U.S. ARMY ENGINEER DIVISION LABORATORY

SOUTH ATLANTIC

LARGE SCALE TRIAXIAL SHEAR AND PERMEABILITY TESTS
SHEARON HARRIS NUCLEAR POWER PLANT
CAROLINA POWER AND LIGHT COMPANY

50-400/401/402/403
ltr 2-2-79
7902220066

APRIL 1975
CORPS OF ENGINEERS
MARIETTA, GEORGIA

Requisition No.
H-02022

Work Order No.
9051

7902220072

PREFACE

The Carolina Power and Light Company (CP & L), Raleigh, North Carolina, in a letter dated 4 October 1974, requested that the U. S. Army Engineer Division Laboratory, South Atlantic, perform laboratory tests on material from a random rockfill sample taken from a test section at their Shearon Harris Nuclear Plant Site. The test program was authorized by Office, Chief of Engineers, in the first indorsement, DAEN-CWO, 11 November 1974, to letter SADEN-L, 25 October 1974, subject: "Request for Approval to Perform 15-In. Triaxial Shear Test Program for Shearon Harris Nuclear Power Plant, Carolina Power and Light Company". Tests conducted were: a 15-in. diameter consolidated undrained triaxial shear test, grain size analyses, and 14-in. diameter constant head permeability tests.

The work was performed under the general direction of Mr. Robert J. Stephenson, P.E., Director, South Atlantic Division Laboratory. The laboratory tests were supervised by Messrs. William L. Tison, Civil Engineer, and Coy A. Colwell, Supervisory Civil Engineering Technician. The analysis of the data and preparation of this report were performed by Mr. William L. Tison.

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
pounds	0.45336	kilograms
cubic feet	0.028317	cubic meters
pounds per square inch (psi)	703.1	kilograms per square meter
tons per square foot	0.9765	kilograms per square centimeter
centimeters per second	1.969	feet per minute

LARGE SCALE TRIAXIAL SHEAR AND PERMEABILITY TESTS
SHEARON HARRIS NUCLEAR POWER PLANT

1. OBJECT:

The object of the test program was to determine the gradation of the rockfill sample and the triaxial shear and permeability characteristics of specimens reconstituted from the random rockfill sample.

2. REFERENCES:

Department of the Army, Office of the Chief of Engineers, Engineer Manual No. 1110-2-1906, Laboratory Soils Testing, 30 November 1970.

3. SPECIAL EQUIPMENT:

a. <u>Controlled-Strain Triaxial Device</u> (Figure 1). The unit accommodates a specimen 15 inches in diameter by 32 inches high and is capable of a maximum chamber pressure of 400 psi. Axial load is applied by a 14-in. diameter, 200,000 lbs. capacity hydraulic ram fastened to a 5 in. diameter piston. The piston seats in a socket on the specimen loading cap. Specimen drainage is through a 2.5-in. diameter Norton porous stone in the pedestal and a similar 1.25-in. diameter stone in the specimen cap. Drainage lines are 1/4-in. polyethelene tubing with Whitey needle valves and Swagelok quick-connect couplers. The interior of the specimen is connected to a 6-in. diameter aluminum saturation reservoir having a capacity of 19,000 ml with 100 ml graduations. The chamber fluid is connected to a 5-in. diameter, 11,500 ml aluminum reservoir with 100 ml graduations. During saturation,

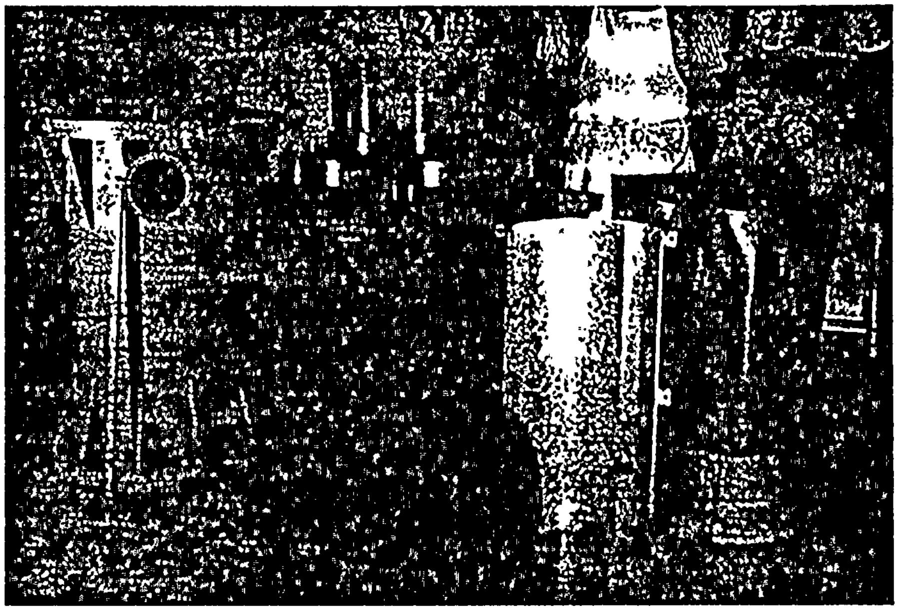


Fig. 1 - Unassembled triaxial shear test apparatus. In the foreground are the collar, split mold, rubber membrane, and membrane stretcher utilized in preparing the test specimens.

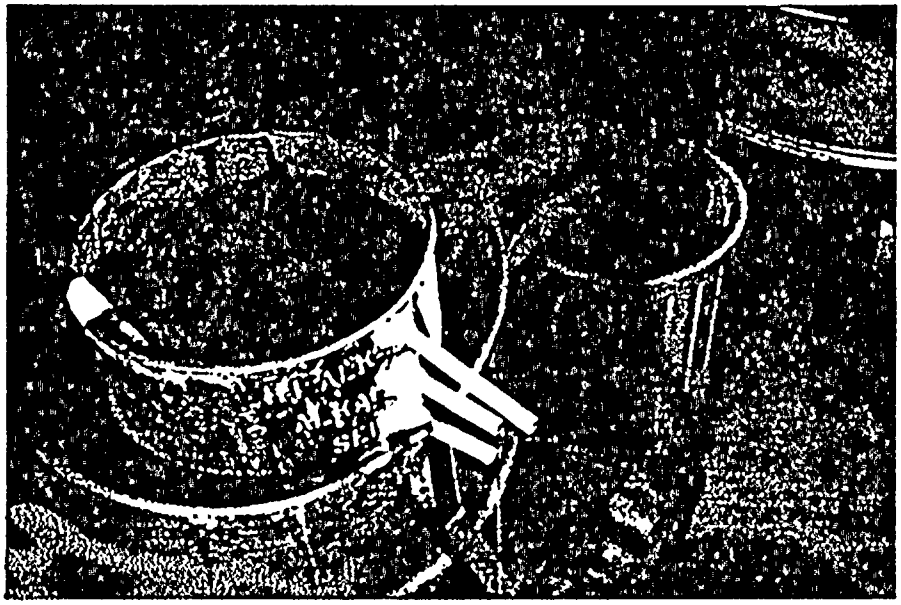


Fig. 2 - Equipment set up for constant-head permeability tests on rockfill material.

a 2000 ml lucite burette with 10 ml graduations is connected to the specimen through the upper drainage line.

b. Permeameter (Figure 2). The permeameter is open ended and accommodates a specimen 14 inches in diameter and 18 inches high. A column of water equal in diameter to the test specimen is the source of flow through the specimen. The permeameter is constructed with three overflow pipes at different heights above the specimen top so the constant head elevation can be varied. The permeameter is placed inside a larger diameter container with an overflow which maintains the tail water at a constant height.

c. Gradation Equipment. A large Tylab mechanical shaker containing six screens from the 3-in. to the 3/8-in. sieve sizes was used. Larger sizes were separated by hand over a series of screens with openings up to 8-inches. Rocks over 8-in. size were measured with templates. Conventional equipment was utilized to grade the No. 4 to the No. 200 sieve sizes.

4. DESCRIPTION OF SAMPLE:

All test specimens were reconstituted with material from an 8-ton random rockfill sample taken from a field test section by CP & L personnel (Figure 3). The material classified as brown silty gravel sizes (GM) with some cobble sizes. All of the sample was finer than 24-in. size and 17 percent was finer than the No. 200 sieve size (Plate 1)*. The soil had a liquid limit of 35 and a plastic limit

*All plates are contained in the Appendix.

of 27. CP & L furnished the field compacted in-place density and moisture content which were 135.0 pcf dry density and 5.0 percent water content, respectively.

5. SCOPE OF TESTS:

The gradation of the total sample, air dried, was obtained and a "replacement gradation" containing minus 3-in. sizes established for the tests. Three 15-in. diameter triaxial specimens with the replaced gradation (Plate 2) were compacted to the field density and moisture conditions and tested in consolidated undrained triaxial shear with pore pressure measurements ($\overline{R}$ Tests). Confining pressures (σ_3) of 1.0, 2.0, and 4.0 tons per square foot were applied. The grain size distribution of each specimen after shear was obtained to determine the degree of particle breakdown due to compaction and shear forces. Three 14-in. diameter specimens were prepared similarly with various gradations for permeability tests. The grain size distribution of these specimens after testing were also determined.

6. TEST PROCEDURES:

a. Gradation. The total sample was spread out and air dried. The plus 8-in. sizes were separated and graded by hand using a series of templates. The minus 8-in. to plus 3-in. sizes were graded by hand using the large screens. The minus 3-in. sizes were graded

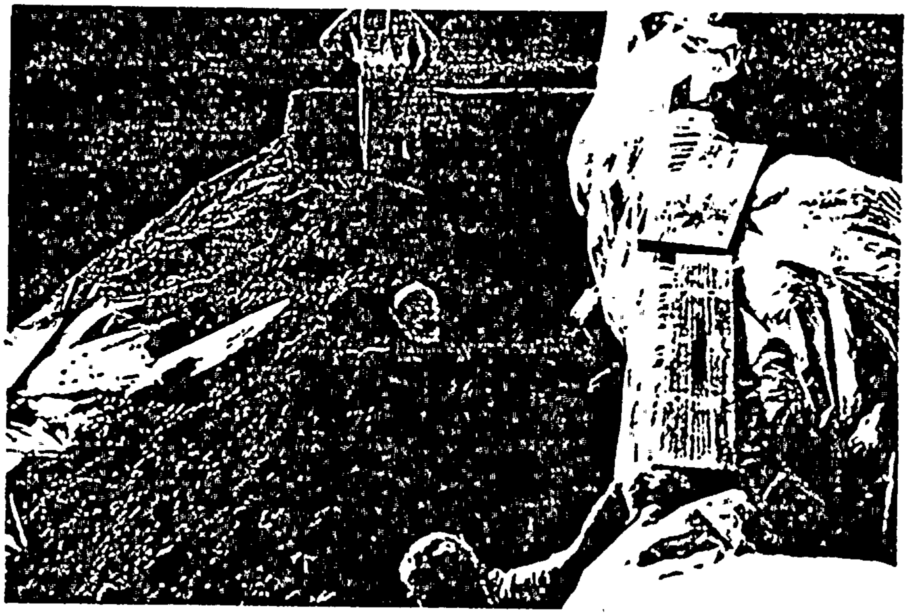


Fig. 3 - Sample from random rockfill test section at Shearon Harris Nuclear Power Plant when delivered to SAD Laboratory.

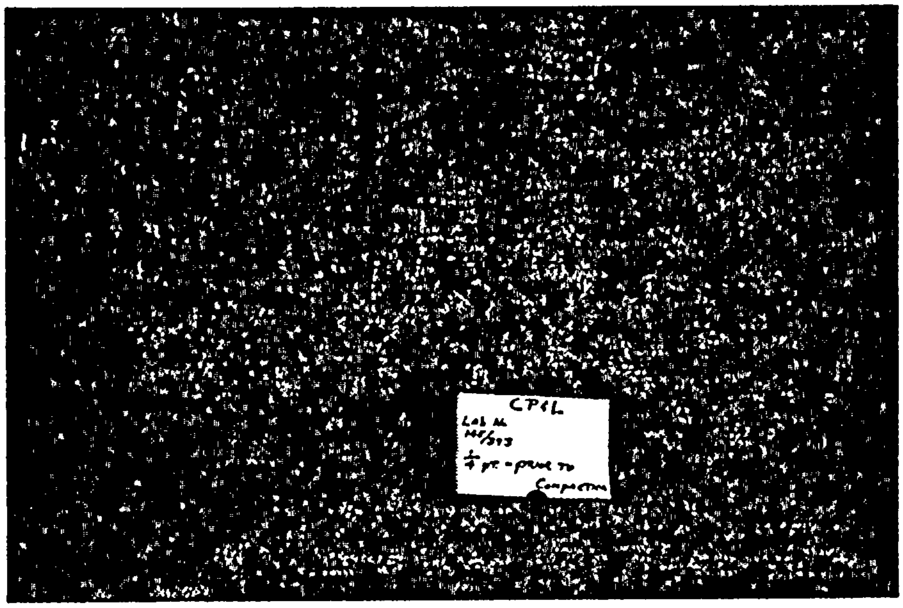


Fig. 4 - Material prepared with the replaced gradation to form one lift in the 15-in. triaxial shear test specimen.

through the Tylab shaker in batches of about 40 lbs. Shaking time was the minimum required to obtain a "clean" separation without unduly breaking down the particles further. This was usually about 8 minutes. A conventional sieve analysis was performed on a representative sample of the minus No. 4 sieve sizes as outlined in App. V of the reference.

b. Triaxial Shear Test. Except as noted below, the triaxial shear test procedure was generally the same as that outlined in paragraph 7 of Appendix X to the reference.

(1) Preparation of Specimen. For each specimen, four separate equal-weight batches of air-dry material were prepared by combining the necessary amount of each sieve size to obtain the minus 3-in. sizes replaced gradation (Figure 4). The replaced gradation was based on a total gradation furnished by CP & L instead of on the total gradation of the sample submitted. The gradation furnished by CP & L had been developed from a number of field tests and was believed to be more representative of the in-situ compacted rockfill without additional processing. Each batch was mixed at 5 percent water content and placed in air tight containers until needed for preparation of the test specimen. Each of the prepared batches was quartered and the quarter-portions compacted individually into the rubber membrane-lined mold and collar placed on the triaxial base. Thus, each specimen was formed in 16 lifts. Each lift was spread inside the mold and then compacted to the required thickness (Figure 5) with a large compaction

Fig. 5 - Top of one lift after compaction inside the mold forming the 15-in. triaxial shear test specimen.

Fig. 6 - Prepared specimen for 15-in. diameter triaxial shear test inclosed by water tight membrane.

hammer previously fabricated for standard compaction tests in a 12-in. diameter mold. The lifts were compacted to obtain a uniform dry density of approximately 135.0 pounds per cubic foot at 5 percent water content. The collar and mold were removed and the specimen cap secured. Initial dimensions of the specimen were measured and water tight membranes placed around the specimen (Figure 6).

(2) Saturation Procedure: The apparatus was completely assembled, (Figure 7), the chamber filled with water, and saturation of the specimen initiated through the bottom by means of a vacuum on the top of the specimen. Approximately 2000 cc of water was allowed to flow from the top of the specimen. The vacuum was then replaced by back pressure. To insure complete saturation, the back pressure was increased in 14 psi increments to a total of 63 psi.

(3) Consolidation Procedure: When 100 percent saturation was indicated, the chamber pressure was increased to the required test confining pressure (σ_3). Volume change measurements were obtained from the interior burette and plotted versus logaritham of time until primary consolidation was accomplished.

(4) Compression Procedure: The piston was brought into contact with the specimen cap and the load indicator set to zero. All valves were closed to prevent drainage and the specimen axially loaded at a controlled strain rate of about 0.1 percent per minute. Load, deflection, and pore pressure measurements were taken during

Fig. 7 - Assembled test chamber for 15-in. diameter triaxial shear test with control console on right.

shear. Loading was discontinued at 20 percent axial strain. The chamber was then dismantled, (Figure 8), the membrane removed, and the oven-dry weight and after-test gradation of the total specimen determined (Figures 9, 10, & 11).

c. Permeability Test:

(1) Preparation of Specimen: Each specimen was prepared similar to the triaxial shear specimen using four equal-weight batches compacted in four lifts to form the specimen inside the permeameter. Various gradations were used in an attempt to produce an after test gradation equivalent to the replaced gradation corresponding to the total gradation furnished by CP & L. This was in order to test a specimen with gradation as close as possible to the in-situ rockfill gradation.

(2) Test Procedure: The permeameter was placed in the large container which was filled with water and the specimen saturated by seepage through the bottom for 24 hours. Water flow into the permeameter was then regulated to maintain a constant head water elevation at the first overflow pipe. Flow through the specimen, top to bottom, produced by the differential head was measured for a given time. This was repeated for two more increasing differential heads. The apparatus was then dismantled and the dry weight and after-test gradation of the entire specimen determined.

Fig. 8 - Specimen after 15-in. triaxial shear test before the membrane has been removed.

Fig. 9 - Specimen after triaxial test at 1 tsf confining pressure (σ_3).

Fig. 10 - Specimen after triaxial test at 2 tsf confining pressure (σ_3).

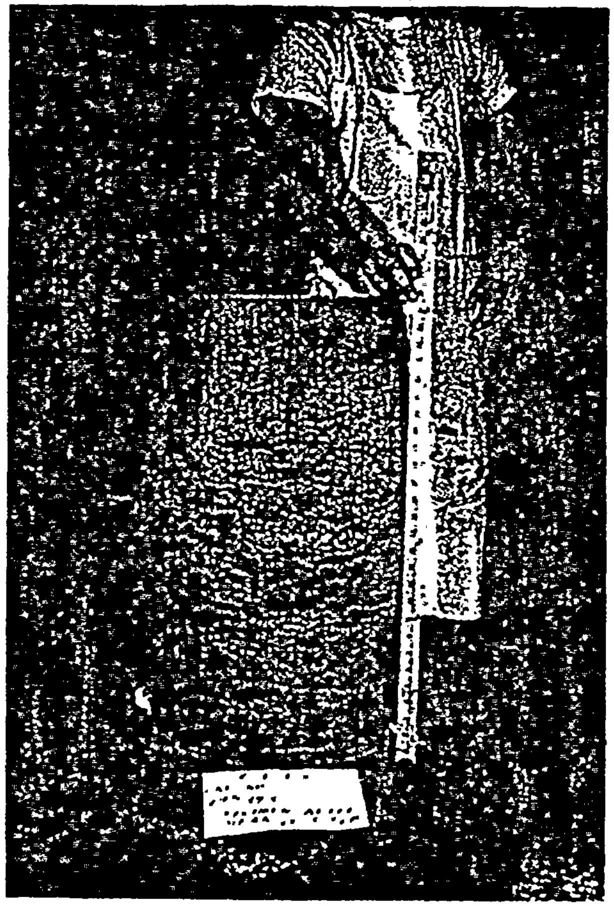


Fig. 11 - Specimen after triaxial test at 4 tsf confining pressure (σ_3).

7. TEST RESULTS:

The results of all the tests are shown on standard forms in the Appendix hereto as listed below.

Test	Plate No.
Total Gradation Report (ENG Form 2087)	1
Gradation Curves for the Triaxial Test (ENG Form 2087)	2
Triaxial Compression Test Report (ENG Form 2089)	3
Permeability Test No. 1 Report (SAD Form 1971)	4
Permeability Test No. 2 Report (SAD Form 1971)	5
Permeability Test No. 3 Report (SAD Form 1971)	6

8. DISCUSSION OF TEST RESULTS:

a. Triaxial Shear (Plate 3). The remolded test specimens averaged 4.5 percent water content and 135.6 pcf dry density. These were considered satisfactory when compared to the field water content of 5.0 percent and dry density of 135.0 pcf. This density was obtained in the laboratory without using what would be considered excessive compactive effort. The procedure did not provide a means to measure particle breakdown due to compaction alone. Figure 5 indicates the larger sizes were breaking down somewhat during specimen preparation. Final saturation computations and pore pressure observations indicated 100 percent saturation was achieved. The strain rate of 0.1 percent per minute was slow enough to allow equalization of the induced pore

pressures throughout the specimens. In each specimen, the maximum induced pore pressure was reached at about 4.5 percent axial strain and showed very little dissipation thereafter. Deviator stress ($\sigma_1 - \sigma_3$) increased with axial strain in each specimen. The shear strength parameters were arbitrarily computed at 15 percent axial strain. The total strength envelope thus obtained indicated an internal friction angle (Ø) of 20° and a cohesion intercept of 0.1 tsf. The corresponding effective strength envelope (Ø') is 40.0° with 0.0 cohesion. These strengths are comparable to data obtained previously on 15-in. diameter tests performed on similar materials.

The after-test gradations for the three triaxial test specimens show there was some breakdown of particles. The percent passing the No. 4 sieve size increased an average of about 4.5 percent. The indication that most of the particle breakdown occurred during specimen preparation rather than during shear was evident since the specimen at the highest confining pressure (56 psi) did not break down significantly more than the one tested at the lowest confining pressure (14 psi).

b. Permeability. Three constant head permeability measurements were made on each of three separate specimens with different gradations. The results are summarized in Table I.

(1) The first gradation was the same as that used in the triaxial test. It produced consistent permeability coefficients

TABLE I

SUMMARY OF PREMEABILITY TEST

RESULTS

Test No.	% Passing No. 4 Sieve Before Test	% Passing No. 4 Sieve After Test	Run No.	Differential Head (cm)	$K_{20} \times 10^{-4}$ (cm/sec)
1	32.4	32.6	(1	11.4	14.9
			(2	18.4	11.2
			(3	52.5	15.4
2	32.4	36.5	(1	11.3	91.7
			(2	18.7	74.6
			(3	36.3	21.2
3	28.0	34.1	(1	11.1	74.6
			(2	18.5	58.5
			(3	36.1	13.9

from 11.2 to 15.4 x 10^{-4} cm/sec. The after-test gradation indicated breakdown of the gravel-size particles but less than one percent increase in the amount passing the No. 4 sieve. The latter was believed to be erroneous because of the amount of breakdown in the gravel sizes. It is likely that when the specimen was oven dried the fines stuck to the larger particles making an accurate gradation difficult.

(2) The second specimen was prepared with a coarser gradation in the gravel sizes but the same percent passing the No. 4 sieve. The range of the measured permeability coefficients were significantly greater (21.2 to 91.7 x 10^{-4} cm/sec). The apparent decrease in permeability during continued testing was attributed to migration of the fines. The after-test gradation indicated an increase of about four percent passing the No. 4 sieve size. This was comparable to the breakdown in the triaxial test. Extra effort was made to obtain a "cleaner" after-test gradation on this specimen.

(3) The third permeability specimen was much coarser with 28.0 percent passing the No. 4 sieve. This gradation was a further attempt to obtain an after-test gradation equal to the actual or theoretical replaced gradation corresponding to the field gradation obtained by CP & L. The after-test percent passing the No. 4 was less than two percent higher than desired, but the permeability coefficients were slightly less than the values obtained in the second test. Though somewhat inconsistent with the gradation, this tended

to confirm the permeability values in the second and third tests.

9. CONCLUSIONS:

a. Triaxial Shear. The shear strength parameters measured in the $\bar{R}$ Tests are comparable to the strengths obtained previously on similar materials. In fact, the characteristics of the sample tested in this program are very much like material tested from the New Hope Dam in North Carolina. Therefore, the data obtained on this sample from the Shearon Harris Nuclear Power Plant are considered quite reliable.

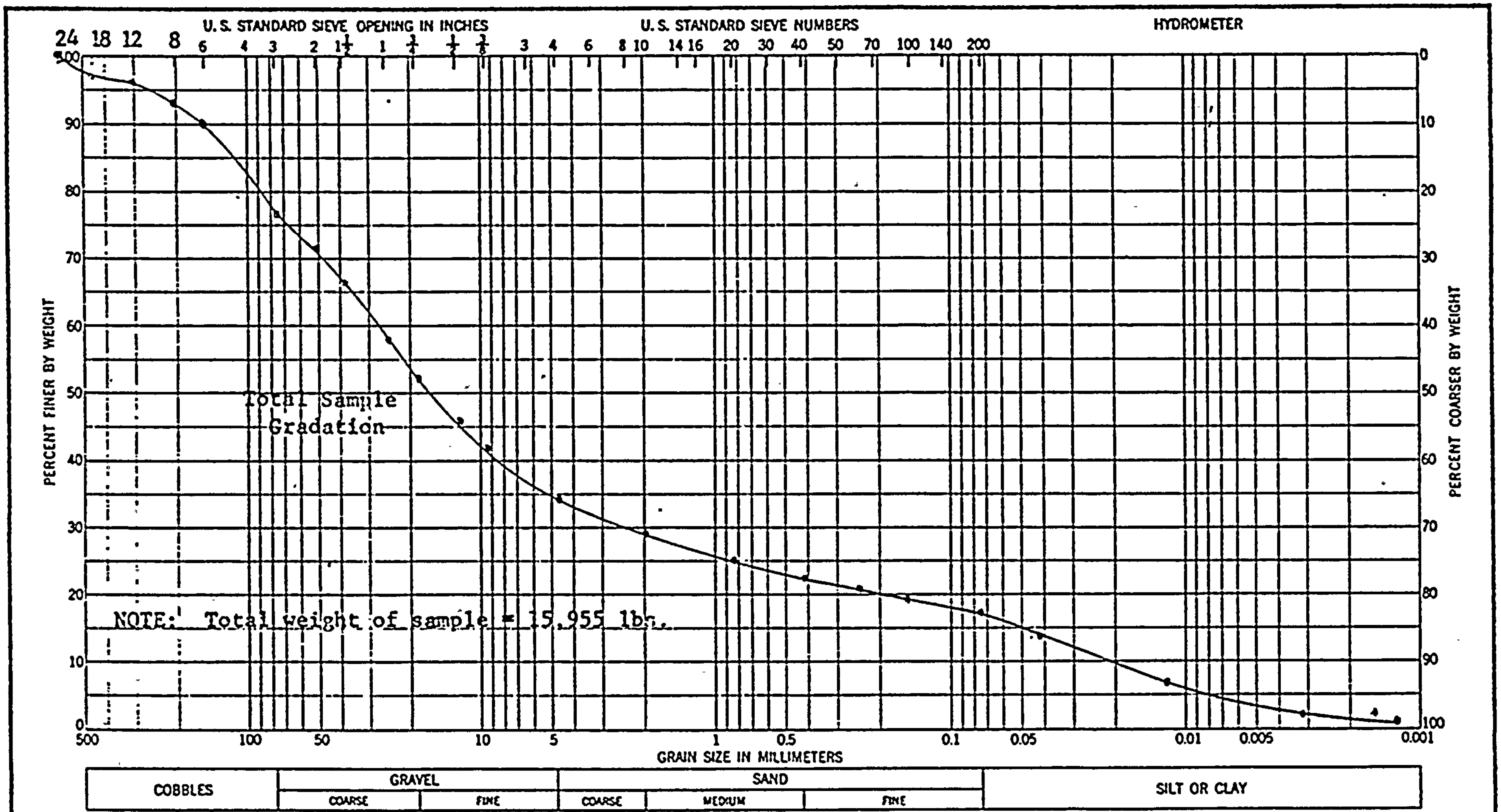
b. Permeability. Although the permeability coefficients measured in these tests varied, experience indicates their order of magnitude is reasonable for this type material. It is difficult to obtain consistent permeability data in laboratory tests with relatively small diameter specimens on very coarse materials that contain significant quantities of finer sizes. The finer particles are often insufficient to fill all of the voids between the coarser rocks so there is little doubt that these finer sizes migrate with the flow of water through the specimen during the test. As a result, they accumulate in spots, restricting the flow of water and producing rather conservative (low permeability) data compared to what would be obtained if a true field sample could be tested. Nevertheless, the permeability coefficients measured on the material in these tests are in the range of "good drainage" suitable for pervious sections of dams and dikes. Typically, values of this order of magnitude are obtained on clean sands or clean sand and gravel mixtures.

APPENDIX

INDIVIDUAL TEST REPORTS

DEPARTMENT OF THE ARMY, SOUTH ATLANTIC DIVISION LABORATORY,
CORPS OF ENGINEERS, 611 SOUTH COBB DRIVE, MARIETTA, GA. 30061

WORK ORDER NO. 9051
REQ. NO. H-02022



Sample No.	Elev or Depth	Classification	w %	LL	PL	PI
VR-24-3-7	210.0'-225.0'	Brown silty gravel sizes (GM) w/some cobble sizes	5.4*	35	27	8
		(*Moisture content of sample when received)				

Project: Shearon Harris Nuclear Power Plant, CP&L

Lab. No. 145/393

Area: Plant Excavation

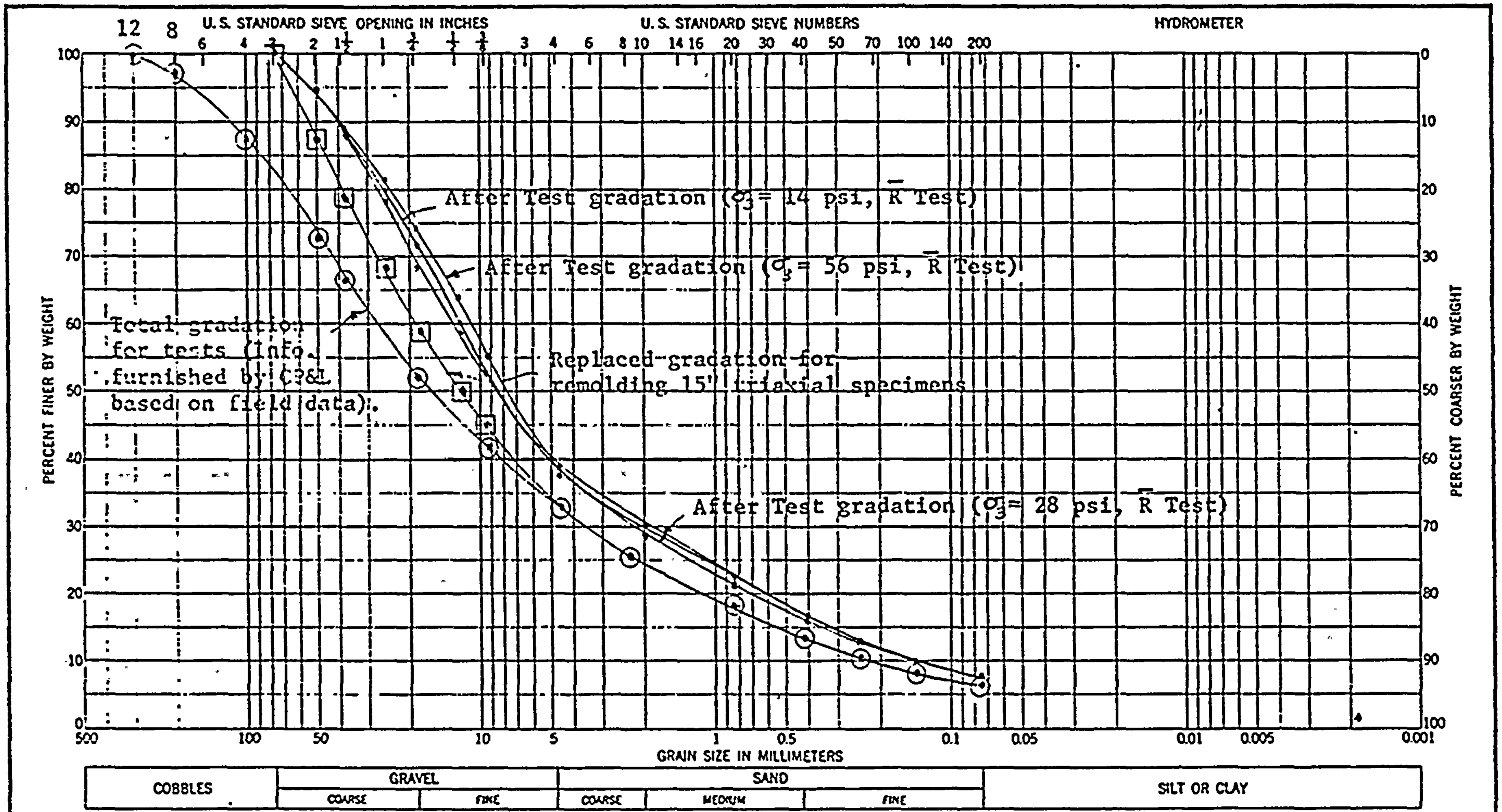
Sample No. VR-24-3-7

Date: 10 January 1975

GRADATION CURVES

DEPARTMENT OF THE ARMY, SOUTH ATLANTIC DIVISION LABORATORY,
CORPS OF ENGINEERS, 611 SOUTH COBB DRIVE, MARIETTA, GA. 30061

WORK ORDER NO. 9051
REQ. NO. CPL NO. H-02022



Sample No.	Elev or Depth	Total Classification	Nat w %	LL	PL	PI
VR-24-3-7	210.0' - 225.0'	Brown well graded silty gravel (GW-GM) w/a little cobbles	6.0	35	27	8

Project Shearon Harris Nuclear Power Plant, CP&L

Lab. No. 145/393 ($\bar{R}$ Test)

Area Plant Excavation

Boring No. Sample No. VR-24-3-7

Date 14 February 1975

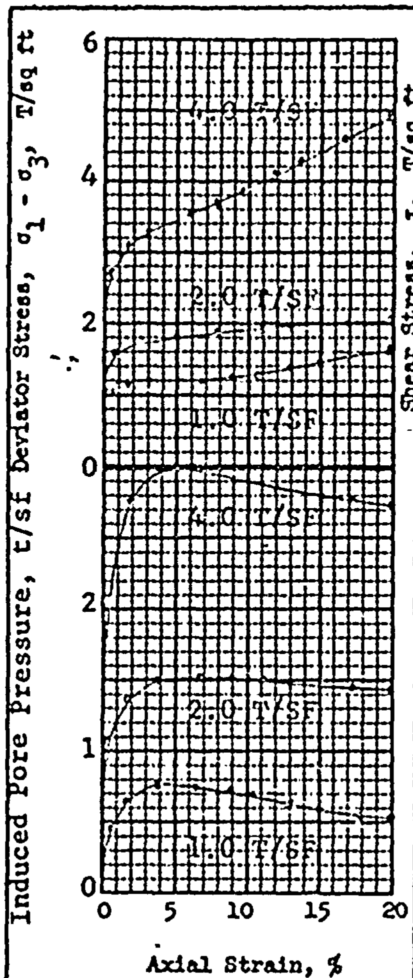
GRADATION CURVES

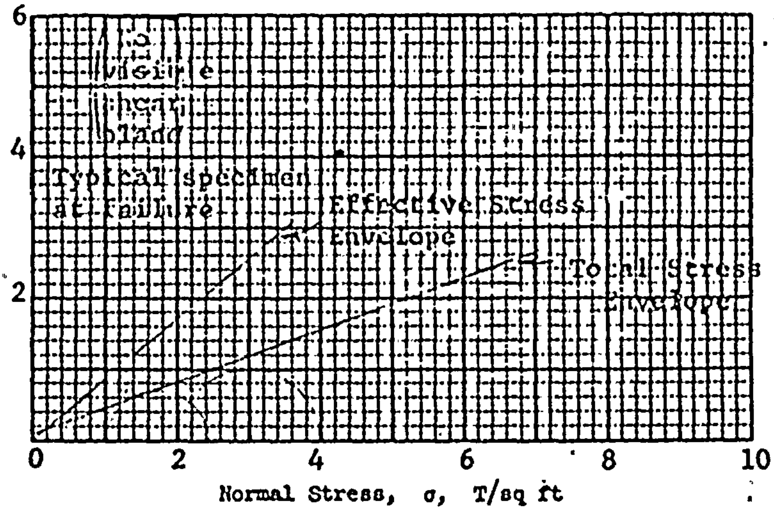
ENG FORM MAY 63 2087

Plate 2

REQN. NO. CPL NO. H02022
W. O. NO. 9051

DEPARTMENT OF THE ARMY, SOUTH ATLANTIC DIVISION LABORATORY,
CORPS OF ENGINEERS, 611 SOUTH COBB DR., MARIETTA, GA. 30061





Test No.			1	2	3	
Initial	Water content	w_o	4.5 %	4.5 %	4.6 %	%
	Void ratio	e_o	.271	.270	.272	
	Saturation	S_o	46.2 %	45.6 %	47.0 %	%
	Dry density, lb/cu ft	γ_d	135.6	135.7	135.5	
Before Shear	Water content	w_c	9.4 %	9.2 %	8.4 %	%
	Void ratio	e_c	.258	.255	.233	
	Saturation	S_c	100.0 %	100.0 %	100.0 %	%
	Final back pressure, T/sq ft	u_o	4.50	4.50	4.50	
Final	Water content	w_f	9.4 %	9.2 %	8.4 %	%
	Void ratio	e_f	.258	.255	.233	
Minor principal stress, T/sq ft		σ_3	1.00	2.00	4.00	
Max deviator stress, T/sq ft		$(\sigma_1-\sigma_3)_{max}$	1.45	1.99	4.49	
Time to failure, min		t_f	150	150	150	
Rate of strain, percent/min			0.10	0.10	0.10	
% Strain at $(\sigma_1-\sigma_3)_{max}$			14.87	14.86	14.93	
Ult deviator stress, T/sq ft		$(\sigma_1-\sigma_3)_{ult}$	1.45	1.99	4.49	
Initial diameter, in.		D_o	14.88	14.88	14.88	
Initial height, in.		H_o	32.00	32.00	32.00	

Shear Strength Parameters

	Total	Effective
ϕ =	20.0°	40.0
tan ϕ =	.364	.839
c =	0.1	0.0 T/sq ft

Method of saturation ________

[ ] Controlled stress
[X] Controlled strain

Type of test $\overline{R}$ — Type of specimen Remolded*

Classification: Brown well graded silty gravel (GW-GM) w/a little cobbles

LL 35 | PL 27 | PI 8 | D_{10} = 0.2 mm Before Test | G_s 2.76 Wtd.Avg.

Remarks 1. See lab classification data on ENG Form 2087.

2. *Specimens requested to be remolded to 135.0 pcf dry density at 5% water content.

Project: Shearon Harris Nuclear Power Plant, CP&L

Lab. No. 145/393

Area: Plant Excavation

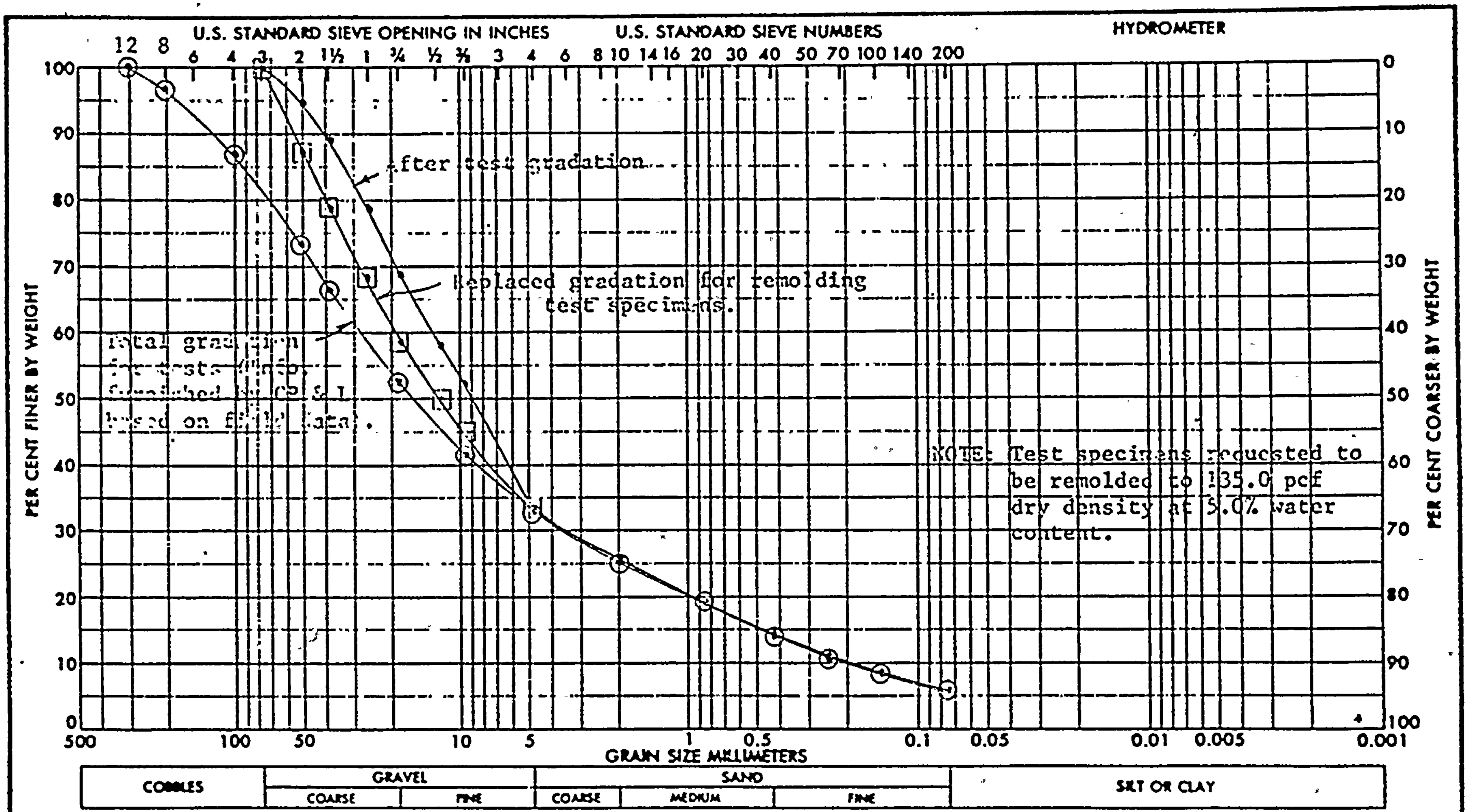
Boring No. --- | Sample No. VR-24-3-7

Depth El 210.0'-225.0' | Date 15 Feb 1975

TRIAXIAL COMPRESSION TEST REPORT

DEPARTMENT OF THE ARMY, SOUTH ATLANTIC DIVISION LABORATORY,
CORPS OF ENGINEERS, 611 SOUTH COBB DR., MARIETTA, GA. 30061

REQN. NO. CPL NO. H-02022
W. O. NO. 9051



Type of Specimen Remolded		Before Test		After Test	
Diam 13.3" in.	Ht 17.63 in.	Water Content, w_o	4.4 %	w_f	9.6 %
Total Classification (GW-GM) w/a little silty gravel cobbles		Void Ratio, e_o	.272	e_f	.272
LL 35	G_s 2.76	Saturation, S_o	44.3 %	S_f	97.3 %
PL 27	D_{10} = 0.2 mm	Dry Density, γ_d	135.4 lb/ft^3	K_{20}	13.2 × 10^{-4} cm/sec

PROJECT Shearon Harris Nuclear Power Plant, CP&L	Lab.No.145/393
AREA Plant Excavation	
BORING NO. ---	SAMPLE NO. VR-24-3-7
DATE 14 Feb 1975	DEPTH El 210.0'-225.0'

Variable/Constant Head PERMEABILITY TEST REPORT Test No. 1

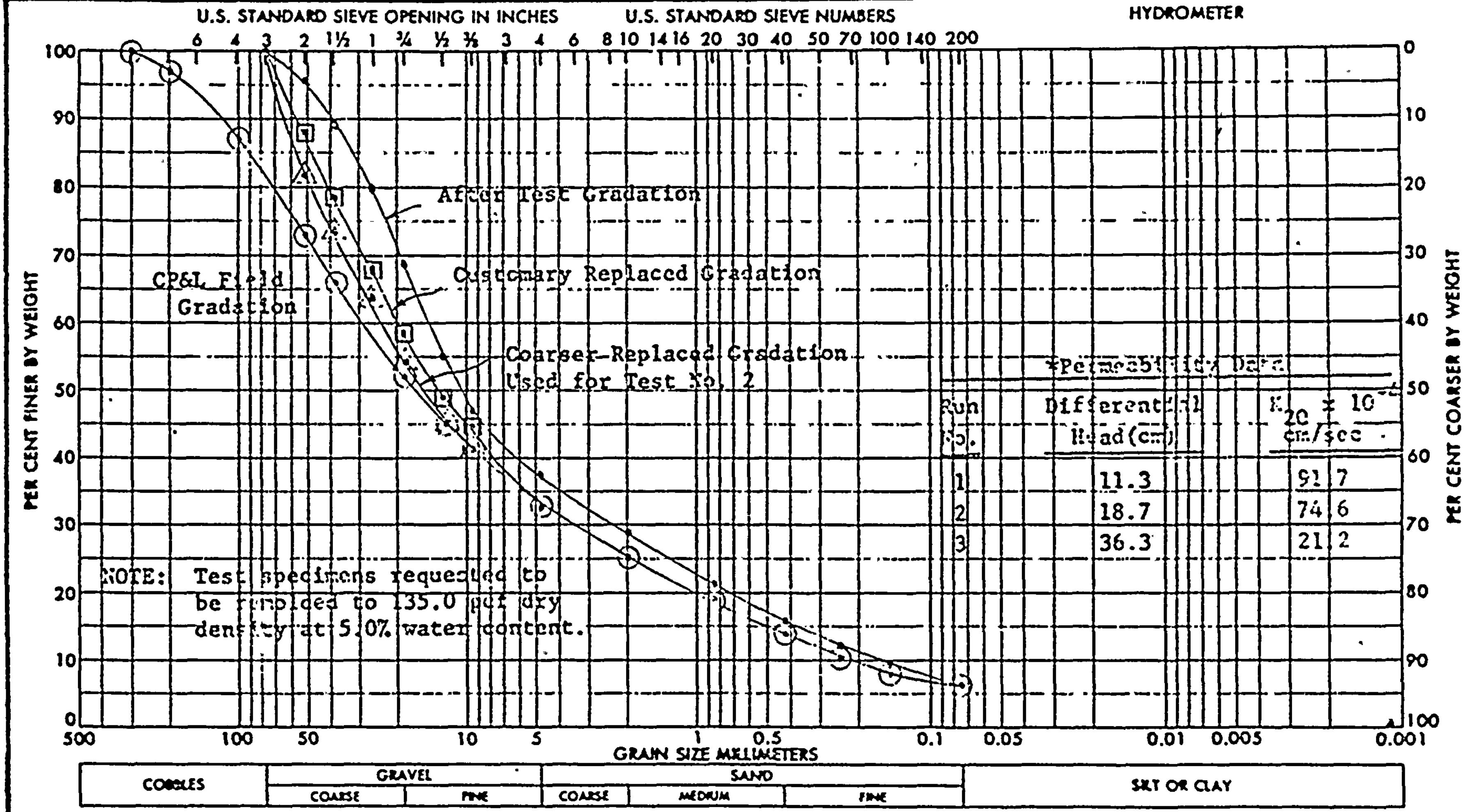
SAD FORM 1971
21 JULY 1964

Plate 4

DEPARTMENT OF THE ARMY, SOUTH ATLANTIC DIVISION LABORATORY, CORPS OF ENGINEERS, 611 SOUTH COBB DR., MARIETTA, GA. 30061

CPL NO. H-C2022
W. O. NO. 9051

A5



Type of Specimen Remolded		Before Test		After Test		PROJECT Shearon Harris Nuclear Power Plant, CP&L	
Diam 13.86 in.	Ht 17.63 in.	Water Content, w_o	5.0 %	w_f	10.0 %	Lab. No. 145/393	
Total Classification Brown, well graded, silty gravel (GW-GM) w/a little cobbles		Void Ratio, e_o	0.277	e_f	0.277	AREA Plant Excavation	
LL 35	G_s 2.76	Saturation, S_o	49.6 %	S_f	99.7 %	BORING NO. ---	SAMPLE NO. VR-14-3-?
PL 27	D_{10} --	Dry Density, γ_d	134.8 lb/ft^3	K_{20}	See Above* cm/sec	DATE 26 Feb 1975	DEPTH El 310.0'-?5.0'

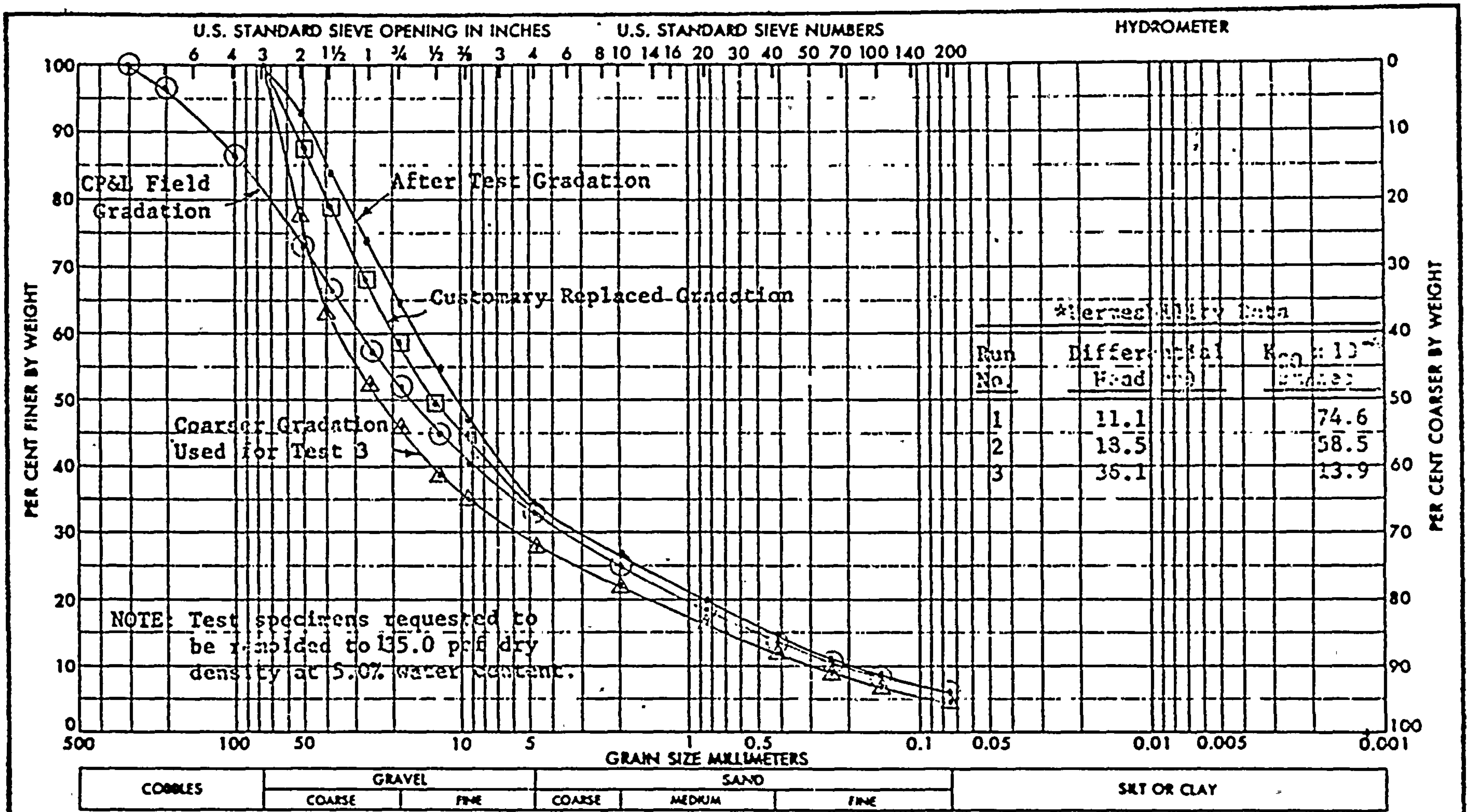
XXXXXXXX/Constant Head PERMEABILITY TEST REPORT — Test No. 2

SAD FORM 1971
21 JULY 1964

Plate 5

DEPARTMENT OF THE ARMY, SOUTH ATLANTIC DIVISION LABORATORY,
CORPS OF ENGINEERS, 611 SOUTH COBB DR., MARIETTA, GA. 30061

CPL NO. H-02022
W. O. NO. 9351



Type of Specimen	Remolded	Before Test		After Test		PROJECT	Shearon Harris Nuclear Power Plant, CP&L
Diam 13.86 in.	Ht 17.63 in.	Water Content, w_o	5.8 %	w_f	10.1 %		Lab. No. 145/393
Classification	Brown, well graded silty gravel (GW-GM) w/a little cobbles	Void Ratio, e_o	0.286	e_f	0.286	AREA	Plant Excavation
LL 35	G_s 2.76	Saturation, S_o	56.0 %	S_f	97.1 %	BORING NO. ---	SAMPLE NO. VR-24-3-[illegible]
PL 27	D_{10}	Dry Density, γ_d	133.9 lb/ft^3	K_{20}	See Above* cm/sec	DATE 10 Feb 1975	DEPTH: El 210.0'-225.[illegible]

XXXXXXXXX Constant Head PERMEABILITY TEST REPORT — Test No. 3

Total

SAD FORM 1971
21 JULY 1964