50.6					220	
				50.6	51.1					220	
				51.1	51.5					220	
22	9 May			51.5	52.0	51.5	53.8	3" undist.	3" tube	140	Clay, silty, firm, gray
22A	9 May			52.0	52.5	53.8	53.9		jar	190	Clay, silty, firm, gray
				52.5	53.0					200	
				53.0	53.5					220	
				53.5	53.9					220	
23	9 May			53.9	54.4	53.9	56.2	3" undist.	3" tube	120	Clay, silty, firm, gray
23A	9 May			54.4	54.9	56.2	56.3		jar	160	Clay, silty, firm, gray
				54.9	55.4					180	
				55.4	55.9					180	
				55.9	56.3					190	(Sheet 8 of 10)

Fig. A6 (Continued). Log of boring S-1007 (samples 21-23)

BORING LOG
FIELD DATA

Project Patoka Dam **Location** **Date** 9 May 1972
Drill Rig CE-3772 **Inspector** K. Waites **Operator** P. Martin **Surface elev**
Levee District **Job No.** 441-S382.12SR41 **Boring No.** S-1007

SAMPLE NUMBER	DATE TAKEN 1972	STRATUM		DRIVE		SAMPLE		TYPE OF SAMPLER		Pres-sure psi	CLASSIFICATION AND REMARKS
		FROM	TO	FROM	TO	FROM	TO				
24	9 May			56.3	56.8	56.3	58.4	3" undist.	3" tube	140	Clay, silty, firm, gray
24A	9 May			56.8	57.3	58.4	58.5		jar	170	Clay, silty, firm, gray
				57.3	57.8					190	
				57.8	58.3					200	
				58.3	58.7					200	
25	9 May			58.7	59.2	58.7	61.0	3" undist.	3" tube	140	Clay, silty, firm, gray
25A	9 May			59.2	59.7	61.0	61.1		jar	180	Clay, silty, firm, gray
				59.7	60.2					200	
				60.2	60.7					200	
				60.7	61.1					210	
26	9 May			61.1	61.6	61.1	63.4	3" undist.	3" tube	160	Clay, silty, firm, gray
26A	9 May			61.6	62.1	63.4	63.5		jar	200	Clay, silty, firm, gray
				62.1	62.6					240	
				62.6	63.1					240	
				63.1	63.5					240	(Sheet 9 of 10)

Fig. A6 (Continued). Log of boring S-1007 (samples 24-26)

BORING LOG
FIELD DATA

Project Patoka Dam
Location
Date 9 May 1972
Drill Rig CE-3772
Inspector K. Waites
Operator P. Martin
Surface elev
Levee District
Job No. 441-S382.12SR41
Boring No. S-1007

SAMPLE NUMBER	DATE TAKEN 1972	STRATUM		DRIVE		SAMPLE		TYPE OF SAMPLER		Pressure psi	CLASSIFICATION AND REMARKS
		FROM	TO	FROM	TO	FROM	TO				
27	9 May			63.5	64.0	63.5	64.4	3" undist.	3" tube	180	Clay, silty, firm, gray
				64.0	64.5					340	Rock on bottom
				64.5	64.7					500	
							BORING COMPLETE				

(Sheet 10 of 10)

Fig. A6 (Concluded). Log of boring S-1007 (sample 27)

BORING LOG
FIELD DATA

Project Patoka Dam
Location 5 ft north of S-1007
Date 10 May 1972
Drill Rig CE-3772
Inspector K. Waites
Operator P. Martin
Surface elev
Levee District
Job No. 441-S382.12SR41
Boring No. S-1007A

SAMPLE NUMBER	DATE TAKEN 1972	STRATUM		DRIVE		SAMPLE		TYPE OF SAMPLER		Pressure psi	CLASSIFICATION AND REMARKS
		FROM	TO	FROM	TO	FROM	TO				
1	10 May	0.0		0.0	27.5			Fish tail			No samples
1	10 May			27.5	28.0	27.5	29.7	3" undist.	3" tube	160	Sand, clayey, wet silty, gray
				28.0	28.5					220	
				28.5	29.0					300	
				29.0	29.5					260	
				29.5	29.9					260	
2	10 May			29.9	30.4	29.9	32.1	3" undist.	3" tube	180	Sand, fine, wet, gray
				30.4	30.9					210	
				30.9	31.4					210	
				31.4	31.9					220	
				31.9	32.3					220	
											(Sheet 1 of 2)

Fig. A7. Log of boring S-1007a (samples 1 and 2)

BORING LOG
FIELD DATA

Project Patoka Dam
Location 5 ft north of S-1007
Date 10 May 1972
Drill Rig CE-3772
Inspector K. Waites
Operator P. Martin
Surface elev
Levee District
Job No. 441-S382.12SR41
Boring No. S-1007A

SAMPLE NUMBER	DATE TAKEN 1972	STRATUM		DRIVE		SAMPLE		TYPE OF SAMPLER		Pressure psi	CLASSIFICATION AND REMARKS
		FROM	TO	FROM	TO	FROM	TO				
3	10 May			32.3	32.8	32.3	34.4	3" undist.	3" tube	160	Sand, fine, wet, gray
				32.8	33.3					180	
				33.3	33.8					190	
				33.8	34.3					200	
				34.3	34.7					200	
4	10 May			34.7	35.2	34.7	36.9	3" undist.	3" tube	160	Sand, silty, clayey, wet, gray
				35.2	35.7					210	
				35.7	36.2					220	
				36.2	36.7					220	
				36.7	37.1					220	
											(Sheet 2 of 2)

Fig. A7 (Concluded). Log of boring S-1007a (samples 3 and 4)

APPENDIX B: SIMPLIFIED PROCEDURE FOR EVALUATING SOIL LIQUEFACTION POTENTIAL

1. Generally, the primary forces acting on a soil element during earthquakes are those resulting from the upward propagation of shear motions fron underlying rock formations. To represent these shearing motions as a uniform cyclic load in the laboratory requires a number of assumptions. The following procedure and assumptions were developed by Seed and his coworkers (references 3 and 7*).

Selection of Shear Stress and Cycles of Loading

2. The shape of a typical earthquake accelerogram is quite irregular in both frequency and amplitude. The problem is therefore to convert the irregular accelerogram into an equivalent system of uniformly intense cyclic stresses such that the response of the soil sample will be identical with the actual field loading. Fig. B1 graphically illustrates the problem.

3. The conversion developed by Seed and Idriss was based upon the assumption that there exists an equivalent number of stress cycles N_{eq}, each of the same uniform average stress intensity τ_{ave}, which would have the same effect on the soil as the actual earthquake-induced loading. The conversion method consists of determining in the laboratory the number of cycles of loading that produced liquefaction at various uniform shear stresses and comparing these cycles with the number of peaks in the earthquake accelerogram at the same shear stresses. By arbitrarily selecting an average shear stress τ_{ave} and proportioning the other shear stresses in the accelerogram, an equivalent number of cycles at τ_{ave} for the accelerogram can be determined. For example, assume that four cycles of uniform shear stress τ_{ave} produced liquefaction in the laboratory and that two cycles of uniform shear stress $\tau_1 (\tau_1 > \tau_{ave})$ also produced liquefaction in the laboratory. Hence,

---

* Reference numbers refer to Literature Cited at the end of main text.

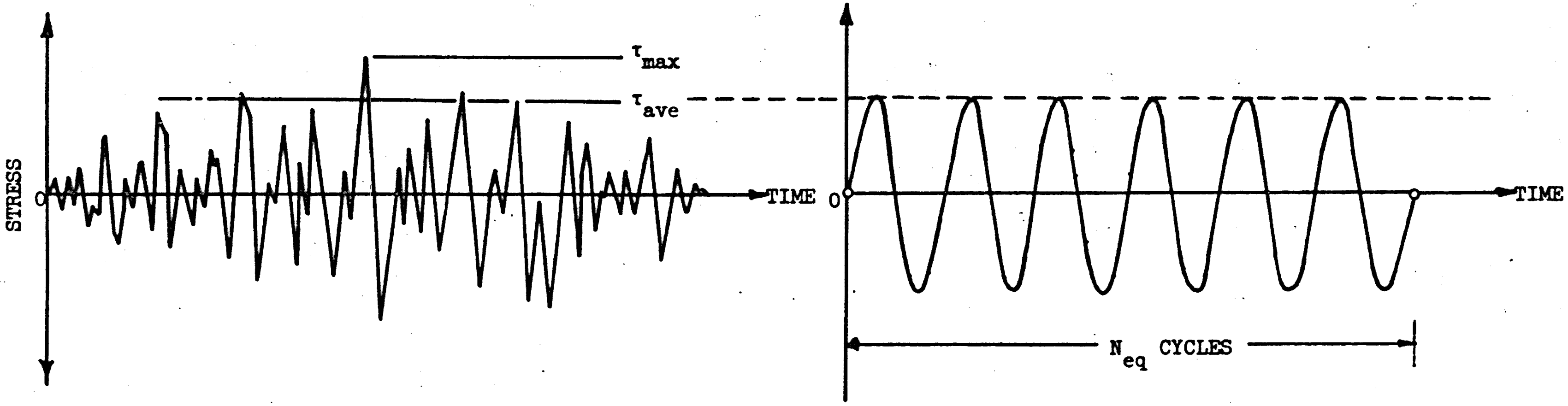


Fig. B1. Actual and equivalent earthquake response

1 cycle at τ_1 is equivalent to 2 cycles at τ_{ave}. Continuing, by counting the number of peaks in the accelerogram that have an intensity equal to τ_1, these peaks can be proportioned and expressed in terms of equivalent cycles of τ_{ave}. For example, assuming that three peaks of magnitude τ_1 existed in the accelerogram, these peaks would be equivalent to $4/2 \times 3 = 6$ cycles of τ_{ave}. Likewise, other intensities can also be expressed in terms of τ_{ave}, and by summing the equivalent cycles for each stress intensity, an overall equivalent number of cycles corresponding to τ_{ave} can be determined. Based upon the study of numerous accelerograms and test results, Seed and Idriss recommended using a value of $\tau_{ave} = 0.65\tau_{max}$ and the following approximate number of cycles of loading for various earthquake magnitudes:

Earthquake Magnitude	Number of Cycles of Loading
7	10
7-1/2	20
8	30

Selection of Cyclic Deviator Stress

4. Having selected a $\tau_{ave} = 0.65\tau_{max}$ for the design earthquake, a cyclic deviator stress σ_{dc} for use in the laboratory tests must be selected such that the response of the triaxial specimen compares favorably with observed field behavior. Accordingly, the following assumptions and procedures have been developed.[7]

5. Assuming that the soil column above a soil element at depth h behaves as a rigid body, then the maximum shear stress on the soil element would be

$$\left(\tau_{max}\right)_r = \frac{\gamma h}{g} \times a_{max} \qquad \text{(B1)}$$

where a_{max} is the maximum peak ground surface acceleration (fig. B2).

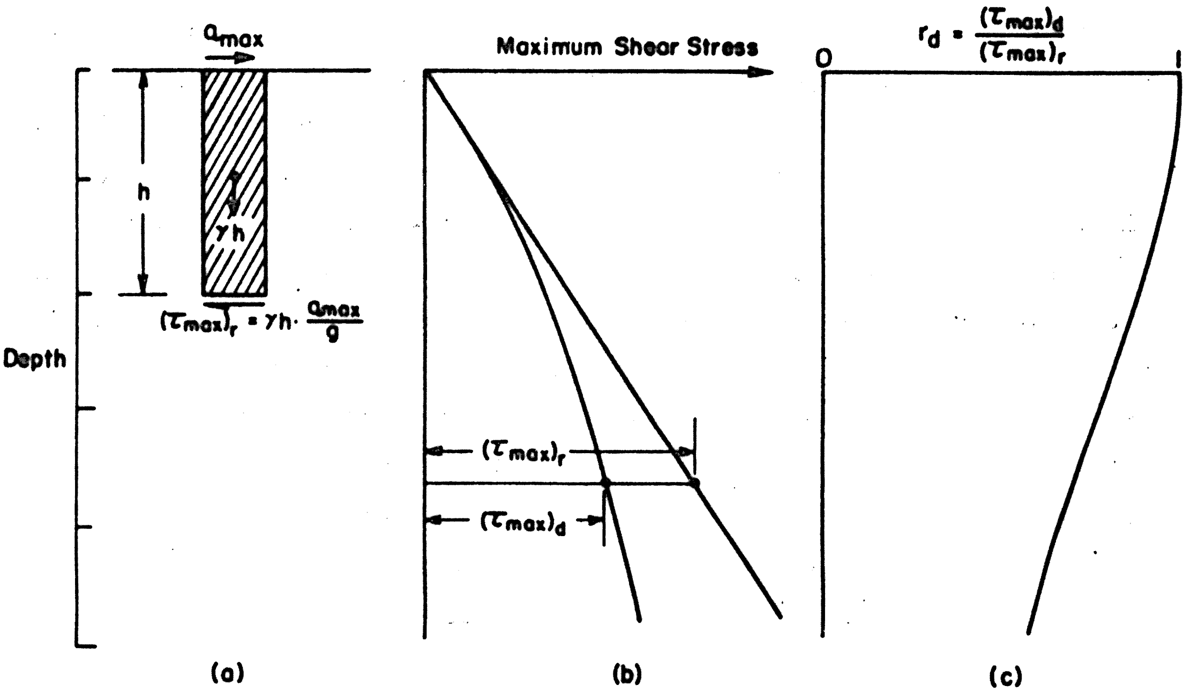


Fig. B2. Determination of maximum shear stress

Since the soil column is a deformable body, the shear stress will be somewhat less or

$$(\tau_{max})_d = (r_d)(\tau_{max})_r \qquad \text{(B2)}$$

where r_d is a correction factor with a value less than 1.

6. Fig. B3 shows the range of typical r_d values with depth. For the Patoka Dam study, the average value was used to a depth of 40 ft, 0.85 was used from 40 to 57 ft, and the lower boundary values were used for depths greater than 57 ft.

7. Since the equivalent number of cycles is based upon $0.65\tau_{max}$, then the average cyclic shear stress may be expressed as:

$$\tau_{ave} = 0.65 \times \frac{\gamma h}{g} \times a_{max} \times r_d \qquad \text{(B3)}$$

However, a comparison of cyclic triaxial test results and observed field

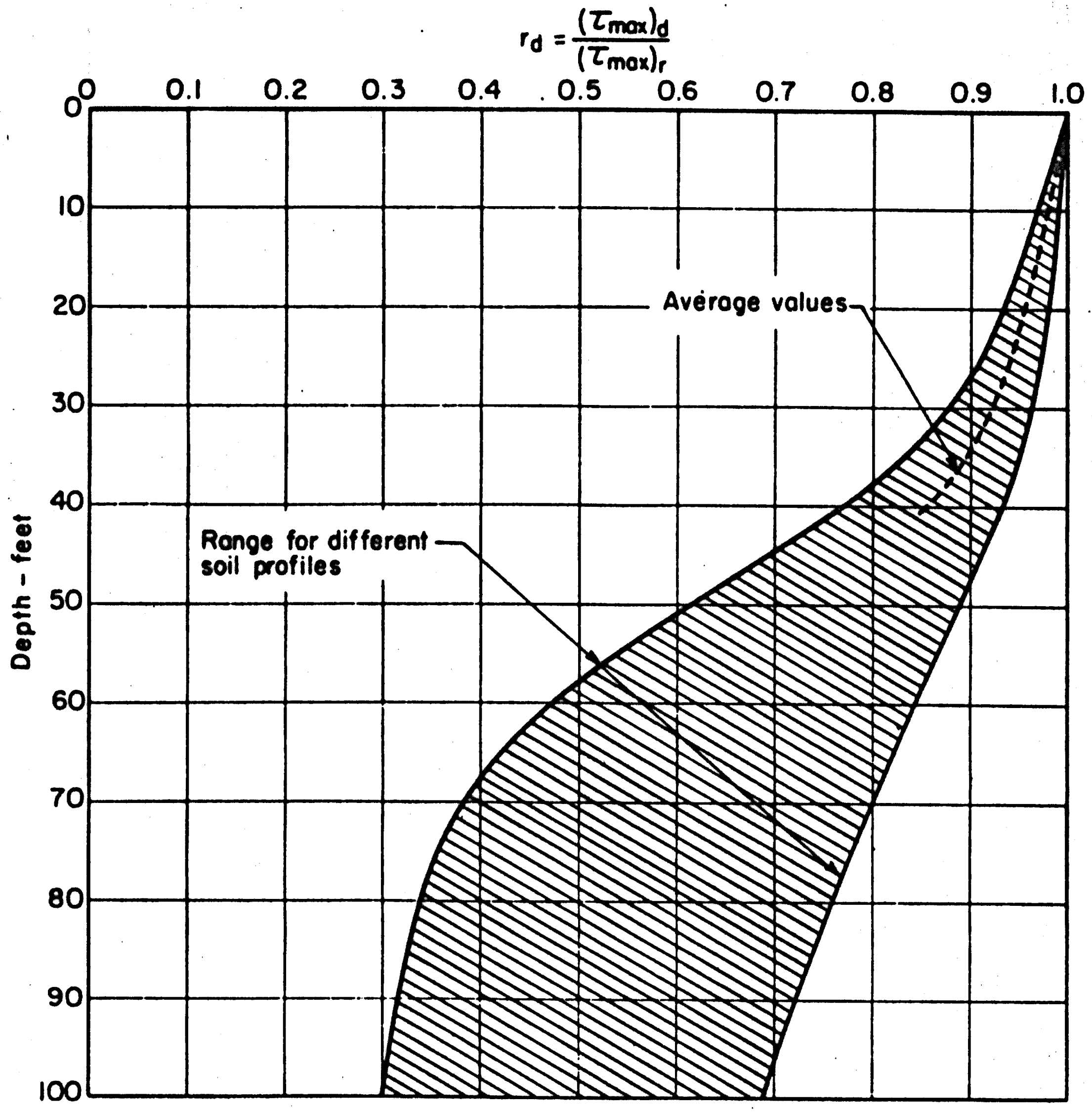
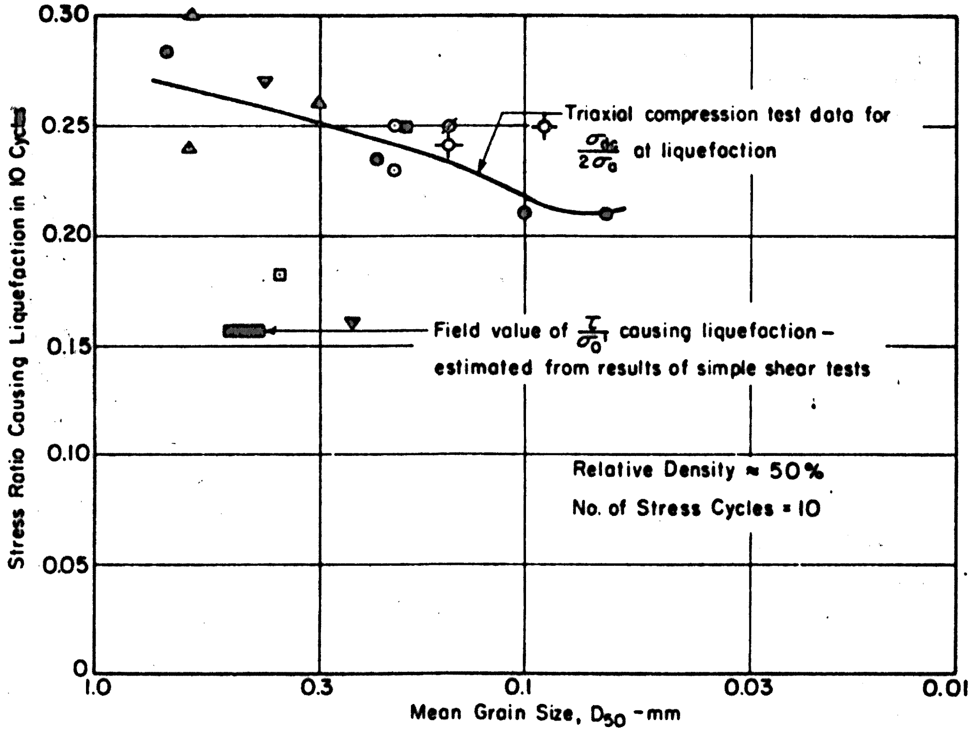


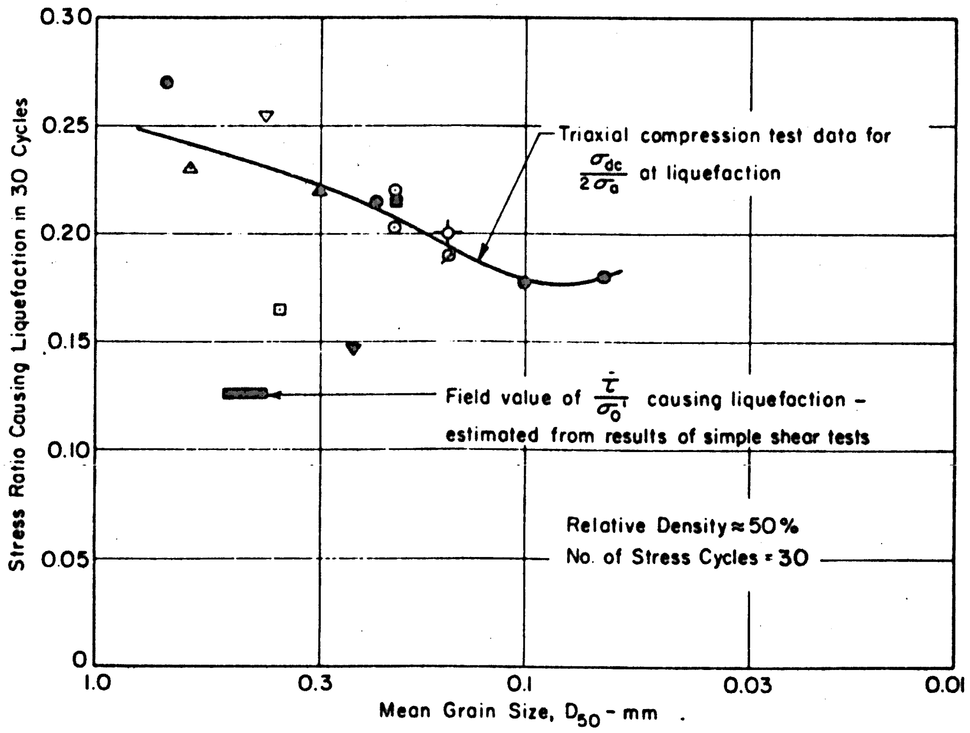
Fig. B3. Range of values of r_d for different soil profiles

behavior (fig. B4) suggests that the cyclic triaxial test overestimates the field strength and that the laboratory results under isotropically consolidated conditions should be reduced by a correction factor C_r . This overestimation by the triaxial test is due to the following factors:

- a. The K field condition is about 2 to 2.5, while K = 1 for the isotropically consolidated triaxial test.
- b. Under field loading conditions, the directions of the major principal stresses vary from about 0 to 40 deg each side of vertical, while the stresses rotate through 90 deg for the triaxial test.



a. Liquefaction in 10 cycles



b. Liquefaction in 30 cycles

Fig. B4. Stress conditions causing liquefaction of sands in 10 and 30 cycles

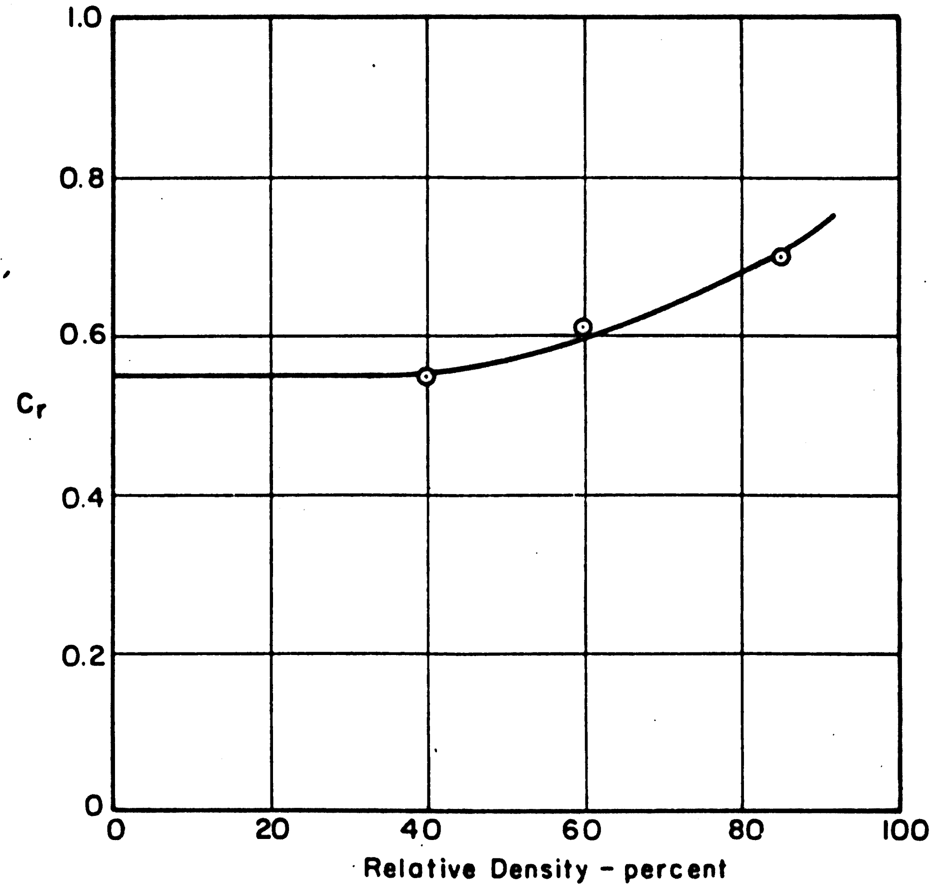


Fig. B5. Relationship between C_r and relative density

c. Necking of the sample, which creates unrealistic stress concentrations and deformations in dense samples, affects results. Accordingly, fig. B5 presents approximate values for C_r under $K = 1$ conditions, and

$$\left(\frac{\tau}{\sigma_o}\right)_{field} = \left(\frac{\sigma_{dc}}{2\sigma_a}\right)_{lab} \times C_r \qquad (B4)$$

8. In the case of anisotropically consolidated specimens $(K \neq 1)$, by assuming that cyclic simple shear tests more closely represent field conditions, comparisons between cyclic simple shear and cyclic triaxial tests suggest that $C_r \simeq 1$ for relative densities $>50\%$, when $K > 1.5$ (Lee*).

---

* Personal communication, Prof. K. L. Lee, University of California at Los Angeles, to Dr. W. F. Marcuson, WES, 14 August 1972.

9. Therefore, by utilizing equations B1 through B4, a cyclic deviator stress σ_{dc} , which corresponds to a field earthquake acceleration, can be calculated for $K = 1$ conditions.

List of Symbols

a_{max}	Maximum horizontal ground acceleration
C_r	Correction factor relating laboratory cyclic triaxial test results to observed field behavior
N_{eq}	Number of equivalent cycles for a given shear stress
r_d	Correction factor reducing behavior of assumed rigid soil column to deformable soil column
σ_a	Ambient consolidation pressure, i.e. chamber pressure for $K = 1$ condition
σ_{dc}	Cyclic deviator stress
σ_o	Overburden pressure, field conditions
τ_{ave}	Average shear stress, i.e. $0.65\tau_{max}$
τ_{max}	Maximum shear stress
$\left(\tau_{max}\right)_d$	Maximum shear stress, deformable soil column
$\left(\tau_{max}\right)_r$	Maximum shear stress, rigid soil column

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)*

U. S. Army Engineer Waterways Experiment Station
Vicksburg, Mississippi

2a. REPORT SECURITY CLASSIFICATION

Unclassified

2b. GROUP

3. REPORT TITLE

EARTHQUAKE LIQUEFACTION POTENTIAL AT PATOKA DAM, INDIANA

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Final report

5. AUTHOR(S) *(First name, middle initial, last name)*

William F. Marcuson III
Paul A. Gilbert

6. REPORT DATE

December 1972

7a. TOTAL NO. OF PAGES

120

7b. NO. OF REFS

7

8a. CONTRACT OR GRANT NO.

b. PROJECT NO.

c. Intra-Army Order No. DC-B-72-105

d.

9a. ORIGINATOR'S REPORT NUMBER(S)

Miscellaneous Paper S-72-42

9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY

U. S. Army Engineer District, Louisville
Louisville, Kentucky

13. ABSTRACT

A preliminary exploration of the damsite revealed foundation materials with extremely low penetration resistance. The site is in a seismic Zone 2 (Algermissen) and near the border of a seismic Zone 3. Consequently, a laboratory study was conducted to evaluate the liquefaction potential of the foundation materials when subjected to an earthquake. To evaluate the liquefaction potential, undisturbed samples of the foundation soils were obtained using a fixed-piston sampler and drilling mud. The materials were found to be fine clayey sands, fine silty sands, fine sandy clays, and silty clays. The in situ dry density was determined to range from 88 to 104 pcf in the depths considered to be critical in regard to liquefaction potential. Cyclic triaxial tests were conducted on material representative of the five depths that were anticipated to be subject to liquefaction. Based on the results of these tests, the foundation is expected to liquefy if subjected to an earthquake of magnitude 6.5 with a peak acceleration of 0.17 g or greater. Logs of borings are given in Appendix A. A simplified procedure for evaluating liquefaction potential is given in Appendix B.

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Dam foundations						
Earthquake resistant structures						
Foundation investigations						
Liquefaction (soils)						
Patoka damsite						