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EFFECT OF DEGREE OF SATURATION ON COMPRESSIBILITY OF SOILS FROM THE DEFENCE RESEARCH ESTABLISHMENT SUFFIELD

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FOREWORD

The soil properties presented herein were obtained for the purpose of clarifying the stress-strain relations which should be used in computer codes for predicting ground motions due to high pressure loading. This work is in conjunction with research on propagation of ground shock through soils being conducted by the Soils Division, U. S. Army Engineer Waterways Experiment Station, for the Defense Atomic Support Agency.

This report was requested and authorized by Mr. J. G. Jackson, Jr., Chief, Impulse Loads Section, Soil Dynamics Branch, under the direction of Mr. W. J. Turnbull, Chief of the Soils Division. The report was prepared under Purchase Order No. WESBPJ-68-67, dated 16 August 1967, issued to M. T. Davisson, Foundation Engineer, Champaign, Illinois.

Directors of the Waterways Experiment Station during the performance of this work and preparation and publication of this report were COL John R. Oswalt, Jr., CE, and COL Levi A. Brown, CE. Technical Directors were Mr. J. B. Tiffany and Mr. F. R. Brown.

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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	1.609344	kilometers
cubic inches	16.3871	cubic centimeters
pounds	453.5924	grams
kips	453.59237	kilograms
pounds per square inch	0.070307	kilograms per square centimeter
pounds per cubic foot	16.02	kilograms per cubic meter
feet per second	30.48	centimeters per second
foot-pounds	0.138255	meter-kilograms

SUMMARY

The soil tests reported herein were conducted to provide information on the influence of degree of saturation on high pressure stress-strain relations of undisturbed and remolded soils from the Defence Research Establishment, Suffield. These high-pressure one-dimensional tests were also to provide input data for computer codes concerning the relation between stress and strain invariants at high pressures. Some investigators were concerned that large strains might develop at high pressures in silt and clay as has been observed for sand due to grain crushing. As expected, the test results presented herein show that large strains do not develop at high pressures in fine-grained soils such as silt and clay

The test program consisted of 12 one-dimensional tests on 4 specimens each of undisturbed and remolded silty clay, and 4 specimens of remolded sandy silt. In all tests the radial strain was essentially zero. Axial and radial stresses and axial strain were measured. The tests were carried to an axial stress of 20,000 psi unless soil extrusion occurred at a lower stress. The following conclusions were reached:

a. The degree of saturation and the initial void ratio are the most significant variables governing the one-dimensional stress-strain relations of soil at high pressures.

b. For pressures exceeding 3000 psi the compacted specimens and undisturbed specimens of Suffield soil yield the same relation if the initial degree of saturation and initial void ratio are identical before loading.

c. A lower bound to the secant modulus of deformation M_s at a given level of axial stress σ_a is given by

$$M_s = \frac{\sigma_a}{\dfrac{\left(1 - \dfrac{S_{ri}}{100}\right) e_i}{1 + e_i} + \dfrac{\sigma_a}{300{,}000 \text{ psi}}}$$

for both compacted and undisturbed samples of fine-grained soil subjected to pressures greater than 3000 psi.

d. The average unloading modulus of Suffield soils subjected to pressures greater than 3000 psi is approximately 10 times the loading secant modulus of deformation M_s.

e. It is probable that the stiffness of the Suffield soils when unsaturated will be greater under dynamic loading than the static values given herein. Previous comparisons of static and dynamic values of constrained moduli of Suffield soils have shown that the dynamic values are twice the static values. This observation is consistent with similar comparisons for NTS Frenchman Flat silt.

EFFECT OF DEGREE OF SATURATION ON COMPRESSIBILITY OF SOILS FROM THE DEFENCE RESEARCH ESTABLISHMENT, SUFFIELD

PART I: INTRODUCTION

OBJECT

1. The object of this study was to determine the high-pressure, static, one-dimensional stress-strain characteristics of compacted and undisturbed soils from the Defence Research Establishment, Suffield (DRES), in Alberta, Canada. Degree of saturation was the major variable investigated. These one-dimensional tests were also to provide input data for computer codes concerning the relation between stress and strain invariants at high pressures. These high-pressure relations were especially important since some investigators were concerned that large strains might develop at high pressures in silt and clay as has been observed for sand due to grain crushing.

SCOPE

2. Two 5-in.*-diam undisturbed Shelby tube samples and remolded samples of two different soils, which were air-dried and passed through a No. 10 sieve, were furnished by the U. S. Army Engineer Waterways Experiment Station (WES) for this study. A total of 12 static-undrained one-dimensional compression tests were performed.

3. Specifically, four tests were performed on the undisturbed samples, and four tests were performed on each of the two remolded soils, the remolded soils were compacted at predetermined water contents and dry densities. The results of the tests are presented in the form of plots of axial stress versus axial strain, secant modulus versus axial stress, and radial stress versus axial stress. The index properties for each of the different soil samples tested, and the test apparatus, experimental procedure, and an interpretation of the test results are also presented.

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

PART II: SOILS INVESTIGATED

SITE CONDITIONS

Location and Topography

4. The location of the site is within the DRES blast range at a location known as Watching Hill. The site is approximately 30 miles north of Medicine Hat, Alberta, Canada.[1] Within the area of interest, the site is essentially level with a ground surface elevation of approximately 2164.0 ft msl.

Geology

5. A brief description of the geology of the site is available in reference 2 along with an estimate of the seismic velocities for the various layers. The site is in the southern end of the Ross Depression which, along with the areas to the south and west, has apparently been covered by a large lake. The soils to a depth of 200 ft are lacustrine deposits consisting of uniform beds of clay and silt with occasional sand lenses. However, glacio-fluvial processes and desiccation have altered approximately the upper 30 ft. In reference 2 a seismic velocity of 2200 fps has been assigned to the upper 30 ft, but indications are given that the upper 4 ft may have a velocity of 700 fps while the lower 26 ft has a velocity of 2550 fps. From 30 to 200 ft, a velocity of 5500 fps is indicated.

6. Bedrock at the site consists of Upper Cretaceous beds of the Foremost formation. These beds may be arenaceous shales and/or sandstones with many coal and carbonaceous beds. In many places the "Pale Beds" overlie the Foremost formation and consist of sandstone, shales, and sandy shales. The seismic velocity for these beds has been estimated as 7500 fps. At great depth, Mississippian limestone is found with a seismic velocity of approximately 20,000 fps.

SUBSURFACE INVESTIGATION

Field Data

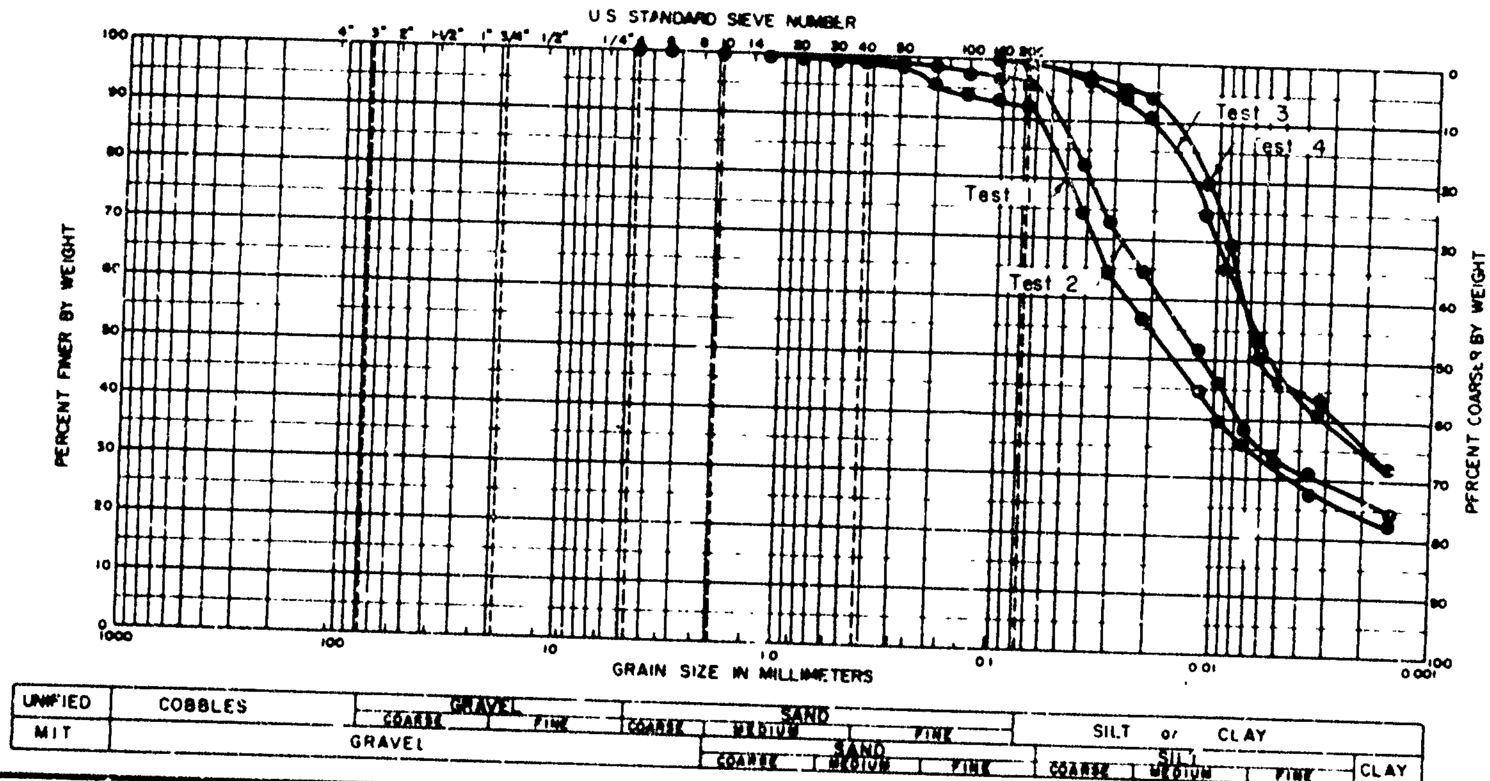
7. Two undisturbed samples from boring 2-U and two remolded samples from boring 5-U, ranging in depth from 0 to 22.5 ft, were furnished for this study. The undisturbed samples were taken with a 5-in.-diam Shelby tube and extruded immediately into 6-in.-diam fiberboard containers.[3] Wax was then used to fill the containers and seal the samples. The remolded samples were air-dried, mixed, and passed through a No. 10 sieve.

8. Additional information on the soil profile at the Watching Hill site can be obtained from references 4, 5, and 6.

Laboratory Testing

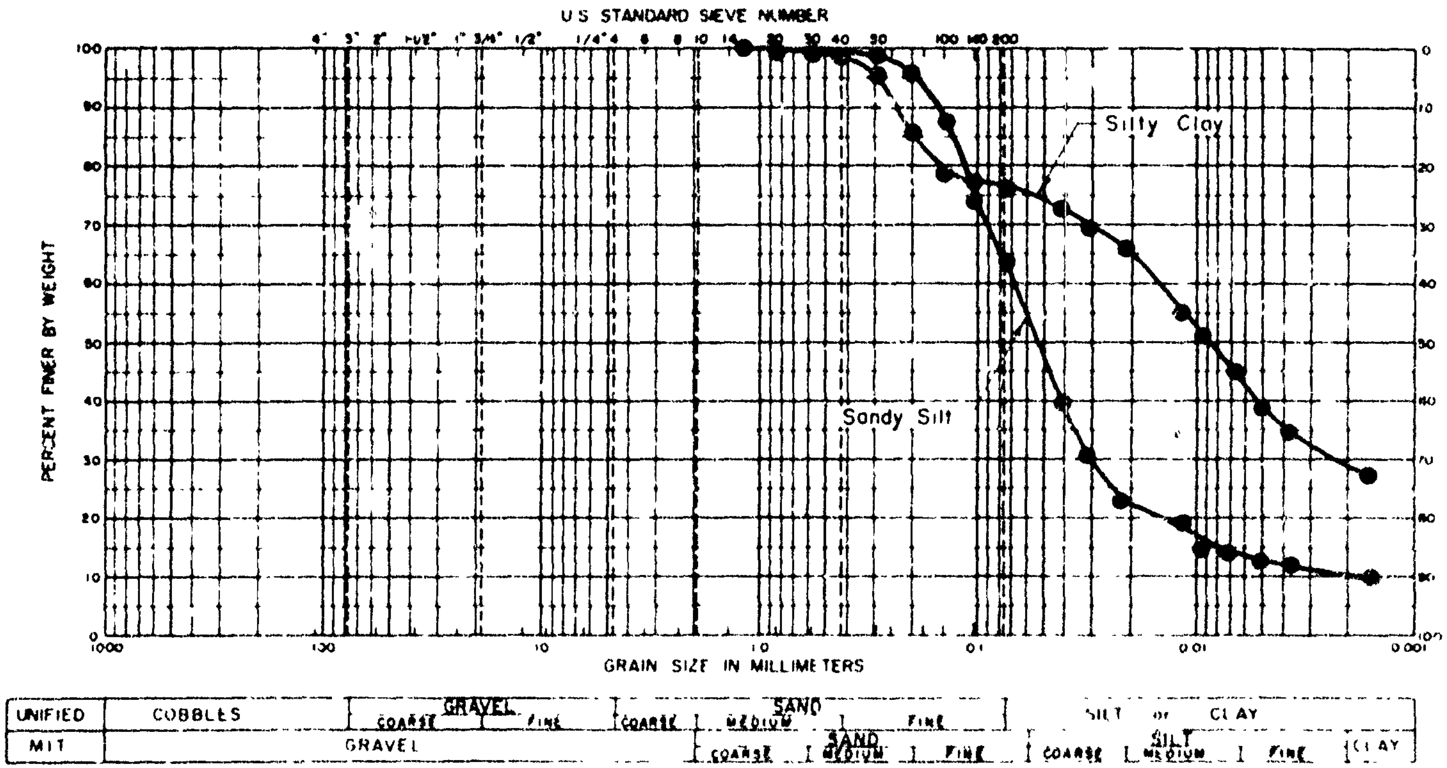
9. All soil samples received in the laboratory were subjected to routine identification and classification. The test number, sample depths, description, Unified classification, Atterberg limits, and specific gravities are listed in table 1. The gradation curves for the undisturbed and remolded samples are presented in figs. 1 and 2, respectively. All index properties for the soil samples were furnished by the WES.

10. The initial weight-volume data for each of the 12 static test specimens are listed in table 2.



Sample No	Elev or Depth	Classification	Sp Gr	LL	PL	PI	
1, Test 1	0 - 0.5 ft	Silty Clay (CL) w/Tr Sand Organic Matter	2.63	37	19	18	Project : Distant Plain Events 6 & 1A
							Defence Research Establishment, Suffield
1, Test 2	0.5 - 1.2 ft	Silty Clay (CL) w/Tr Sand (Brown)	2.66	38	18	20	Area : Watching Hill Site
2, Test 3	1.2 - 1.7 ft	Silty Clay (CL) (Brown)	2.69	42	21	21	Boring No 2-U
2, Test 4	1.7 - 2.3 ft	Silty Clay (CL) (Brown)	2.69	44	23	21	Date 19 Sept 67

Fig. 1. Gradation curves for undisturbed samples



Boring No.	Elev or Depth	Classification	Sp Gr	LL	PL	PI
Bag Sample	0-5 ft	Silty Clay (CL)	2 69	34	16	18
5-U	5 - 22 ft	Sandy Silt (ML)	2 67	20	19	N/P

Project Distant Plain Events 6 & 1A

Defence Research Establishment, Suffield

Area Watching Hill Site

Note Soil air-dried, mixed and passed thru No 10 sieve

Date 20 Aug 67

Fig 2. Gradation curves for remolded samples

PART III TEST PROCEDURES

DESCRIPTION OF APPARATUS

11 The apparatus used for the static one-dimensional tests, shown in fig. 3, consisted of a confining ring assembly which contained the soil specimen The confining ring was centered on the baseplate with the aid of a lucite guide ring as shown in fig 3 The piston was also centered on the soil specimen with the aid of a second lucite guide ring A split ring was mounted on the piston and furnished a reaction for the dial indicator which measured the axial deformation to the nearest 0.001 in. A 300-kip universal Riehle hydraulic testing machine was used to apply the axial stress to the soil specimen through the

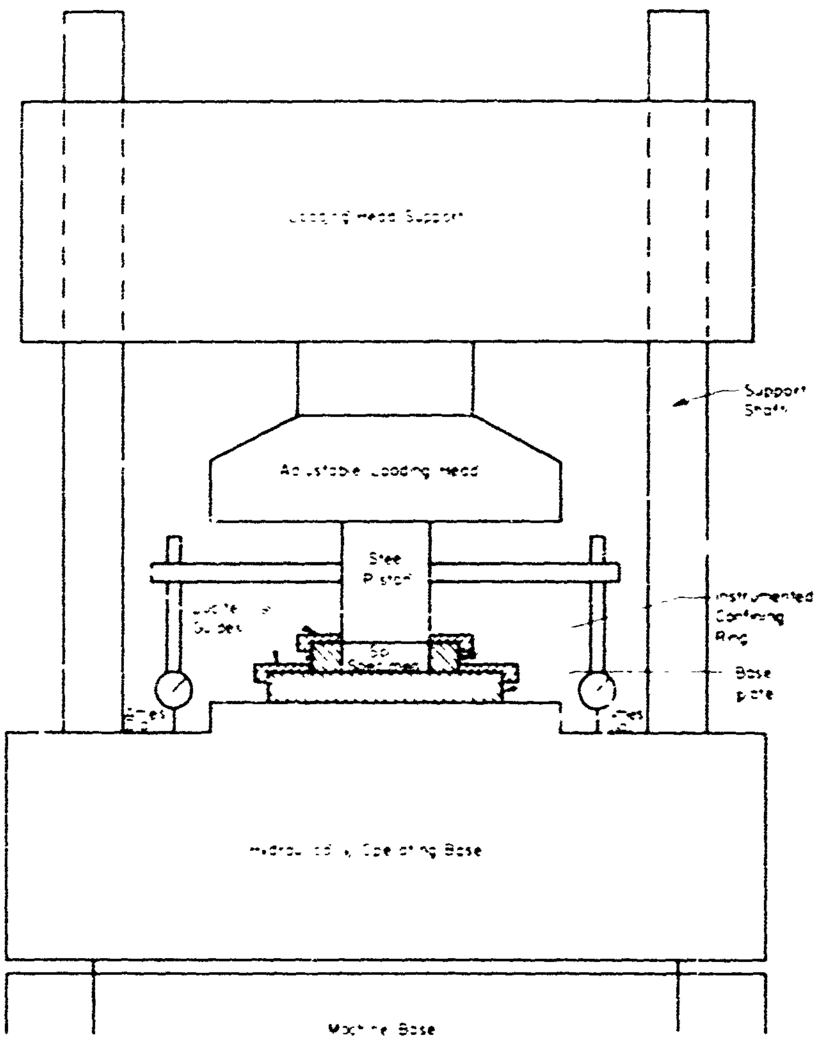
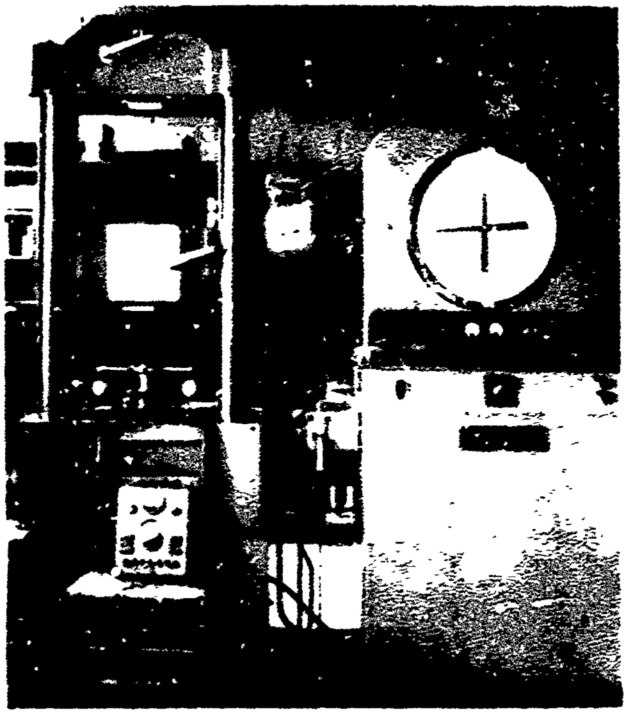
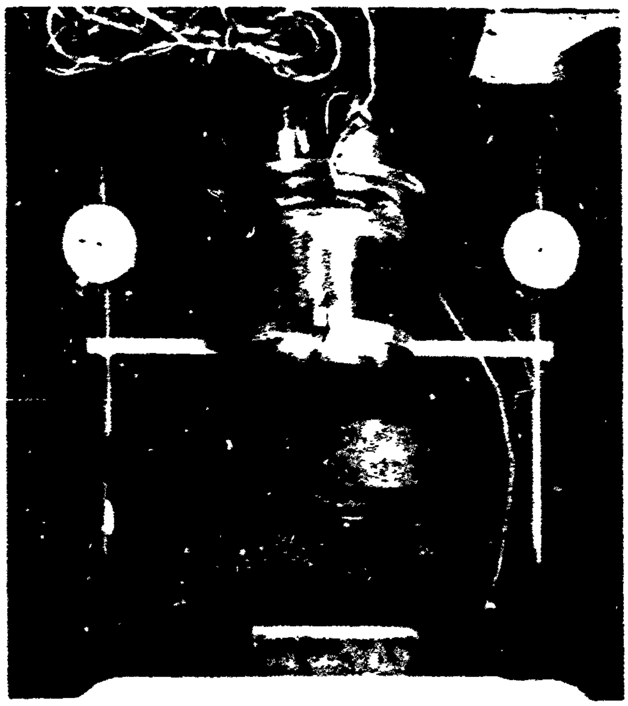


Fig 3 Schematic of static loading machine showing axial strain instrumentation

loading piston. A photograph of this static test machine is shown in fig 4a, a close-up of the confining ring assembly is shown in fig 4b.



a Static test machine



b. Close-up of confining ring assembly

Fig. 4. Test apparatus

12. A steel ring 1.0 in. high with 4-in. inside diameter and a wall thickness of 1.0 in. was used to confine the test specimens. An attempt was made to limit the radial strains to the minimum value required to facilitate accurate recording by use of the SR-4 gages. The output of the SR-4 gages was monitored with an SR-4 indicator Calibrations of the confining rings were performed previously as described in reference 4.

EXPERIMENTAL PROCEDURE

Preparation of Test Specimens

13. For the tests of undisturbed samples, it was mandatory to develop a trimming operation. The trimming procedure involved placing the waxed soil sample in the hydraulic press along with the sample trimming equipment. The important feature of the trimming equipment is the trimming ring. The trimming ring has a 4-in. inside diameter, equal to that of the confining ring, but the outside face is beveled to form a sharp cutting edge. The outer face of the ring has a shoulder that fits the outside diameter of the 1.0-in.-thick confining ring. When the confining ring and the trimming ring are pressed together, an integral unit is obtained that can be forced into a soil sample in a manner similar to the use of a thin-wall sampler in a field sampling operation. Excess soil and wax were trimmed away with a knife as the trimming ring was forced into the sample. When the trimming ring had penetrated the soil a sufficient distance, the ring was carefully removed and the soil specimen was trimmed level with the height of the confining ring. Sample trimmings from each test specimen were set aside for specific gravity, Atterberg limits, and grain-size determinations. Water content samples were also taken from the Shelby tube sections before and during the trimming process.

14. The tare weight of the confining ring is known along with its dimensions. Therefore, the weight of the ring and soil specimen furnishes sufficient data to calculate the initial density of the soil. With the specific gravity and water content data, complete weight-volume determinations can be made for the test specimen.

15. The final step is to place the confining ring on the baseplate and to assemble the confining ring assembly. A height determination for the assembly is made in a dial comparator to an accuracy of 0.001 in. Because the height of the assembly itself is known, the dial comparator reading furnishes a check on the initial height of the specimen.

16. The remolded specimen was compacted into the trimming ring with a Vicksburg tamper after soil batches were properly mixed to the desired water contents and allowed to equilibrate for 24 hr. The soil specimens were compacted in two layers with nine evenly distributed blows per layer. The height of fall of the 4-lb hammer was varied to obtain the predetermined dry densities.

17. The compaction energy varied from 0.2 ft-lb/in.^{3} to 1.1 ft-lb/in.^{3} of soil. All remolded specimens were prepared with the compaction tamper except the sandy silt specimen at a water content of 27 percent. In order to obtain the desired density this specimen was prepared by hand-placing the soil into the confining ring. After compaction, the trimming was carried out in the same manner used for the undisturbed specimens.

Test Procedure

18. The confining ring assembly was placed in the static test machine as shown in fig. 3. The dial indicators were set at zero under the load of the piston itself which corresponds to a stress of approximately 1 psi. Succeeding loads were applied in predetermined increments and held until the dial indicator and radial stress observations were made. A similar procedure was followed during unloading, however, at zero

applied load the soil specimen was allowed to rebound for approximately 5 min, whereas the load increments required approximately 1 min for completion. All tests were loaded to the 20,000-psi stress level or soil extrusion prior to the 20,000-psi stress.

19. Upon removing the confining ring assembly from the test machine, the height was determined with the dial comparator. This reading was compared with the initial dial comparator reading and served as a check on the residual deflection. The confining ring and specimen were removed from the assembly and a careful inspection was made for extrusion before a final water content determination was made

PART IV: TEST RESULTS AND INTERPRETATION OF RESULTS

20. The individual test results are tabulated in figs. A1-A12. The soil index properties are presented as well as the individual test data such as axial stress, axial strain, secant modulus, and corrected radial stress. An attempt to correct the measured radial stresses has been made by dividing the load determined from a hydraulic calibration on the full height of the ring (1 in.) by the actual height of the specimen.

21. These results have also been plotted in the form of axial stress versus corrected axial strain, constrained modulus versus axial stress, and corrected radial stress versus axial stress. The data points have not been shown on the plots because none of the points deviate from the curves. The axial stress versus axial strain plots for the 12 static tests are given in figs. B1-B12. Similarly, the constrained secant modulus versus axial stress plots are given in figs. C1-C12 and the radial stress versus axial stress plots in figs. D1-D12. The boxes in the upper left corner of the figures contain initial weight-volume data for the samples.

22. A summary of the static test data is presented in table 3. For each test the initial degree of saturation is given. At the maximum axial stress the corresponding values of axial strain and the ratio of radial stress to axial stress (denoted as K_o) are given. A pseudo-Poisson's ratio (μ) has been calculated assuming that elastic theory is applicable. The residual axial strain and the ratio of residual to maximum axial strain are also presented. A notation is made in table 3 wherever soil extrusion occurred. Otherwise, the static test results can be interpreted in a straightforward manner.

STRESS-STRAIN RELATIONS

23. A summary of the axial stress-strain relations for the undisturbed samples of silty clay, compacted samples of silty clay, and compacted samples of sandy silt are shown in figs. 5, 6, and 7, respectively. The axial stress-strain curves for all static tests were concave toward the stress axis throughout the complete loading cycle; therefore, the compressibility decreases as the stress level is increased. The absence of the small initial concave downward curvature in the stress-strain diagram of the compacted samples is believed to be caused by the negligible preload effect because of the low compaction energy necessary to yield the desired dry densities of 80-88 pcf. The unloading portions of the stress-strain curves, which are shown on the individual test plots in Appendix B, are very steep at high stress ranges, but the slope decreases at a stress of approximately 500 psi. Table 3 is a list of the maximum axial strains and ratio of the residual strain to maximum strain for all tests. The maximum strain at the peak stress of 20,000 psi varied from 0.299 to 0.457 in./in. The ratio of residual to maximum strain varied from 0.85 to 0.96 for all test specimens.

24. The stress-strain relations of the compacted or remolded samples of silty clay given in fig. 6 show the effect of the initial degree of saturation for a dry density similar to field conditions. As the initial degree of saturation increases, the strain at which the stress-strain curve turns abruptly upward is reduced because of the amount of pore air decrease. However, the stress-strain curves shift downward toward the strain axis at low stress levels for samples with increasing degrees of saturation. Thus at low stress levels the samples with a high degree of saturation are more compressible than those with a low degree of saturation. However, the wetter specimens reach 100% saturation at lower strains and become stiffer than the dryer specimens at lower strains, resulting in a crossover of the stress-strain curves as illustrated by tests 7 and 8 in fig. 6. Also, variation of the dry density at a particular initial degree of saturation indicates a more compressible soil structure at a lower dry density as shown by tests 6 and 7, fig. 6. The behavior of the compacted specimens of sandy silt is similar to that of the silty clay;

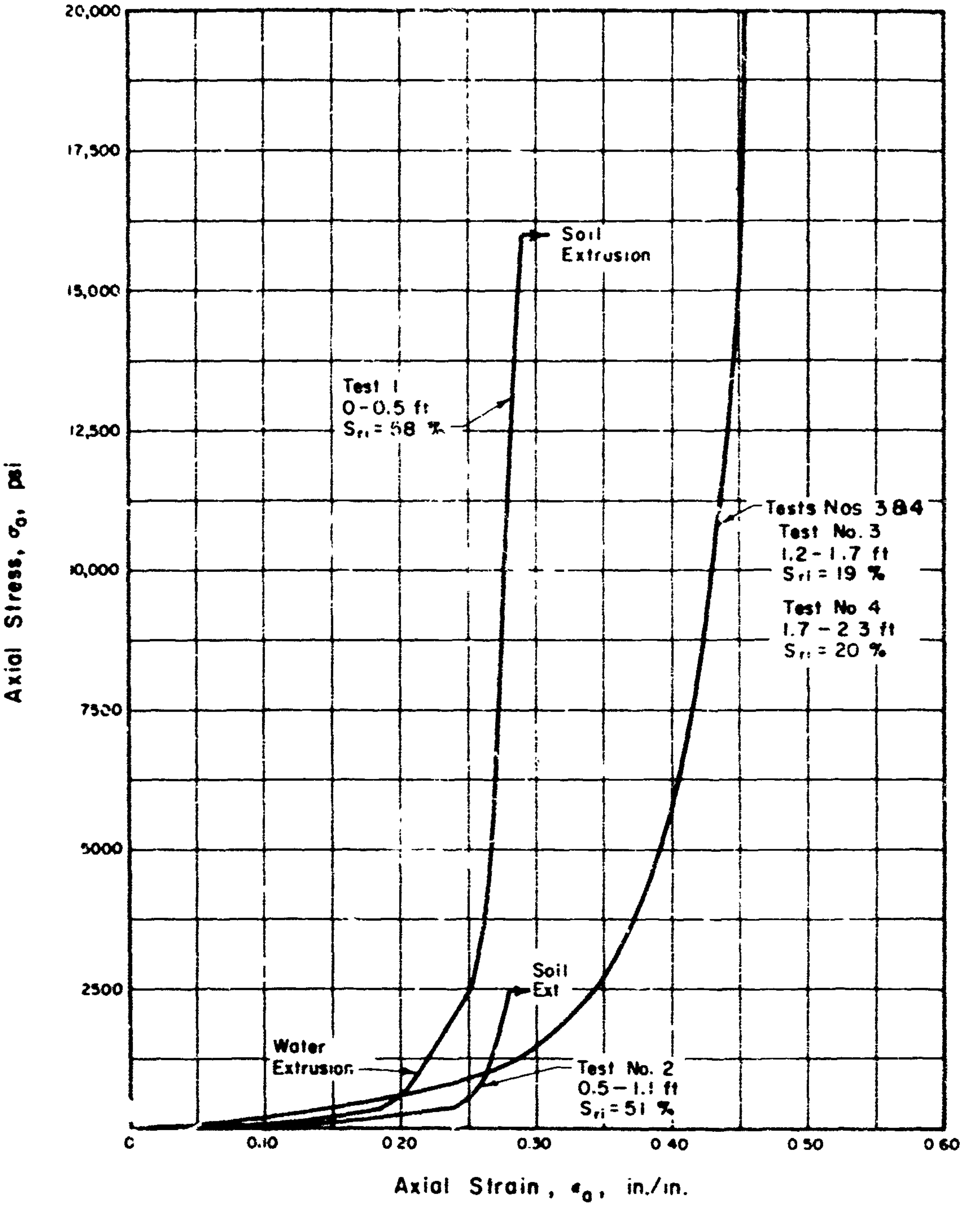


Fig. 5. Summary of stress-strain curves for the undisturbed samples of silty clay

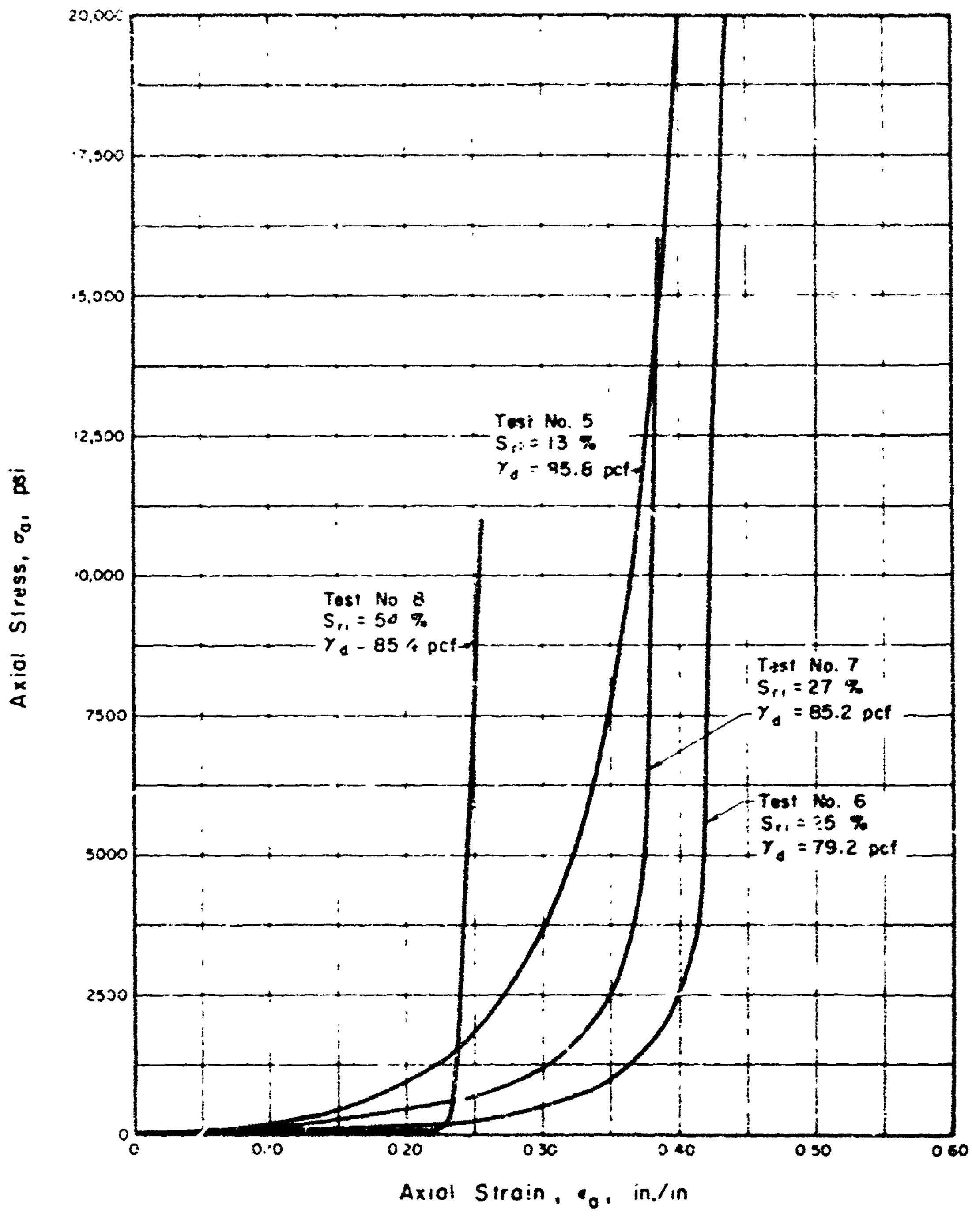


Fig. 6. Summary of stress-strain curves for the compacted samples of silty clay

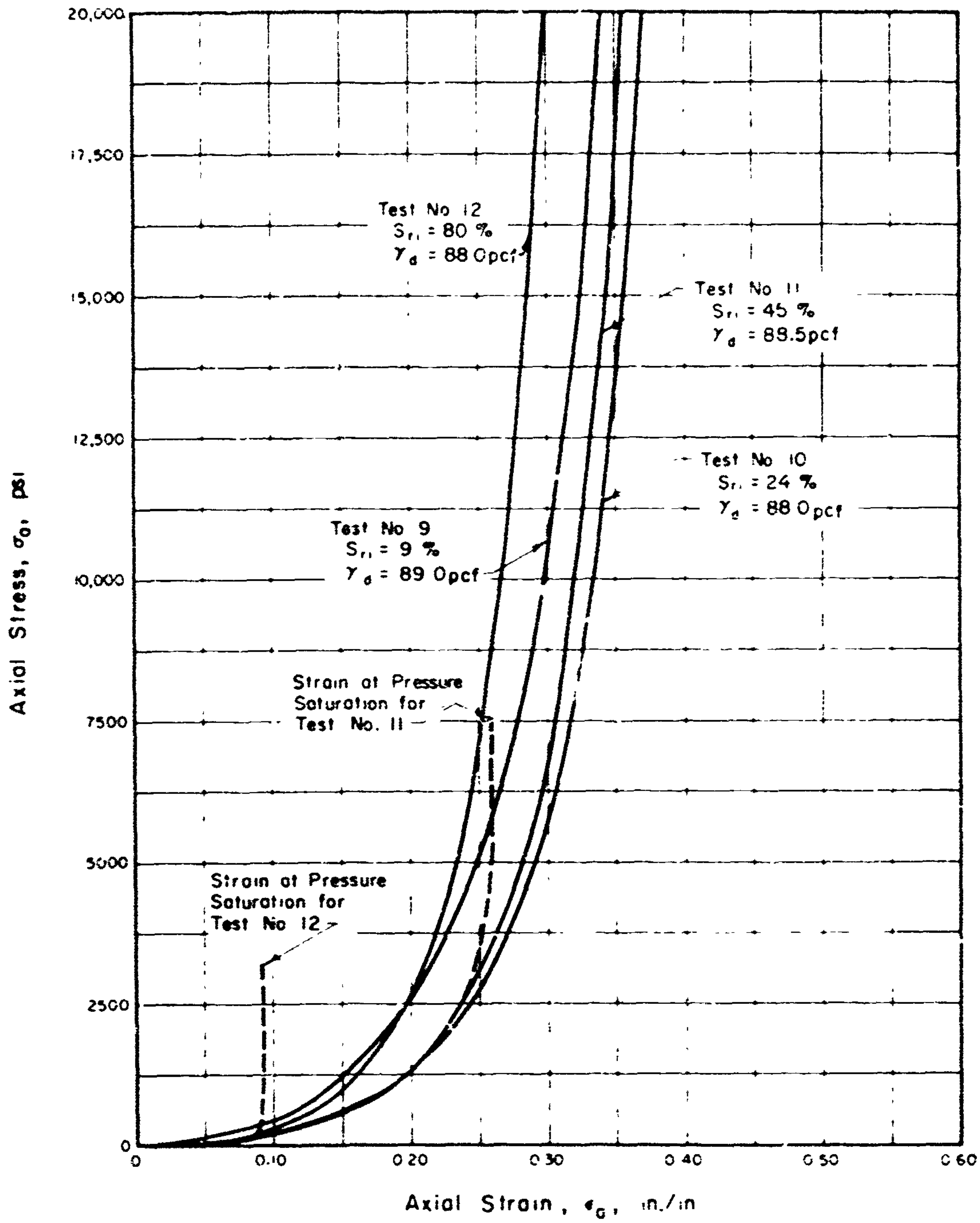


Fig. 7. Summary of stress-strain curves for the compacted samples of sandy silt

however, extrusion of the specimens with a high initial degree of saturation (tests 11 and 12) distorts the true confined stress-strain curves (fig. 7). The calculations of strain at pressure saturation indicate a modification of the stress-strain curves for tests 11 and 12. The strain at saturation can be readily calculated as

$$\epsilon = \frac{\Delta e}{1 + e_i} = \frac{\left(1 - \frac{S_{ri}}{100}\right) e_i}{1 + e_i} \quad \text{in./in.}$$

where e_i is the initial void ratio, S_{ri} is the initial degree of saturation, and ϵ is the axial strain at saturation of the specimen

25. The stress-strain curves for the remolded samples approximate the shape of the curves for the undisturbed samples as shown in fig. 5, but the behavior is different Tests 3 and 4 were plotted as one curve because the difference between them was not distinguishable In general the behavior of the undisturbed samples is similar to that of the compacted samples of silty clay except that the undisturbed samples are less compressible in the low stress ranges (less than 2500 psi).

26. The shape of the stress-strain curves (concave upward) for the undisturbed samples at the shallow depths is indicative of uncemented soils. This behavior is contrary to the behavior at greater depths as reported previously.[4] The data in reference 4 indicate an initial concave downward stress-strain diagram and then a change in curvature as the stress level increases. With an increase in stress, the stress-strain diagram is concave upward as the initial stiffness due to preload is destroyed.

27 A typical variation of degree of saturation with depth for the Watching Hill site is presented in fig 8 as determined from undisturbed specimens reported in references 4 and 5 These data are given for the purpose of enabling one to select the appropriate stress-strain curve from this report that is consistent with the degree of saturation at the particular depth for which the high-pressure moduli are desired.

SECANT MODULI-STRESS RELATIONS

28 Many of the ground motion problems in protective construction can be approximated by assuming that the displacements occur in the direction of the stress-wave propagation. Under these imposed strain conditions, the constrained modulus is the significant property of the soil controlling the ground motions. A constrained secant modulus of deformation M_s is by definition the ratio of the axial stress to the axial strain under conditions of zero radial strain.

29. All the graphs of the secant modulus versus axial stress are shown in figs C1-C12. The shapes of the modulus-stress curves follow directly from the changes of the stress-strain curves just examined, and thus require little additional discussion The secant moduli vary linearly with axial stress for both the loading and unloading curve The secant moduli are dependent on the initial degree of saturation, initial void ratio and the axial stress level The lower bound secant modulus of deformation for stress levels above 3000 psi can be approximated by

$$M_s = \frac{\sigma_a}{\dfrac{\left(1 - \dfrac{S_{ri}}{100}\right) e_i}{1 + e_i} + \dfrac{\sigma_a}{300\,000 \text{ psi}}}$$

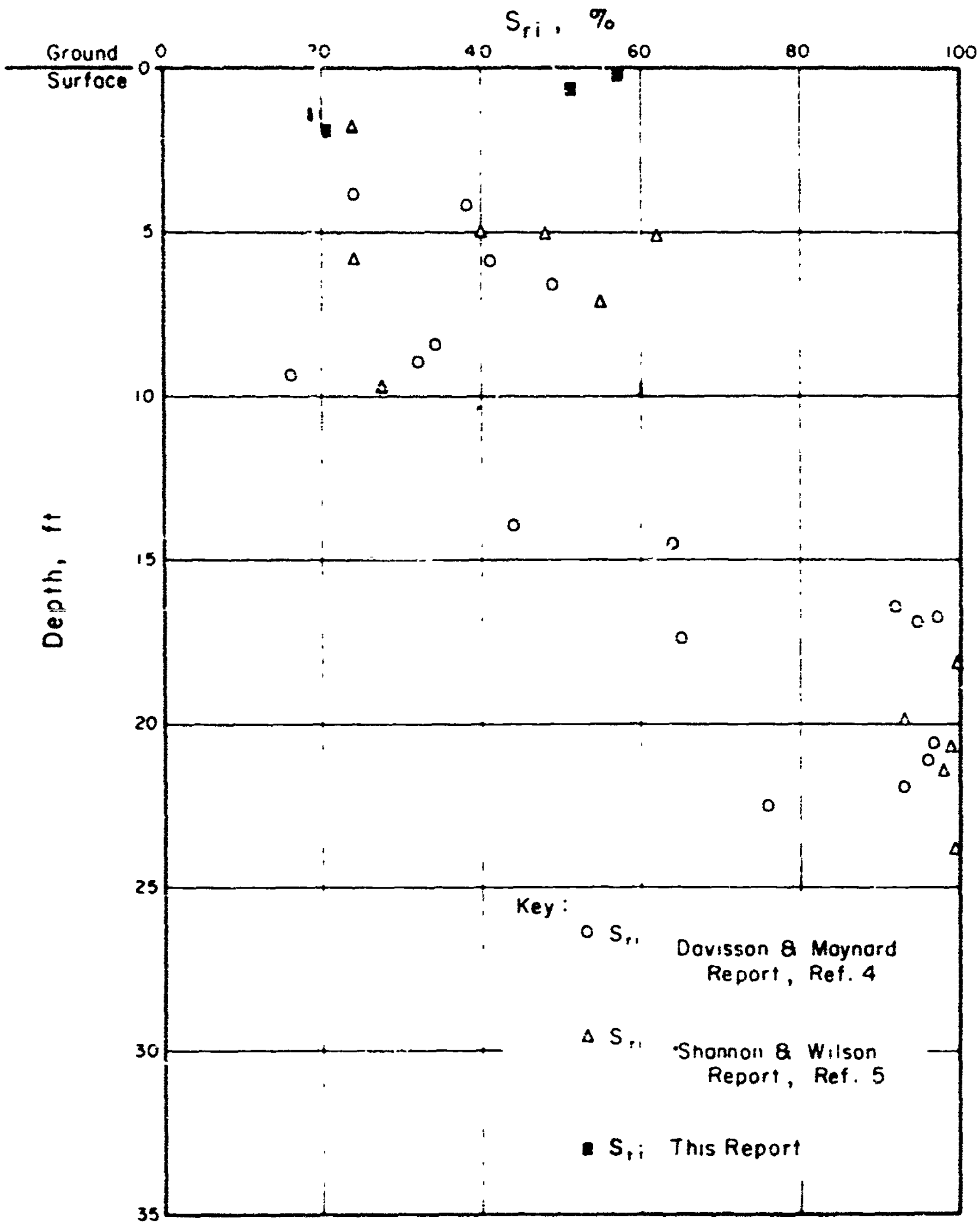


Fig. 8. Soil profile data from referenced reports

for the soils tested in this study. The average unloading secant modulus from the residual strain intercept is given by

$$M_u = 10M_s$$

AXIAL STRESS-RADIAL STRESS RELATIONS

30. At any given stress level, the ratio of radial stress to axial stress is denoted as K_o. In this series of one-dimensional static tests full drainage could not occur; therefore, the ratio of radial stress to axial stress determined for these tests is essentially in terms of total stresses.

31 In general, the value of K_o is closely related to the degree of saturation. As the degree of saturation increases, the value of K_o increases and approaches a value of unity for saturated soils. Because the degree of saturation depends on the axial strain, the value of K_o can vary continuously throughout the test. The values of K_o presented in table 3 vary from 0.38 to 1.00, and a pseudo-Poisson's ratio varied from 0.28 to 0.50.

32. In situ, K_o may be considered as unity for soils below the water table. For soils above the water table having high degrees of saturation, by capillarity or otherwise, the value of K_o will be nearly unity. Where the water table fluctuates, as it does at the DRES, the values of K_o (and secant modulus) will depend on the applied stress and the degree of saturation existing at the time a field test is performed.

33. During the unloading cycle, the radial stresses are reduced at a slower rate than the axial stress, this causes a concave downward curve that lies above the loading curve. Therefore, values of K_o often exceed unity during unloading.

FORMULATION OF THREE-DIMENSIONAL STRESS-STRAIN RELATIONS

34. The test data given in Appendix A have been used to compute: (a) octahedral shearing stress, (b) octahedral normal stress and (c) octahedral linear strain; tabulated data for each test are presented in Appendix E. From these data, graphs have been prepared of octahedral normal stress versus octahedral linear strain; the graphs are presented in Appendix F. The relations between octahedral shearing stress and octahedral normal stress are given in Appendix G in the form of graphs.

35. A detailed discussion of the data in Appendixes F and G is beyond the scope of this report; only general comments will be made. Such data are useful in the formulation of generalized stress-strain relations for soils. For instance, the graphs shown in Appendix F show the average principal strain or octahedral linear strain which results from the average principal stress or octahedral normal stress. The slope of these curves is equal to three times that of the bulk modulus of the specimen. Note that in all instances the curves in Appendix F become very steep at some value of the strain. This value of strain is essentially that required for the soil to become fully saturated. The numerical value of the strain at this point is dependent upon the initial degree of saturation and the initial void ratio. At higher strains the bulk modulus is equal to or greater than that of water.

36. The data presented graphically in Appendix G are useful in establishing yield criteria to be used in multidimensional computer programs. Note the curves for tests 9, 10, 11, and 12 which show a nearly linear relation between octahedral shearing stress and octahedral normal stress during loading. This is not surprising since these samples were silty sand, and the shearing resistance of sand increases linearly with

normal pressure. Note that the specimens of relatively dry silty clay, tests 3, 4, and 5, showed the same behavior because the initial degree of saturation was low and the specimens probably never became saturated. Thus the shear strength increased with pressure throughout the entire test. Note the results of test 2, 6, 7 and 8, however, where the octahedral shearing stress approaches a constant as the octahedral normal stress increases. In each case the specimen has become saturated and is behaving as if $\phi = 0$ beyond the pressure at which the curve turns horizontal. In each of these cases the soil is a silty clay with a relatively high initial degree of saturation.

PART V CONCLUSIONS

37 The following conclusions were drawn from the investigation

a The degree of saturation and the initial void ratio are the most significant variables governing the one-dimensional stress-strain relations of soil at high pressures

b For pressures exceeding 3000 psi the compacted specimens and undisturbed specimens of Suffield soil yield the same relation if the initial degree of saturation and initial void ratio are identical before loading

c A lower bound to the secant modulus of deformation M_s at a given level of axial stress σ_a is given by

$$M_s = \frac{\sigma_a}{\dfrac{\left(1 - \dfrac{S_n}{100}\right)e_1}{1 + e_1} + \dfrac{\sigma_a}{300{,}000 \text{ psi}}}$$

for both compacted and undisturbed samples of fine-grained soil subjected to pressures greater than 3000 psi.

d The average unloading modulus of Suffield soils subjected to pressures greater than 3000 psi is approximately 10 times the loading secant modulus of deformation M_s.

e It is probable that the stiffness of the Suffield soils when unsaturated will be greater under dynamic loading than the static values given in this report Previous comparisons of static and dynamic values of constrained moduli of Suffield soils (reference 4) have shown that the dynamic values are twice the static values. This observation is consistent with similar comparisons for NTS Frenchman Flat silt (reference 7)

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Table 1

Description and Classification of Soil Samples

Test No.	Sample from Distant Plain 6	Depth ft	Description	Unified Classification	w %	LL %	PL %	G_s
1	Undisturbed sample 1, boring 2-U	0-0.5	Brown silty clay, with sand, trace of organic matter	CL	19.9	37	19	2.63
2	Undisturbed sample 1, boring 2-U	0.5-1.1	Brown silty clay with trace of sand	CL	19.1	38	18	2.66
3	Undisturbed sample 2, boring 2-U	1.2-1.7	Brown silty clay	CL	8.3	42	21	2.69
4	Undisturbed sample 2, boring 2-U	1.7-2.3	Brown silty clay	CL	9.0	44	23	2.69
5, 6, 7, 8	Remolded sample, boring 5-U	0-5	Brown silty clay	CL	-	34	16	2.69
9, 10, 11, 12	Remolded sample, boring 5-U	5-22	Brown sandy silt	ML	-	20	19	2.67

Table 2

Initial Specimen Data

Test No.	Type of Sample	Dry Density γ_{di}, pcf	Water Content w_i, %	Degree of Saturation S_n, %	Void Ratio e_i	Specific Gravity G_s
1	Undisturbed, 0-0.5 ft	86.2	19.9	58 0	0.902	2 63
2	Undisturbed, 0.5-1.1 ft	83.3	19 1	51 2	0 993	2 66
3	Undisturbed, 1.2-1.7 ft	77.5	8 3	19 1	1 170	2 69
4	Undisturbed, 1.7-2.3 ft	76.2	9.0	20 1	1.200	2 69
5	Remolded silty clay, 0-5 ft	85.8	4.8	13 5	0.960	2 69
6		79.2	9.7	25 3	1 120	2 69
7		85.2	9.8	27 1	0 972	2.69
8		85.4	19.6	54.3	0.970	2 69
9	Remolded sandy silt, 5-22 ft	89.0	3.1	9.4	0 876	2.67
10		88.0	8.1	24.1	0.898	2 67
11		88.5	15.0	45.0	0.888	2.67
12		88.0	27.2	80 3	0.898	2.67

Table 3

Summary of Static Test Data

Test No.	Sample Type and Location	Initial Value S_1, %	σ_a, psi	Initial Peak $\epsilon_{a_{max}}$, in./in.	K_o	Poisson's Ratio $\mu = K_o/1 + K_o$	Residual Strain $\epsilon_{a_{resid}}$, in./in	Ratio of Residual Strain to Maximum Strain $\epsilon_{a_{resid}}/\epsilon_{a_{max}}$
1*	Undisturbed, 0-0.5 ft	58.0	16,000	0.292				
2*	Undisturbed, 0.5-1.1 ft	51.2	2,500	0.284	0.94	0.48		
3	Undisturbed, 1.2-1.7 ft	19.1	20,000	0.454	0.55	0.35	0.424	0.93
4	Undisturbed, 1.7-2.3 ft	20.1	20,000	0.457	0.39	0.28	0.424	0.93
5	Remolded silty clay, 0-5 ft	13.5	20,000	0.399	0.48	0.32	0.377	0.94
6		25.3	20,000	0.437	0.89	0.47	0.418	0.96
7		27.1	16,000	0.385	0.89	0.47	0.366	0.95
8**		54.3	11,000	0.273	1.00	0.50	0.244	0.96
9	Remolded sandy silt, 5-22 ft	9.4	20,000	0.340	0.41	0.29	0.305	0.90
10		24.1	20,000	0.370	0.41	0.29	0.316	0.85
11**		45.0	20,000	0.358	0.47	0.32	0.304	0.85
12**		80.3	20,000	0.299	0.38	0.28	0.262	0.88

* Soil extrusion at initial peak axial stress.
** Water extrusion.

APPENDIX A: TABULATED TEST DATA

ONE-DIMENSIONAL STATIC TEST DATA

Test No 1 Soil Type Undisturbed Silty Clay Soil Location Depth 0 - 0.5 ft. Boring 2-U, Distant Plain 6

w_i 19.9 % S_{ri} 58.0 % γ_i 103.2 pcf γ_{di} 86.2 pcf S_s 2.63 e_i 0.902

L_w 37 % P_w 19 % Classification Brown Silty Clay w/ sand & trace of organic matter (CL)

Axial Stress σ_a	Axial Strain ϵ_a	Secant Modulus M_s	Radial Stress σ_r	Degree of Saturation S_r
psi	in/in	psi	psi	%
0	0	–	0	58.0
10	0.009	1110	–	
200	0.154	1300		
400	0.194	2060		
600	0.205	2930		
800	0.211	3780		
1000	0.216	4620		
1500	0.229	6550		
2000	0.242	8250		
2500	0.252	9900		
3000	0.257	11700		
3500	0.260	13450		
4000	0.263	15200		
5000	0.266	18800		
6000	0.269	22200		
7000	0.271	25800		
8000	0.274	29200		
9000	0.275	32800		
10000	0.277	36200		
11000	0.279	39500		
12000	0.281	42600		
13000	0.284	46800		
14000	0.286	49000		
15000	0.288	52000		
16000	0.292	54800		
	Soil Extrusion			
4000	0.351	11400		
3000	0.354	8500		
2000	0.353	5660		

Axial Stress σ_a	Axial Strain ϵ_a	Secant Modulus M_s	Radial Stress σ_r	Degree of Saturation S_r
psi	in/in	psi	psi	%
1000	0.352	2840		
500	0.351	1420		
200	0.351	570		
0	0.344	0		
0 (5 min)	0.344	0	–	

Note: Water Extrusion at σ_a = 1000 psi. Radial Stress was not recorded for this test. About 6 gms of water was extruded during the test.

Fig. A1

ONE-DIMENSIONAL STATIC TEST DATA

Test No 2 Soil Type Undisturbed Silty Clay Soil Location Depth 0.5 - 11 ft. Boring 2-U, Distant Plain 6

w_i 19.1 % S_{ri} 51.2 % γ_i 99.1 pcf γ_{di} 83.3 pcf S_s 2.66 e_i 0.993

L_w 38 % P_w 18 % Classification Brown Silty Clay w/ trace of sand. (CL)

Axial Stress σ_a	Axial Strain ϵ_a	Secant Modulus M_s	Radial Stress σ_r	Degree of Saturation S_r	Axial Stress σ_a	Axial Strain ϵ_a	Secant Modulus M_s	Radial Stress σ_r	Degree of Saturation S_r
psi	in/in	psi	psi	%	psi	in/in	psi	psi	%
0	0	—	0						
10	0.008	1250	0						
50	0.054	840	10						
100	0.120	834	50						
200	0.188	1060	98						
300	0.221	1355	130						
400	0.240	1670	210						
500	0.250	2000	264						
600	0.255	2350	358						
800	0.259	3090	515						
1000	0.262	3820	710						
1500	0.269	5560	1290						
2000	0.276	7250	1830						
2500	0.294	8500	2340						
	Soil Extrusion								
2000	0.374	5350	1980						
1500	0.448	3350	1542						
1000	0.486	2060	1110						
800	0.487	1640	933						
600	0.487	1230	750						
400	0.486	820	560						
300	0.486	620	468						
200	0.485	410	374						
100	0.484	206	298						
50	0.484	104	278						
10	0.482	21	222						
0	0.478	0	220						

Fig. A2

ONE-DIMENSIONAL STATIC TEST DATA

Test No 3 Soil Type Undisturbed Silty Clay Soil Location Depth 1.2 - 17 ft, Boring 2-U, Distant Plain 6

w_i 8.3 % S_{ri} 19.1 % γ_i 84.0 pcf γ_{di} 77.5 pcf S_s 2.69 e_i 1.170

L_w 42 % P_w 21 % Classification Brown Silty Clay (CL)

Axial Stress σ_a	Axial Strain ϵ_a	Secant Modulus M_s	Radial Stress σ_r	Degree of Saturation S_r
psi	in/in	psi	psi	%
0	0	—	0	
10	0.004	2500	0	
50	0.016	3120	29	
100	0.036	2780	88	
200	0.090	2220	128	
300	0.135	2260	201	
400	0.167	2400	266	
500	0.193	2590	357	
600	0.213	2820	388	
800	0.243	3290	447	
1000	0.265	3770	655	
1500	0.302	4970	905	
2000	0.327	6120	1140	
2500	0.345	7250	1450	
3000	c 359	8360	1640	
35?0	0.369	9480	1840	
?,000	0.379	10520	2140	
5000	0.393	12700	2530	
6000	0.403	14900	3020	
7000	0.412	17000	3590	
8000	0.419	19100	4100	
9000	0 4?4	21200	4610	
10000	0.430	23200	—	
11000	0.435	25300	5630	
12000	0.439	27400	6410	
13000	0.442	29400	?150	
14000	0.445	31500	7900	
15000	0.447	33600	8500	
16000	0.449	36700	9060	

Axial Stress σ_a	Axial Strain ϵ_a	Secant Modulus M_s	Radial Stress σ_r	Degree of Saturation S_r
psi	in./in	psi	psi	%
17000	0.450	37800	9600	
18000	0.451	39900	10100	
19000	0.452	42000	10500	
20000	0.454	44000	11000	
17500	0.454	38600	10200	
15000	0.454	33000	9190	
12500	0.452	27700	8070	
10000	0.451	22100	7150	
8000	0.449	17700	6250	
6000	0.447	13410	5250	
4000	0.444	9070	4270	
2000	0.441	4540	2960	
1000	0.436	2290	2210	
500	0.432	1160	1690	
200	0.429	466	1372	
100	0.429	233	1270	
50	0.428	116	1160	
0	0.424	0	1030	

Fig A3

ONE-DIMENSIONAL STATIC TEST DATA

Test No 4 Soil Type *Undisturbed Silty Clay* Soil Location *Depth 1.7 - 2.3 ft. Boring 2-4, Distant Plain 6*

w_i 9.0 % S_{ri} 20.1 % γ_i 83.1 pcf γ_{di} 76.2 pcf S_s 2.69 e_i 1.200

L_w 44 % P_w 23 % Classification *Brown Silty Clay (CL)*

Axial Stress σ_a	Axial Strain ϵ_a	Secant Modulus M_s	Radial Stress σ_r	Degree of Saturation S_r
psi	in/in	psi	psi	%
0	0	–	0	
10	0.002	5000	0	
50	0.008	6260	10	
100	0.018	5550	20	
200	0.067	2990	103	
300	0.119	2520	141	
400	0.159	2520	216	
500	0.187	2670	236	
600	0.209	2870	266	
800	0.240	3340	391	
1000	0.262	3820	520	
1500	0.300	5000	712	
2000	0.324	6160	990	
2500	0.342	7310	1160	
3000	0.356	8420	1470	
3500	0.368	9500	1660	
4000	0.378	10600	1860	
5000	0.391	12820	2350	
6000	0.402	14950	2740	
7000	0.410	17000	3170	
8000	0.418	19100	3680	
9000	0.423	21200	3970	
10000	0.429	23300	4340	
11000	0.434	25400	4650	
12000	0.439	27400	5110	
13000	0.443	29300	5420	
14000	0.446	31300	5750	
15000	0.449	33200	6060	
16000	0.451	35500	6450	

Axial Stress σ_a	Axial Strain ϵ_a	Secant Modulus M_s	Radial Stress σ_r	Degree of Saturation S_r
psi	in/in	psi	psi	%
17000	0.452	37600	6810	
18000	0.454	39700	7000	
19000	0.455	41700	7400	
20000	0.457	43700	7800	
17500	0.456	38400	7440	
15000	0.455	33000	6860	
12500	0.455	27500	6350	
10000	0.453	22100	5750	
6000	0.449	13400	4350	
4000	0.447	8950	3500	
2000	0.443	4500	2410	
1000	0.439	2280	1880	
500	0.437	1140	1360	
200	0.432	460	–	
100	0.431	230	–	
50	0.429	120	920	
0	0.424	–	830	

Fig. A4

ONE-DIMENSIONAL STATIC TEST DATA

Test No 5 Soil Type Remolded Silty Clay Soil Location Depth 0-5 ft. Bag Sample, Distant Plain 6

w_i 4.8 % S_i 13.5 % γ_i 90.0 pcf γ_{di} 85.8 pcf S_s 2.69 e_i 0.960

L_w 34 % P_w 16 % Classification Brown Silty Clay (CL)

Axial Stress σ_a	Axial Strain ε_a	Secant Modulus M_s	Radial Stress σ_r	Degree of Saturation S_r
psi	in/in	psi	psi	%
0	0		0	
10	0.011	1000	0	
50	0.037	1300	10	
100	0.062	1600	71	
200	0.097	2100	106	
300	0.122	2500	131	
400	0.141	2800	212	
500	0.153	3300	225	
600	0.167	3600	287	
800	0.188	4200	365	
1000	0.205	4900	495	
1500	0.233	6500	750	
2000	0.256	7800	1001	
2500	0.272	9200	1260	
3000	0.286	10500	1470	
3500	0.296	11800	1700	
4000	0.307	13000	1950	
5000	0.323	15500	2420	
6000	0.333	18000	2870	
7000	0.343	20400	3360	
8000	0.351	22800	3820	
9000	0.357	25200	4300	
10000	0.363	27600	4810	
11000	0.369	29800	5170	
12000	0.374	32100	5630	
13000	0.378	34400	6040	
14000	0.382	36700	6500	
15000	0.386	39000	7000	
16000	0.389	41200	7500	

Axial Stress σ_a	Axial Strain ε_a	Secant Modulus M_s	Radial Stress σ_r	Degree of Saturation S_r
psi	in./in.	psi	psi	%
17000	0.391	43500	8070	
18000	0.393	46000	8500	
19000	0.397	48000	9090	
20000	0.399	50000	9600	
17500	0.399	43800	9350	
15000	0.398	37700	8850	
12500	0.397	31500	8250	
10000	0.396	25300	7500	
6000	0.392	15300	5500	
4000	0.390	10200	4350	
2000	0.388	5200	3050	
1000	0.385	2600	2230	
500	0.383	1300	1760	
200	0.382	500	1400	
100	0.382	300	1320	
50	0.380	100	1220	
0	0.377	0	1600	

Fig A5

ONE-DIMENSIONAL STATIC TEST DATA

Test No. 6 Soil Type Remolded Silty Clay Soil Location Depth 0-5 ft. Bag Sample, Distant Plain 6

w_i 9.7 % S_{ri} 25.3 % γ_i 86.8 pcf γ_{di} 79.2 pcf s 2.69 e_i 1.120

L_w 36 % P_w 16 % Classification Brown Silty Clay (CL)

Axial Stress σ_a	Axial Strain ϵ_a	Secant Modulus M_s	Radial Stress σ_r	Degree of Saturation S_r
psi	in./in.	psi	psi	%
0	0	—	0	
10	0.003	1000	0	
50	[illegible]81	600	21	
100	0.147	700	56	
200	0.219	900	122	
300	0.255	1200	167	
400	0.284	1400	253	
500	0.301	1700	272	
600	0.313	1900	290	
800	0.336	2400	433	
1000	0.352	2800	470	
1500	0.374	4000	760	
2000	0.390	5100	975	
2500	0.401	6200	1260	
3000	0.408	7300	1490	
3500	0.413	8500	1790	
4000	0.416	9600	2130	
5000	0.419	12000	2800	
6000	0.420	14300	3450	
7000	0.422	16600	4600	
8000	0.423	19000	5520	
9000	0.423	21200	6330	
10000	0.424	23600	7300	
11000	0.425	25900	8250	
12000	0.426	28100	9180	
14000	0.428	32700	11400	
15000	0.430	35000	12600	
16000	0.430	37300	-	
17000	0.431	39500	-	

Axial Stress σ_a	Axial Strain ϵ_a	Secant Modulus M_s	Radial Stress σ_r	Degree of Saturation S_r
psi	in./in.	psi	psi	%
18000	0.432	41800	-	
19000	0.435	43700	-	
20000	0.437	45800	-	
17500	0.436	40000	-	
15000	0.435	34500	-	
12500	0.434	28800	-	
10000	0.433	23100	-	
8000	0.432	18500	-	
6000	0.431	14000	-	
4000	0.430	9300	-	
2000	0.430	4600	-	
1000	0.428	2300	-	
500	0.426	1200	-	
200	0.425	500	-	
100	0.424	200	-	
50	0.423	100	-	
0	0.418	0	-	

Note: Strain gages on the confining ring yielded at an axial stress of 14,000 psi.

Fig. A6

ONE-DIMENSIONAL STATIC TEST DATA

Test No 7 Soil Type Remolded Silty Clay Soil Location Depth 0-5 ft. Bag Sample, Distant Plain 6

w_i 9.8 % S_{ri} 27.1 % γ_i 93.5 pcf γ_{di} 85.2 pcf S_s 2.69 e_i 0.972

L_w 34 % P_w 16 % Classification Brown Silty Clay (CL)

Axial Stress σ_a	Axial Strain ϵ_a	Secant Modulus M_s	Radial Stress σ_r	Degree of Saturation S_r
psi	in / in	psi	psi	%
0	0	—	0	
10	0.005	2000	0	
50	0.024	2100	56	
100	0.087	1100	101	
200	0.152	1300	119	
300	0.193	1500	182	
400	0.220	1800	248	
500	0.244	2000	280	
600	0.257	2300	372	
[illegible]00	0.280	2900	512	
1000	0.295	3400	587	
1500	0.322	4700	895	
2000	0.338	5900	1250	
2500	0.349	7200	1550	
3000	0.360	8300	1920	
3500	0.365	9600	2260	
4000	0.368	10900	2780	
5000	0.372	13400	3830	
6000	0.374	16000	4900	
7000	0.377	18600	6080	
8000	0.378	21100	7550	
9000	0.380	23700	8000	
10000	0.380	26300	8950	
11000	0.381	28900	9700	
12000	0.382	31500	10600	
13000	0.383	34000	11500	
14000	0.383	36600	12300	
15000	0.384	39100	13200	
16000	0.385	41500	14200	

Axial Stress σ_a	Axial Strain ϵ_a	Secant Modulus M_s	Radial Stress σ_r	Degree of Saturation S_r
psi	in./in.	psi	psi	%
15000	0.385	39000	14000	
12500	0.384	32600	12200	
10000	0.383	26100	11800	
8000	0.381	21000	8750	
4000	0.380	10500	5350	
2000	0.378	5300	3500	
1000	0.376	2700	2510	
500	0.373	1300	1930	
200	0.371	500	1620	
100	370	300	1480	
50	0.368	100	1390	
0	0.366	0	1190	

Note: Axial load was stopped at 16,000 psi because of capacity of strain gages on confining ring.

Fig A7

ONE-DIMENSIONAL STATIC TEST DATA

Test No. 8 Soil Type Remolded Silty Clay Soil Location Depth 0-5 ft. Bag Sample Distant Plain 6

w_i 19.6 % S_{ri} 54.3 % γ_i 102.0 pcf γ_{di} 85.4 pcf G_s 2.69 e_i 0.970

L_w 34 % P_w 16 % Classification Brown Silty Clay (CL)

Axial Stress σ_a	Axial Strain ϵ_a	Secant Modulus M_s	Radial Stress σ_r	Degree of Saturation S_r	Axial Stress σ_a	Axial Strain ϵ_a	Secant Modulus M_s	Radial Stress σ_r	Degree of Saturation S_r
psi	in./in.	psi	psi	%	psi	in./in	psi	psi	%
0	0	0	0		6000	0.247	24300	6000	
10	0.022	500	0		7000	0.248	28200	7000	
50	0.186	300	0		8000	0.250	32000	7970	
100	0.220	500	12		9000	0.251	36000	8880	
150	0.228	700	48		10000	0.252	39700	9850	
200	0.230	900	96		11000	0.253	43500	11000	
300	0.231	1300	191		8000	0.252	31700	8000	
400	0.232	1700	276		6000	0.250	24000	6000	
500	0.232	2200	358		4000	0.249	16000	4040	
600	0.233	2600	480		3000	0.248	12100	3070	
700	0.234	3000	588		2000	0.247	8100	2070	
800	0.234	3400	685		1000	0.246	4100	1010	
900	0.234	3900	744		500	0.246	2000	600	
1000	0.234	4300	850		200	0.246	800	256	
1100	0.235	4700	890		100	0.246	400	134	
	0.235	–	975		50	0.246	200	97	
1150	0.235	4900	1000		0	0.244	0	36	
1275	0.236	5400	1110						
1500	0.237	6300	1340		Note:	Water extrusion at			
1600	0.238	6700	1460			σ_a = 400 psi	< 2 gms of water.		
1800	0.238	7800	1640			Loading was stopped at			
2000	0.239	8400	1830			11,000 psi because of			
2250	0.239	9400	2080			capacity of strain gages			
2500	0.240	10400	2370			on the confining ring.			
2750	0.240	11500	2660						
3000	0.240	12500	2920						
3500	0.242	14590	3400						
4000	0.244	16400	3900						
5000	0.246	20300	5000						

Fig. A8

ONE-DIMENSIONAL STATIC TEST DATA

Test No 9 Soil Type Remolded Sandy Silt Soil Location Depth 5-22 ft Boring 5-U, Distant Plain 6

w, 3.1 % S_{ri} 9.4 % γ_i 92.0 pcf γ_{di} 89.0 pcf S_s 2.67 e_i 0.876

L_w 20 % P_w 19 % Classification Brown Sandy Silt (ML)

Axial Stress σ_a	Axial Strain ϵ_a	Secant Modulus M_s	Radial Stress σ_r	Degree of Saturation S_r
psi	in/in	psi	psi	%
0	0	—	0	
10	.008	1250	0	
50	033	1515	37.1	
100	050	2000	48.4	
200	066	3030	108	
300	083	3620	150.5	
400	.095	4220	173	
500	105	4750	247	
600	114	5250	270	
800	129	6200	370	
1000	141	7100	450	
1500	.163	9200	615	
2000	.184	10900	834	
2500	199	12600	998	
3000	212	14150	1225	
3500	225	15600	1440	
4000	233	17150	1630	
5000	248	20100	2020	
6000	261	23000	2430	
7000	.272	25700	2850	
8000	281	28500	3270	
9000	289	31100	3590	
10000	296	33800	4000	
11000	.303	36300	4410	
12000	.309	38800	4750	
13000	.315	41460	5160	
14000	.320	43700	5640	
15000	.323	46400	5940	
16000	.327	49000	6360	

Axial Stress σ_a	Axial Strain ϵ_a	Secant Modulus M_s	Radial Stress σ_r	Degree of Saturation S_r
psi	in/in	psi	psi	%
17000	.330	51500	6860	
18000	333	54000	7240	
19000	336	56600	7640	
20000	340	58800	8150	
17500	339	51600	7950	
15000	338	44400	7580	
12500	.338	37000	7020	
10000	338	29600	6310	
8000	336	23800	5670	
6000	332	18100	4910	
4000	331	12100	4280	
2000	328	6100	3080	
1000	323	3100	2380	
500	320	1560	1960	
200	.317	630	1550	
100	316	316	1400	
50	314	159	1280	
0	.305	—	980	

Fig A9

ONE-DIMENSIONAL STATIC TEST DATA

Test No 10 Soil Type Remolded Sandy Silt Soil Location Depth 5-22 ft. Boring S-4, Distant Plain 6

w_i 8.1 % S_{ri} 24.1 % γ_i 95.3 pcf γ_{di} 88.0 pcf S_s 2.67 e_i 0.898

L_w 20 % P_w 19 % Classification Brown Sandy Silt (ML)

Axial Stress σ_a	Axial Strain ϵ_a	Secant Modulus M_s	Radial Stress σ_r	Degree of Saturation S_r	Axial Stress σ_a	Axial Strain ϵ_a	Secant Modulus M_s	Radial Stress σ_r	Degree of Saturation S_r
psi	in/in	psi	psi	%	psi	in/in	psi	psi	%
0	0	—	0		17000	.362	47000	6770	
10	.007	1430	46.4		18000	.365	49400	7020	
50	.031	1610	85.5		19000	.367	51700	7550	
100	.059	1695	98		20000	.370	54000	8050	
200	.093	2160	132		17500	.370	47400	7750	
300	.115	2610	188		15000	.369	41900	7400	
400	.131	3050	212		12500	.369	33900	6830	
500	.142	3520	226		10000	.367	27200	6120	
600	.151	3970	304		8000	.366	21800	5540	
800	.171	4670	346		6000	.364	16500	4780	
1000	.183	5460	450		4000	.362	11050	3900	
1500	.210	7140	641		2000	.358	5590	2760	
2000	.230	8700	839		1000	.354	2820	1995	
2500	.244	10250	1035		500	.349	1430	1410	
3000	.257	11700	1240		200	.345	580	1160	
3500	.267	13100	1435		100	.342	292	726	
4000	.276	14450	1640		50	.339	147	588	
5000	.290	17250	2050		0	.316	0	337	
6000	.301	19900	2420						
7000	.312	22400	2830						
8000	.320	25000	3250						
9000	.326	27600	3580						
10000	.333	30000	4000						
11000	.339	32500	4340						
12000	.344	34900	4760						
13000	.348	37400	5170						
14000	.352	39800	5550						
15000	.356	42100	5850						
16000	.360	44500	6300						

Fig. A10

ONE-DIMENSIONAL STATIC TEST DATA

Test No *11*   Soil Type *Remolded Sandy Silt*   Soil Location *Depth 5-22 ft. Boring S-4, Distant Plain 6*

w_i *15.0* % S_{ri} *45.0* % γ_i *101.8* pcf γ_{di} *88.5* pcf S_s *2.67* e_i *0.888*

L_w *20* % P_w *19* % Classification *Brown Sandy Silt (ML)*

Axial Stress σ_a	Axial Strain ϵ_a	Secant Modulus M_s	Radial Stress σ_r	Degree of Saturation S_r
psi	in / in	psi	psi	%
0	0	—	0	
10	.010	1000	0	
50	.046	1090	9.3	
100	.074	1355	67.6	
200	101	1980	199	
300	120	2500	256	
400	136	2940	314	
500	144	3470	330	
600	153	3920	397	
800	167	4800	442	
1000	184	5420	552	
1500	208	7200	688	
2000	223	8960	926	
2500	237	10550	1110	
3000	250	12000	1345	
3500	258	13550	1550	
4000	268	14900	1900	
5000	283	17700	2070	
6000	293	20500	2570	
7000	303	23100	3040	
8000	310	25800	3470	
9000	316	28400	3980	
10000	320	31300	4530	
11000	326	33800	4950	
12000	.331	36300	5470	
13000	336	38700	5960	
14000	341	41000	6190	
15000	.344	43600	6750	
16000	.348	46000	7270	

Axial Stress σ_a	Axial Strain ϵ_a	Secant Modulus M_s	Radial Stress σ_r	Degree of Saturation S_r
psi	in/in	psi	psi	%
17000	.350	48500	7800	
18000	.353	51000	8190	
19000	355	53500	8710	
20000	358	55900	9300	
17500	.358	48900	8730	
15000	358	41900	8150	
12500	358	34900	7500	
10000	355	28200	6590	
8000	.354	22600	5860	
6000	352	17000	5090	
4000	.349	11400	4310	
2000	.346	5770	3060	
1000	342	2920	2240	
500	337	1485	1675	
200	333	600	1230	
100	330	303	947	
50	326	153.5	822	
0	304	0	461	

Note: water extrusion at σ_a = 2500 psi. ≈ 16 gms. of water extruded during test.

Fig. A11

ONE-DIMENSIONAL STATIC TEST DATA

Test No *12* Soil Type *Remolded Sandy Silt* Soil Location *Depth 5-22 ft. Boring 5-U, Distant Plain 6*

w_i *27.2* % S_{ri} *80.3* % γ_i *112.0* pcf γ_{di} *88.0* pcf S_s *2.67* e_i *0.898*

L_w *20* % P_w *19* % Classification *Brown Sandy Silt (ML)*

Axial Stress σ_a	Axial Strain ϵ_a	Secant Modulus M_s	Radial Stress σ_r	Degree of Saturation S_r
psi	in/in	psi	psi	%
0	0	—	0	
10	.032	321	0	
50	.058	860	0	
100	.076	1318	9.5	
150	.088	1700	9.8	
200	.094	2130	29.9	
250	.101	2480	50.5	
300	.107	2800	81.2	
350	.112	3120	92	
400	.117	3420	103	
450	.121	3720	104	
500	.124	4030	115	
600	.131	4580	126	
700	.137	5100	192	
800	.143	5600	215	
900	.147	6120	237	
1000	.152	6560	314	
1250	.162	7700	425	
1500	.171	8780	500	
1750	.178	9840	560	
2000	.185	10800	677	
2500	.196	12750	860	
3000	.206	14560	1042	
3500	.214	16350	1270	
4000	.223	17900	1420	
5000	.232	21600	1800	
6000	.241	24900	2190	
7000	.247	28400	2580	
8000	.253	31600	2970	

Axial Stress σ_a	Axial Strain ϵ_a	Secant Modulus M_s	Radial Stress σ_r	Degree of Saturation S_r
psi	in/in	psi	psi	%
9000	.258	34800	3360	
10000	.263	38000	3740	
11000	.270	40700	4100	
12000	.274	43800	4450	
13000	.278	46800	4850	
14000	.282	49600	5300	
15000	.286	52500	5550	
16000	.288	55500	5950	
17000	.291	58500	6350	
18000	.294	61100	6630	
19000	.295	64500	7050	
20000	.299	66900	7470	
17500	.299	58500	7080	
15000	.298	50400	6700	
12500	.298	42000	6270	
10000	.296	33800	5610	
8000	.295	27100	4960	
6000	.292	20500	4250	
4000	.291	13700	3450	
2000	.288	6950	2380	
1000	.284	3520	1675	
500	.280	1790	1260	
200	.278	719	882	
100	.276	362	650	
50	.274	182	607	
0	.262	—	375	
Note:	Water extrusion at			
	σ_a = 10 psi ≈ 48 gms of water			
	extruded during test.			

Fig. A12

APPENDIX B AXIAL STRESS VERSUS AXIAL STRAIN

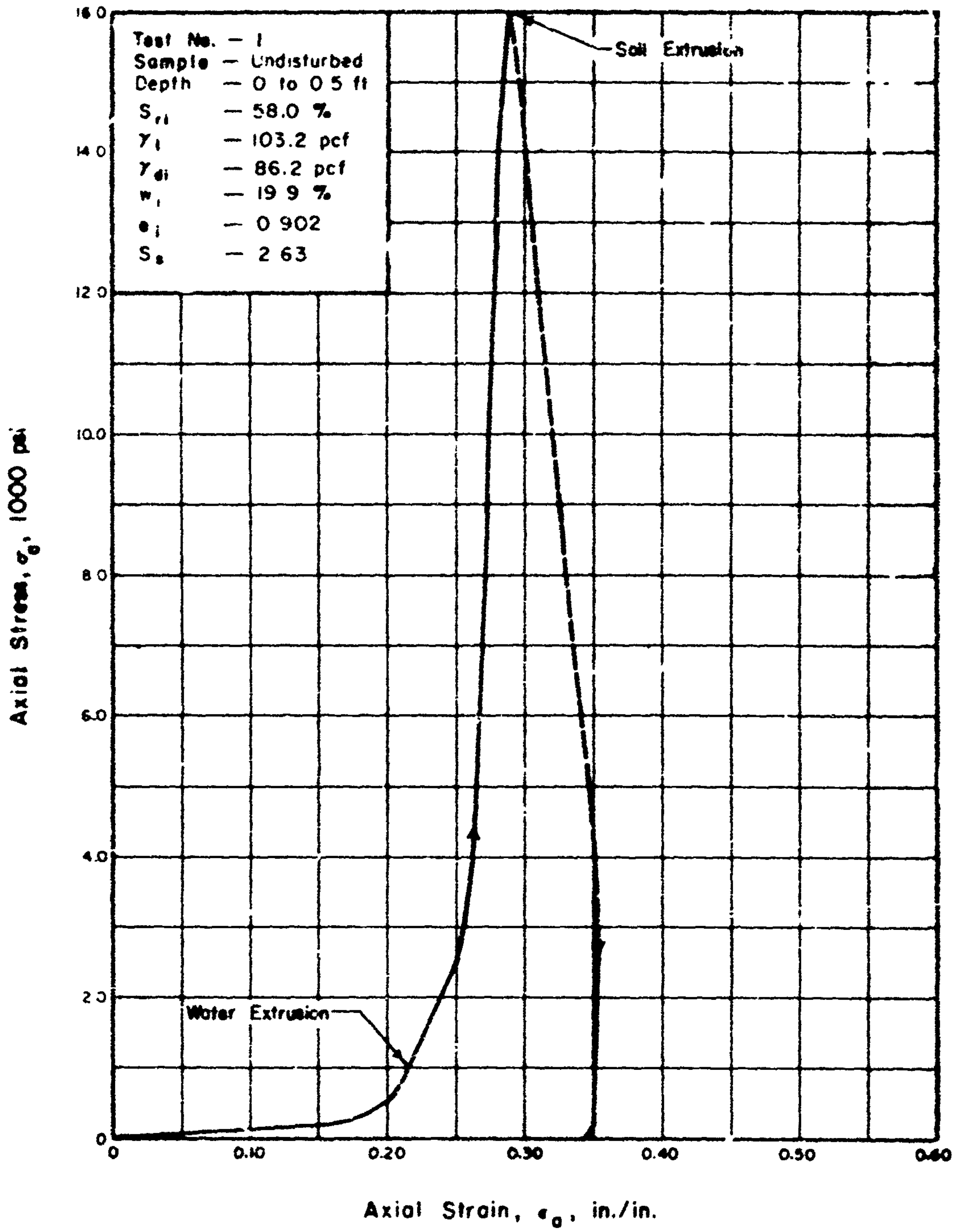

Fig B1. Stress-strain relation in one-dimensional compression, test 1

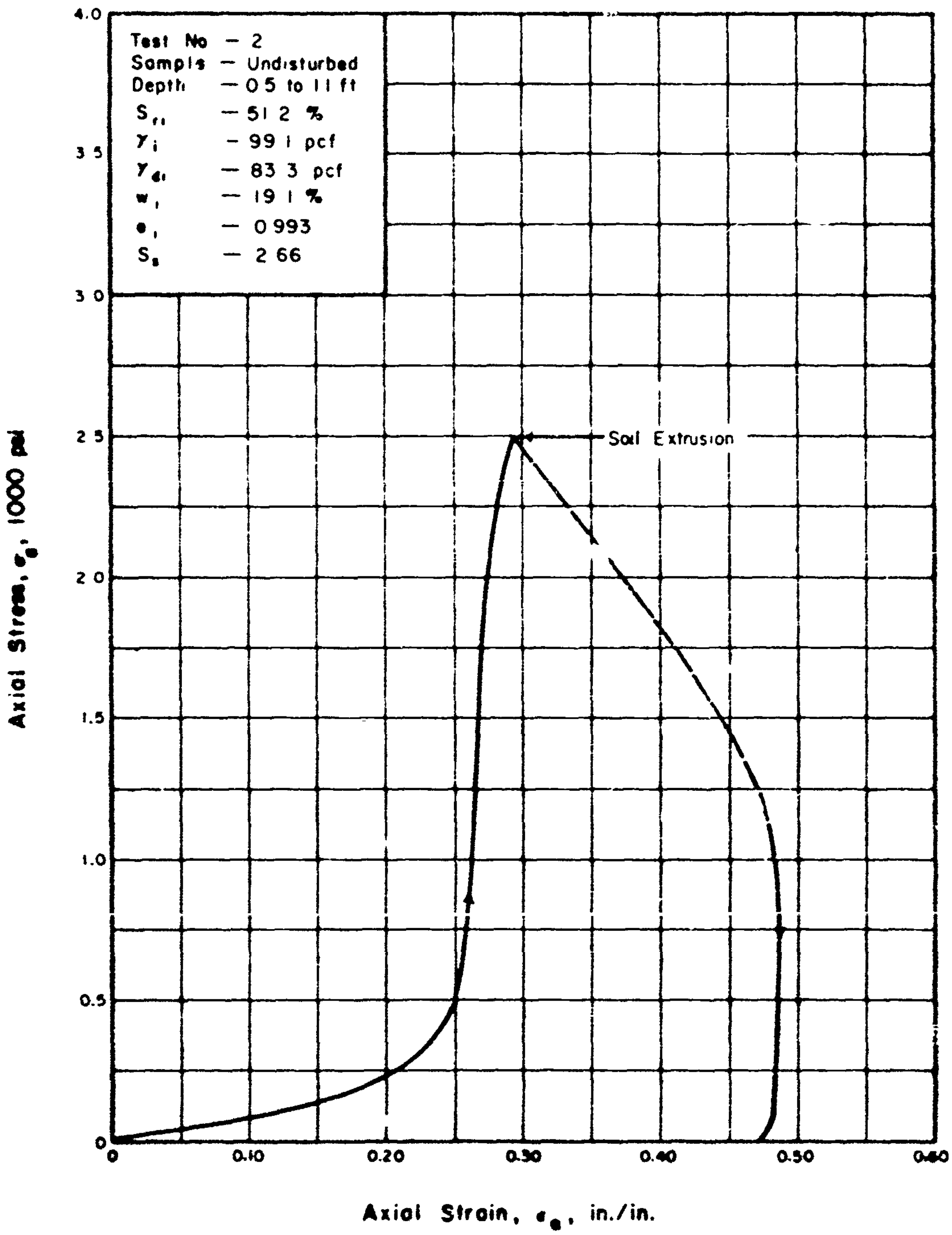

Fig. B2. Stress-strain relation in one-dimensional compression, test 2

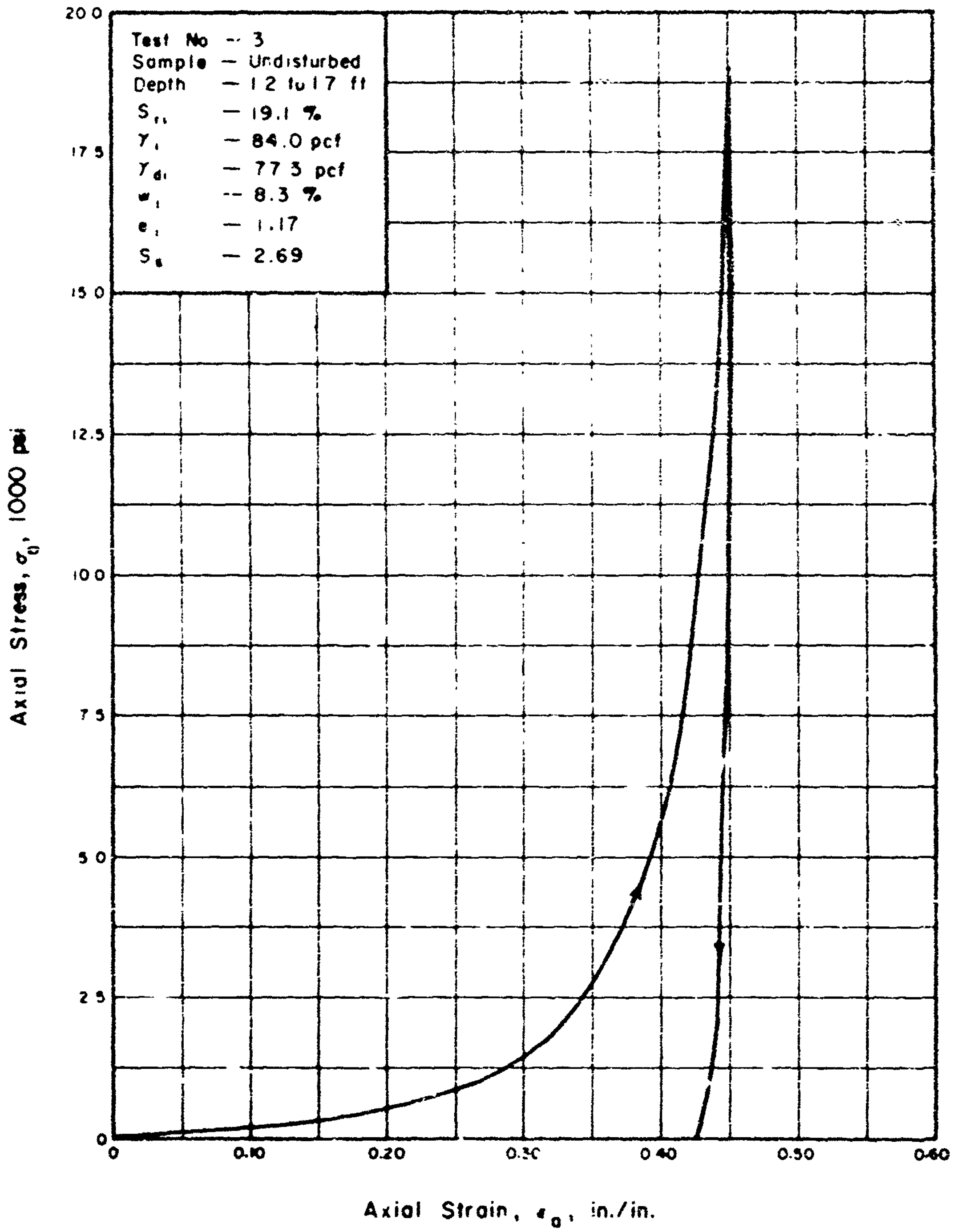

Fig B3. Stress-strain relation in one-dimensional compression, test 3

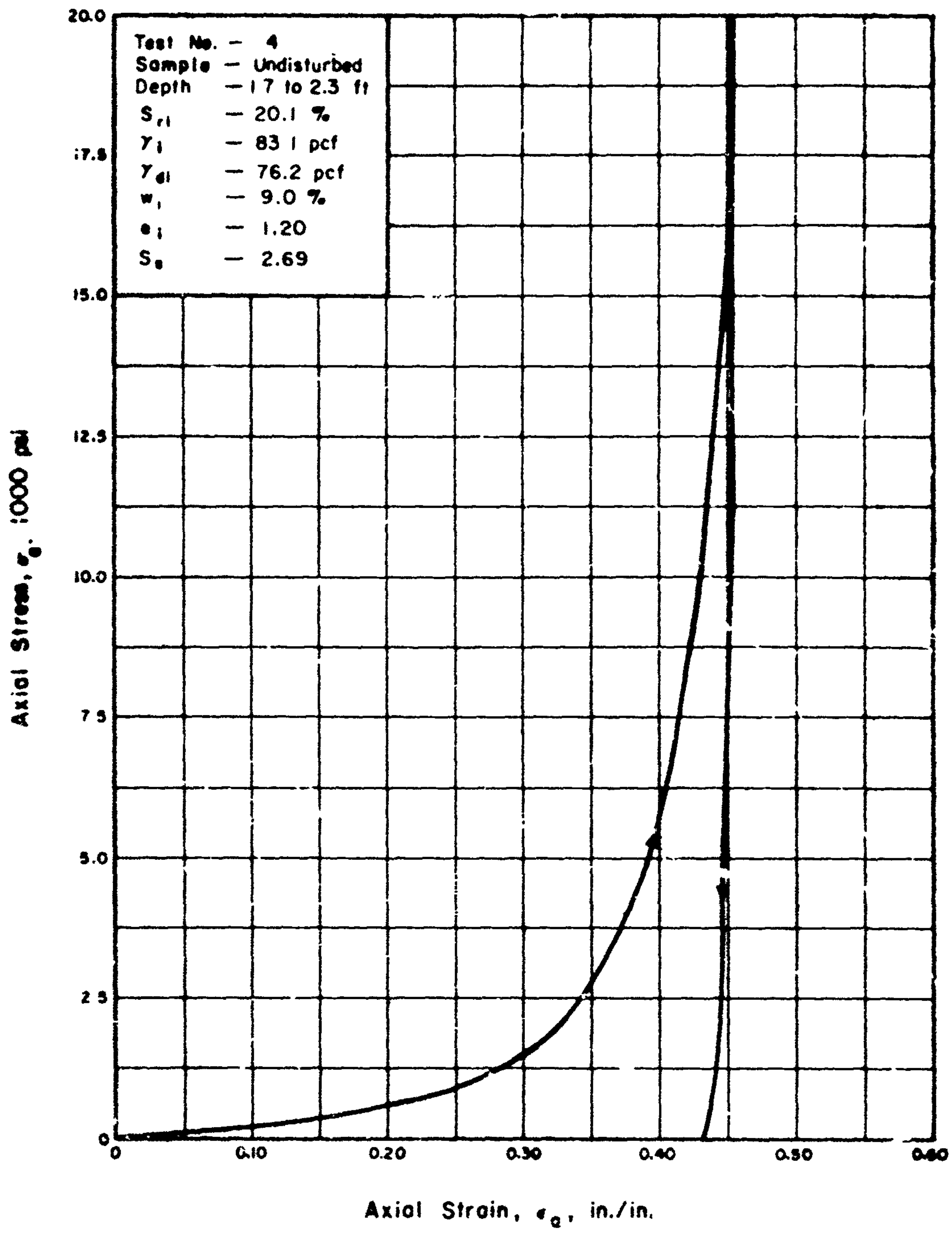

Fig B4. Stress-strain relation in one-dimensional compression test 4

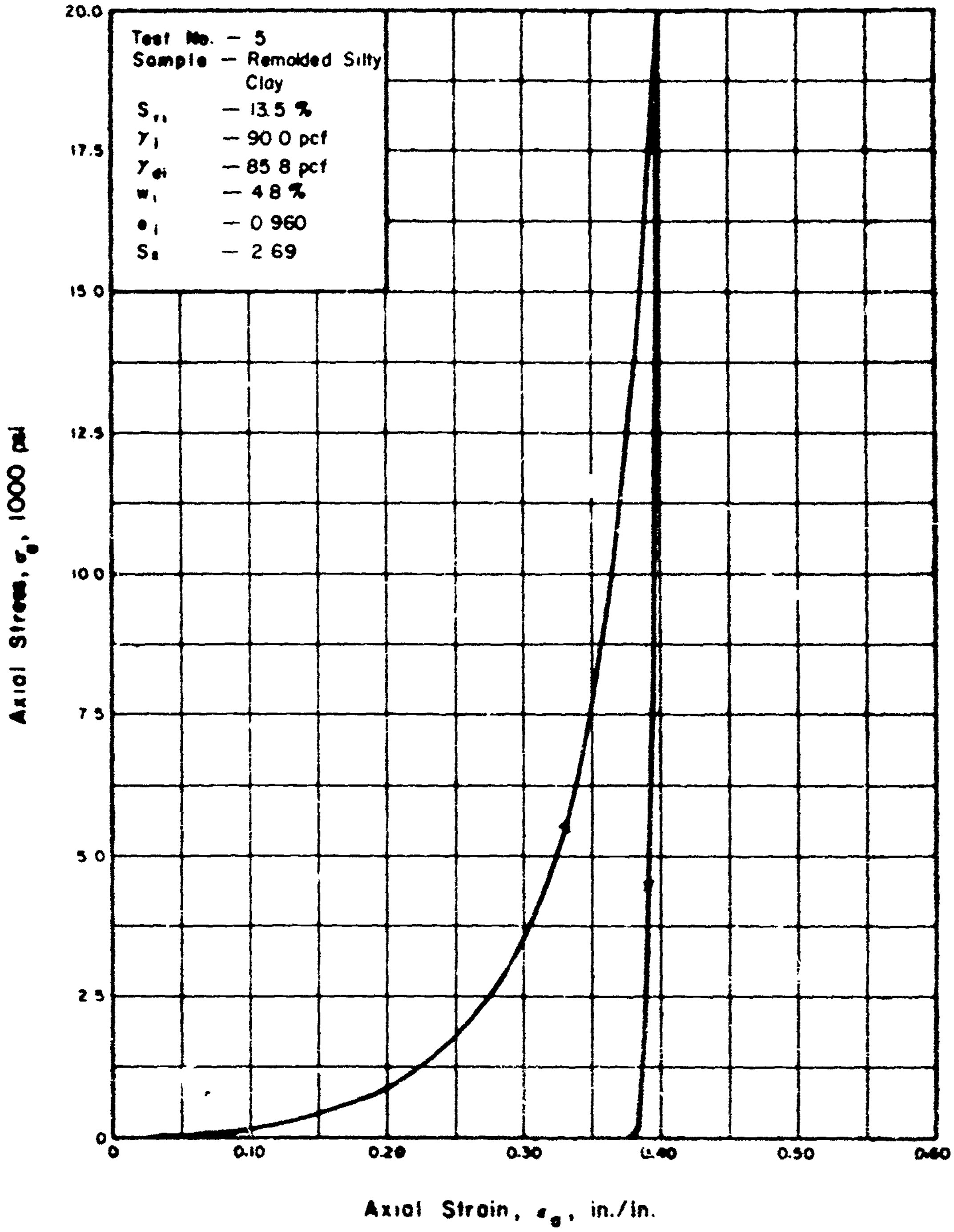

Fig B5 Stress-strain relation in one-dimensional compression test 5

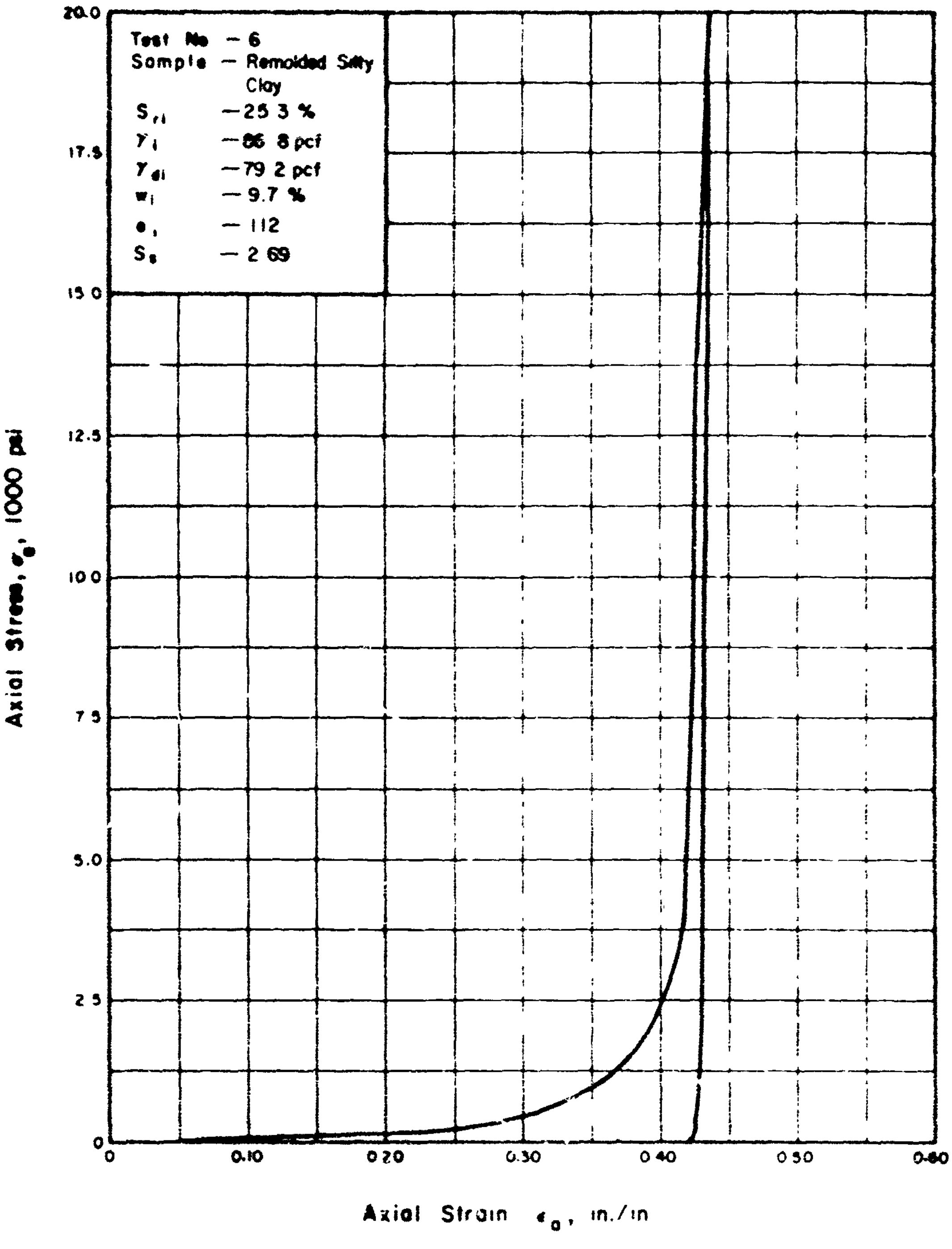

Fig B6 Stress-strain relation in one dimensional compression test 6

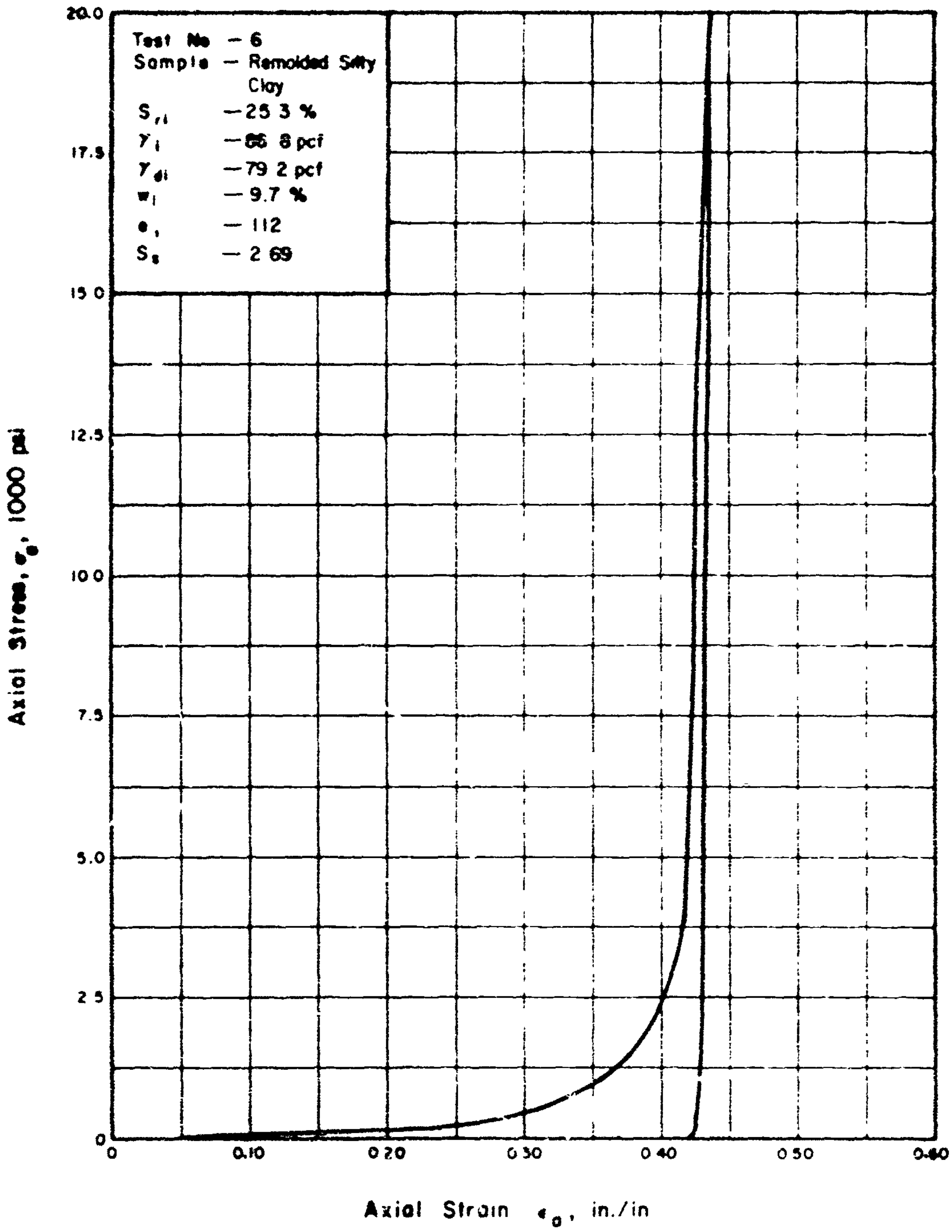

Fig. B6 Stress-strain relation in one dimensional compression test 6

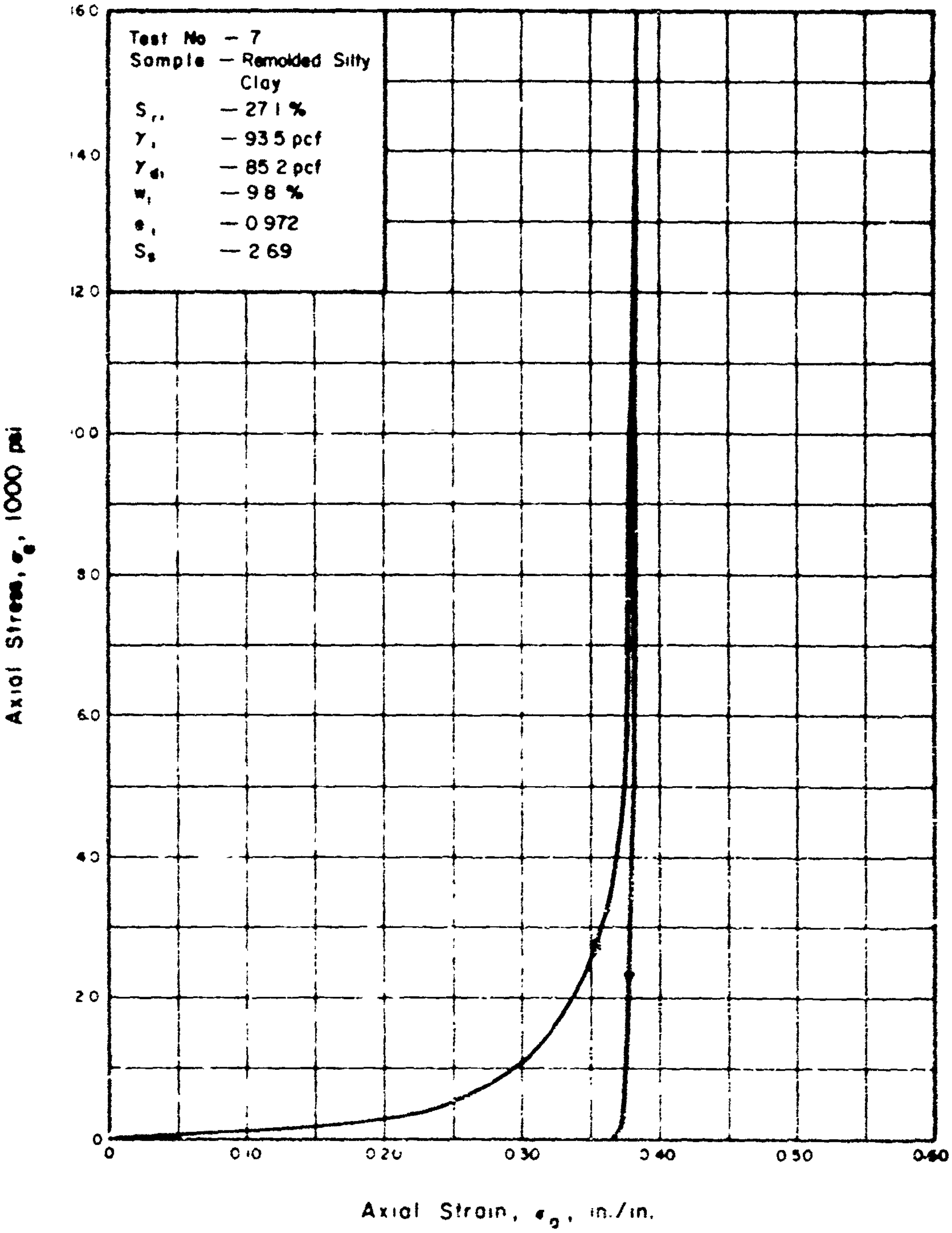

Fig. B7 Stress-strain relation in one dimensional compression, test 7

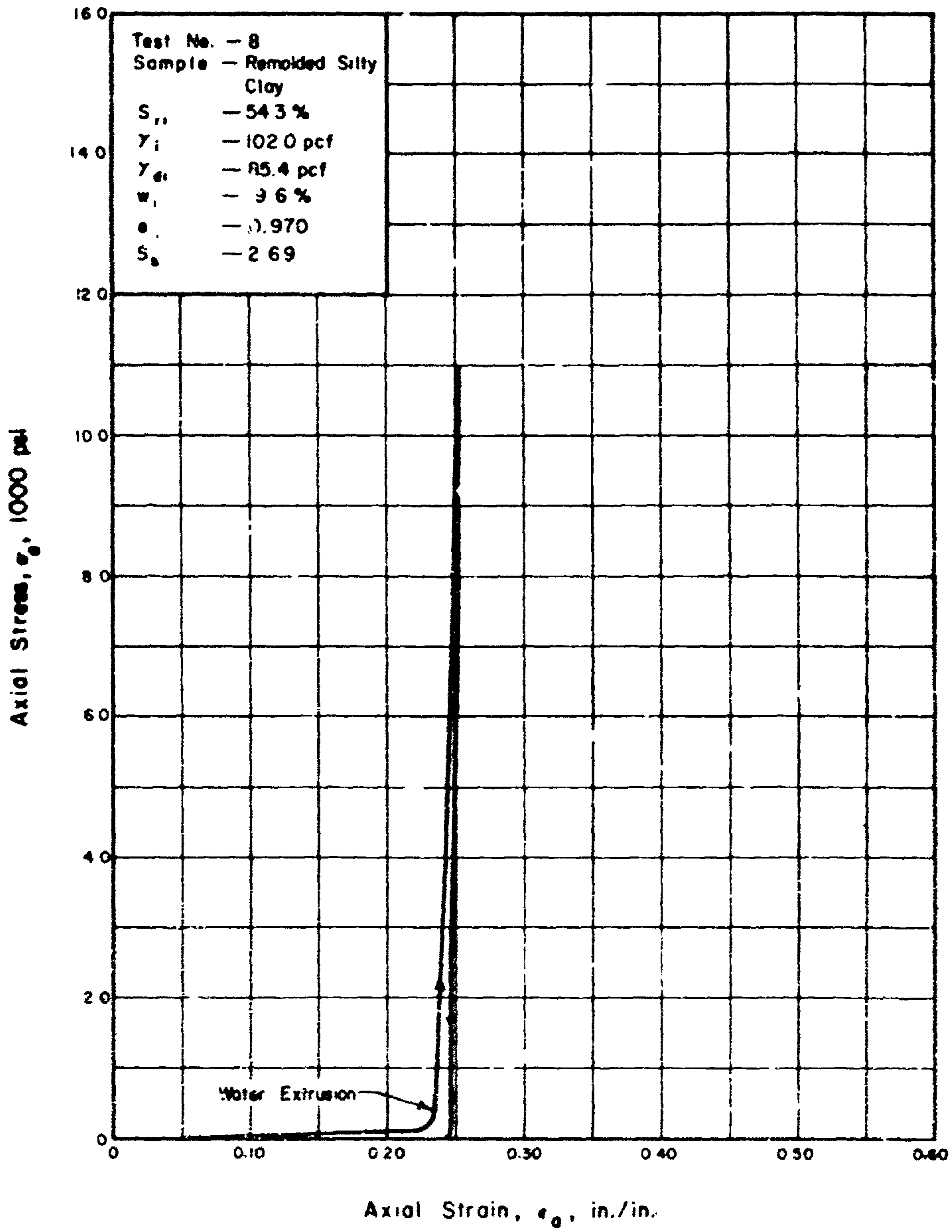

Fig B8 Stress-strain relation in one-dimensional compression, test 8

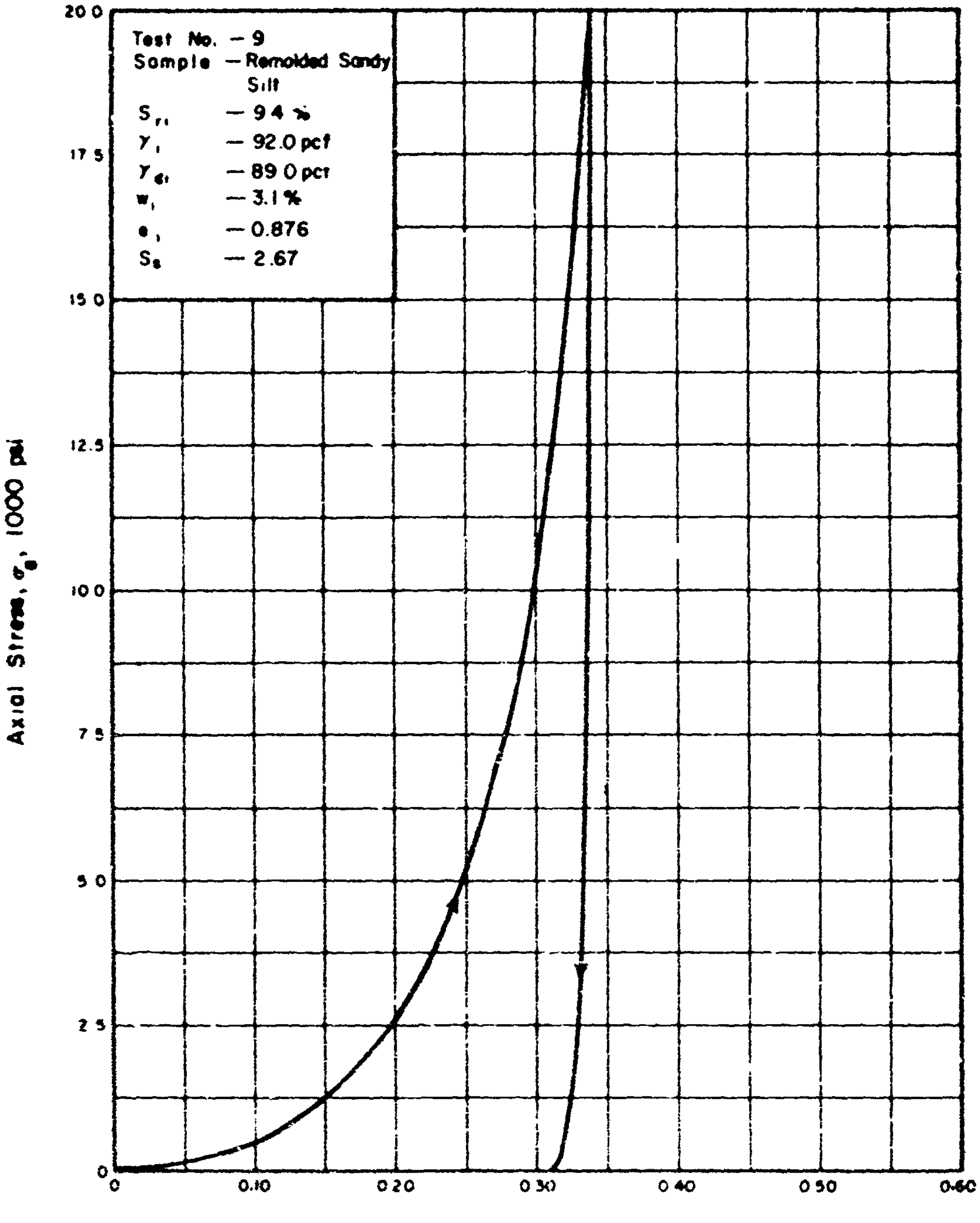

Fig. B9. Stress-strain relation in one-dimensional compression test 9

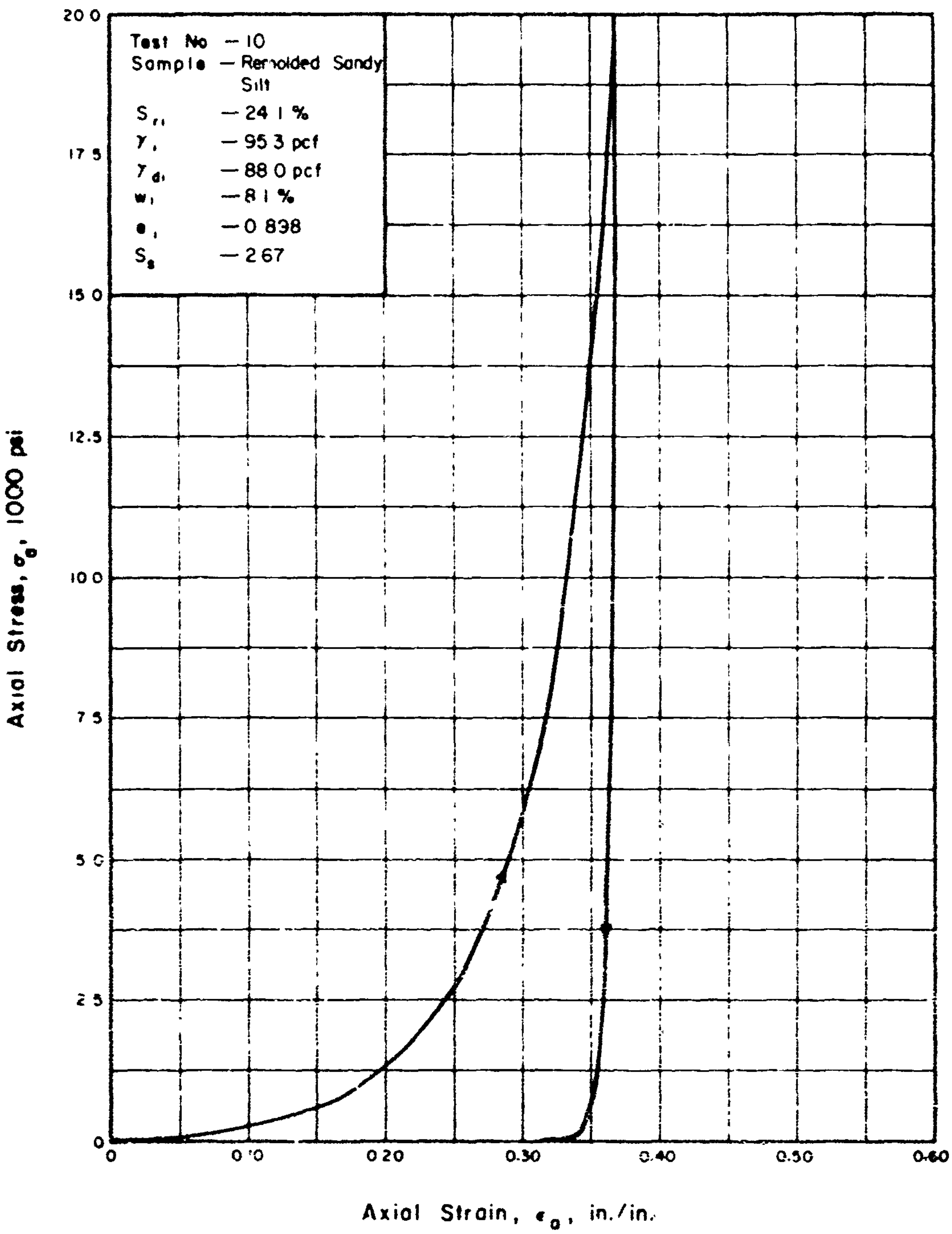

Fig B10 Stress-strain relation in one dimensional compression, test 10

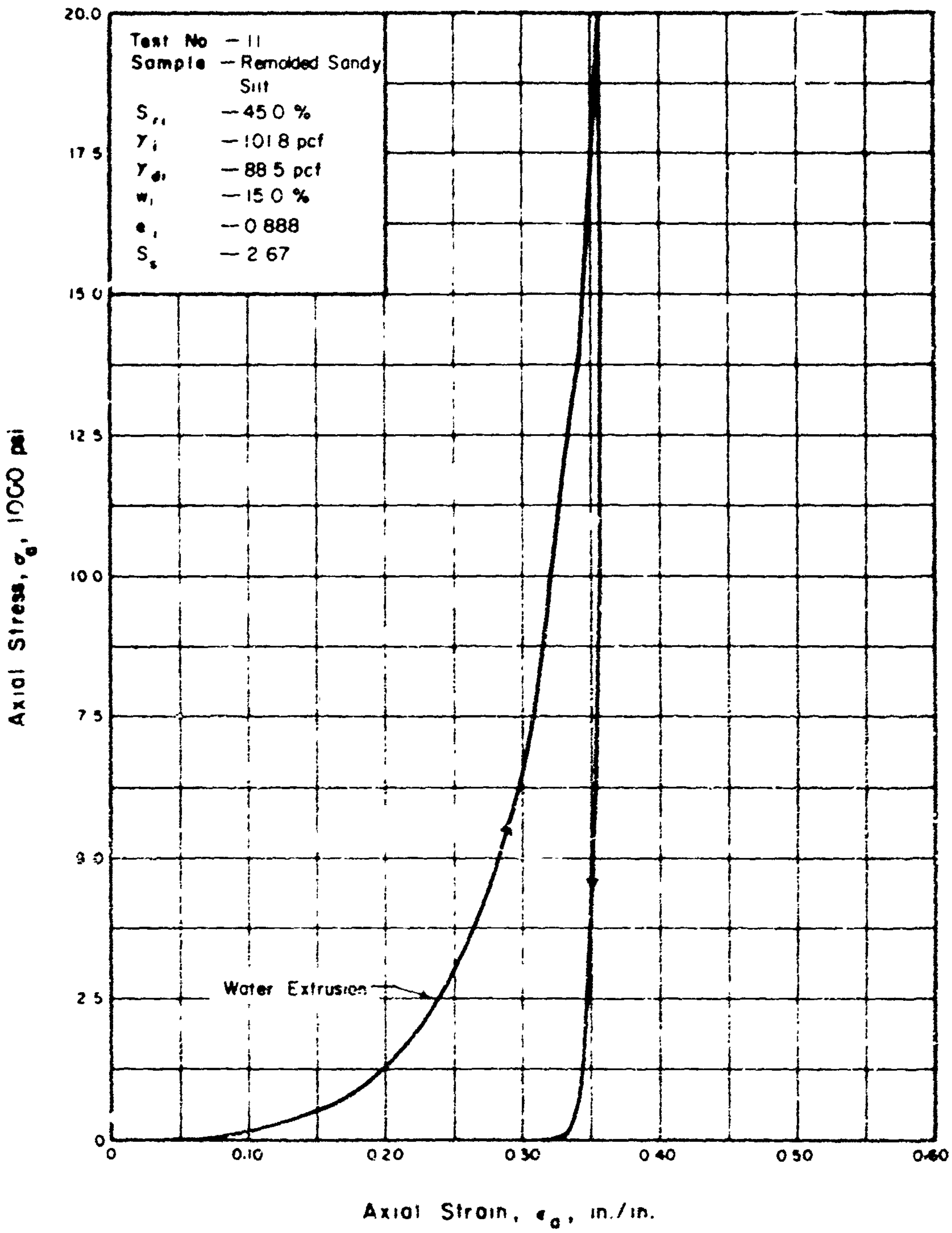

Fig B11 Stress-strain relation in one-dimensional compression, test 11

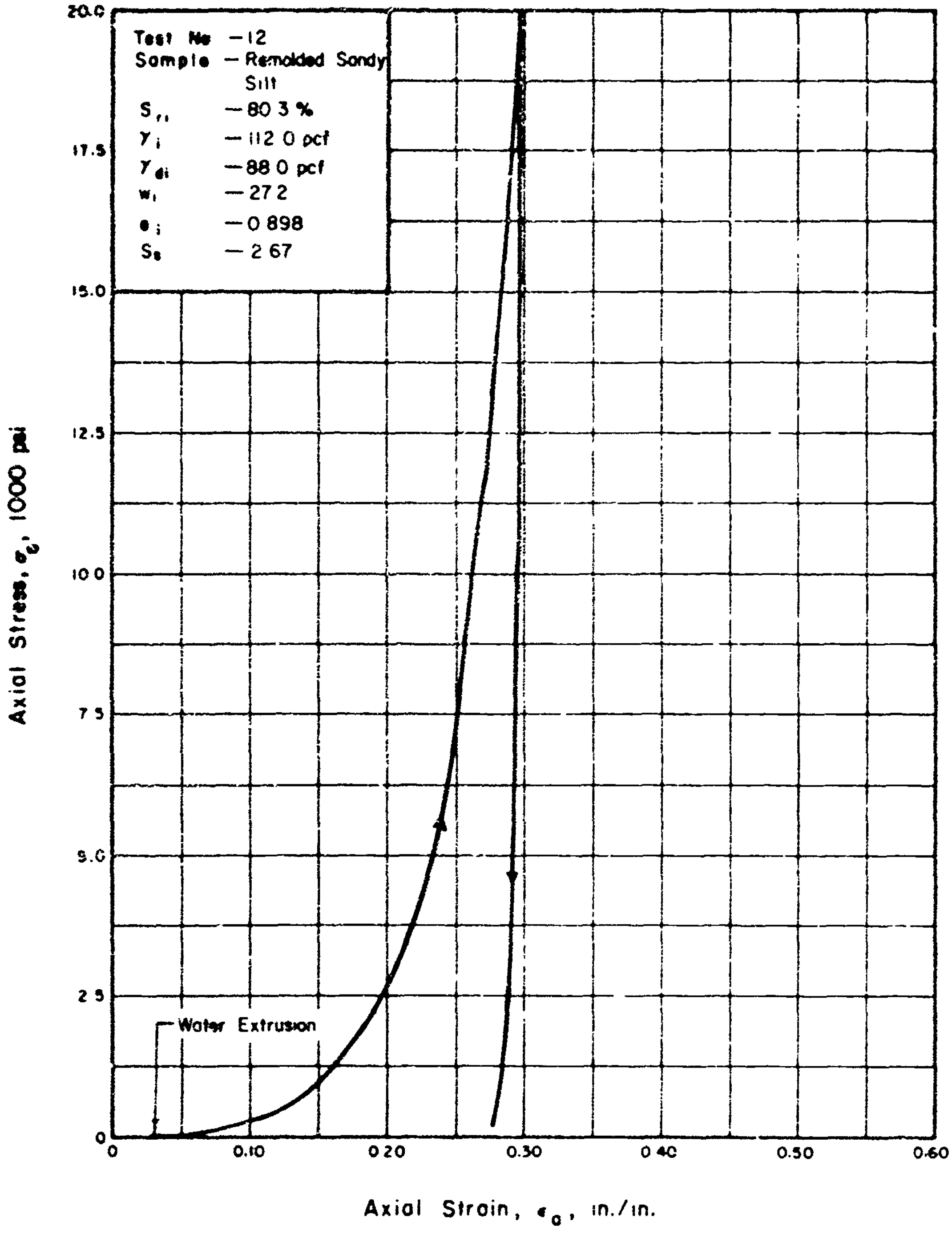

Fig. B12. Stress-strain relation in one-dimensional compression, test 12

APPENDIX C. CONSTRAINED MODULUS VERSUS AXIAL STRESS

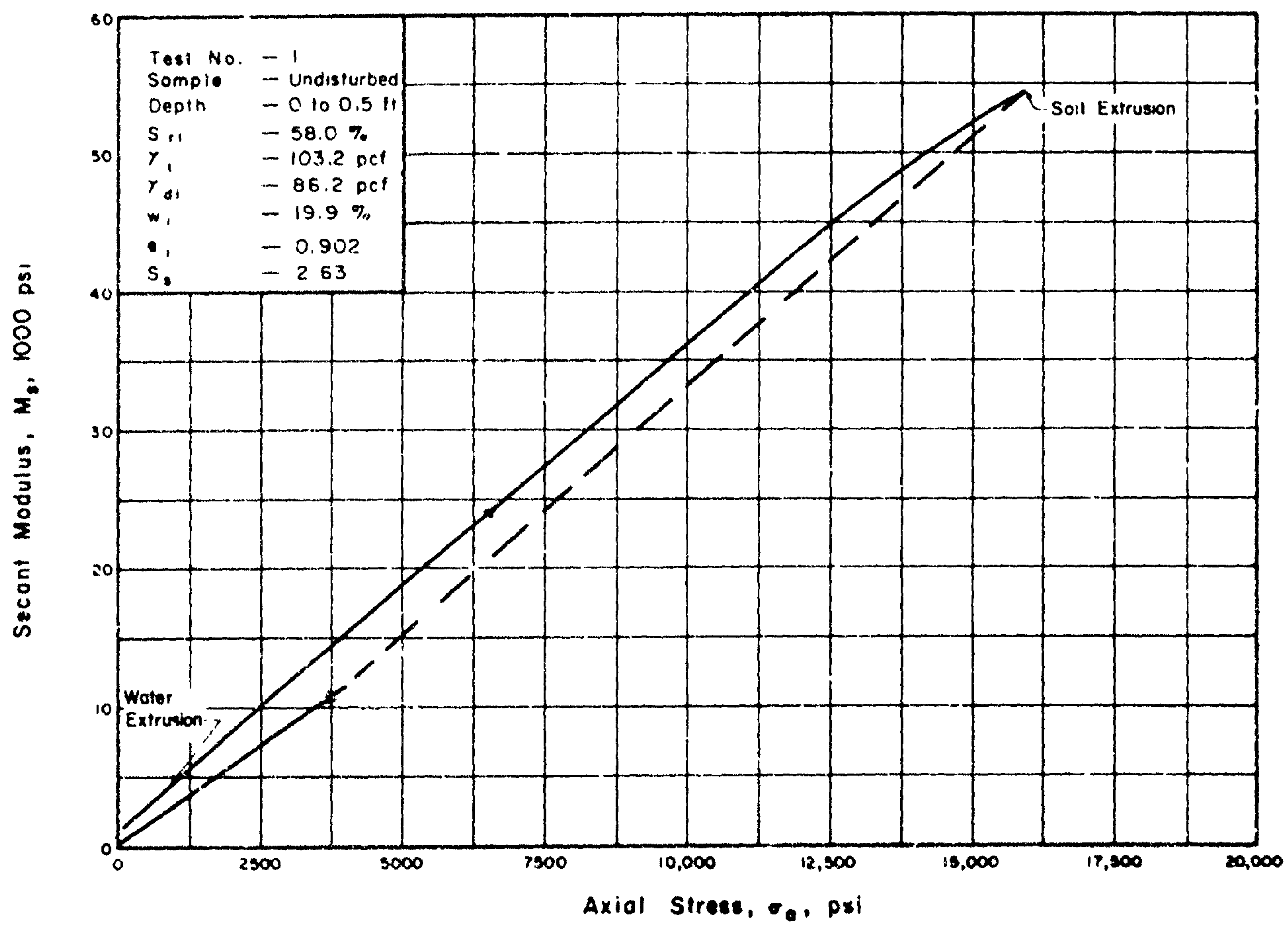

Fig C1 Relation between secant modulus and axial stress, test 1

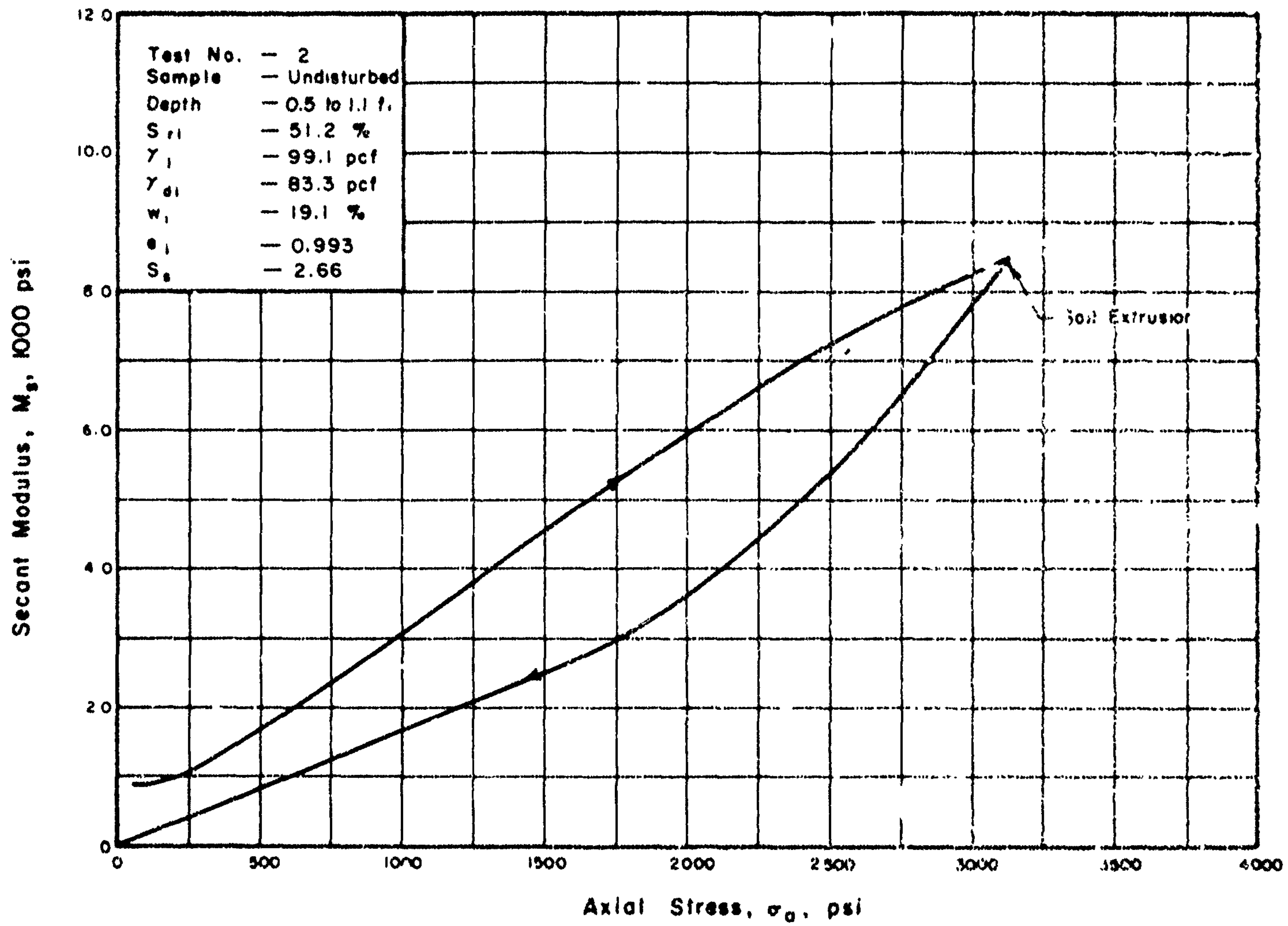

Fig. C2. Relation between secant modulus and axial stress, test 2

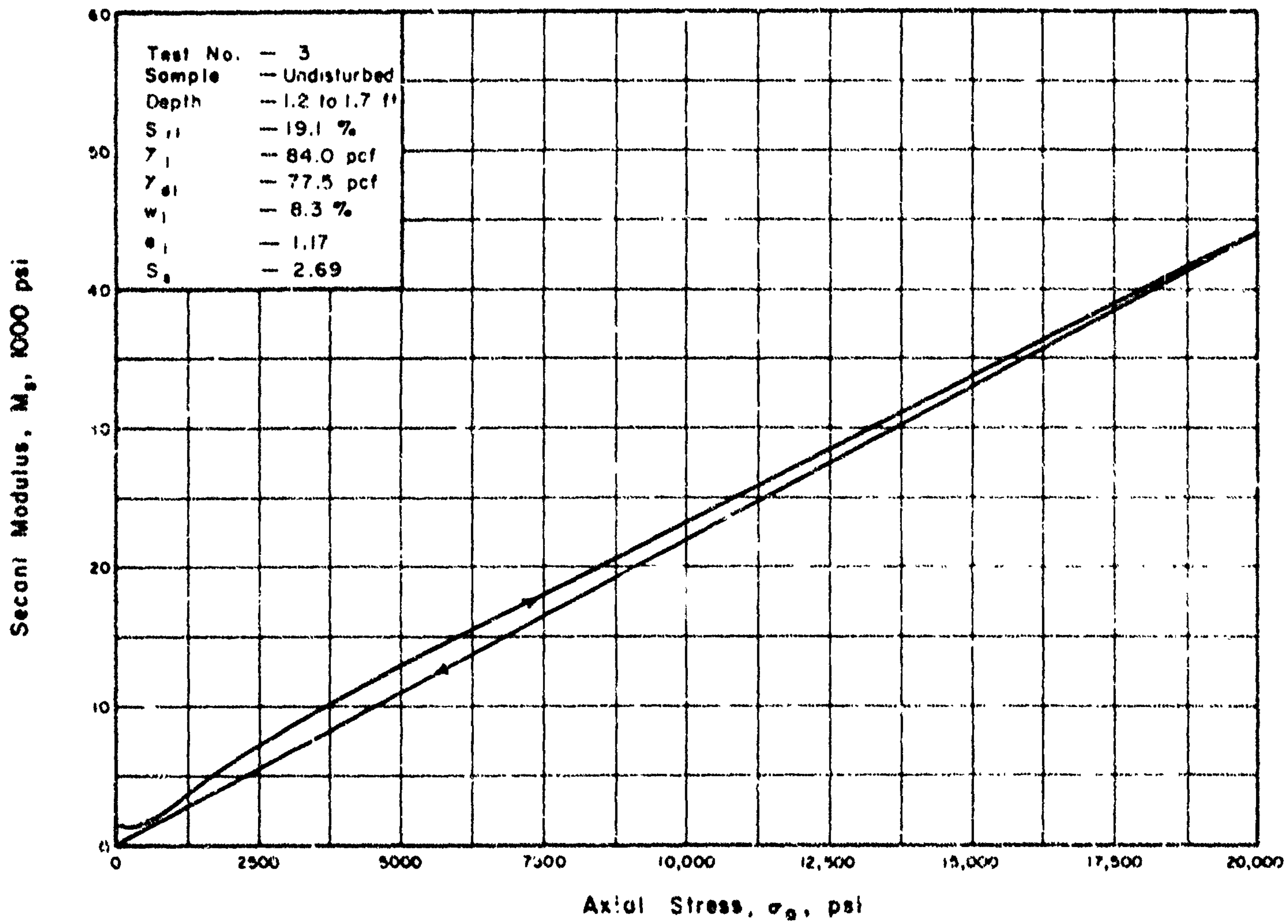

Fig. C3. Relation between secant modulus and axial stress, test 3

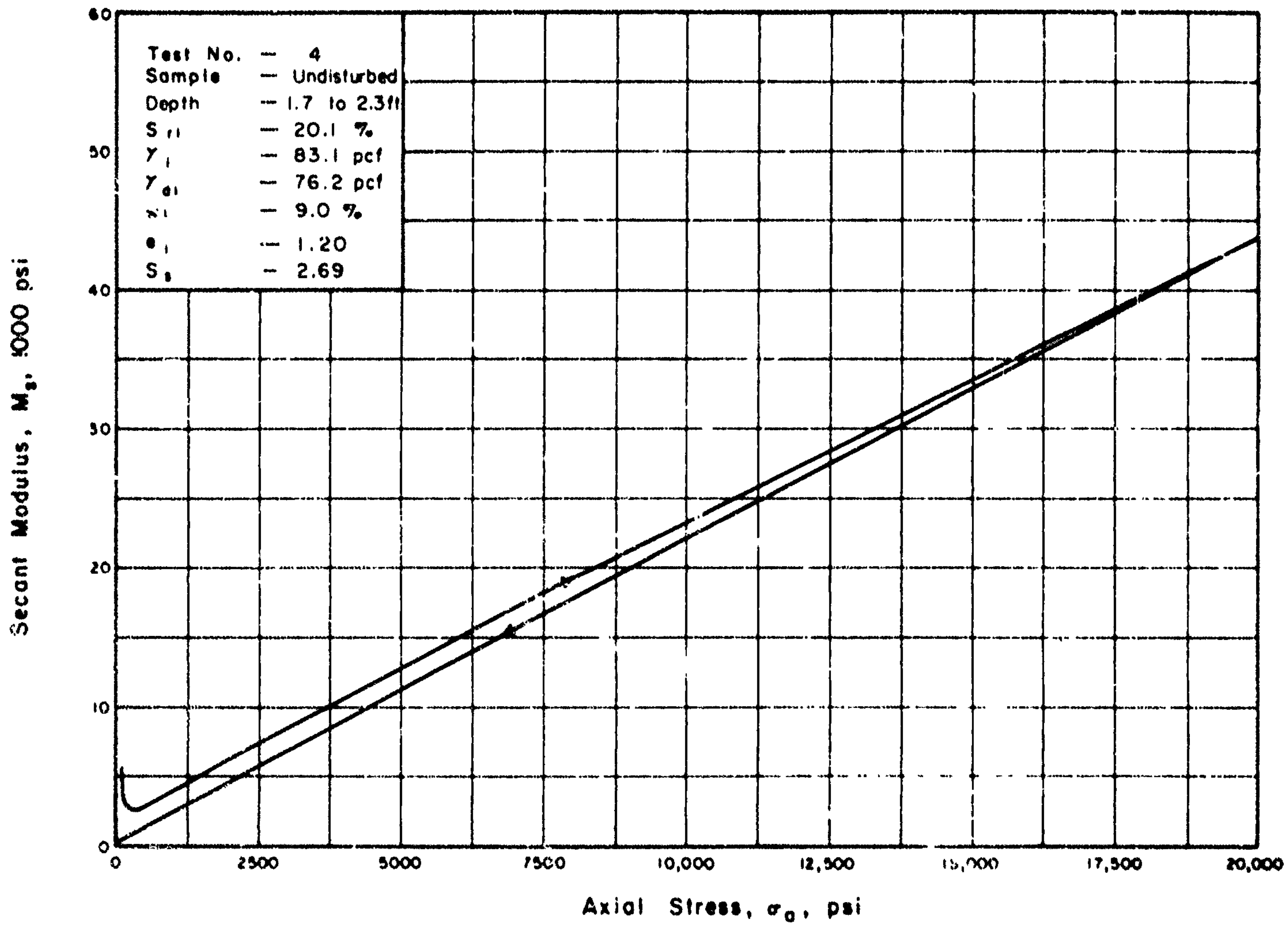

Fig. C4. Relation between secant modulus and axial stress, test 4

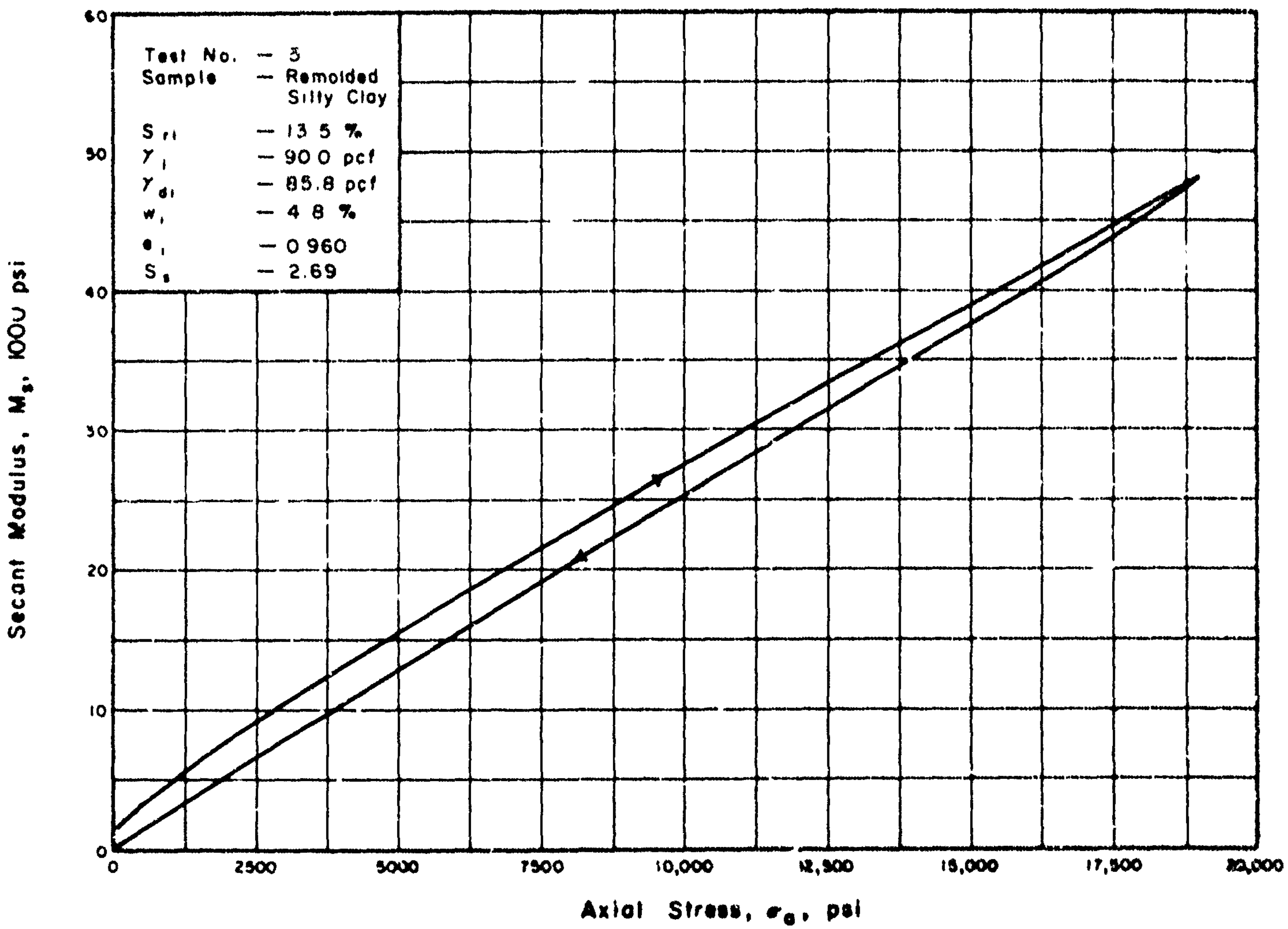

Fig. C5. Relation between secant modulus and axial stress, test 5

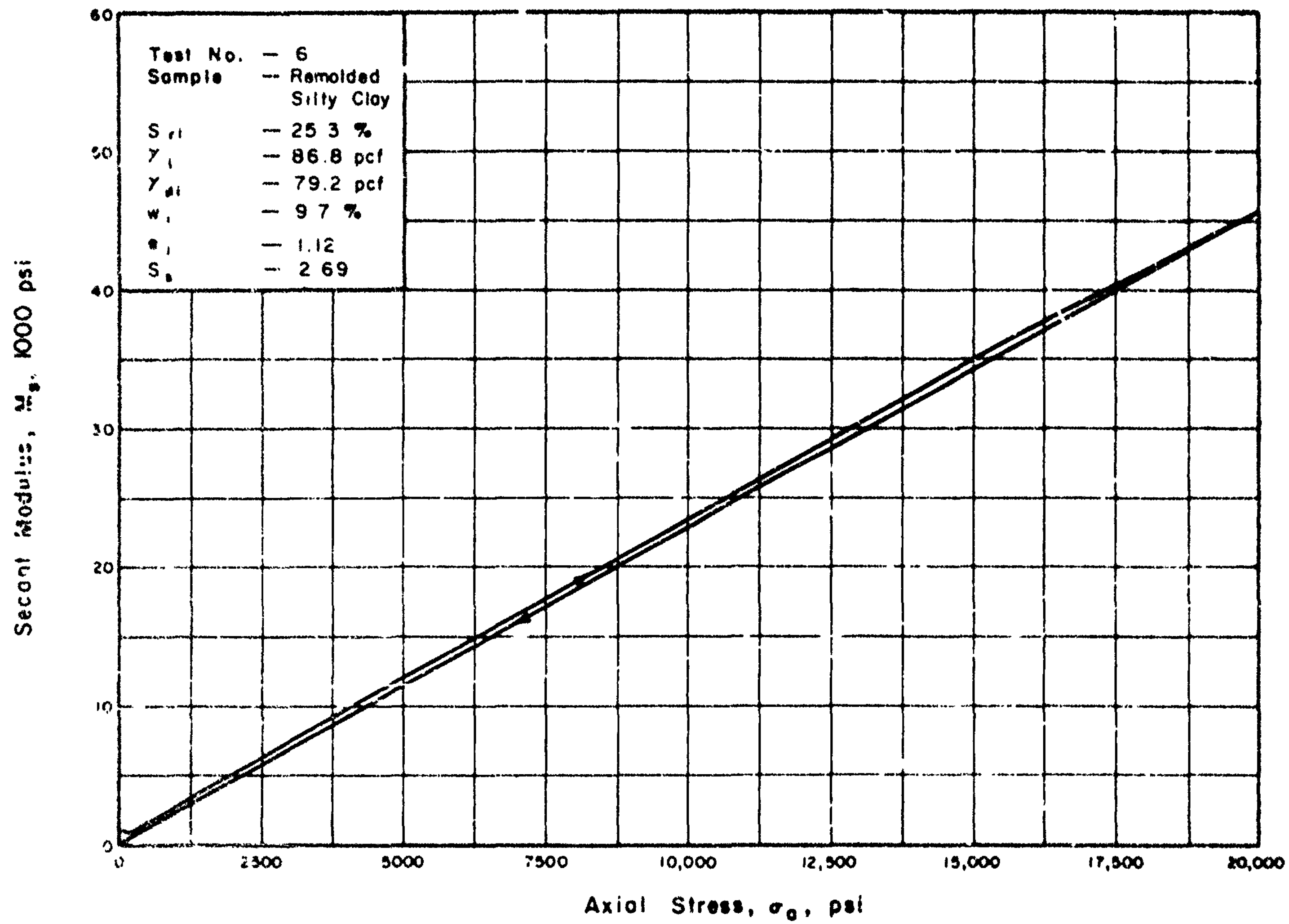

Fig. C6. Relation between secant modulus and axial stress, test 6

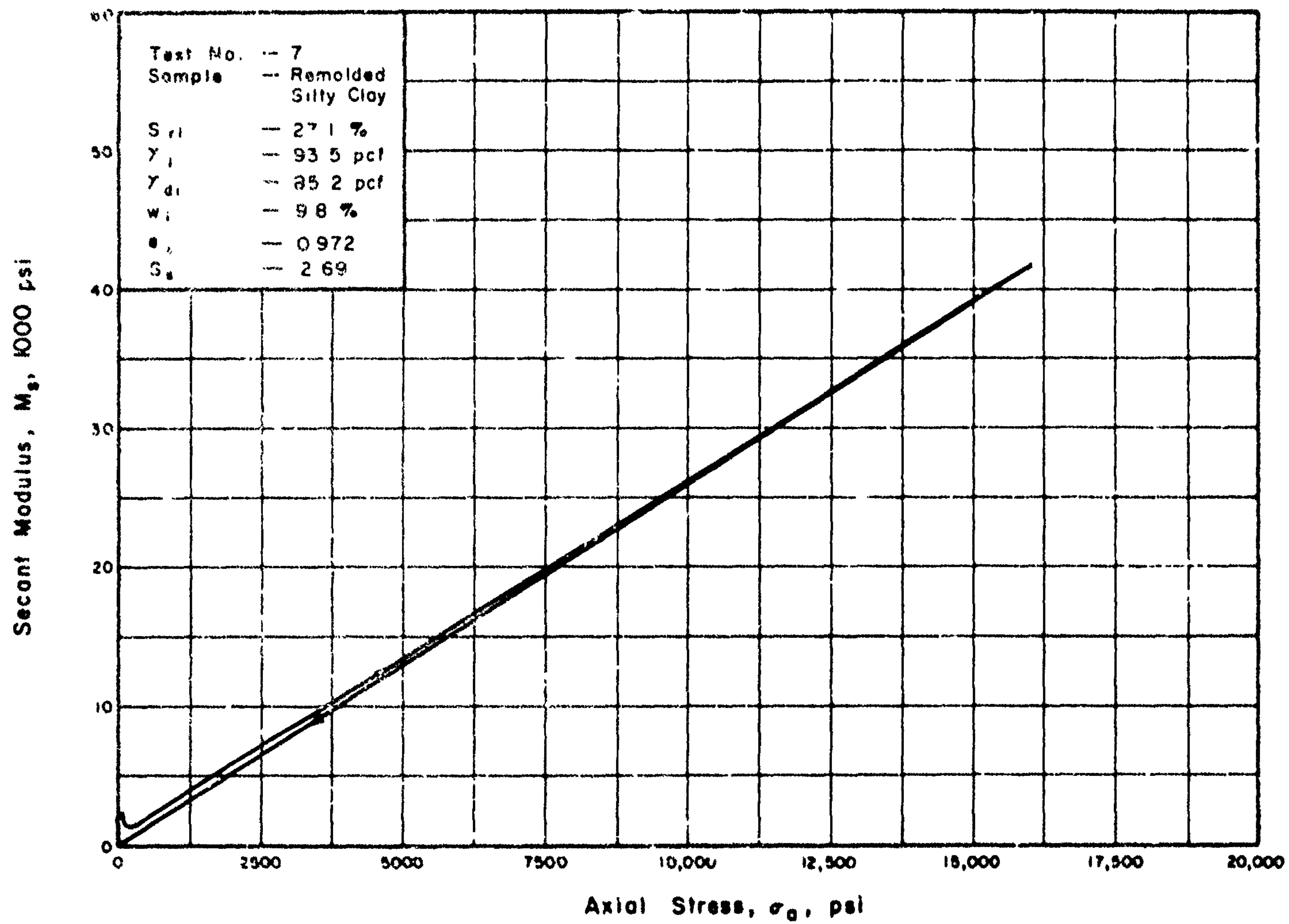

Fig. C7. Relation between secant modulus and axial stress, test 7

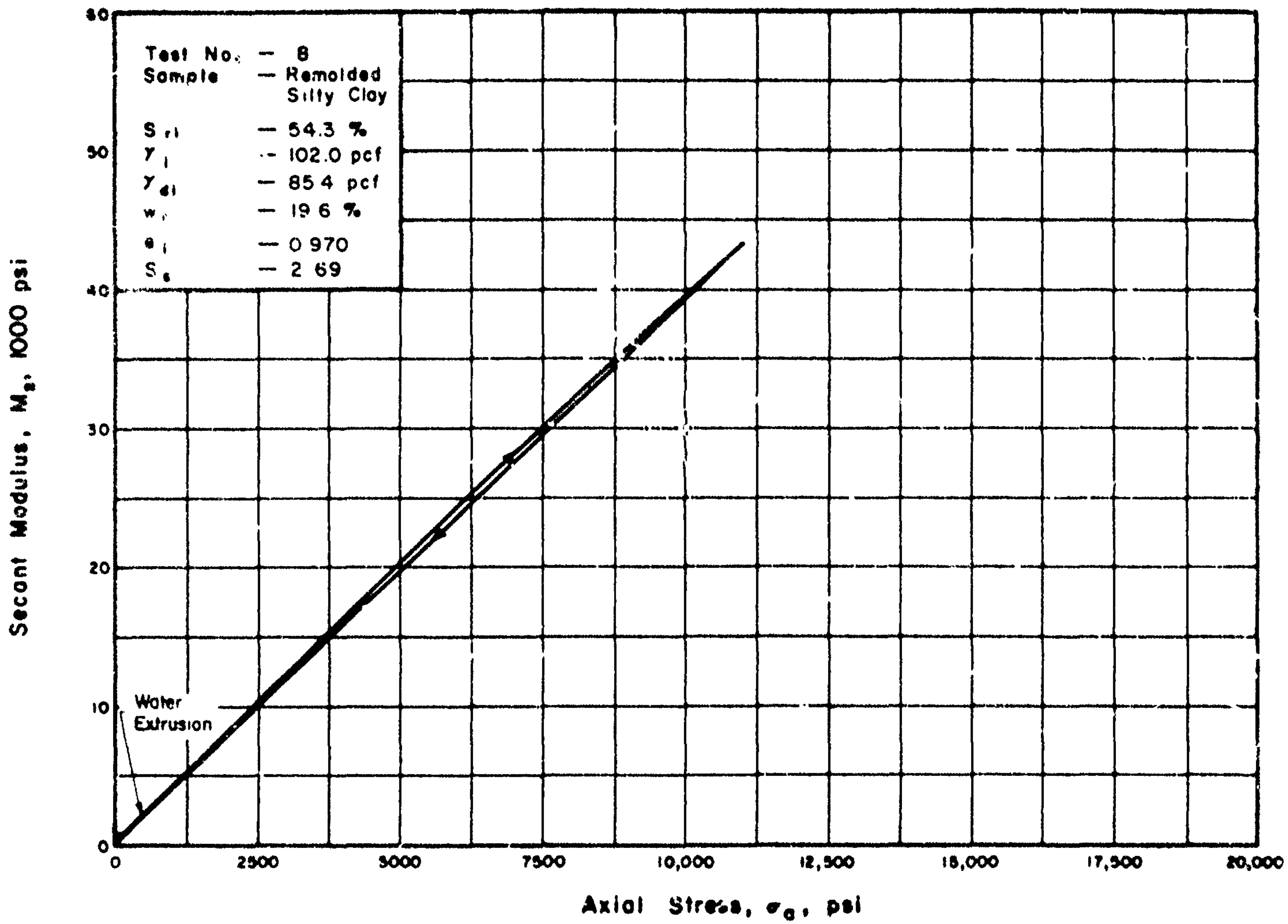

Fig. C8. Relation between secant modulus and axial stress, test 8

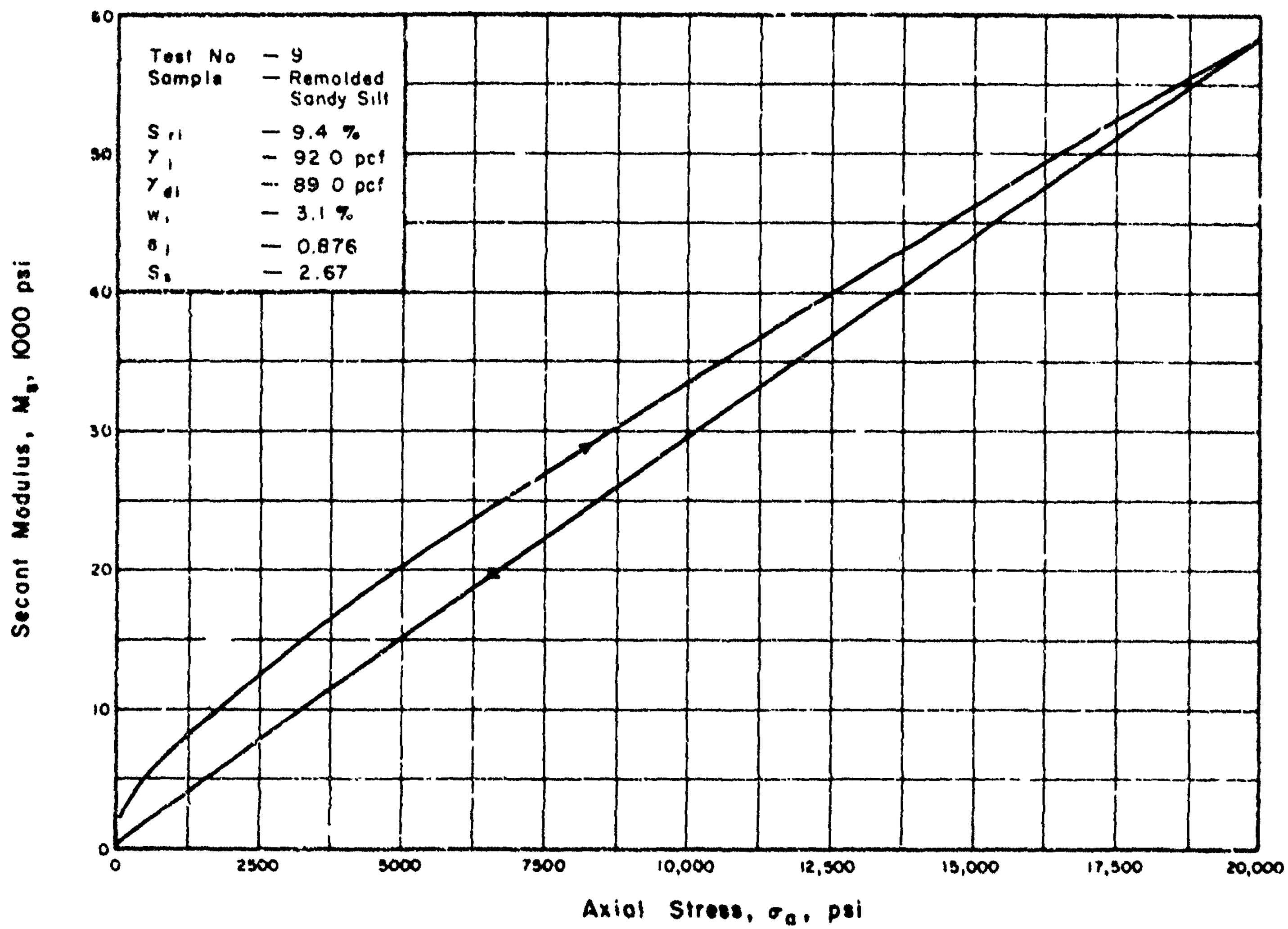

Fig. C9. Relation between secant modulus and axial stress, test 9

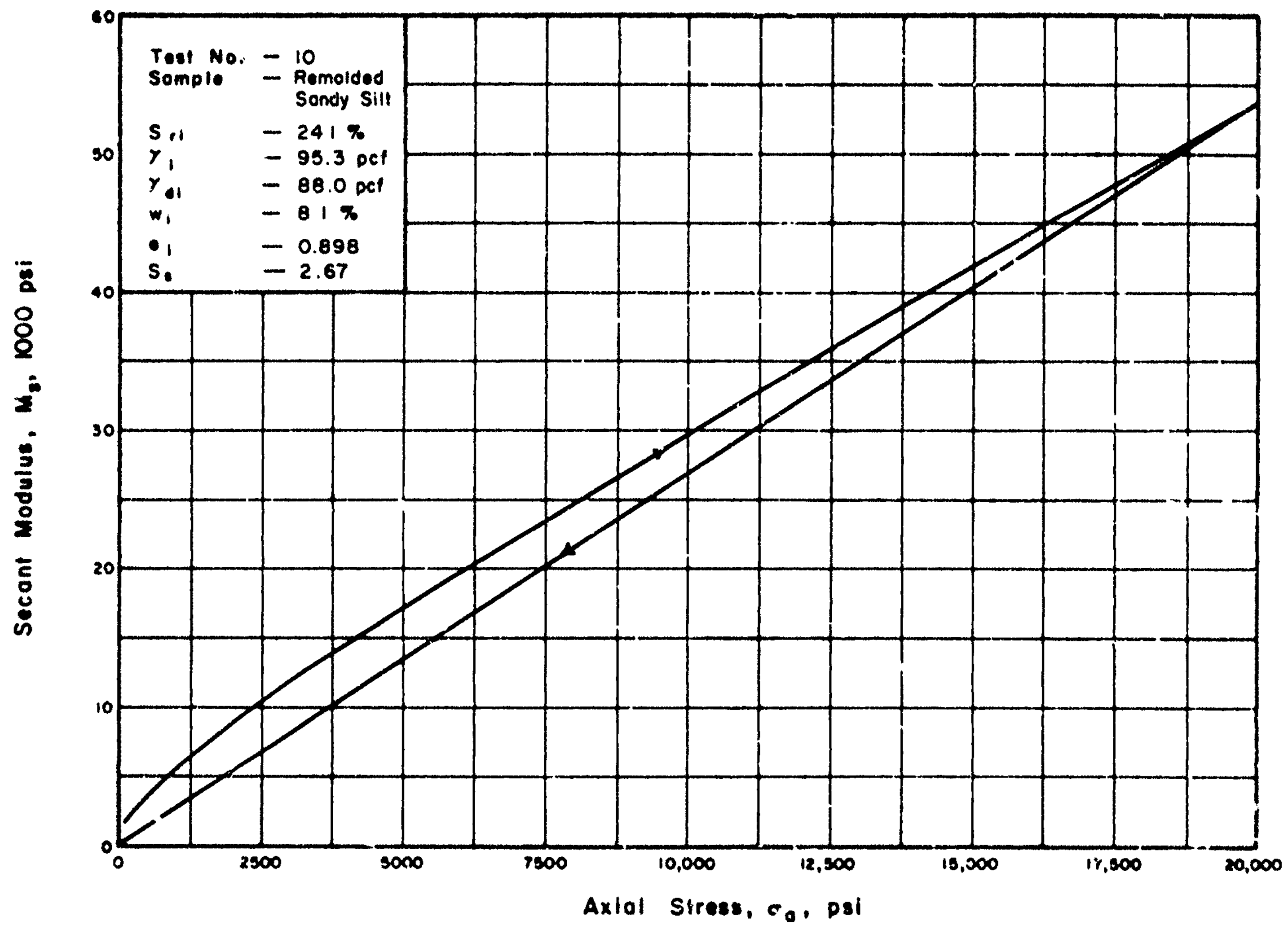

Fig. C10. Relation between secant modulus and axial stress test 10

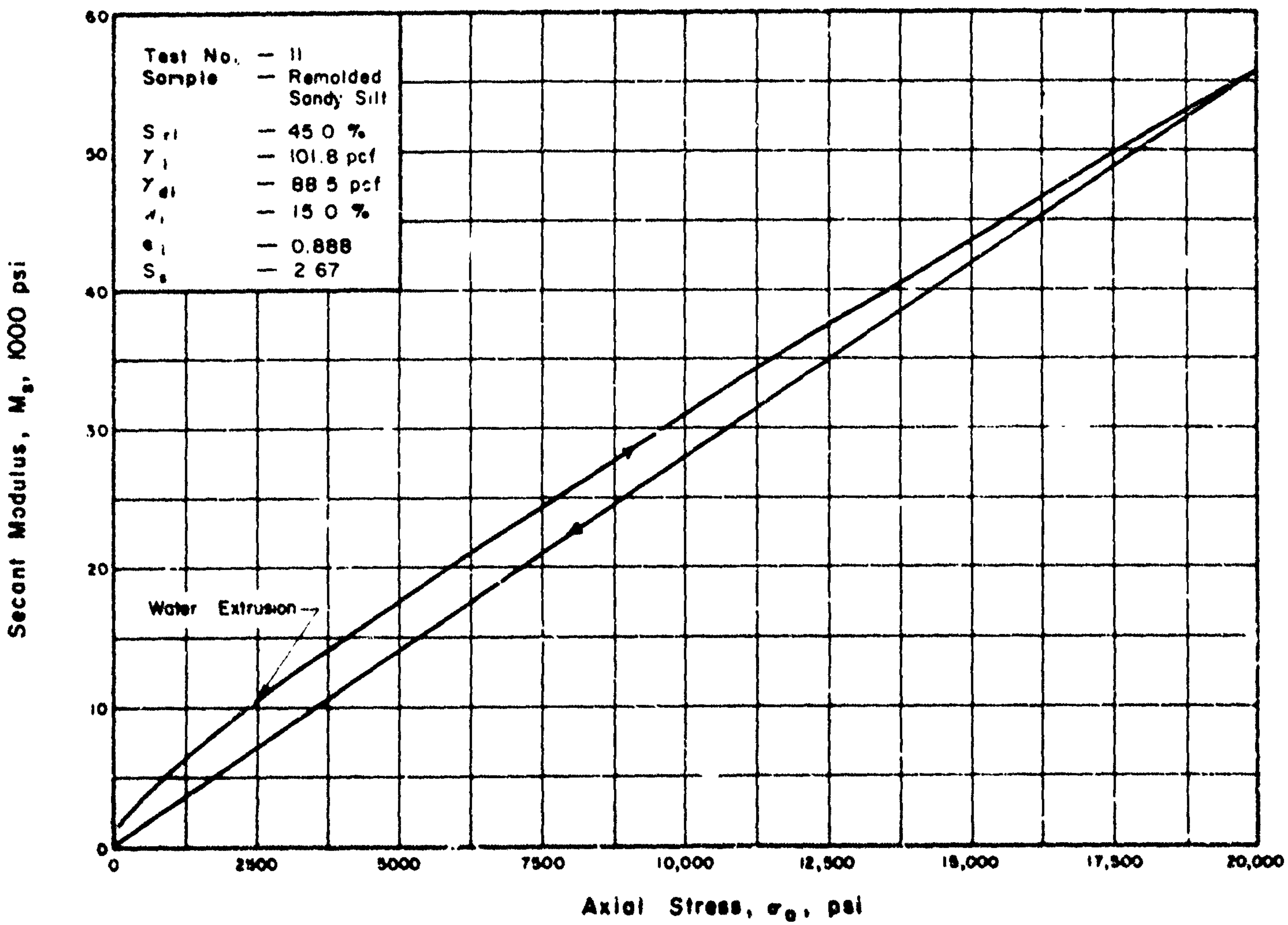

Fig. C11. Relation between secant modulus and axial stress, test 11

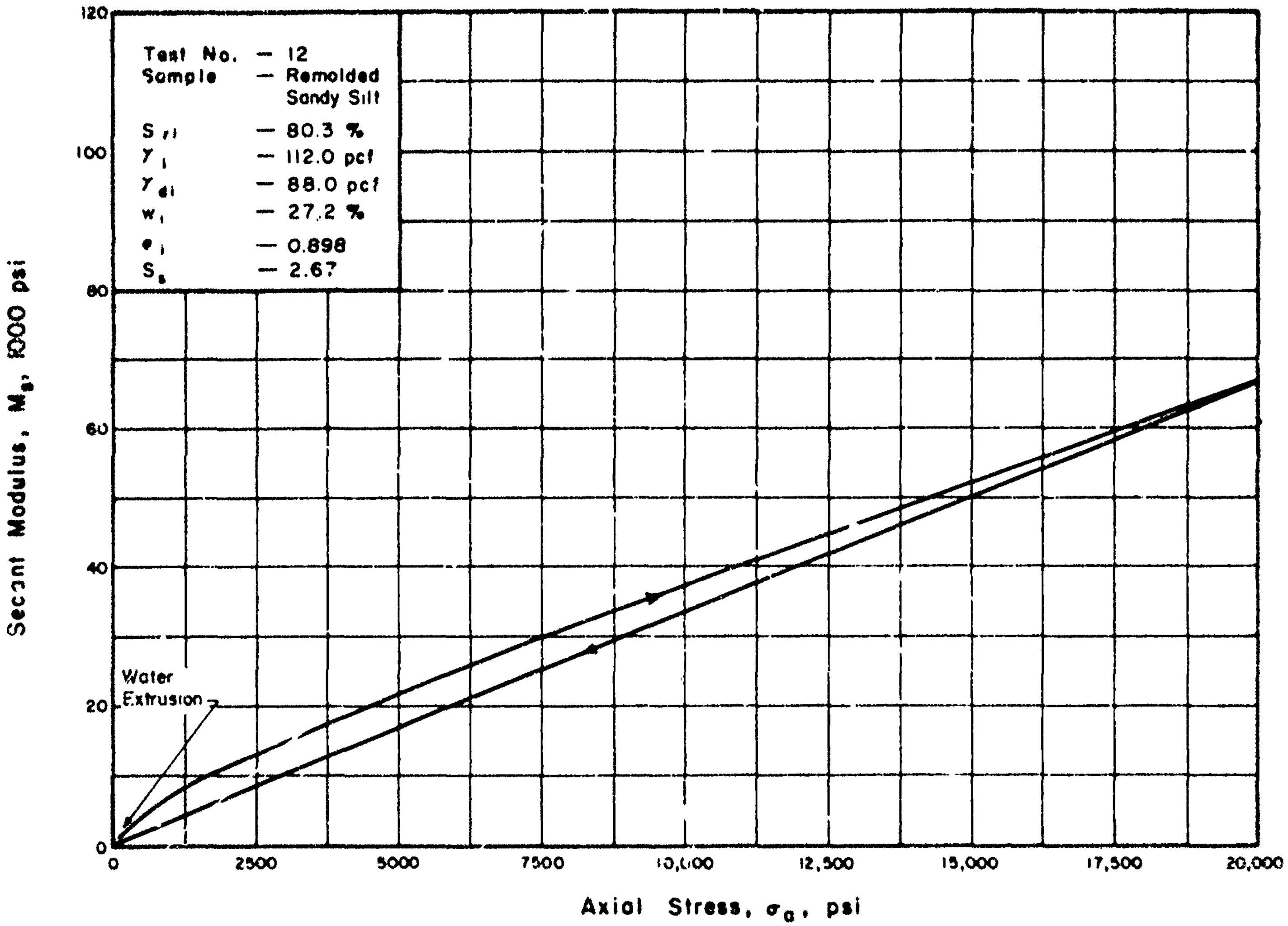

Fig C12. Relation between secant modulus and axial stress, test 12

APPENDIX D RADIAL STRESS VERSUS AXIAL STRESS

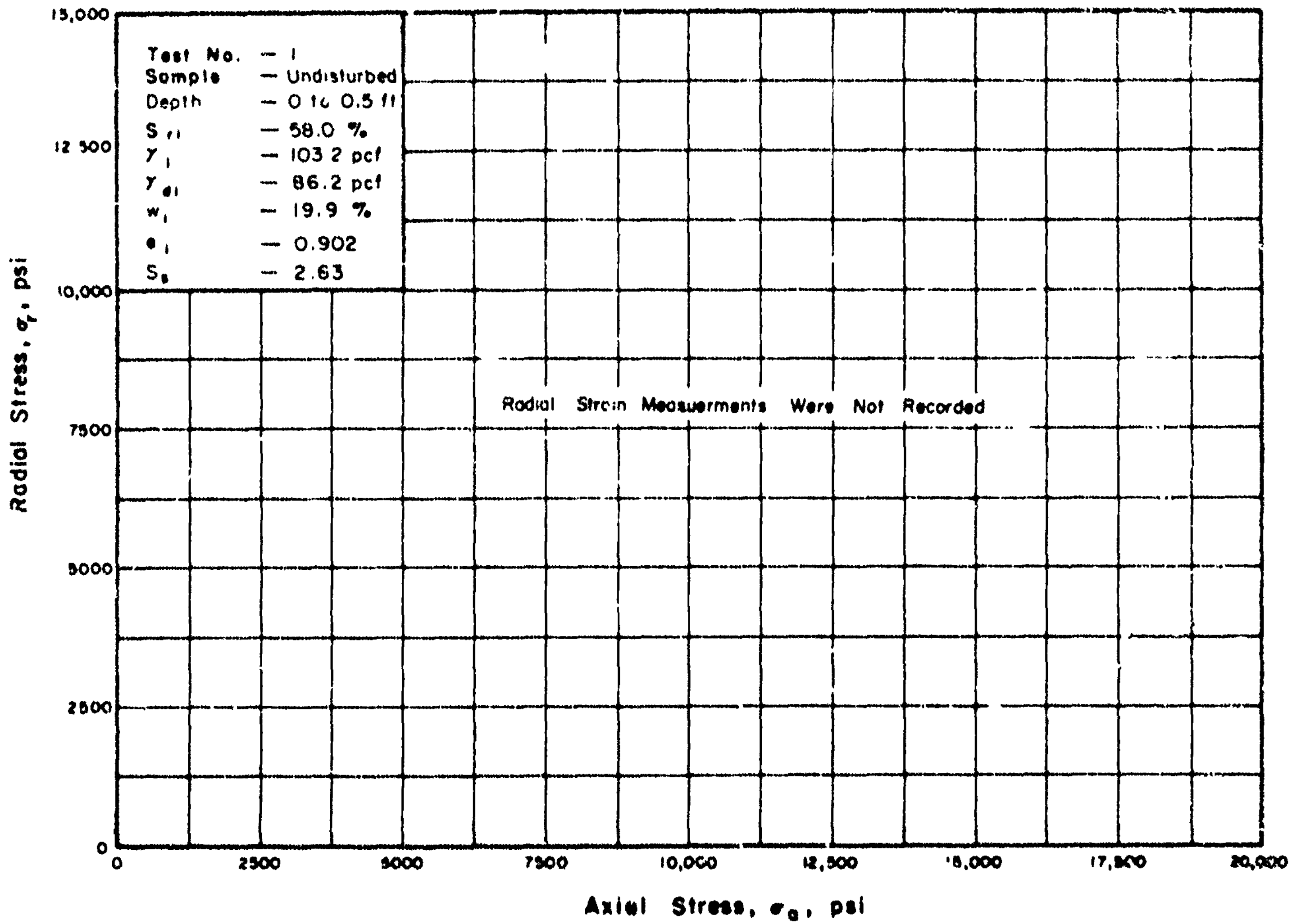

Fig. D1. Relation between radial and axial stress, test 1

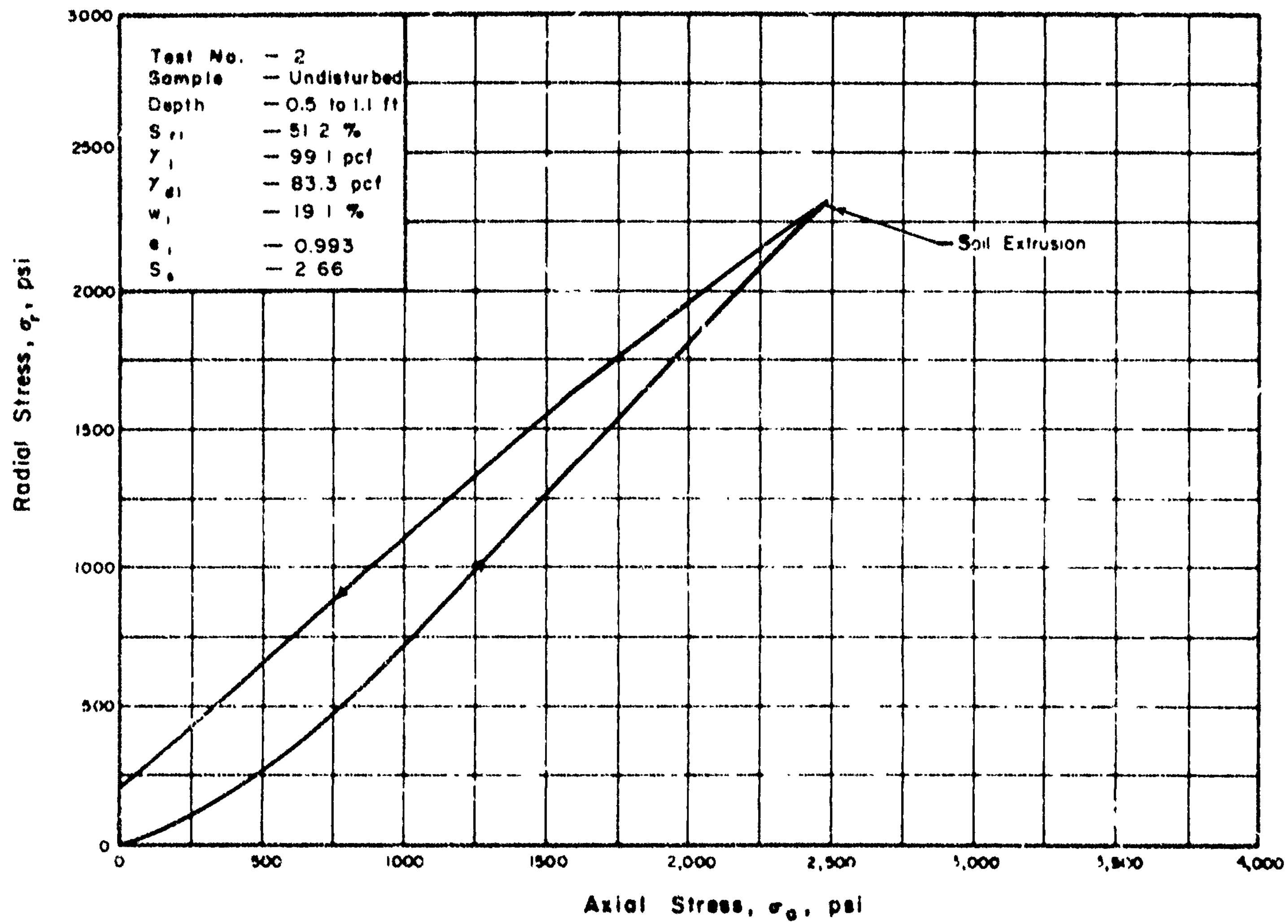

Fig D2 Relation between radial and axial stress, test 2

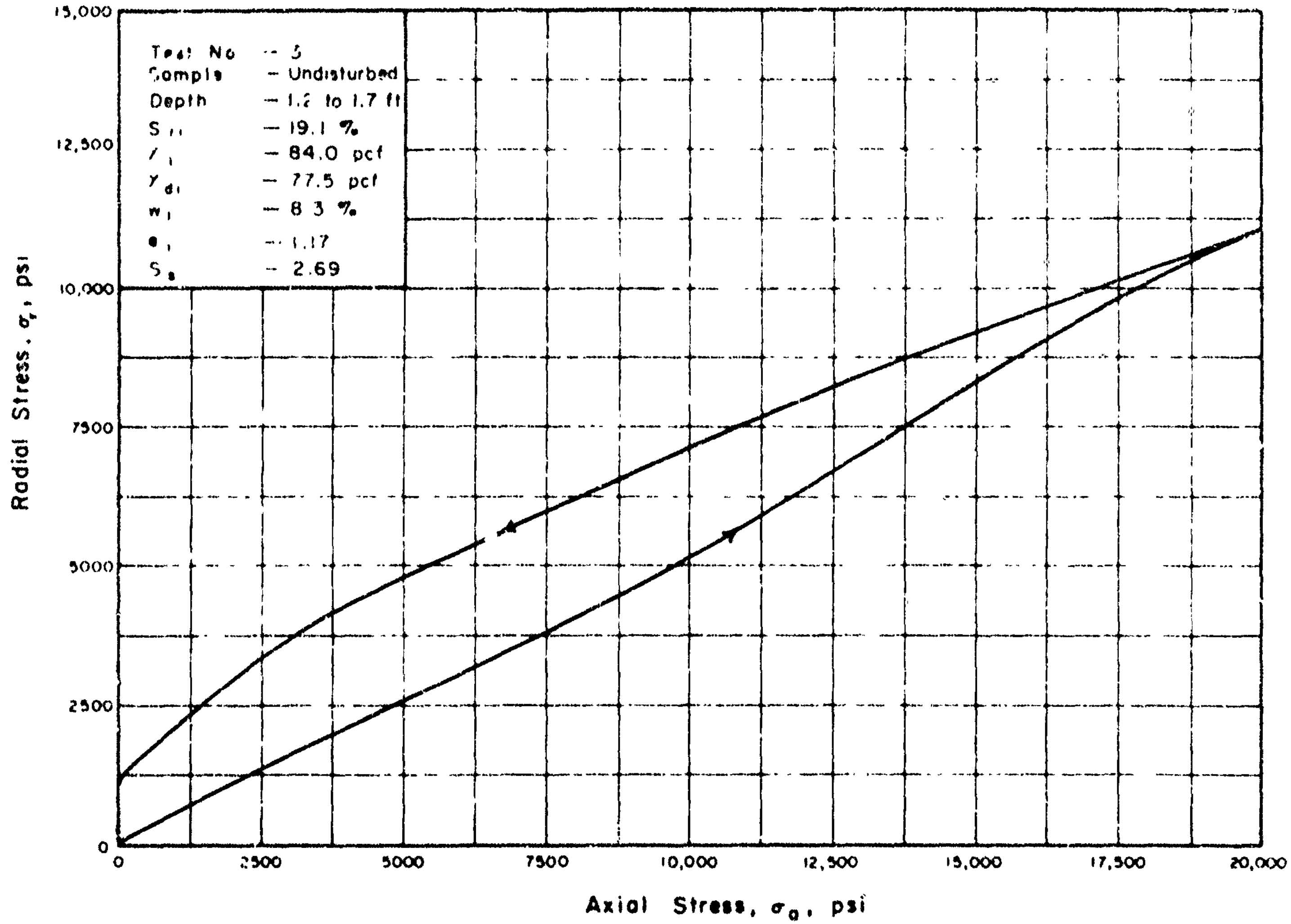

Fig. D3. Relation between radial and axial stress, test 3

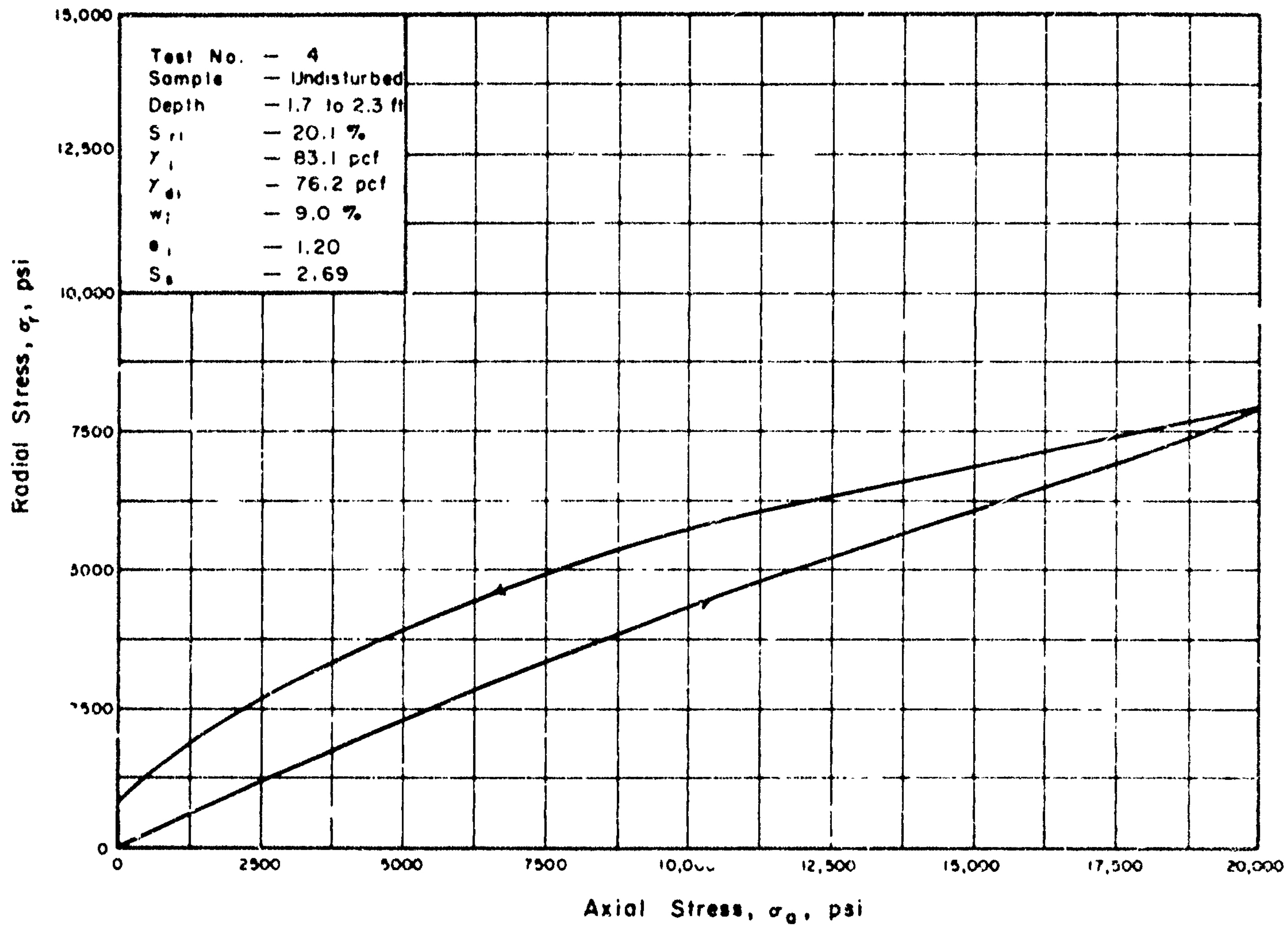

Fig. D4. Relation between radial and axial stress, test 4

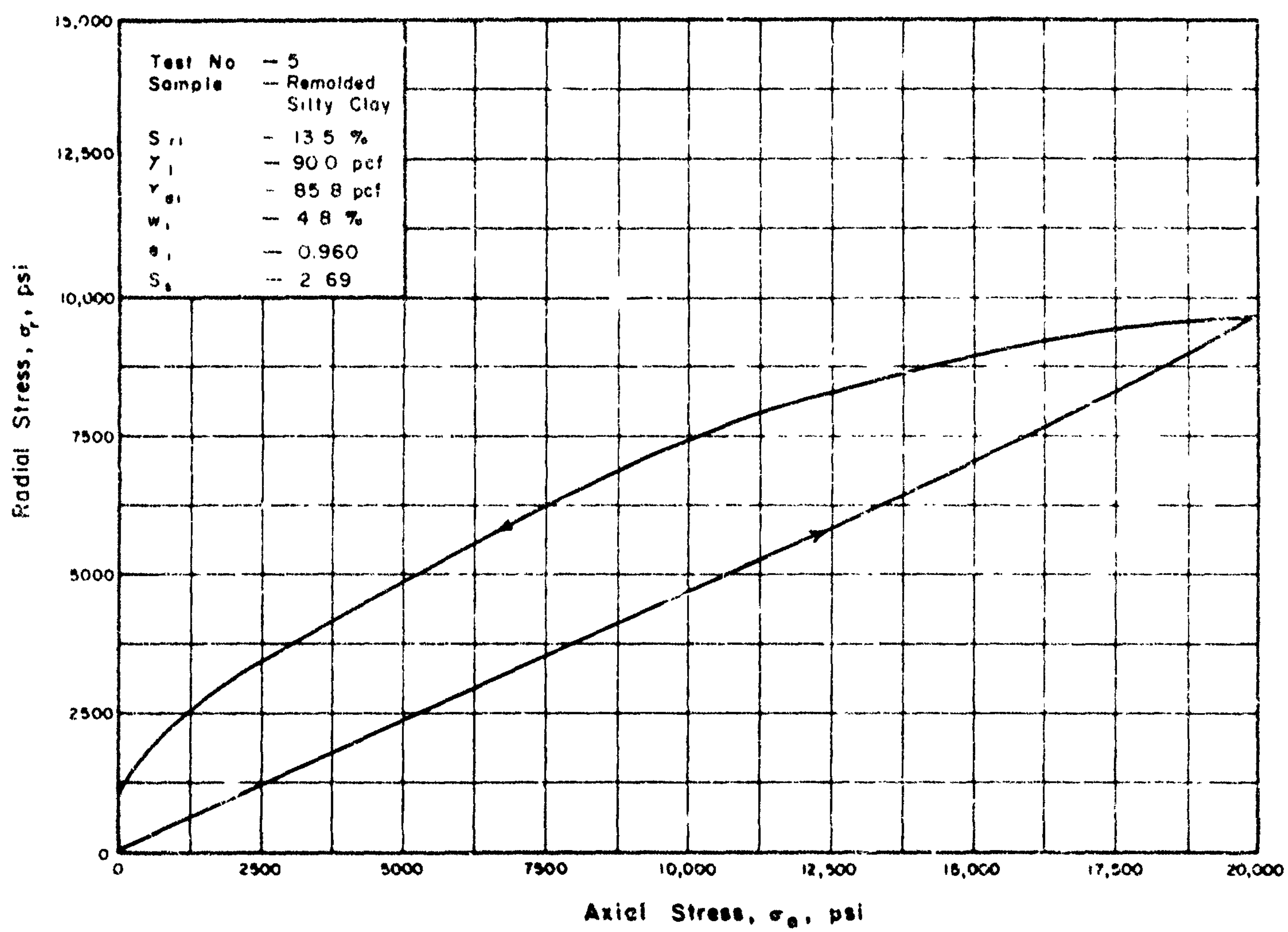

Fig. D5. Relation between radial and axial stress, test 5

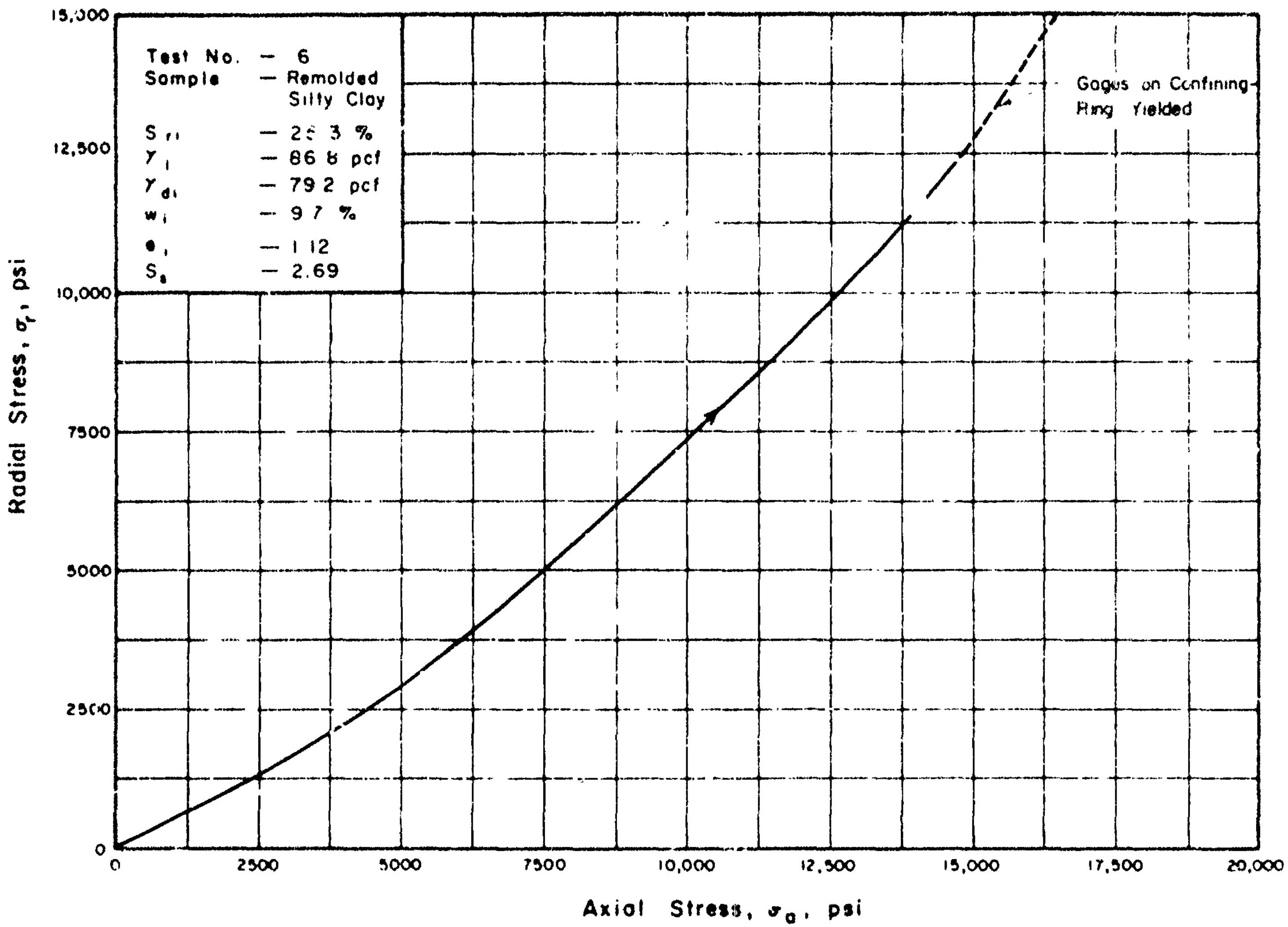

Fig. D6. Relation between radial and axial stress, test 6

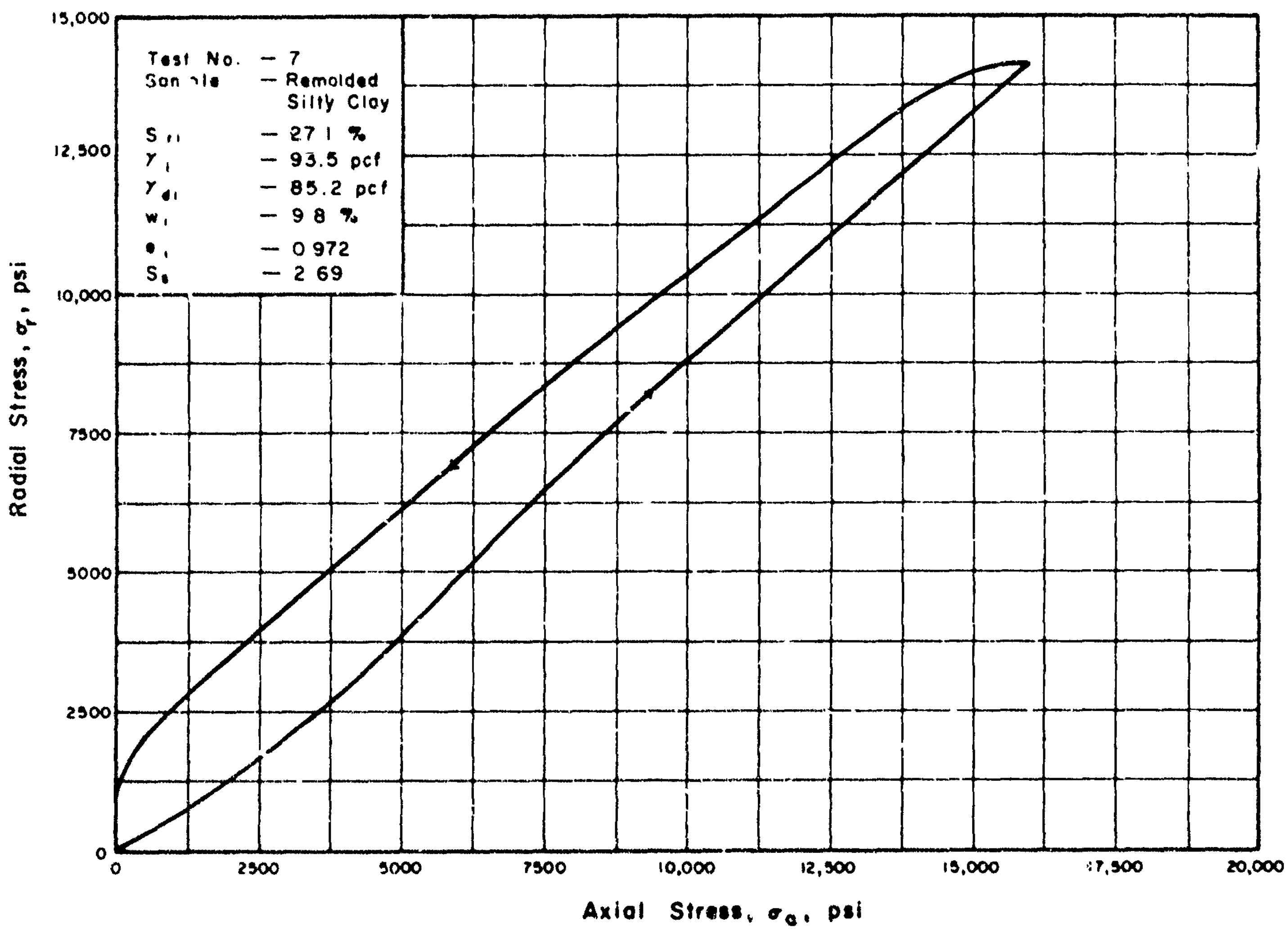

Fig. D7. Relation between radial and axial stress, test 7

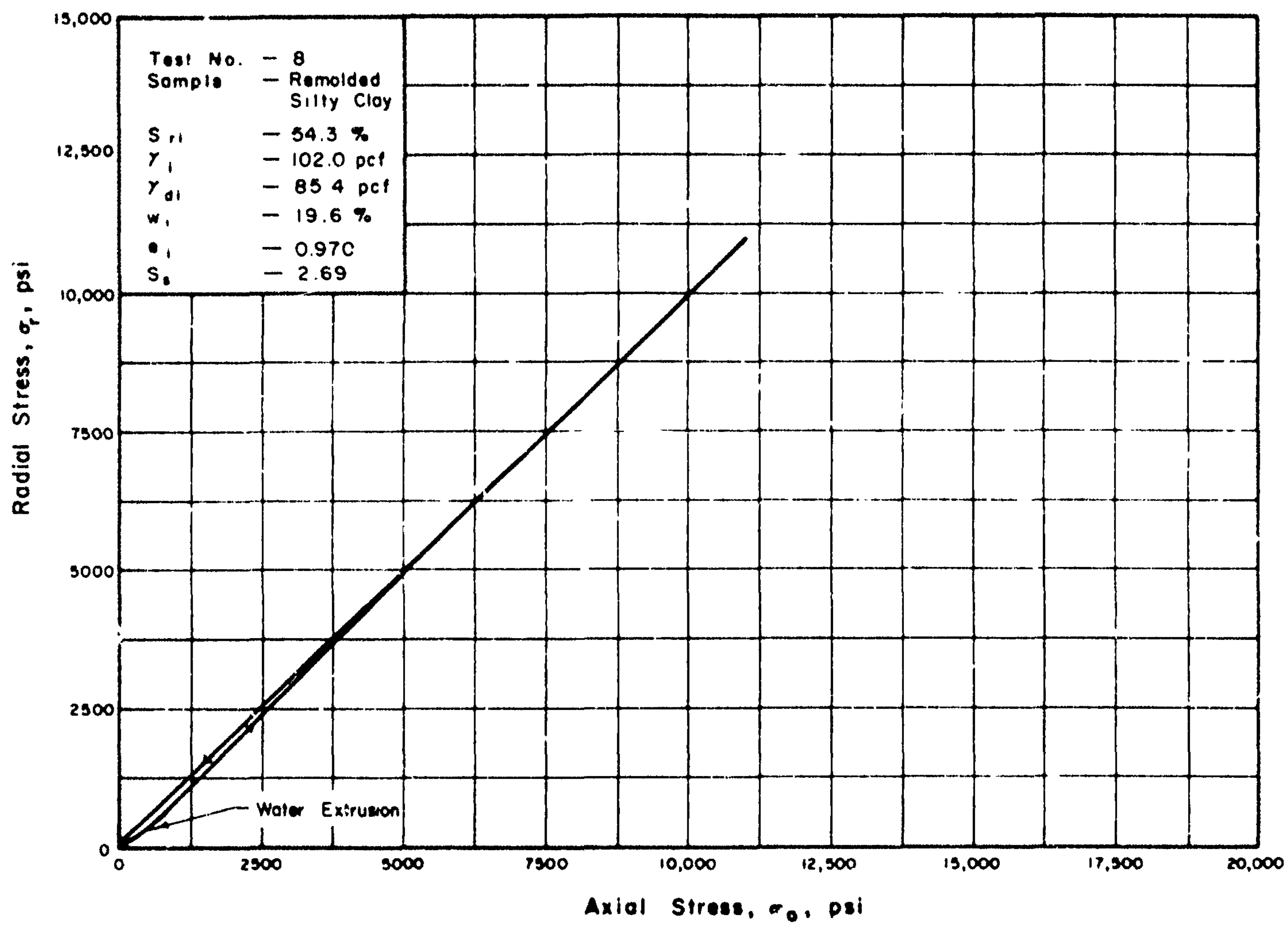

Fig. D8. Relation between radial and axial stress, test 8

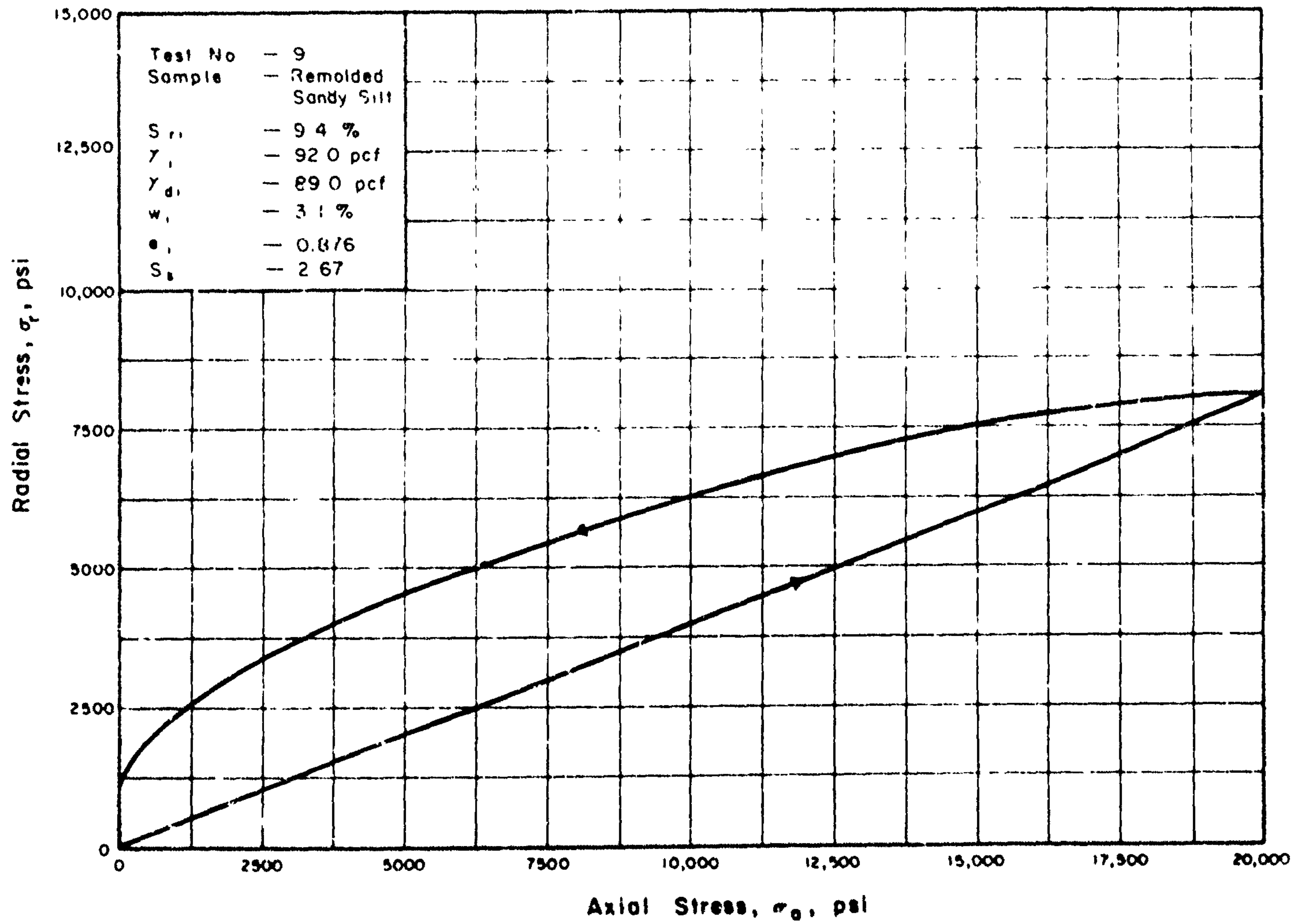

Fig. D9. Relation between radial and axial stress, test 9

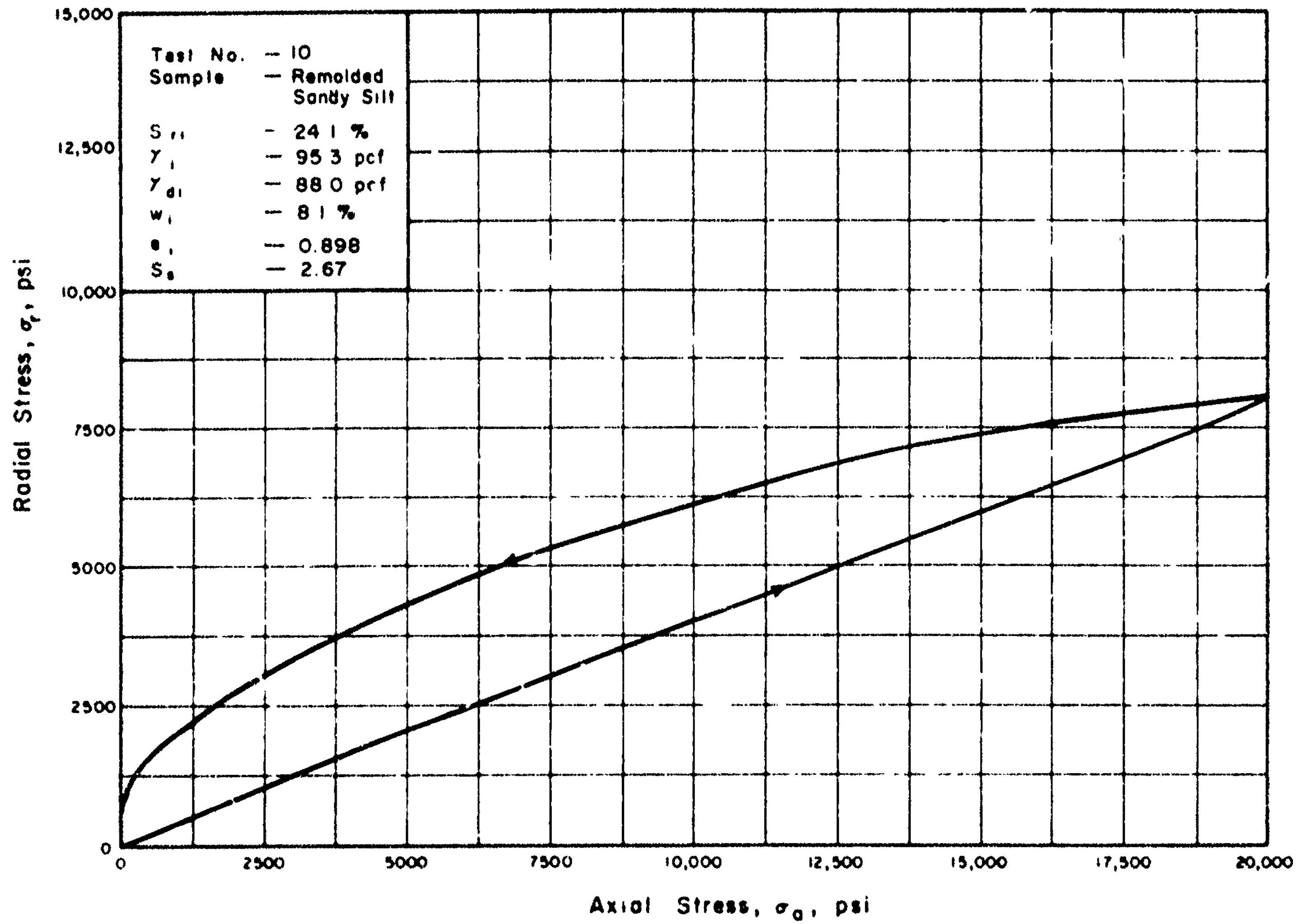

Fig. D10 Relation between radial and axial stress, test 10

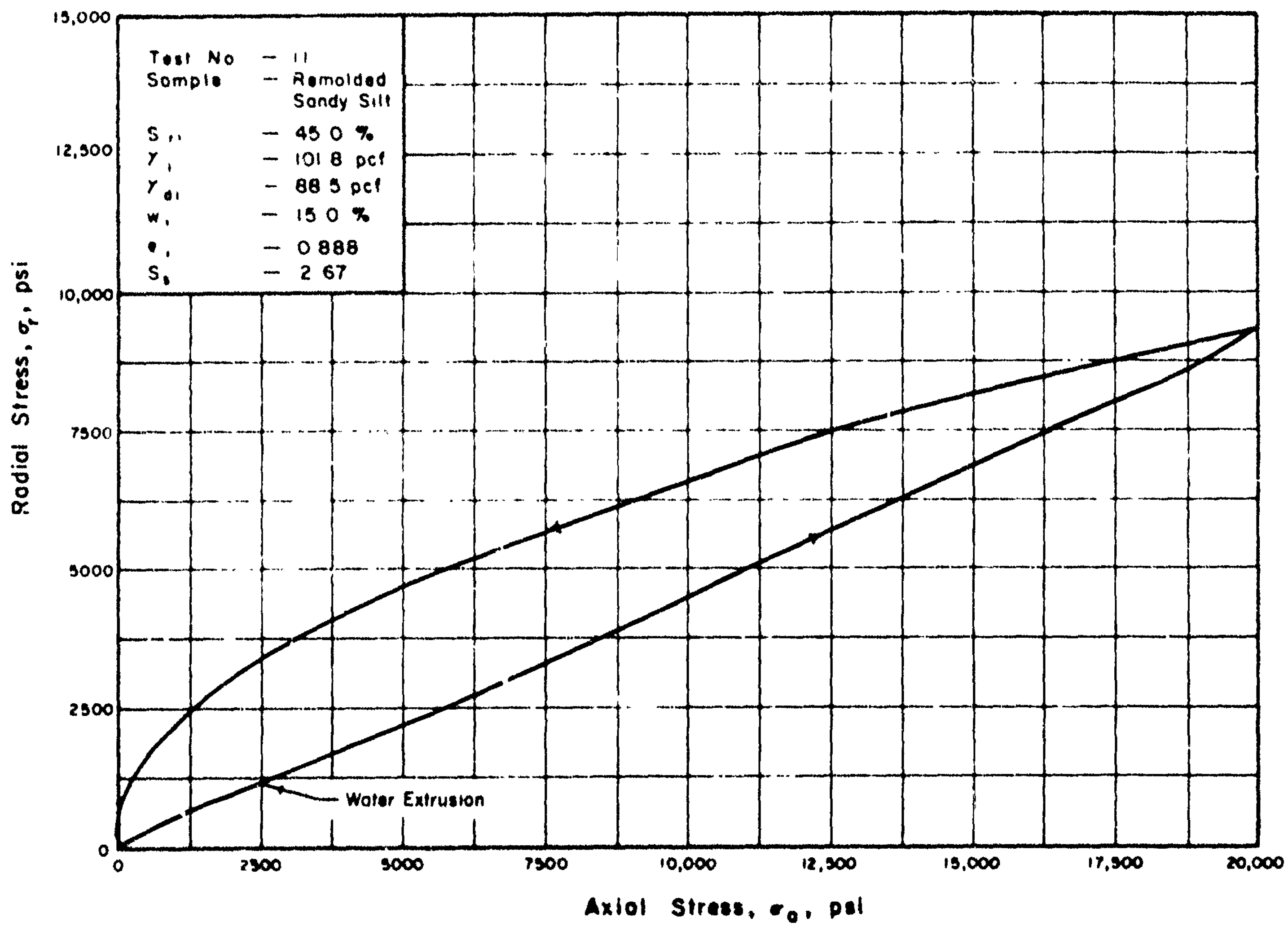

Fig. D11. Relation between radial and axial stress, test 11

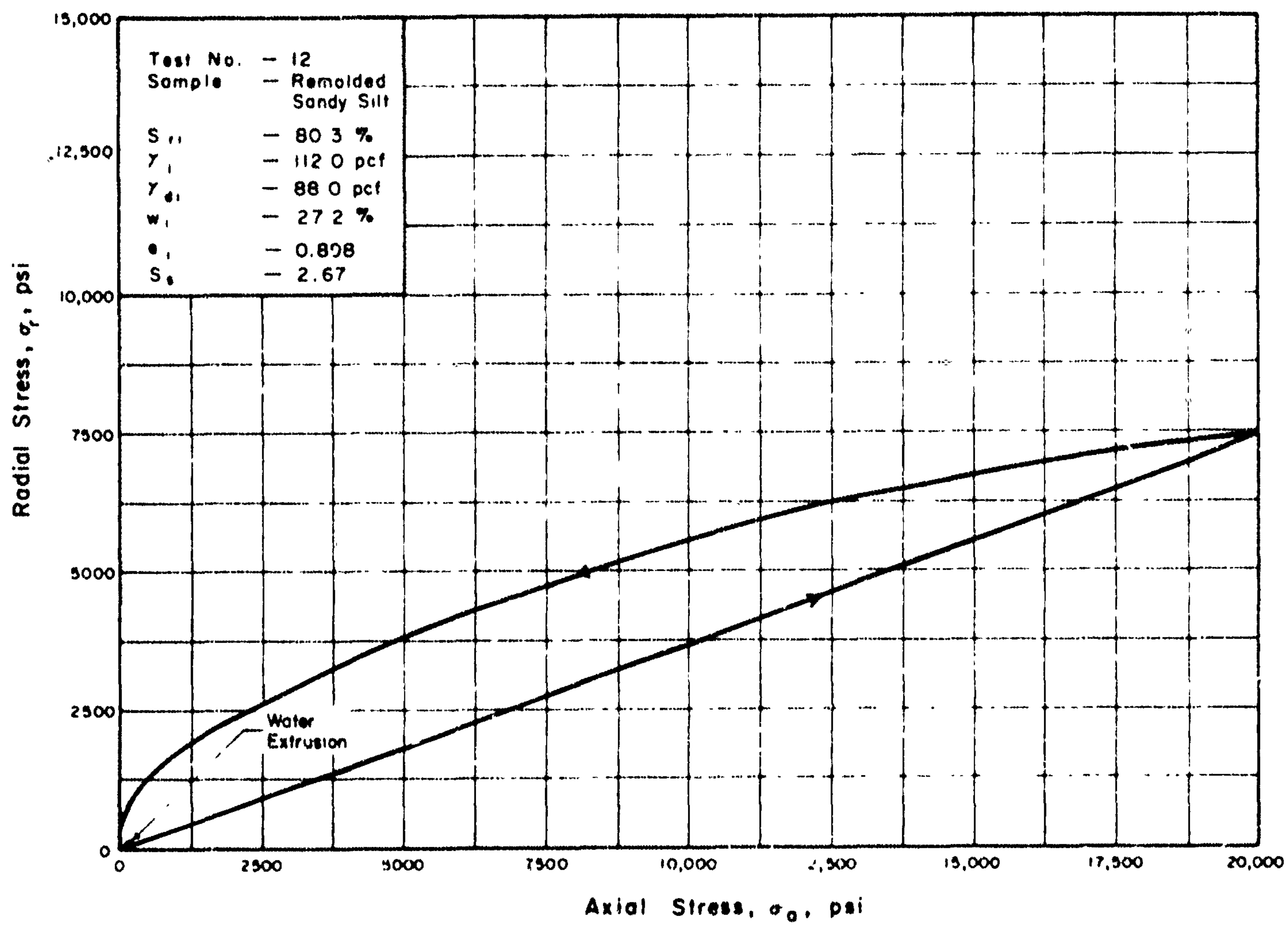

Fig. D12. Relation between radial and axial stress test 12

APPENDIX E: TABULATED DATA FOR THREE-DIMENSIONAL STRESS-STRAIN RELATIONS

ONE-DIMENSIONAL STATIC TEST DATA

Test No 1 Soil Type Undisturbed Silty Clay Soil Location Depth 0-0.5 ft. Boring 2-U, Distant Plain 6

w 19.9 % S_r 58.0 % γ_t 103.2 pcf γ_d 86.2 pcf G_s 2.63 e 0.902

w_L 37 % P_w 19 % Classification Brown Silty Clay w/ sand & trace of organic matter (CL)

$\frac{\sigma_a+2\sigma_r}{3}$	$\frac{\epsilon_a}{3}$	$\frac{\sqrt{2}}{3}(\sigma_a-\sigma_r)$	Radial Stress σ_r	Degree of Saturation S_r	$\frac{\sigma_a+2\sigma_r}{3}$	ϵ_a	$\frac{\sqrt{2}}{3}(\sigma_a-\sigma_r)$	Radial Stress σ_r	Degree of Saturation S_r
psi	in/in	psi	psi	%	psi	in/in	psi	psi	%
Note: Radial Stresses were not recorded for this test.									

Fig E1

ONE-DIMENSIONAL STATIC TEST DATA

Test No ___2___ Soil Type *Undisturbed Silty Clay* Soil Location *Depth 0.5 - 1.1 ft. Boring 2-U, Distant Plain 6*

w_i *19.1* % S_{ri} *51.2* % γ_i *99.1* pcf γ_{di} *83.3* pcf S_s *2.66* e_i *0.993*

L_w *38* % P_w *18* % Classification *Brown Silty Clay w/ trace of sand (CL)*

$\frac{\sigma_a + 2\sigma_r}{3}$	$\frac{\epsilon_a}{3}$	$\frac{\sqrt{2}}{3}(\sigma_a - \sigma_r)$	Radial Stress σ_r	Degree of Saturation S_r	$\frac{\sigma_a + 2\sigma_r}{3}$	$\frac{\epsilon_a}{3}$	$\frac{\sqrt{2}}{3}(\sigma_a - \sigma_r)$	Radial Stress σ_r	Degree of Saturation S_r
psi	in/in	psi	psi	%	psi	in/in	psi	psi	%
0	0	0							
3	0.003	5							
23	0.018	19							
66	0.040	24							
132	0.063	48							
187	0.074	80							
273	0.080	90							
342	0.083	114							
438	0.085	114							
609	0.086	134							
905	0.087	137							
1360	0.089	99							
1890	0.092	80							
2390	0.098	75							
	Soil Extrusion								
1990	0.125	9							
1520	0.149	-19							
1070	0.162	-56							
890	0.162	-63							
700	0.162	-71							
472	0.162	-75							
410	0.162	-79							
3[illegible]	0.162	-82							
232	0.161	-93							
204	0.161	-107							
150	0.161	-100							
147	0.159	-114							

Fig. E2

ONE-DIMENSIONAL STATIC TEST DATA

Test No 3 Soil Type Undisturbed Silty Clay Soil Location Depth 1.2 - 1.7 ft Boring 2-U, Distant Plain 6

w_i 8.3 % S_{ri} 19.1 % γ_i 84.0 pcf γ_{di} 77.5 pcf S_s 2.69 e_i 1.170

L_w 42 % P_w 21 % Classification Brown Silty Clay (CL)

$\frac{\sigma_a+2\sigma_r}{3}$	$\frac{\epsilon_a}{3}$	$\frac{\sqrt{2}}{3}(\sigma_a-\sigma_r)$	Radial Stress σ_r	Degree of Saturation S_r
psi	in/in	psi	psi	%
0	0	0		
3	0.001	5		
36	0.005	10		
92	0.012	6		
152	0.030	34		
234	0.044	47		
311	0.056	63		
405	0.064	67		
458	0.071	100		
600	0.081	166		
735	0.088	163		
1100	0.101	280		
1430	0.109	405		
1800	0.115	495		
2090	0.120	640		
2390	0.123	780		
2740	0.126	875		
3440	0.131	1160		
4130	0.134	1400		
4710	0.137	1610		
5400	0.140	1840		
6050	0.141	2070		
—	0.143	—		
7400	0.145	2530		
8250	0.146	2640		
9100	0.147	2760		
9900	0.148	2880		
10700	0.149	3070		
11400	0.150	3270		
12100	0.150	3490		
12700	0.150	3720		
13300	0.151	4000		
14000	0.151	4240		
12500	0.151	3440		
11100	0.151	2740		
9500	0.151	1620		
8100	0.150	1350		
6820	0.150	825		
5500	0.149	350		
4150	0.148	-127		
2640	0.147	-452		
1800	0.145	-570		
1290	0.144	-560		
980	0.143	-550		
880	0.143	-550		
790	0.143	-520		
68[illegible]	0.141	-465		

Fig. E3

ONE-DIMENSIONAL STATIC TEST DATA

Test Nr 4 Soil Type Undisturbed Silty Clay Soil Location Depth 1.7- 2.3 ft. Boring 2-U, Distant Plain 6

w, 90 % S_{ri} 20.1 % γ, 83.1 pcf γ_{d}, 76.2 pcf S_s 2.69 e, 1.200

L_w 44 % P_w 23 % Classification Brown Silty Clay (CL)

$\frac{\sigma_1+2\sigma_r}{3}$	$\frac{\epsilon_a}{3}$	$\frac{\sqrt{2}}{3}(\sigma_a-\sigma_r)$	Radial Stress σ_r	Degree of Saturation S_r	$\frac{\sigma_1+2\sigma_r}{3}$	$\frac{\epsilon_a}{3}$	$\frac{\sqrt{2}}{3}(\sigma_a-\sigma_r)$	Radial Stress σ	Degree of Saturation S_r
psi	in/in	psi	psi	%	psi	in/in	psi	psi	%
0	0	0			10200	0.151	4800		
3	0.001	5			10700	0.151	5180		
23	0.003	19			11300	0.152	5470		
47	0.006	38			11850	0.152	5750		
135	0.022	46			10750	0.152	4720		
193	0.039	75			9550	0.152	3840		
277	0.053	87			9400	0.152	2900		
324	0.062	125			7150	0.151	2000		
376	0.070	157			4900	0.150	780		
525	0.080	192			3660	0.149	236		
680	0.087	226			2260	0.148	-193		
970	0.100	372			1580	0.146	-415		
1320	0.108	475			1110	0.146	-405		
1610	0.114	630			—	0.144	—		
1940	0.119	720			—	0.144	—		
2270	0.123	870			620	0.143	-410		
2570	0.126	1010			150	0.141	-390		
3230	0.130	1250							
3820	0.134	1540							
4440	0.137	1810							
5100	0.139	2040							
5630	0.141	2370							
6200	0.143	2670							
6750	0.145	3000							
7350	0.146	3250							
7950	0.148	3580							
8500	0.149	3900							
9020	0.150	4220							
9600	0.150	4500							

Fig. E4

ONE-DIMENSIONAL STATIC TEST DATA

Test No 5 Soil Type Remolded Silty Clay Soil Location Depth 0-5 ft. Bag Sample, Distant Plain 6

w_i 4.8 % S_{ri} 13.5 % γ_i 90.0 pcf γ_{di} 85.8 pcf S_s 2.69 e_i 0.960

L_w 34 % P_w 16 % Classification Brown Silty Clay (CL)

$\frac{\sigma_a + 2\sigma_r}{3}$	$\frac{\epsilon_a}{3}$	$\frac{\sqrt{2}}{3}(\sigma_a - \sigma_r)$	Radial Stress σ_r	Degree of Saturation S_r
psi	in/in	psi	psi	%
0	0	0	0	
3	0.004	5	0	
23	0.012	19	10	
81	0.021	14	71	
137	0.032	44	106	
187	0.041	80	31	
275	0.047	89	212	
317	0.051	130	225	
391	0.056	147	287	
510	0.063	205	365	
663	0.068	238	495	
1000	0.078	353	750	
1334	0.085	470	1001	
673	0.091	585	1260	
980	0.095	722	1470	
2300	0.099	849	700	
2633	0.102	967	1950	
3280	0.108	1217	2420	
3913	0.111	1477	2870	
4573	0.114	1718	3360	
5213	0.117	1970	3820	
5867	0.119	2220	4300	
6580	0.121	2420	4870	
7 [illegible] 3	0.123	2750	5170	
7753	0.125	3005	5630	
8360	0.126	3280	6040	
9000	0.127	3540	6500	
9667	0.129	3770	7000	
10,333	0.130	4000	7500	

$\frac{\sigma_a + 2\sigma_r}{3}$	$\frac{\epsilon_a}{3}$	$\frac{\sqrt{2}}{3}(\sigma_a - \sigma_r)$	Radial Stress σ_r	Degree of Saturation S_r
psi	in/in	psi	psi	%
1,047	0.130	4220	8070	
,667	0.131	4470	8500	
2,323	0.132	4600	9070	
3,067	0.133	4400	9600	
2,367	0.133	3830	9350	
0,900	0.133	2890	8850	
9,667	0.132	2000	8250	
8,333	0.132	175	7500	
5667	0.13	235	5500	
4233	0.130	-65	-350	
2700	0.129	-474	3050	
820	0.128	-579	2230	
1307	0.128	-524	760	
1000	0.127	-565	400	
93	0.127	-574	1320	
830	0.127	-550	220	
667	0.126	-471	000	

Fig. E5

ONE-DIMENSIONAL STATIC TEST DATA

Test No 6 Soil Type Remolded Silty Clay Soil Location Depth 0-5 ft. Bag Sample, Dist. → Plain 6

w_i 9.7 % S_{ri} 25.3 % γ_i 86.0 pcf γ_{di} 79.2 pcf S_s 2.69 e_i 1.120

L_w 34 % P_w 16 % Classification Brown Silty Clay (CL)

$\frac{\sigma_a+2\sigma_r}{3}$	$\frac{\epsilon_a}{3}$	$\frac{\sqrt{2}}{3}(\sigma_a-\sigma_r)$	Radial Stress σ_r	Degree of Saturation S_r	$\frac{\sigma_a+2\sigma_r}{3}$	$\frac{\epsilon_a}{3}$	$\frac{\sqrt{2}}{3}(\sigma_a-\sigma_r)$	Radial Stress σ_r	Degree of Saturation S_r
psi	in./in.	psi	psi	%	psi	in./in	psi	psi	%
0	0	—	0		—	0.144	—	—	
3	0.003	5	0		—	0.144	—	—	
31	0.027	14	21		—	0.146	—	—	
71	0.049	21	56		—	0.145	—	—	
148	0.073	37	122		—	0.145	—	—	
212	0.085	63	167		—	0.145	—	—	
302	0.095	69	253		—	0.144	—	—	
348	0.100	107	272		—	0.143	—	—	
393	0.104	146	290		—	0.143	—	—	
555	0.112	173	433		—	0.143	—	—	
646	0.117	250	470		—	0.143	—	—	
1010	0.125	348	760		—	0.143	—	—	
1320	0.130	480	975		—	0.142	—	—	
1680	0.134	582	1260		—	0.142	—	—	
1990	0.136	710	1490		—	0.141	—	—	
2360	0.138	803	1790		—	0.141	—	—	
2760	0.139	878	2130		—	0.139	—	—	
3530	0.140	1035	2800						
4300	0.140	1200	3450						
5400	0.141	1130	4600						
6380	0.141	1168	5520						
7220	0.141	1255	6330						
8200	0.141	1270	7300						
9167	0.142	1292	8250						
10,1[illegible]0	0.143	1327	9180						
12267	0.143	1220	11400						
13400	0.143	1130	12600						
—	0.143	—	—						
—	0.143	—	—						

Fig. E6

ONE-DIMENSIONAL STATIC TEST DATA

Test No 7 Soil Type Remolded Silty Clay Soil Location Depth 0-5ft Bag Sample, Distant Plain 6

w, 9.8 % S_r, 27.1 % γ, 93.5 pcf γ_d, 85.2 pcf S_s 2.49 e, 0.972

L_w 34 % P_w 16 % Classification Brown Silty Clay (CL)

$\frac{\sigma_a + 2\sigma_r}{3}$	$\frac{\epsilon_a}{3}$	$\frac{\sqrt{2}}{3}(\sigma_a - \sigma_r)$	Radial Stress σ_r	Degree of Saturation S_r
psi	in/in	psi	psi	%
0	0	—	0	
3	0.002	5	0	
54	0.008	-3	56	
101	0.029	0	101	
149	0.051	38	119	
22[illegible]	0.064	56	182	
299	0.073	76	248	
356	0.081	106	280	
450	0.086	107	372	
608	0.093	135	512	
725	0.098	194	587	
1017	0.107	284	895	
1500	0.113	352	1250	
1867	0.116	446	1550	
2280	0.120	508	1920	
2673	0.122	583	[illegible]260	
[illegible]	0.123	573	[illegible]80	
4220	0.124	550	3830	
5267	0.125	517	4900	
6387	0.126	432	6080	
7700	0.126	212	7550	
8333	0.127	470	8000	
9300	0.127	493	8950	
10133	0.127	610	9700	
11067	0.127	658	10600	
12000	0.128	704	11500	
12867	0.128	800	12300	
13800	0.128	845	13200	
14800	0.128	845	14200	

$\frac{\sigma_a + 2\sigma_r}{3}$	$\frac{\epsilon_a}{3}$	$\frac{\sqrt{2}}{3}(\sigma_a - \sigma_r)$	Radial Stress σ_r	Degree of Saturation S_r
psi	in/in	psi	psi	%
14333	0.128	470	14000	
12300	0.128	141	12200	
11200	0.128	283	11800	
8500	0.127	-353	8750	
4900	0.127	-634	5350	
3000	0.126	-704	3500	
2007	0.125	-710	2510	
1453	0.124	-671	1930	
1147	0.124	-667	1620	
1020	0.123	-648	1480	
943	0.123	-630	1390	
793	0.122	-560	1190	

Fig. E7

ONE-DIMENSIONAL STATIC TEST DATA

Test No 8 Soil Type Remolded Silty Clay Soil Location Depth 0-5 ft Bag Sample, District Plain 6

w_i 19.6 % S_{ri} 84.2 % γ_i 102.0 pcf γ_{di} 85.4 pcf S_s 2.69 e_i 0.970

L_w 34 % P_w 16 % Classification Brown Silty Clay (CL)

$\frac{\sigma_a+2\sigma_r}{3}$	ϵ_a	$\frac{\sqrt{2}}{3}(\sigma_a-\sigma_r)$	Radial Stress σ_r	Degree of Saturation S_r
psi	in/in	psi	psi	%
0	0	0	0	
3	0.007	5	0	
17	0.062	24	0	
41	0.072	41	12	
82	0.076	48	48	
131	0.077	49	96	
227	0.077	51	191	
317	0.077	58	276	
405	0.077	67	358	
520	0.078	56	480	
625	0.078	53	588	
723	0.078	54	685	
796	0.078	73	744	
900	0.078	70	850	
960	0.078	99	890	
—	0.078	—	975	
1050	0.078	70	1000	
1165	0.079	78	1110	
1397	0.079	75	1340	
1507	0.079	66	1460	
1693	0.079	75	1640	
1887	0.080	80	1830	
2137	0.080	80	2080	
2413	0.080	61	2370	
2690	0.080	42	2660	
2947	0.080	38	2920	
3433	0.080	47	3400	
3933	0.081	47	3900	
5000	0.082	0	5000	

$\frac{\sigma_a+2\sigma_r}{3}$	ϵ_a	$\frac{\sqrt{2}}{3}(\sigma_a-\sigma_r)$	Radial Stress σ_r	Degree of Saturation S_r
psi	in/in	psi	psi	%
6000	0.082	0	6000	
7000	0.083	0	7000	
7980	0.083	14	7970	
8920	0.084	56	8880	
9900	0.084	70	9850	
11000	0.084	0	11000	
8000	0.084	0	8000	
6000	0.083	0	6000	
4027	0.083	-19	4040	
3047	0.083	-33	3070	
2047	0.082	-33	2070	
1007	0.082	-5	1010	
567	0.082	-47	600	
237	0.082	-26	256	
123	0.082	-16	134	
81	0.082	-22	97	
24	0.081	-17	36	

Fig. E8

ONE-DIMENSIONAL STATIC TEST DATA

Test No 9 Soil Type Remolded Sandy Silt Soil Location Depth 5-22 ft Boring S-U, Distant Flank

w_i 31 % S_{ri} 9.4 % γ_i 92.0 pcf γ_{di} 89.0 pcf S_s 2.67 e_i 0.876

L_w 20 % P_w 19 % Classification Brown Sandy Silt (ML)

$\frac{\sigma_a + 2\sigma_r}{3}$	$\frac{\epsilon_a}{3}$	$\frac{\sqrt{2}}{3}(\sigma_a - \sigma_r)$	Radial Stress σ_r	Degree of Saturation S_r
psi	in/in	psi	psi	%
0	0	0		
33	002	4.7		
41.4	011	6.1		
65.5	016	24.3		
137	022	43.5		
200	.028	70.5		
249	031	107		
331	035	119		
380	.038	156		
513	043	202		
634	047	260		
910	054	417		
1220	061	550		
1492	066	710		
1815	.071	839		
2190	074	970		
2420	078	1110		
3010	082	1400		
3620	087	1670		
4230	091	1960		
4850	094	2230		
5300	.096	2550		
6000	.099	2830		
6680	101	3100		
7160	103	3420		
7760	.105	3690		
8430	106	3950		
8960	108	4270		
9550	.109	4540		

$\frac{\sigma_a + 2\sigma_r}{3}$	$\frac{\epsilon_a}{3}$	$\frac{\sqrt{2}}{3}(\sigma_a - \sigma_r)$	Radial Stress σ_r	Degree of Saturation S_r
psi	in/in	psi	psi	%
10240	.110	4790		
10710	111	5080		
11410	.112	5450		
12100	113	5600		
11130	.113	4500		
10050	.113	3500		
8850	113	2120		
7550	113	1740		
6450	.112	1100		
5280	.111	515		
4180	110	-132		
2720	.109	-510		
1920	108	-650		
1473	.107	-690		
1100	106	-638		
965	105	-614		
870	105	-580		
653	.102	-460		

Fig E9

ONE-DIMENSIONAL STATIC TEST DATA

Test No 10 Soil Type Remolded Sandy Silt Soil Location Depth 5-22 ft Boring S-4, Distant Plain 6

w, 81 % S_r, 241 % γ, 95.3 pcf γ_d, 88.0 pcf S_s 2.67 e, 0.898

L_w 20 % P_w 19 % Classification Brown Sandy Silt (ML)

$\frac{\sigma_a+2\sigma_r}{3}$	$\frac{\epsilon_a}{3}$	$\frac{\sqrt{2}}{3}(\sigma_a-\sigma_r)$	Radial Stress σ_r	Degree of Saturation S_r
psi	in/in	psi	ps	%
0	0	0		
34	.002	-171		
70	.010	-16.1		
99	.020	1		
155	.031	32		
226	.038	56		
274	.043	89		
317	.047	129		
402	.050	139		
497	.057	214		
653	.061	260		
927	.070	404		
1236	.077	550		
1523	.081	691		
1826	.086	830		
2123	.089	925		
2440	.092	1100		
3030	.097	1390		
3620	.100	1690		
4210	.104	1970		
4830	.106	2240		
5380	.109	2560		
6000	.111	2830		
6550	.11	3140		
7180	.115	3410		
7790	.116	3690		
8370	.117	3980		
8900	.119	4300		
9540	.120	4560		

$\frac{\sigma_a+2\sigma_r}{3}$	$\frac{\epsilon_a}{3}$	$\frac{\sqrt{2}}{3}(\sigma_a-\sigma_r)$	Radial Stress σ_r	Degree of Saturation S_r
psi	in/in	psi	psi	%
10162	.121	4840		
10700	.122	5150		
11402	.122	5400		
12030	.123	5650		
11000	.123	4600		
9930	.123	3680		
8720	.123	2670		
7930	.122	1840		
6350	.122	1160		
5190	.121	575		
3940	.121	47		
2500	.119	-358		
1660	.118	-470		
1106	.116	-430		
840	.115	-452		
517	.114	-295		
409	.113	-254		
224	.105	-159		

Fig. E10

ONE-DIMENSIONAL STATIC TEST DATA

Test No 11 Soil Type Remolded Sandy Silt Soil Location Depth 5-27 ft Boring S-11, Distant Plain in

w, 15.0 % S_r, 45.0 % γ, 101.8 pcf γ_d, 88.5 pcf S_s 2.67 e, 0.[illegible]

L_w 20 % P_w 19 % Classification Brown Sandy Silt (ML)

$\frac{\sigma_a + 2\sigma_r}{3}$	$\frac{\epsilon_a}{3}$	$\frac{\sqrt{2}}{3}(\sigma_a - \sigma_r)$	Radial Stress σ_r	Degree of Saturation S_r
psi	in/in	psi	psi	%
0	0	0		
3	.003	4 7		
22 8	015	19.2		
78.5	.025	15.3		
192	034	.5		
271	040	20 8		
323	045	40.5		
387	.048	80		
465	051	96		
560	056	169		
702	061	211		
959	069	383		
1117	074	506		
1572	079	655		
1890	083	780		
2200	.086	920		
2600	089	990		
3050	.094	1380		
3710	098	1620		
4350	101	1870		
4980	103	2130		
5650	105	2370		
6530	107	2580		
6970	.108	2850		
7650	.110	3080		
8300	.112	3320		
8780	114	3680		
9600	115	3900		
10180	116	4110		

$\frac{\sigma_a + 2\sigma_r}{3}$	$\frac{\epsilon_a}{3}$	$\frac{\sqrt{2}}{3}(\sigma_a - \sigma_r)$	Radial Stress σ_r	Degree of Saturation S_r
psi	in/in	psi	psi	%
10860	117	4340		
11850	.118	4640		
12150	.118	4850		
12860	119	5050		
11620	.119	4140		
10420	.119	3230		
9160	119	2360		
7700	.118	1610		
6570	118	1010		
5350	.117	430		
4140	.116	-99		
2705	.115	-500		
1830	114	-585		
1284	.112	-555		
885	.111	-485		
665	.110	-400		
565	109	-364		
307	101	-218		

Fig E11

ONE-DIMENSIONAL STATIC TEST DATA

Test No 12 Soil Type Remolded Sandy Silt Soil Location Depth 5-22 ft. Boring S-4 Distant Plain 6

w_i 27.2 % S_{ri} 80.3 % γ_i 112.0 pcf γ_{di} 88.0 pcf S_s 2.67 e_i 0.898

L_w 20 % P_w 19 % Classification Brown Sandy Silt (ML)

$\frac{\sigma_a + 2\sigma_r}{3}$	$\frac{\epsilon_a}{3}$	$\frac{\sqrt{2}}{3}(\sigma_a - \sigma_r)$	Radial Stress σ_r	Degree of Saturation S_r
psi	in/in	psi	psi	%
0	0	0		
3	.011	4.7		
7	.019	23.6		
40	.025	43.5		
56	.029	66		
87	.031	80		
117	.034	94		
154	.036	103		
178	.037	122		
202	.039	140		
219	.040	163		
243	.041	182		
285	.044	223		
362	.046	239		
410	.048	276		
459	.049	312		
542	.051	324		
700	.054	389		
835	.057	470		
940	.059	560		
1112	.062	625		
1410	.064	773		
1690	.069	923		
2010	.071	1050		
2280	.074	1210		
2860	.077	1510		
3460	.080	1800		
4050	.082	2080		
4650	.084	2372		

$\frac{\sigma_a + 2\sigma_r}{3}$	$\frac{\epsilon_a}{3}$	$\frac{\sqrt{2}}{3}(\sigma_a - \sigma_r)$	Radial Stress σ_r	Degree of Saturation S_r
psi	in/in	psi	psi	%
5250	.086	2660		
5830	.088	2950		
6400	.090	3260		
6970	.091	3560		
7570	.093	3840		
8150	.094	4150		
8720	.095	4450		
9310	.096	4700		
9910	.097	5040		
10420	.098	5360		
11100	.098	5640		
11100	.100	5920		
10550	.100	4910		
9460	.099	3920		
8360	.099	2940		
7100	.098	2070		
5990	.098	1430		
4830	.097	825		
3640	.097	260		
2260	.096	-179		
1650	.095	-318		
910	.093	-358		
656	.093	-312		
466	.092	-260		
421	.091	-263		
250	.087	-176		

Fig. E12

APPENDIX F· OCTAHEDRAL NORMAL STRESS VERSUS OCTAHEDRAL LINEAR STRAIN

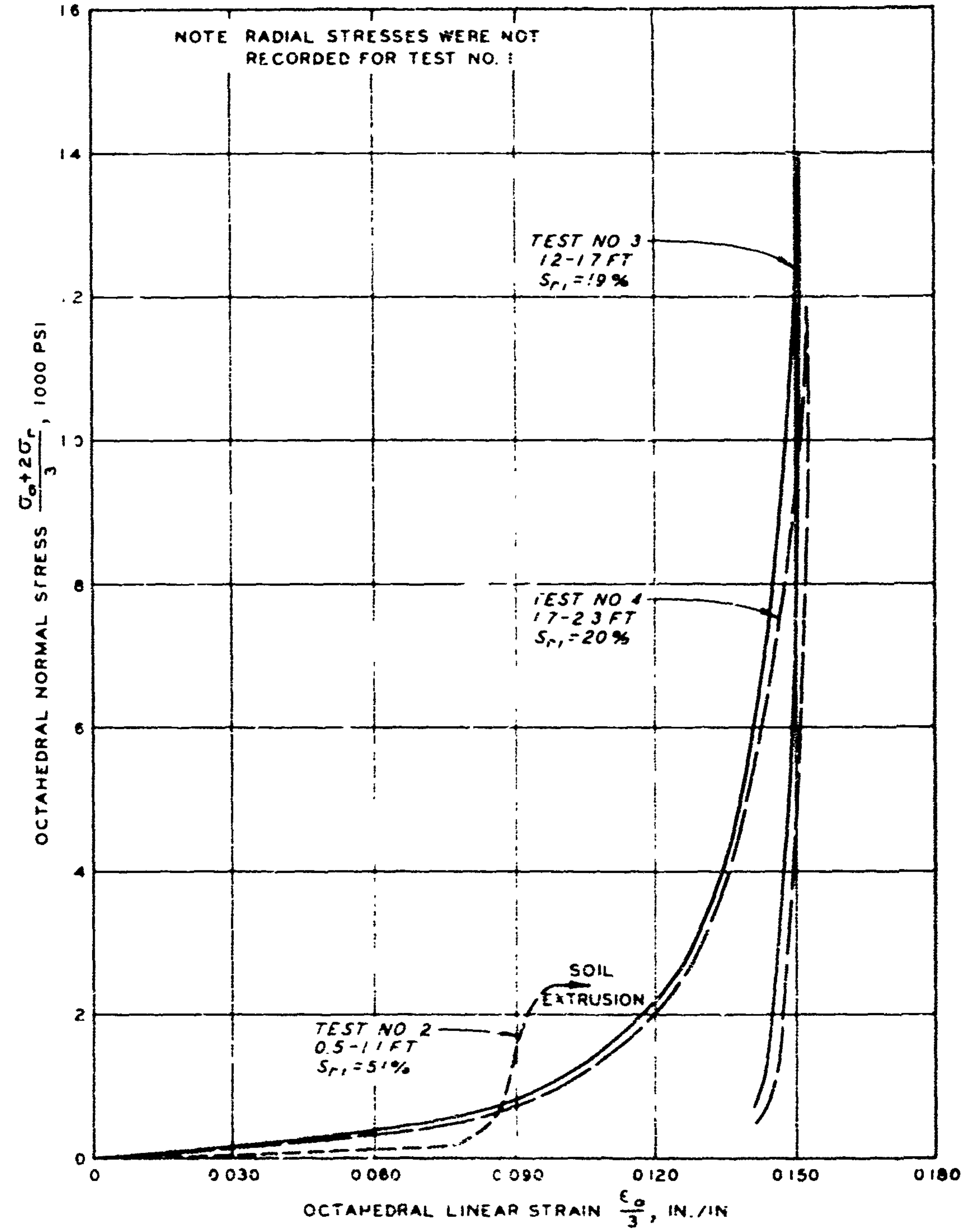

Fig. F1. Octahedral normal stress versus octahedral linear strain for the undisturbed samples of silty clay

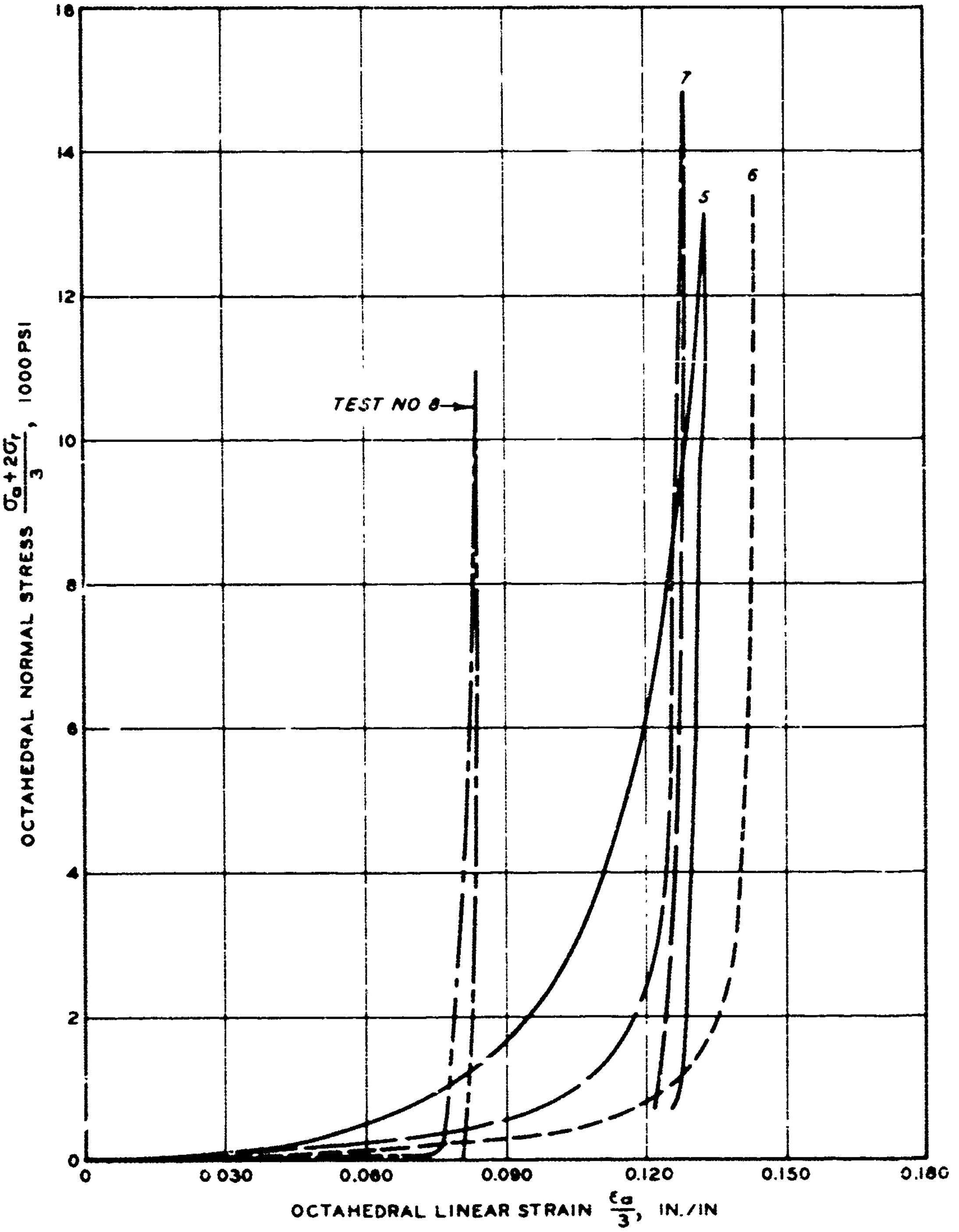

Fig. F2. Octahedral normal stress versus octahedral linear strain for the compacted samples of silty clay

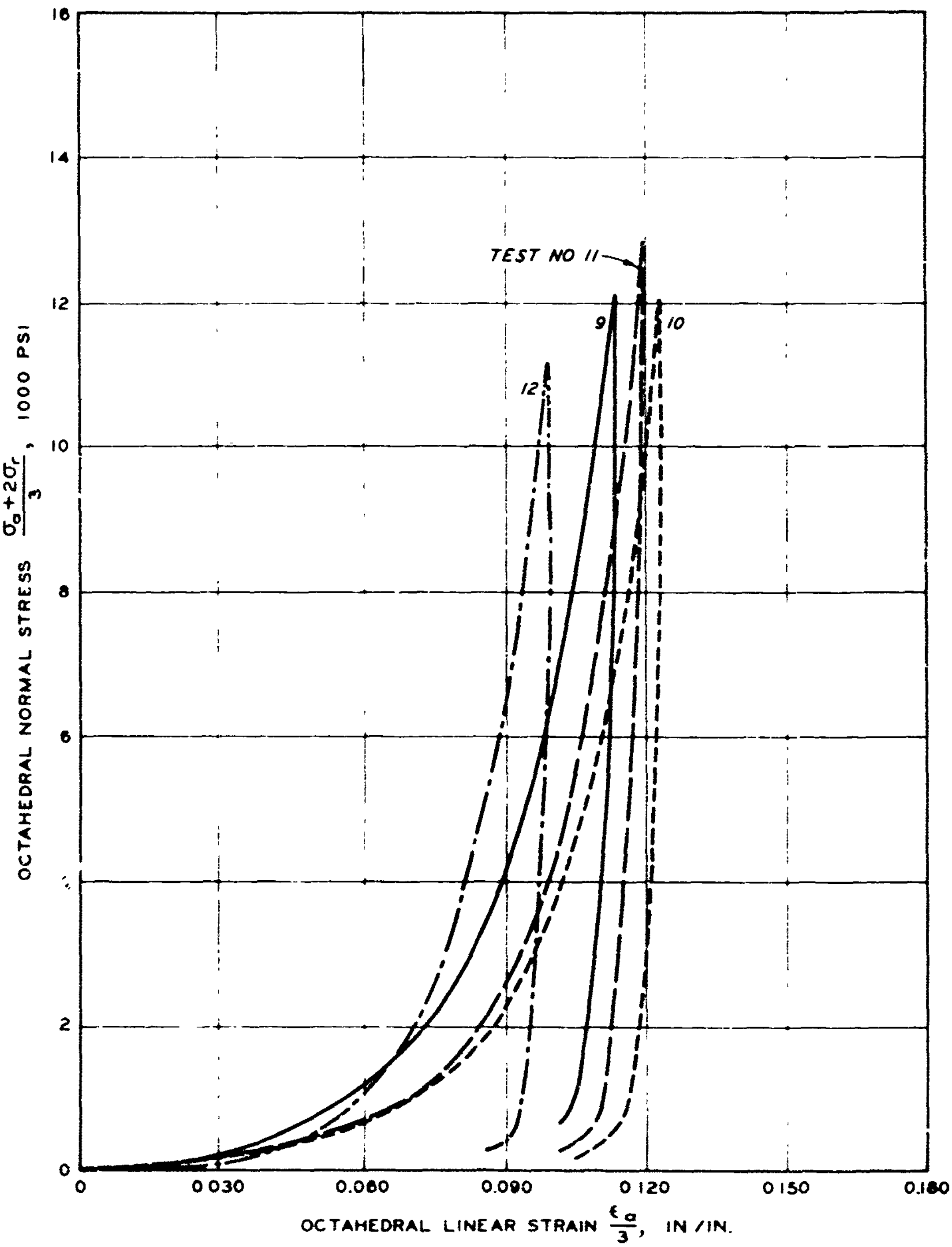

Fig. F3 Octahedral normal stress versus octahedral linear strain for the compacted samples of sandy silt

APPENDIX G: OCTAHEDRAL SHEARING STRESS VERSUS OCTAHEDRAL NORMAL STRESS

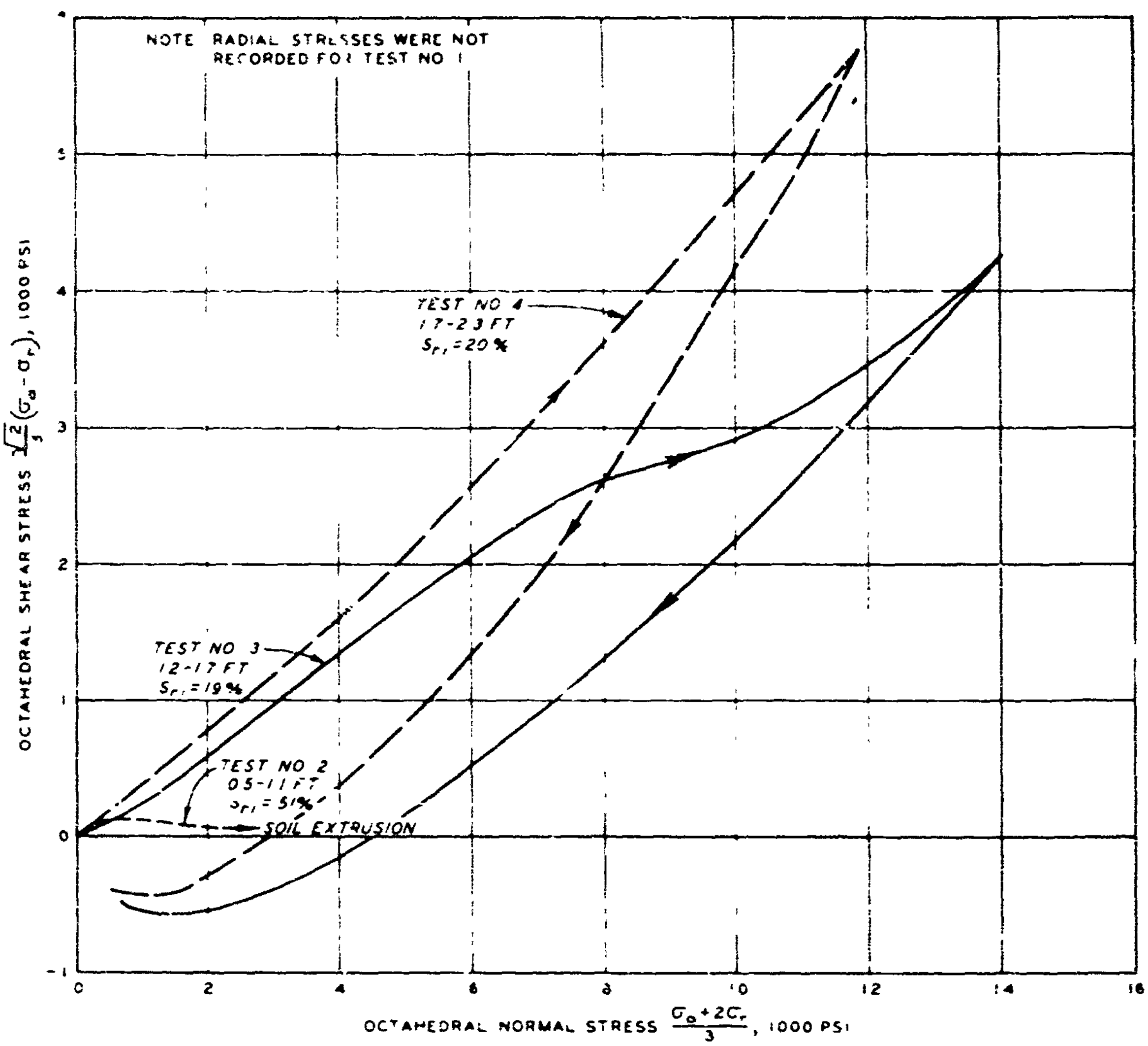

Fig G1 Octahedral shearing stress versus octahedral normal stress for the undisturbed samples of silty clay

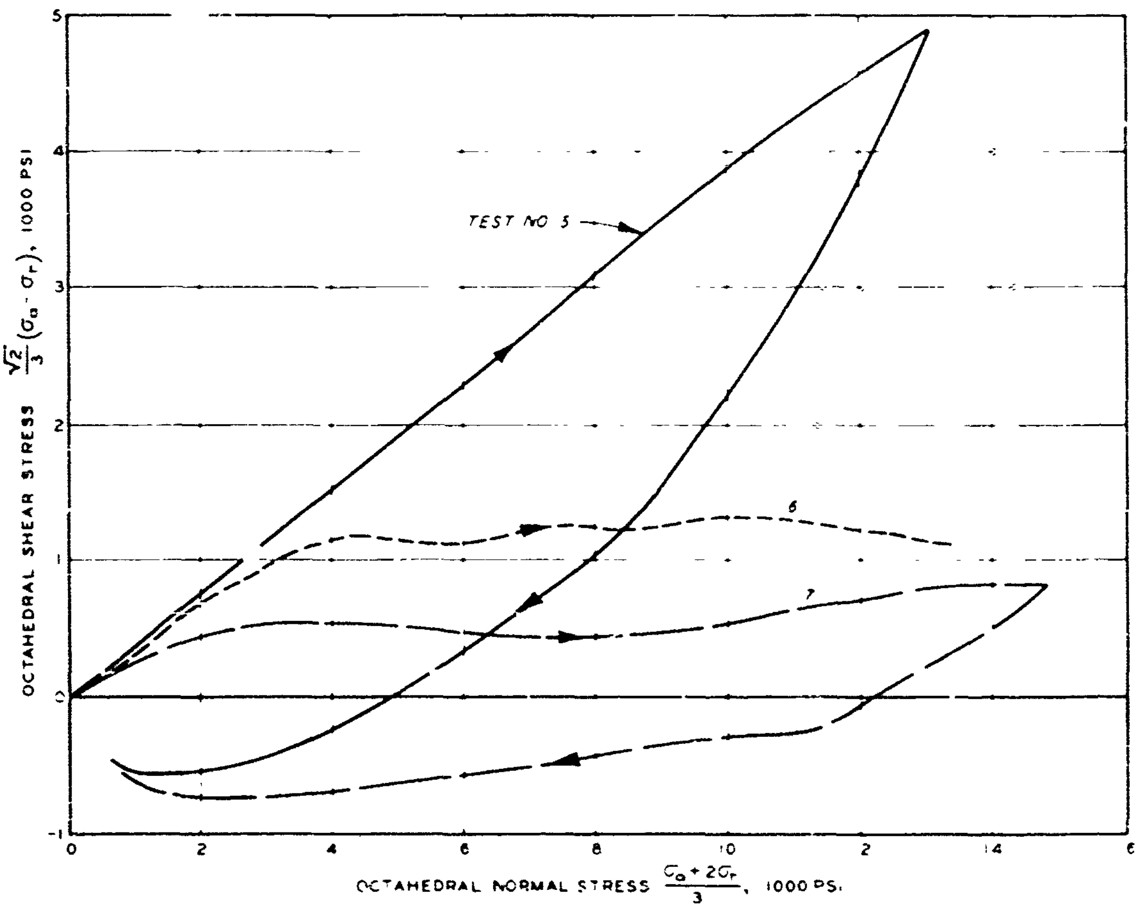

Fig. G2. Octahedral shearing stress versus octahedral normal stress for the compacted samples of silty clay

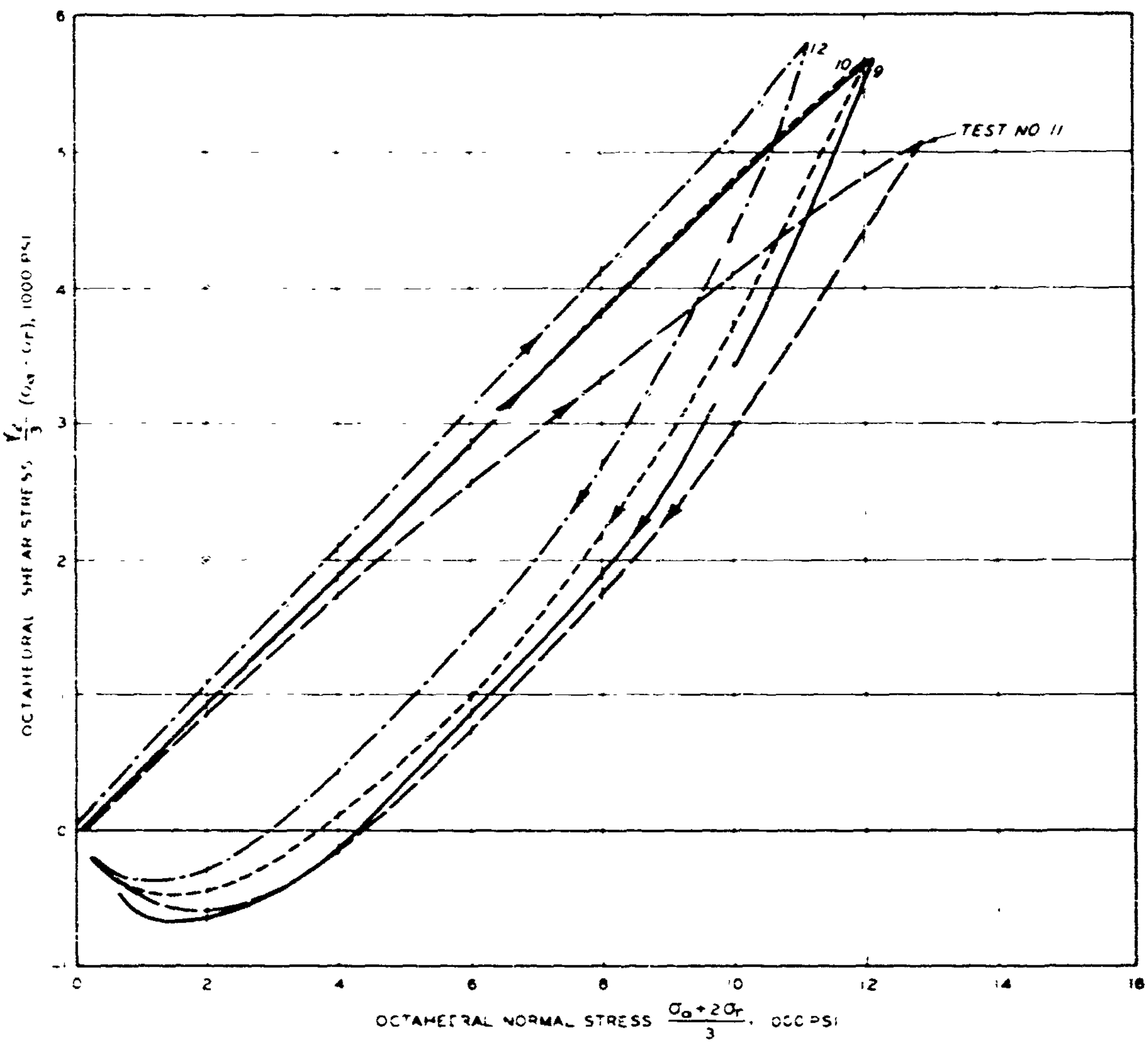

Fig G3. Octahedral shearing stress versus octahedral normal stress for the compacted samples of sandy silt

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13. ABSTRACT

Soil tests were conducted to provide information on the influence of degree of saturation on high-pressure stress-strain relations of undisturbed and remolded soils from the Defence Research Establishment, Suffield, and to provide input data for computer codes concerning the relation between stress and strain invariants at high pressures. As expected, the test results presented herein show that large strains do not develop at high pressures in fine-grained soils such as silt and clay. The test program consisted of 12 one-dimensional tests on 4 specimens each of undisturbed and remolded silty clay, and 4 specimens of remolded sandy silt. In all tests the radial strain was essentially zero. Axial and radial stresses and axial strain were measured. The tests were carried to an axial stress of 20,000 psi unless soil extrusion occurred at a lower stress. The following conclusions were reached. The degree of saturation and the initial void ratio are the most significant variables governing the one-dimensional stress-strain relations of soil at high pressures. For pressures exceeding 3000 psi the compacted specimens and undisturbed specimens of Suffield soil yield the same relation if the initial degree of saturation and initial void ratio are identical before loading. A lower bound to the secant modulus of deformation M_s at a given level of axial stress σ_a is given for both compacted and undisturbed samples of fine-grained soil subjected to pressures greater than 3000 psi. The average unloading modulus of Suffield soils subjected to pressures greater than 3000 psi is approximately 10 times the loading secant modulus of deformation M_s. It is probable that the stiffness of the Suffield soils when unsaturated will be greater under dynamic loading than the static values given herein. Previous comparisons of static and dynamic values of constrained moduli of Suffield soils have shown that the dynamic values are twice the static values. This observation is consistent with similar comparisons for NTS Frenchman Flat silt.

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