WAR DEPARTMENT C-348

CORPS OF ENGINEERS, U. S. ARMY

U. S. WATERWAYS EXPERIMENT STATION

VICKSBURG, MISSISSIPPI

December 20, 1939

Technical Memorandum No. 164-1

RESULTS OF SOIL TESTS ON MATERIAL FROM PROPOSED MUD MOUNTAIN DAM, WHITE RIVER, WASHINGTON

EXPERIMENT AUTHORIZED April 3, 1939

EXPERIMENT COMPLETED December 20, 1939

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of the

U. S. WATERWAYS EXPERIMENT STATION

Vicksburg, Mississippi

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WAR DEPARTMENT
MISSISSIPPI RIVER COMMISSION
U. S. WATERWAYS EXPERIMENT STATION
P. O. BOX 80
VICKSBURG, MISSISSIPPI

December 20, 1939

Subject: Transmittal of final report on results of soil tests on material from proposed Mud Mountain Dam, White River, Washington.

To: The Division Engineer, North Pacific Division, Portland, Oregon.

Herewith is Technical Memorandum No. 164-1 which constitutes the report on soil tests conducted at the U. S. Waterways Experiment Station on material from proposed Mud Mountain Dam, White River, Washington. Included in this report are text, tables and figures. The basic data have been retained in the files of the Experiment Station.

K. E. Fields
K. E. Fields
1st Lieut., Corps of Engineers
Director

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RESULTS OF SOIL TESTS ON MATERIAL FROM

PROPOSED MUD MOUNTAIN DAM, WHITE RIVER, WASHINGTON

Introduction

1. This memorandum is a report of the results of soil tests performed on material to be used in the construction of the proposed Mud Mountain Dam, White River, Washington. The tests were performed for the Division Engineer of the North Pacific Division by the personnel of the Soil Mechanics Laboratory of the U. S. Waterways Experiment Station, Vicksburg, Mississippi.

Scope

2. In accordance with the requests of the Office of the Division Engineer, North Pacific Division, as indicated in letters from the Division Engineer to the Experiment Station dated April 11, 1939, and June 19, 1939, the results of the tests performed were reported to that office as soon as they were available. This memorandum contains all pertinent data previously forwarded, together with additional data not yet reported.

Authority

3. Authority for the performance of the tests was granted by the Office, Chief of Engineers, as indicated by a letter from the Division Engineer to the Experiment Station dated April 3, 1939, Subject: "Tests of material for rolled fill dam". Authority for additional testing was granted by the Office, Chief of Engineers by letter to the Division

Engineer on June 8, 1939, Subject: "Test Embankments of Unaltered Till Mixed with Sand and Gravel - Mud Mountain Dam".

Purpose

4. The purpose of this investigation was (a) to ascertain the physical properties of the natural materials to be used in the construuction of the dam, and (b) to obtain test data on mixtures of the materials.

Materials Tested

5. The materials to be used in the construction of the dam are of two types; the first, a soil identified locally as a sand and gravel, and the second, a soil identified locally as glacial till. The number and locations of all samples submitted for testing are shown in Table 1, below.

Table 1

Location and Number of Samples

Sample No. as rec'd.	U.S.W.E.S. Reference No.	Location of Sample	Type of Material
2	1	Test Pit No. 1	Proposed core material
2	2	Test Pit No. 3	" " "
2	3	Test Pit No. 8	" " "
2	4	Test Pit No. 9	" " "
2	5	Spillway surface fill	" " "
1	1	Vicinity dam site or borrow pit	Unaltered glacial till
2	2	" " "	" "
3	3	Exposed face of borrow pit area	Sand and gravel
4	4	" " "	"
5	5	" " "	"
6	6	" " "	"

Tests

6. The study was initiated to determine the triaxial compression characteristics of the dam material under varying hydrostatic pressures. These tests, together with mechanical analysis and compaction tests were performed on the spillway and test pit materials listed in Table 1. Following a conference held in the Office of the Chief of Engineers on May 25 and 26, 1939, additional testing was recommended to determine the feasibility of mixing unaltered glacial till and sand and gravel for core material, and to select the mixture which would give the desired imperviousness with consolidation characteristics approximately equal to the shell material. Consequently, triaxial, consolidation and permeability tests were performed together with mechanical analysis and compaction tests on the six samples of sand and gravel and glacial till listed in Table 1.

Test Procedures

7. The procedures followed in performing the mechanical analysis and compaction tests were in accordance with present accepted methods. Because of the general nature of these tests, no discussion regarding their details will be given here. However, the procedures followed are described fully in a manual of the Experiment Station, entitled: "Laboratory Procedure in Testing Soils and Sediment". The procedures followed for performing the triaxial compression, consolidation, and permeability tests are described below.

8. Triaxial compression tests - Test pit samples. The procedure followed for performing triaxial compression tests on the test pit samples was essentially the same as that described in a report prepared by the District Engineer, U. S. Engineer Office, Boston, Mass., entitled: "Critical Density Investigation of Cohesionless Materials for Franklin Falls Dam". Exceptions to that procedure are described as follows:

a. Testing apparatus. The testing apparatus used is known as a large triaxial machine, requiring a specimen of 2.8 inches in diameter and about 8 inches in height. General arrangement of this apparatus is shown in Plate 1.

b. Specimen. The procedure for the test makes it necessary for the specimen to be sufficiently stable so as to remain unsupported for a short time between the removal of the forming cylinder and the application of the lateral (hydrostatic) pressure. It was found after repeated trials that when the material contained 19% to 22% moisture (dry weight basis) as specified by the North Pacific Division, the specimen would not stand unsupported. Therefore, it was necessary to prepare the specimen at a reduced water content; approval for this deviation from the specifications was secured from Mr. Grimm, of the North Pacific Division, on April 25, 1939.

c. Consolidation. Full consolidation of each of the test specimens was accomplished before developing the major stress.

d. Loading schedule. The time interval between the application of the increments of major stress was such that full strain developed under each increment. Thus, the effective stress was made equal to the total stress in all cases up to the maximum stress. Proof of this was indicated by cessation of the outflow of water from the specimen, as indicated by pipette readings.

e. Drainage system. Drainage of the test specimen was provided during the entire test by means of a filter paper jacket inserted just inside the rubber membrane about the entire periphery of the specimen. This jacket of filter paper was made to extend below the pervious stone in the base of the specimen.

9. Triaxial compression tests - Sand and gravel and glacial till samples. The triaxial compression procedure followed in testing the sand and gravel, and glacial till samples, was the same as described above with

the exception of certain limiting specifications on the maximum size of particles. All of the specimens of the samples of sand and gravel and glacial till were prepared in a manner agreed upon at a conference in the Office of the Chief of Engineers on May 26, 1939. At that conference, it was agreed that the maximum allowable grain-size of test specimens would be 1/16 the minimum dimension of the testing apparatus. The minimum dimension of the apparatus was 2.8 inches; consequently, all material coarser than 0.17 inch should have been removed. It was found, however, that material slightly larger could be tested; hence, all material coarser than 1/4 inch was removed. Test specimens were loaded at approximately their natural water content.

10. Consolidation tests. This test was not requested for the spillway or test pit samples. The procedure used in performing consolidation tests on the sand and gravel, glacial till, and mixtures of both is the same as described in the Laboratory Manual previously mentioned, except for the details noted below:

a. Testing apparatus. The testing apparatus used and shown in Plate 2 was a large hydraulic consolidometer capable of testing a specimen 28 inches in diameter and 8 inches in height. The machine was essentially the same as a standard consolidometer. Baffled steel plates, together with large porous stones and adequate drains provided for escape of water during consolidation of the specimen. Vertical loads were applied by means of a hydrostatic pressure arrangement, and the amount of consolidation measured by means of an Ames dial.

b. Size of specimens. The specifications regarding the size of specimens were the same as outlined in paragraph 9 above. The minimum dimension of the consolidation device was approximately 8 inches. Consequently, all material coarser than 1/2 inch was removed. Test specimens were loaded at approximately their natural water content. Test specimens were also compacted at their optimum water contents and loaded in this condition for comparative purposes.

11. Permeability tests. This test was not requested for the spillway or test pit samples. The procedure followed in performing this test on the sand and gravel, glacial till and mixtures of both is as described in the previously mentioned Laboratory Manual. The hydraulic consolidometer was fitted with a standpipe and overflow arrangement to simulate a constant head permeameter. All permeability tests were performed in conjuction with the consolidation tests.

Results of Tests

12. Test pit samples. The results of the mechanical analysis and compaction tests performed on the test pit samples listed in Table 1 are shown by Figures 1 to 7, incl. In addition, the results of the triaxial compression tests performed on these materials are shown by the stress-strain curves, consolidation curves and Mohr's circles of stress of Figures 8 to 27, incl., and are summarized in Table 2.

13. Sand and gravel and glacial till samples. Results of mechanical analysis and compaction tests performed on representative sand and gravel, glacial till, and a mixture of 80% sand and gravel and 20% glacial till, are shown by Figures 28 to 39, incl. Stress-strain and time-consolidation diagrams, together with Morh'r circles of stress which present triaxial compression data on these samples, are shown by Figures 40 to 66. In addition, the results of the triaxial compression tests are summarized, and shown in Table 3. Figures 67 and 68 indicate the grain-size distribution of representative sand and gravel and glacial till samples as received. The results of consolidation tests performed in the hydraulic consolidometer, together with mechanical analyses of the consolidation specimens

actually tested are shown in Figures 69 to 94, incl. Permeability test results obtained in connection with the performance of the consolidation tests are shown by Figure 95.

Discussion of Results - Test Pit Samples

14. Standard tests. The data obtained from mechanical analyses, water content, unit weight and compaction tests performed on these samples are self-explanatory. It can be noted that compaction tests were performed on samples from Test Pits 1 and 8, only. Classification of material from all test pits showed them to be very similar; hence, only two compaction tests were performed as shown. These were sufficient to indicate the compaction characteristics of the material.

15. Triaxial compression tests. It can be noted that triaxial compression tests were not performed on the sample representative of the spillway surface fill denoted herein as Sample No. 2, U.S.W.E.S. Reference No. 5. An insufficient supply of the material prohibited the performance of the test. However, as stated above, the five samples submitted originally for testing were all very similar, hence, the triaxial compression tests performed are considered adequate for the proposed core material as furnished.

16. In the consolidation of the sample from Test Pit No. 1 (Figure 11), a break in the curve was experienced after the lapse of approximately 2100 minutes. This break was due to the inadvertent closing of the drainage valve from the testing apparatus. Opening the valve allowed continuation of the drainage. Examination of the specimen indicated that no apparent damage had been experienced through the interruption of this

drainage. It was found that, upon the completion of the 20-ton test of the same sample, that glycerin had entered the top of the specimen during the test. Every possible check had been made of the apparatus prior to the test, and no plausible explanation can be given for the entrance of the glycerin. Its entrance was not discovered until the test was completed. The only apparent effect of this glycerin upon the results of the test is indicated in the excessive unit weight (wet) (Table 2) after the completion of the test, and in the void ratios after consolidation and at the conclusion of the test (both extremely low).

17. The consolidation of the specimens was accomplished by the direct application of full hydrostatic pressure (15 or 20 tons, as the case may have been). This procedure was used in order to expedite the tests, and to produce a condition analogous to that desired in a minimum time. The void ratios resulting from consolidation by this manner may be different from those resulting from: (1) allowing consolidation under successively increasing increments of load, until full consolidation had developed under the pressure desired (2) by compaction of the material at its optimum moisture content, as indicated by Figures 6 and 7, and then producing consolidation by successively increasing increments of load. Inasmuch as resistance to shear is a function of void ratio, the values given in Table 2 may not be the maximum that the material is capable of developing because the resulting void ratios may be higher than the actual void ratios developed by the material within the structure. It is interesting to note that a comparison of the unit weights, both wet and dry, and corresponding void ratios for the specimen tested correspond closely to the data shown by the compaction curves, Figures 6 and 7.

Table No. 2

Summary of Test Data - Triaxial Compression Tests
Test Pit Samples

.S.W.E.S. eference No.	Test No.	Lateral Pressure T/sq.ft.	W.C. when Loaded %	Unit Weight Lb. per Cu. Ft. Before Cons.	After Cons.	After Test	Void Ratio Before Cons.	After Cons.	After Test	*Angle of Internal Friction
1	1	15	15.18	117.87 a	133.60 a	137.77 a	0.43	0.27	0.23	38°30'
				135.78 b	145.58 b	148.16 b				
1	2	20	16.62	113.82 a	141.40 a	148.64 a	0.49	0.20	0.14	36°52'
				138.15 b	156.50 b	161.30 b				
2	1	15	17.30	113.88 a	128.54 a	135.10 a	0.48	0.31	0.25	37°30'
				132.97 b	142.08 b	146.08 b				
2	2	20	19.21	112.82 a	129.79 a	133.80 a	0.49	0.30	0.26	36°17'
				133.10 b	143.77 b	146.28 b				
3	1	15	15.26	116.69 a	131.85 a	137.16 a	0.44	0.27	0.22	36°30'
				135.03 b	144.52 b	147.83 b				
3	2	20	15.90	113.59 a	129.60 a	133.54 a	0.48	0.30	0.26	37°30'
				131.65 b	141.71 b	145.27 b				
4	1	15	21.00	108.26 a	120.24 a	124.55 a	0.54	0.39	0.34	37°37'
				131.48 b	139.09 b	141.84 b				
4	2	20	19.90	107.45 a	123.49 a	127.73 a	0.55	0.35	0.30	34°59'
				128.83 b	138.81 b	141.36 b				

a - denotes dry weight
b - denotes wet weight
* Computed assuming Mohr's envelope a straight line and passing through origin.

18. The shear characteristics of a material are illustrated graphically by means of Mohr's circles of stress. In this case, however, the data are not sufficient to determine the actual rupture line (Mohr's envelope) with any degree of accuracy. However, Figures 12, 17, 22 and 27 represent the test data as obtained. If it is assumed that the rupture line is a straight line passing through the origin instead of as shown, a value for the angle of internal friction may be computed from the formula:

$$\frac{\sigma_I}{\sigma_{III}} = \tan^2 \left(45 - \frac{\phi}{2}\right)$$

in which σ_I is the major principal stress and σ_{III} is the minor principal stress. The effect of cohesion upon the shear strength is neglected and all shear strength is attributed to internal friction. The effect of cohesion in these tests was negligible because of the high pressures used.

19. Efforts were made to observe the effect of failure on the grains of the material along the plane of failure. The test specimens after having failed were cut longitudinally with a band-saw. The cut surface was carefully brushed with a fine wire brush immediately after the test and after various stages of drying. Due to the extremely dense condition of the sand it could not be determined whether or not any crushing of the grain had occurred.

Discussion of Results - Sand and Gravel and Glacial Till Samples

20. Standard tests. The data obtained from the mechanical analysis, compaction tests and water contents performed on these samples and mixtures thereof, are shown by the inclosed diagrams representative of each and are self-explanatory.

Table 3

Summary of Test Data - Triaxial Compression Tests
Sand and Gravel - Glacial Till Samples

U.S.W.E.S. Reference No.	Test No.	Lateral Pressure T/sq.ft.	W.C. when Loaded %	Unit Weight - Lbs. per Cu. Ft.			Void Ratio			*Angle of Internal Friction
				Before Cons.	After Cons.	After Test	Before Cons.	After Cons.	After Test	
4	3	5	21.10	108.83 a 131.51 b	122.14 a 139.96 b	126.67 a 142.84 b	0.57	0.40	0.35	37° 17'
4	4	10	21.10	108.94 a 131.58 b	125.75 a 142.26 b	129.94 a 144.92 b	0.57	0.36	0.32	36° 44'
4	5	15	21.10	107.10 a 129.71 b	127.09 a 142.28 b	132.24 a 145.51 b	0.60	0.35	0.29	33° 42'
4	6	20	20.00	110.53 a 132.64 b	129.71 a 144.82 b	132.59 a 146.65 b	0.55	0.32	0.29	31° 30'
1	1	5	21.75	106.33 a 129.20 b	121.41 a 138.67 b	125.23 a 141.08 b	0.58	0.38	0.34	39° 23'
1	2	10	21.75	105.25 a 128.14 b	125.55 a 140.82 b	129.60 a 143.35 b	0.60	0.34	0.30	38° 10'
1	3	15	21.75	104.90 a 127.72 b	124.78 a 140.09 b	129.89 a 143.27 b	0.60	0.35	0.29	36° 29'
1	4	20	21.75	106.32 a 129.19 b	129.64 a 143.85 b	133.87 a 146.51 b	0.58	0.29	0.25	35° 34'
80% No. 4) 20% No. 1)	1	5	20.00	109.17 a 131.00 b	126.24 a 141.74 b	130.14 a 144.19 b	0.56	0.35	0.31	37° 37'
"	2	10	20.00	106.37 a 127.65 b	124.96 a 139.05 b	128.79 a 141.40 b	0.60	0.36	0.32	35° 10'
"	3	15	20.00	107.03 a 130.22 b	130.38 a 145.02 b	134.74 a 147.78 b	0.59	0.31	0.26	34° 25'
"	4	20	20.00	109.43 a 131.74 b	131.23 a 145.56 b	135.04 a 147.97 b	0.56	0.30	0.26	32° 50'

a - denotes dry weight
b - denotes wet weight
* Computed assuming Mohr's envelope a straight line and passing through origin.

21. Triaxial compression tests. It can be noted that these tests were performed on the samples tested at lateral pressures of approximately 5, 10, 15 and 20 tons per square foot. The consolidation of all specimens occurred quite rapidly under these loads as indicated by the time-consolidation diagrams accompanying the stress-strain curves for each set of tests. Reference to Table 3 shows that the angles of internal friction for the glacial till under the various lateral pressures were consistently higher than for the natural sand and gravel, whereas the angles of internal friction for the mixture of 80% sand and gravel and 20% glacial till, and the sand and gravel were practically identical for the various lateral pressures. The values for the angles of internal friction were computed using the same method and assumptions described in paragraph 18. Reference to the stress-strain curves for the various samples tested show that the specimens decreased in volume in every instance upon application of stress.

22. Consolidation tests. Reference to the time-consolidation diagrams for the specimens consolidated in the large hydraulic consolidometer showed that consolidation occurred rapidly under the various loads for the samples placed in both the saturated and compacted states. It is also indicated that specimens compacted at the optimum water content (10% to 14% by dry weight) consolidated more rapidly and experienced less consolidation than did those specimens placed in the consolidometer in a saturated condition (19% to 30% by dry weight). This is as would be expected because soils placed initially at their optimum water contents are capable of obtaining their maximum degrees of density much more so than at any other water content. As indicated before, these two types of tests were performed

for comparative purposes and indicate very much the desirability of controlling the initial moisture content so that a minimum amount of settlement will occur. Further review of the consolidation data indicated that apparently only small differences exist between the consolidation characteristics of the natural materials and of the 80% sand and gravel and 20% glacial till mixture, and the 60% sand and gravel and 40% glacial till mixture. It can be noted that check tests were performed on each specimen.

23. Permeability tests. As indicated in Figure 95, the average permeability of the natural sand and gravel is greater than that of the two mixtures, and of the unaltered glacial till. The glacial till was more impervious than any specimen or mixture tested.

Summary

24. The shearing strength of the materials tested can be attributed to internal friction only as the effect of cohesion is negligible when subjected to the high pressures used in these tests and which will be existent in the dam structure.

25. The consolidation characteristics of the materials tested are very similar and indicate that consolidation will occur quite rapidly whether in a saturated or compacted at optimum water content state. It is further indicated that much more consolidation will take place in the saturated than the compacted state. This latter factor shows the desirability of controlling the moisture content of the fill in order to reduce settlement to a minimum.

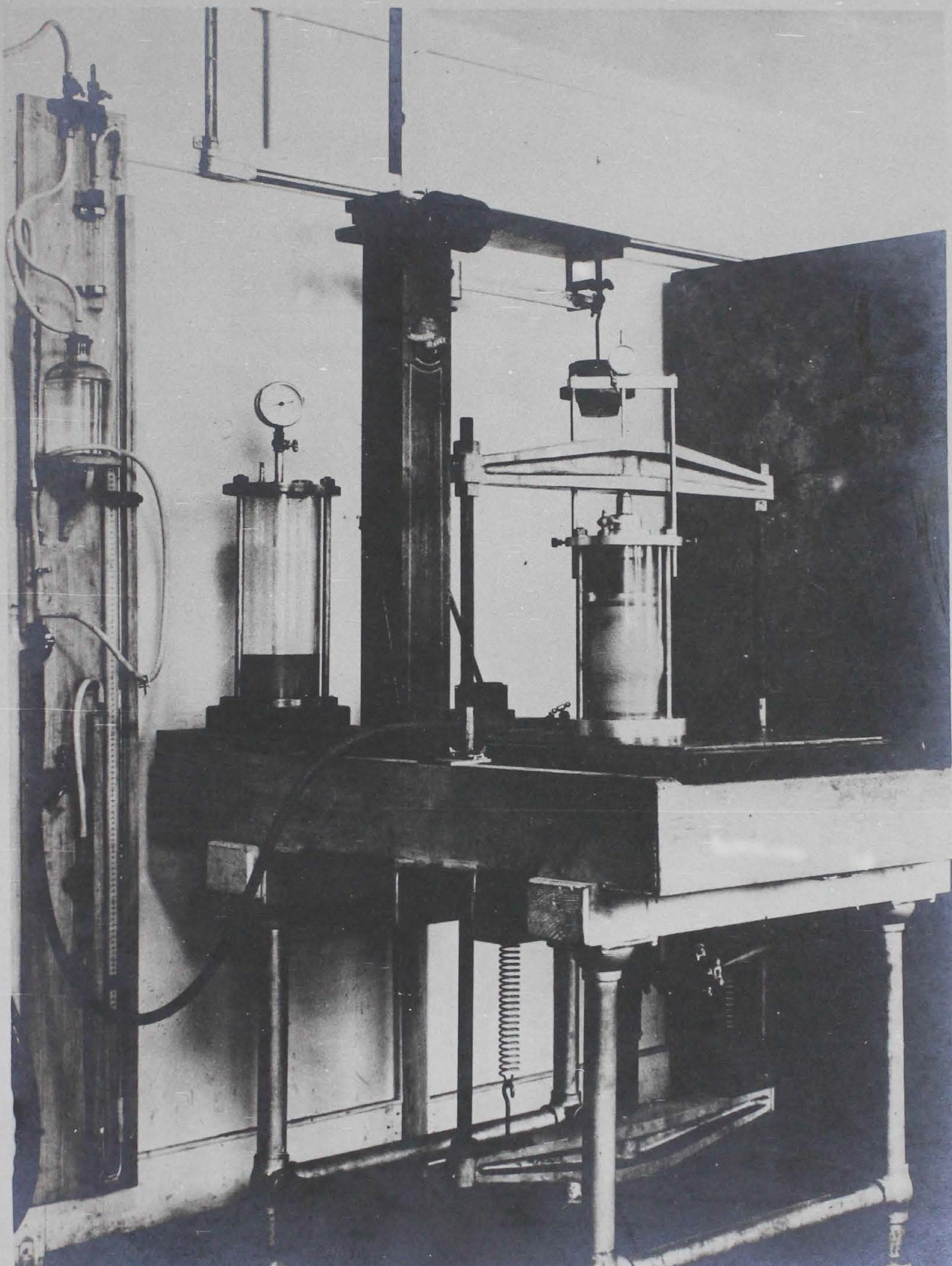
26. The average permeability of the two natural materials and the two mixtures tested are approximately in the same range. The glacial till is the most impervious of the whole group. The difference between

the mixtures of 80% sand and gravel and 20% glacial till, and 60% sand and gravel and 40% glacial till, does not appear large enough to warrant control of the amounts of each natural material used.

(END OF MEMORANDUM PROPER)

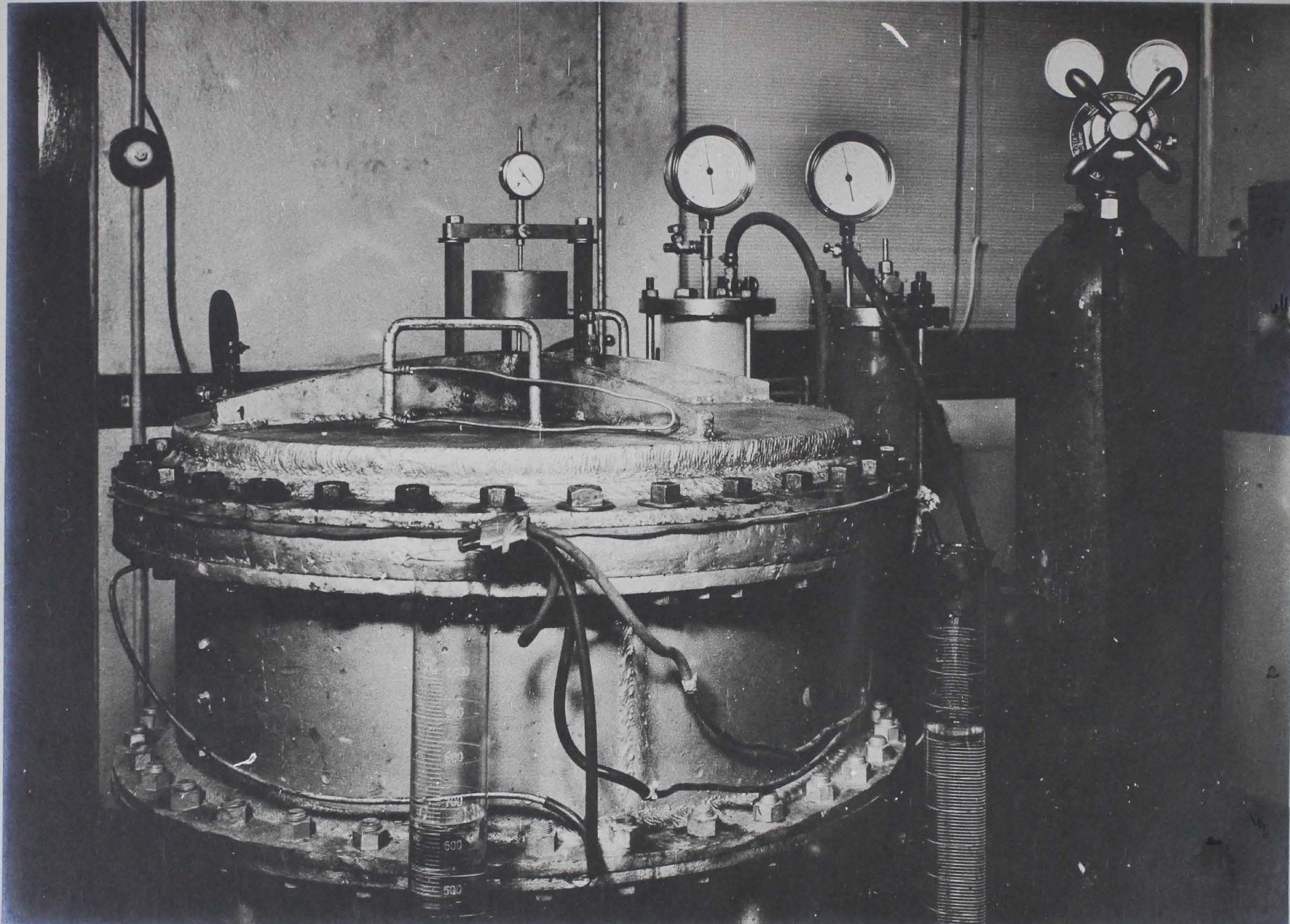
(FIGURES AND PLATES FOLLOW)

PLATES



GENERAL ARRANGEMENT OF TRI-AXIAL
COMPRESSION APPARATUS

PLATE I



GENERAL ARRANGEMENT OF HYDRAULIC CONSOLIDOMETER

PLATE 2

FIGURES FOR

TEST PIT SAMPLES

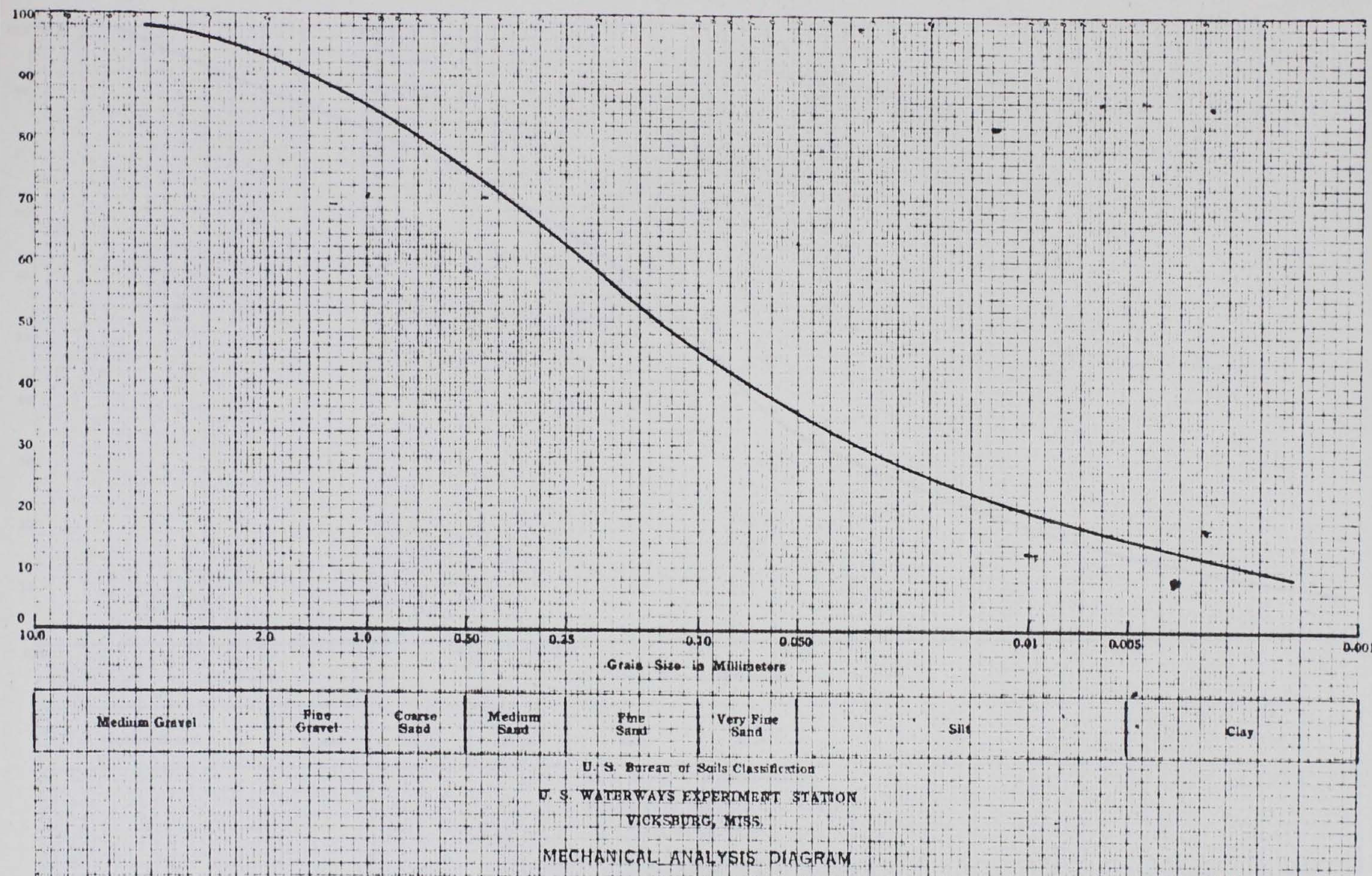


Figure 1

Sample No. 2 - Test Pit No. 1

Location of Sample Proposed Mud Mountain Dam

Remarks Core Material

Date Sample Taken

Date Sample Tested 4-12-39

Specific Gravity of Sample 2.71

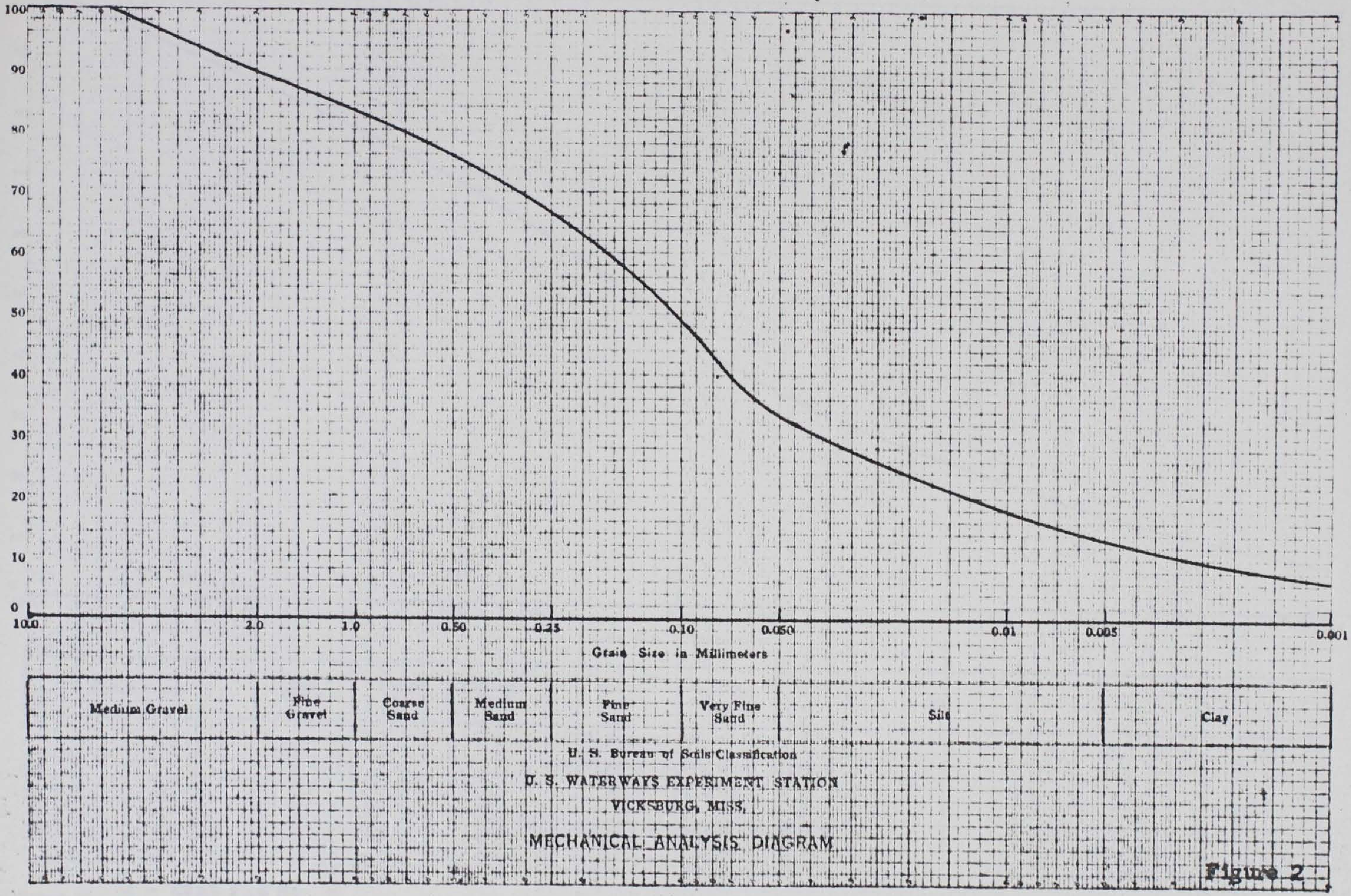


Figure 2

Sample No. 2 - Test Pit No. 3

Location of Sample Proposed Mud Mountain Dam
Core Material

Date Sample Taken

Date Sample Tested 4-12-39

Specific Gravity of Sample 2.70

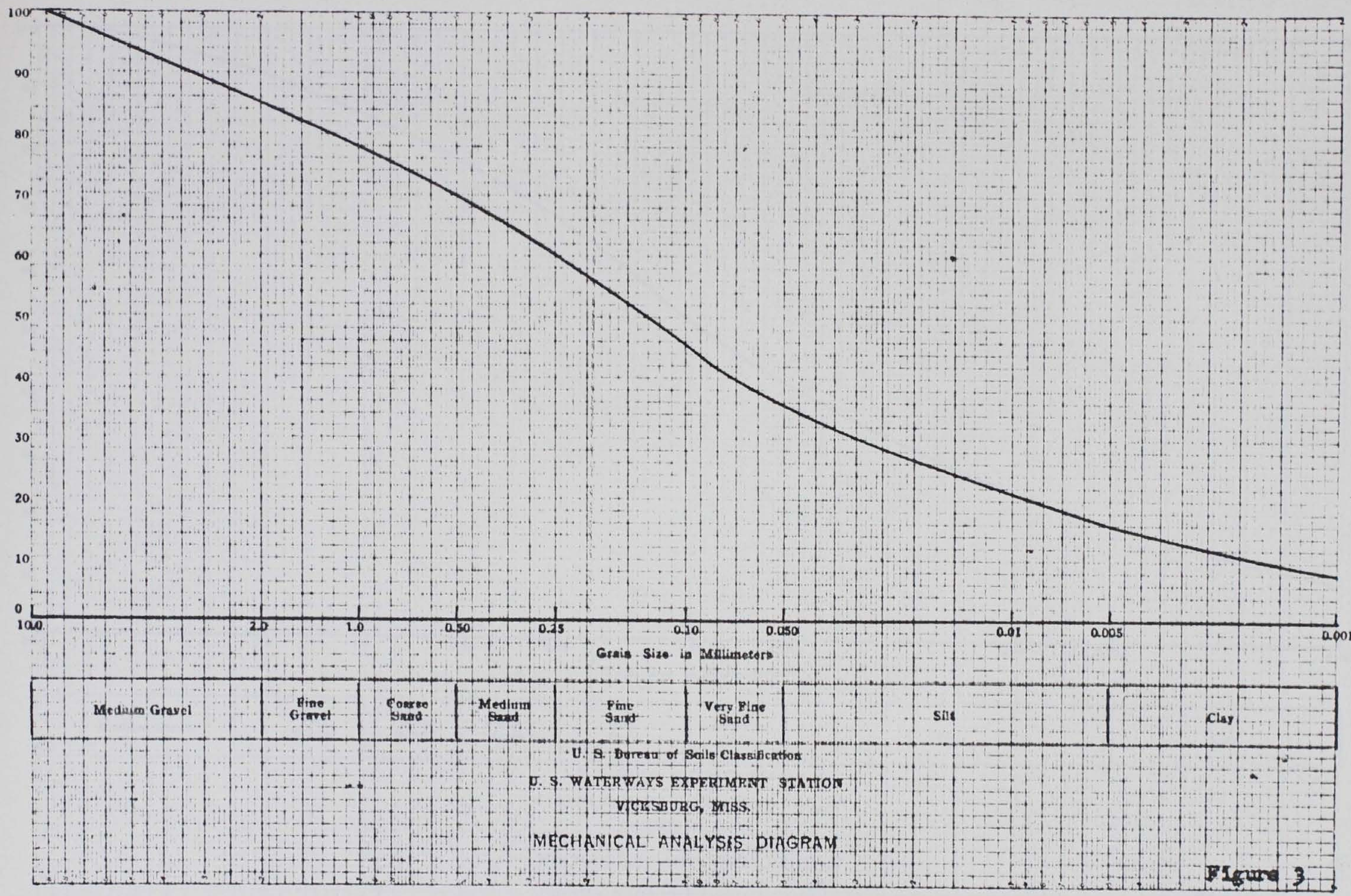


Figure 3

Sample No. 2 - Test Pit No. 8

Location of Sample Proposed Mud Mountain Dam

Remarks Core Material

Date Sample Taken

Date Sample Tested 4-12-39

Specific Gravity of Sample 2.69

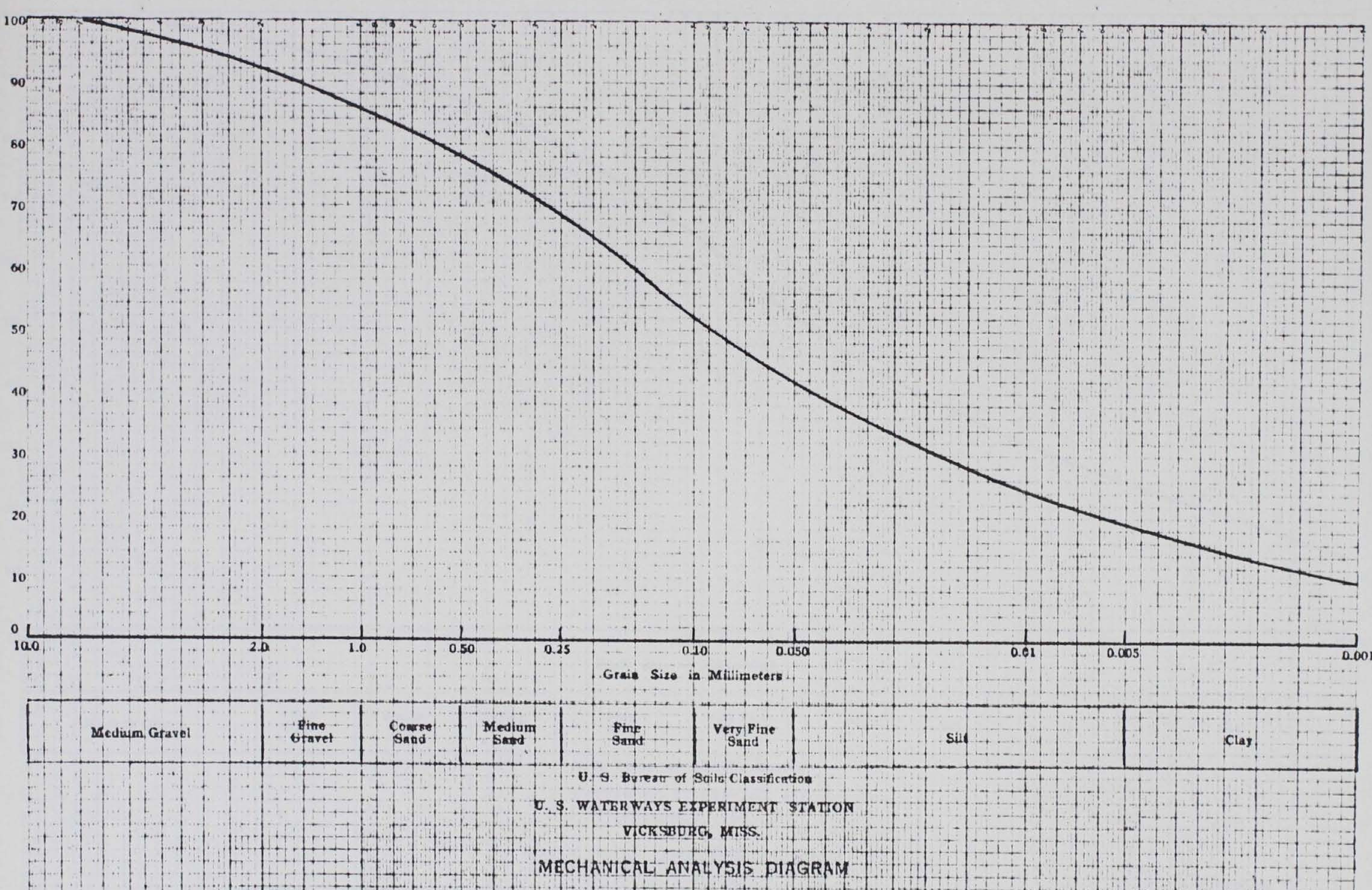


Figure 4

Sample No. 2 - Test Pit No. 9

Location of Sample Proposed Mud Mountain Dam

Remarks Core Material

Date Sample Taken

Date Sample Tested 4-12-39

Specific Gravity of Sample 2.67

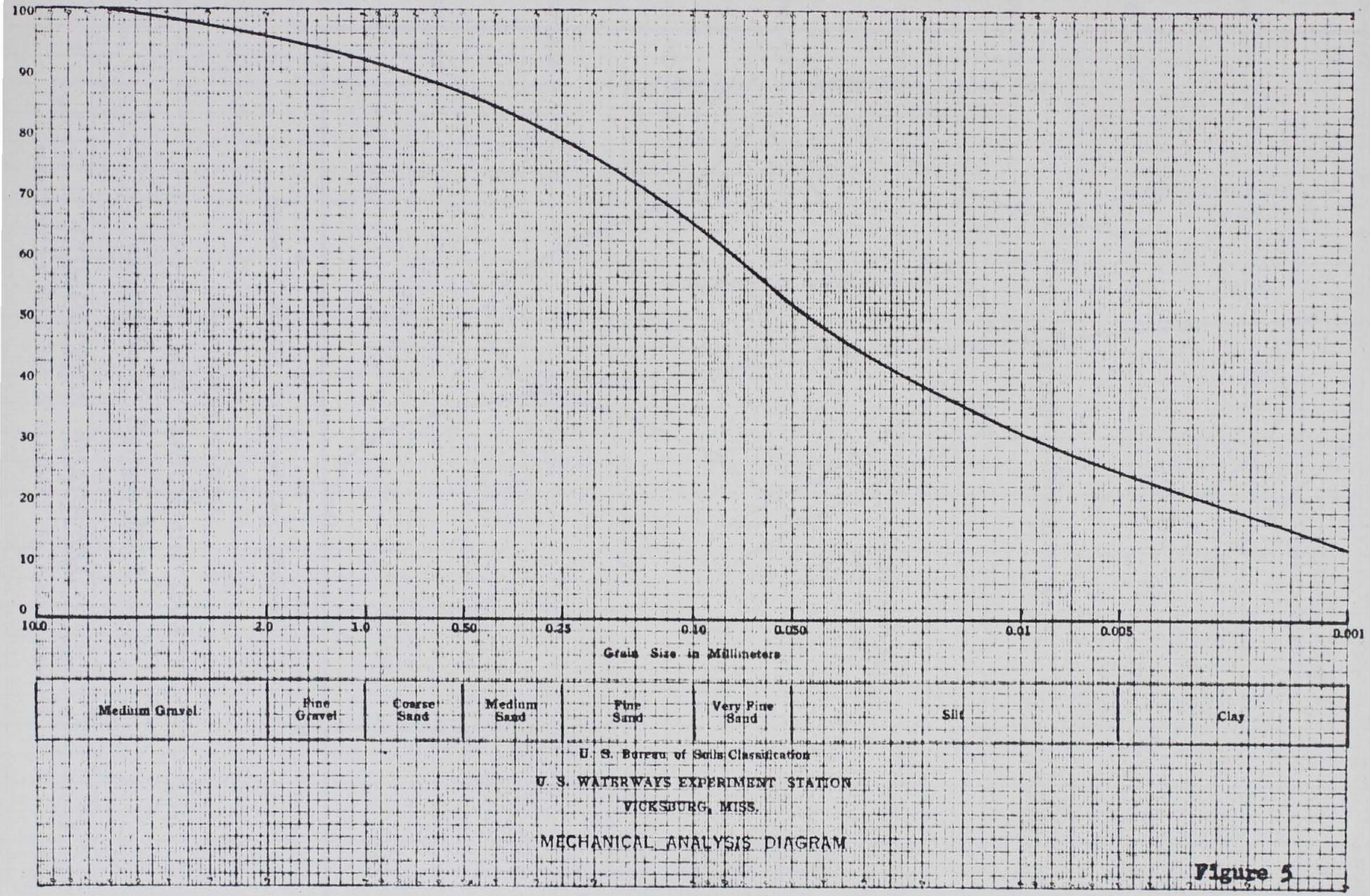


Figure 5

Sample No. 2 - Spillway Surface Fill

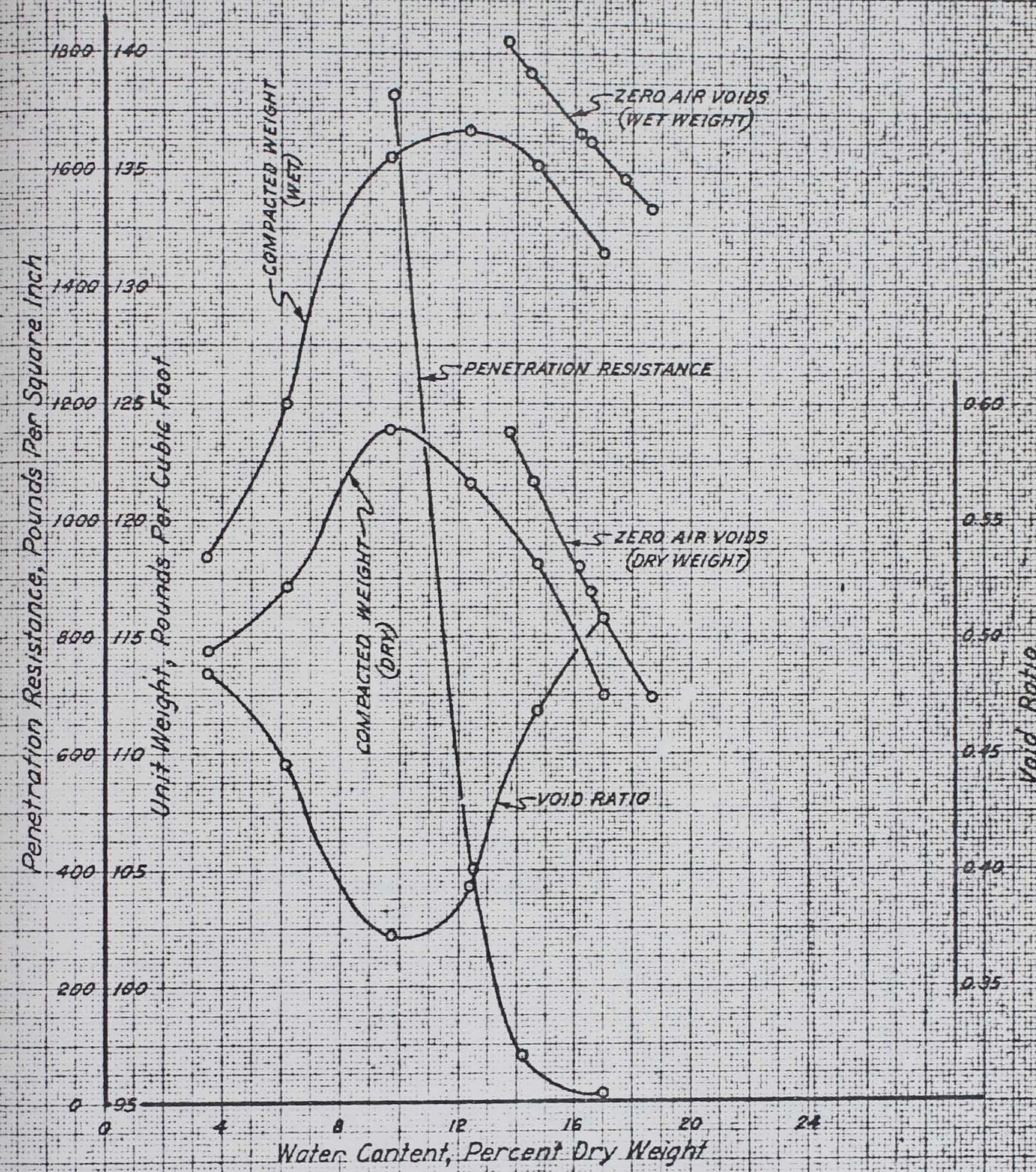
Location of Sample Proposed Mud Mountain Dam

Remarks Core Material

Date Sample Taken

Date Sample Tested 4-12-39

Specific Gravity of Sample 2.69



EMBANKMENT MATERIAL

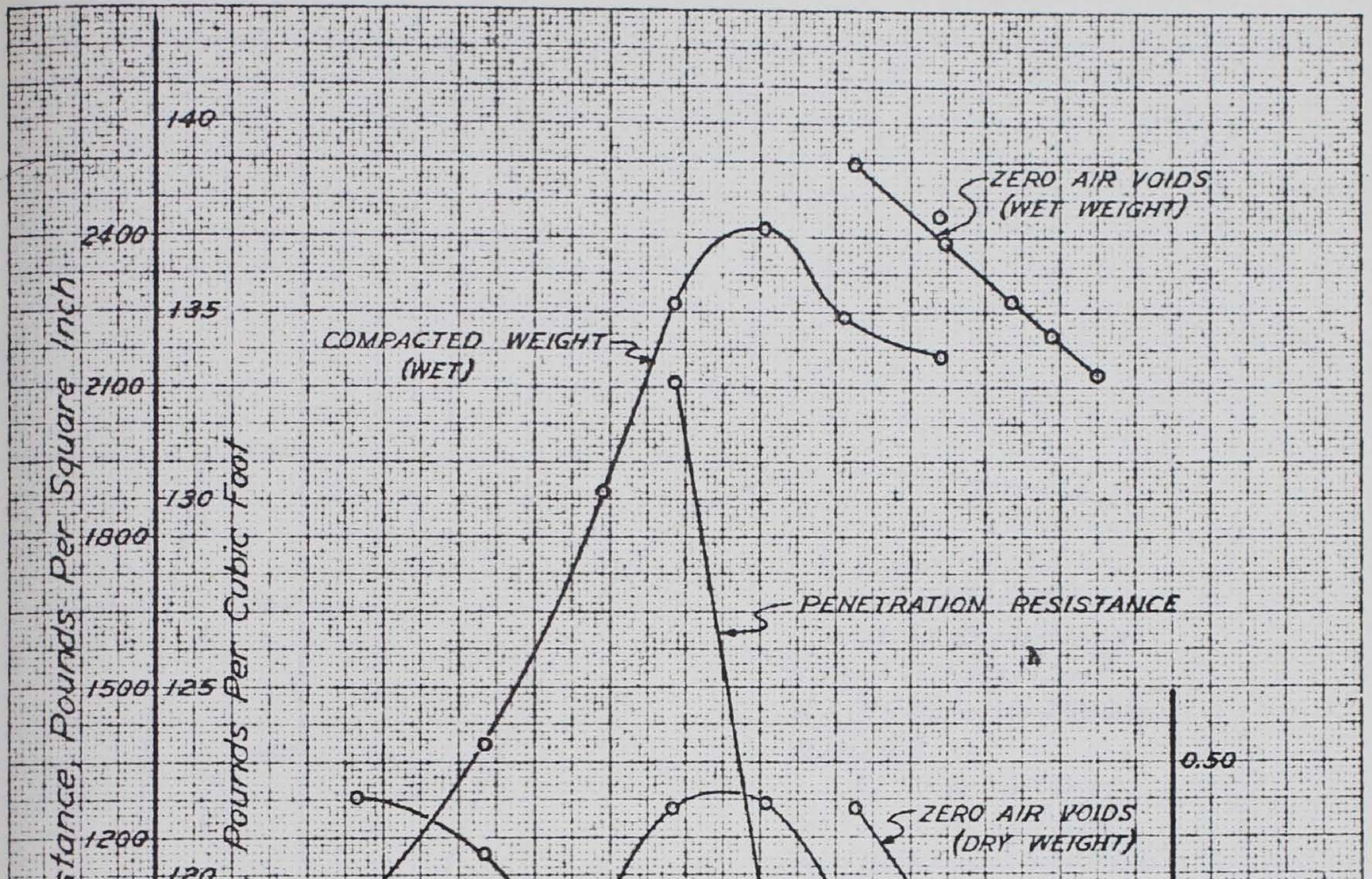
PROPOSED MUD MOUNTAIN DAM

Test Pit No. 1 Sample No. 2

COMPACTION DIAGRAM

COMPACTED BY 25 BLOWS OF STANDARD $5\frac{1}{2}$ POUND HAMMER

FIGURE 6



EMBANKMENT MATERIAL

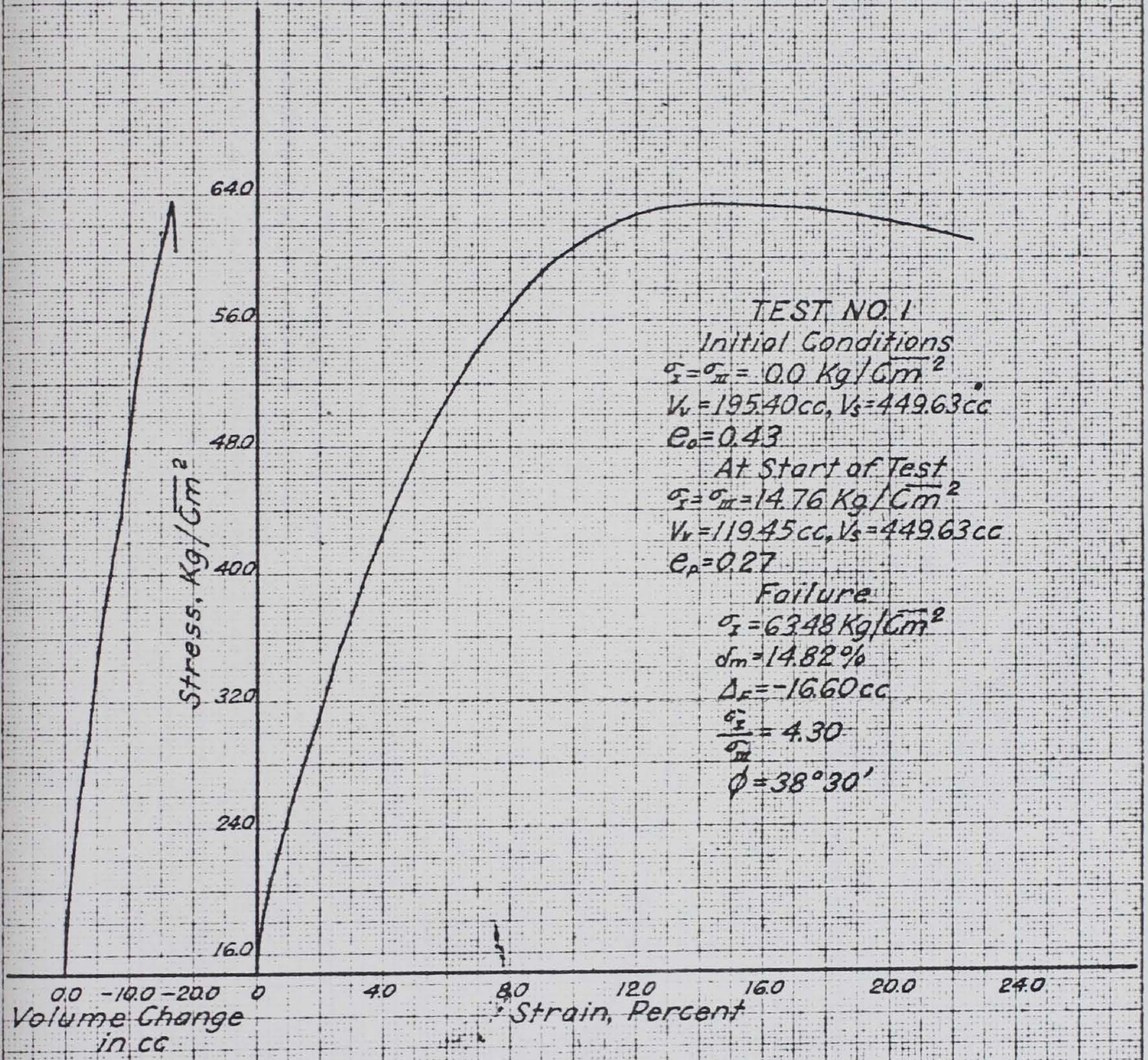
PROPOSED MUD MOUNTAIN DAM

Test Pit No. 8 Sample No. 2

COMPACTION DIAGRAM

COMPACTED BY 25 BLOWS OF STANDARD 5½ POUND HAMMER

FIGURE 7



CORE MATERIAL

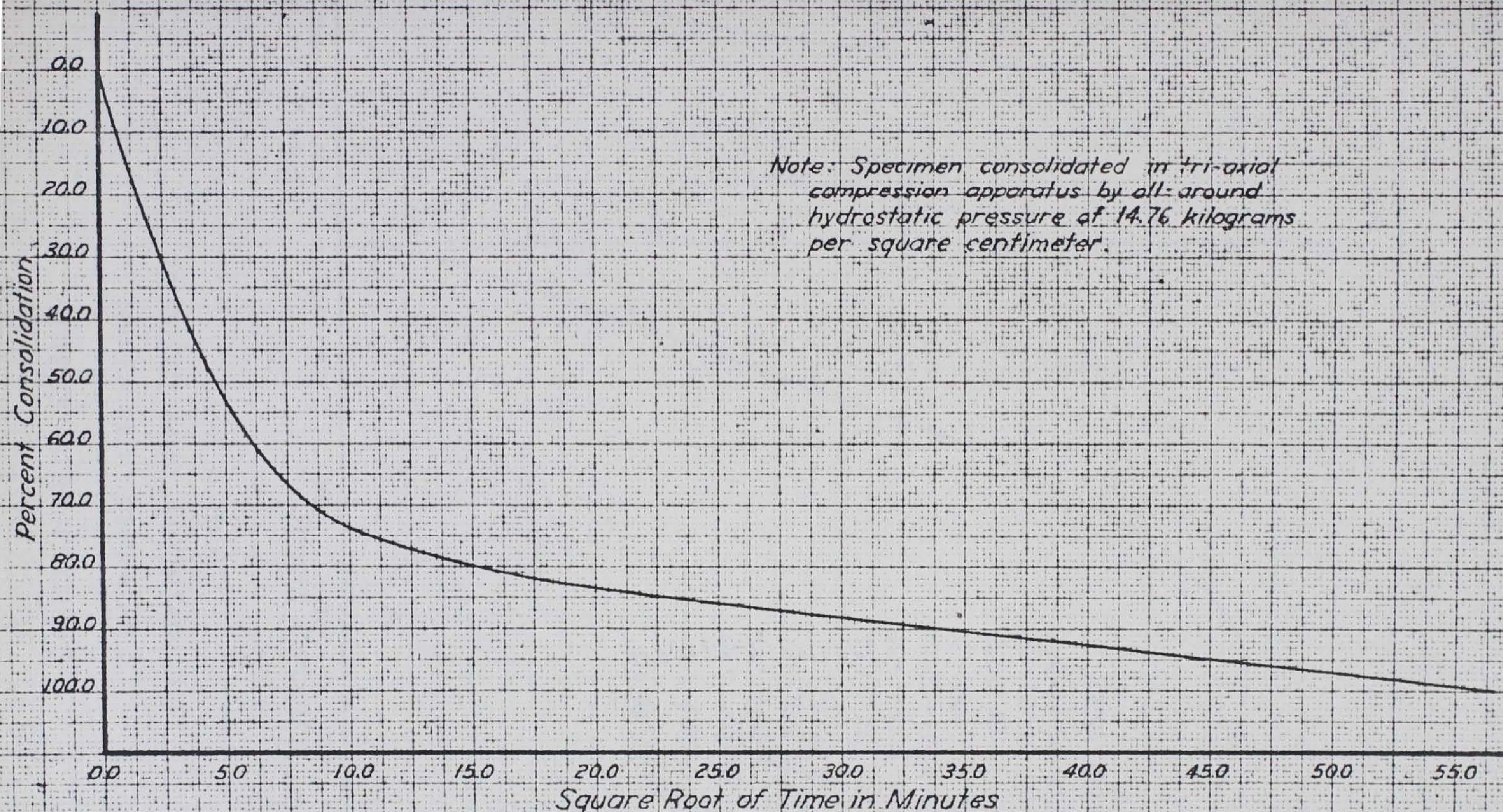
PROPOSED MUD MOUNTAIN DAM

Test Pit No. 1 Sample No. 2

STRESS STRAIN CURVE

TRI-AXIAL COMPRESSION TEST

FIGURE 8



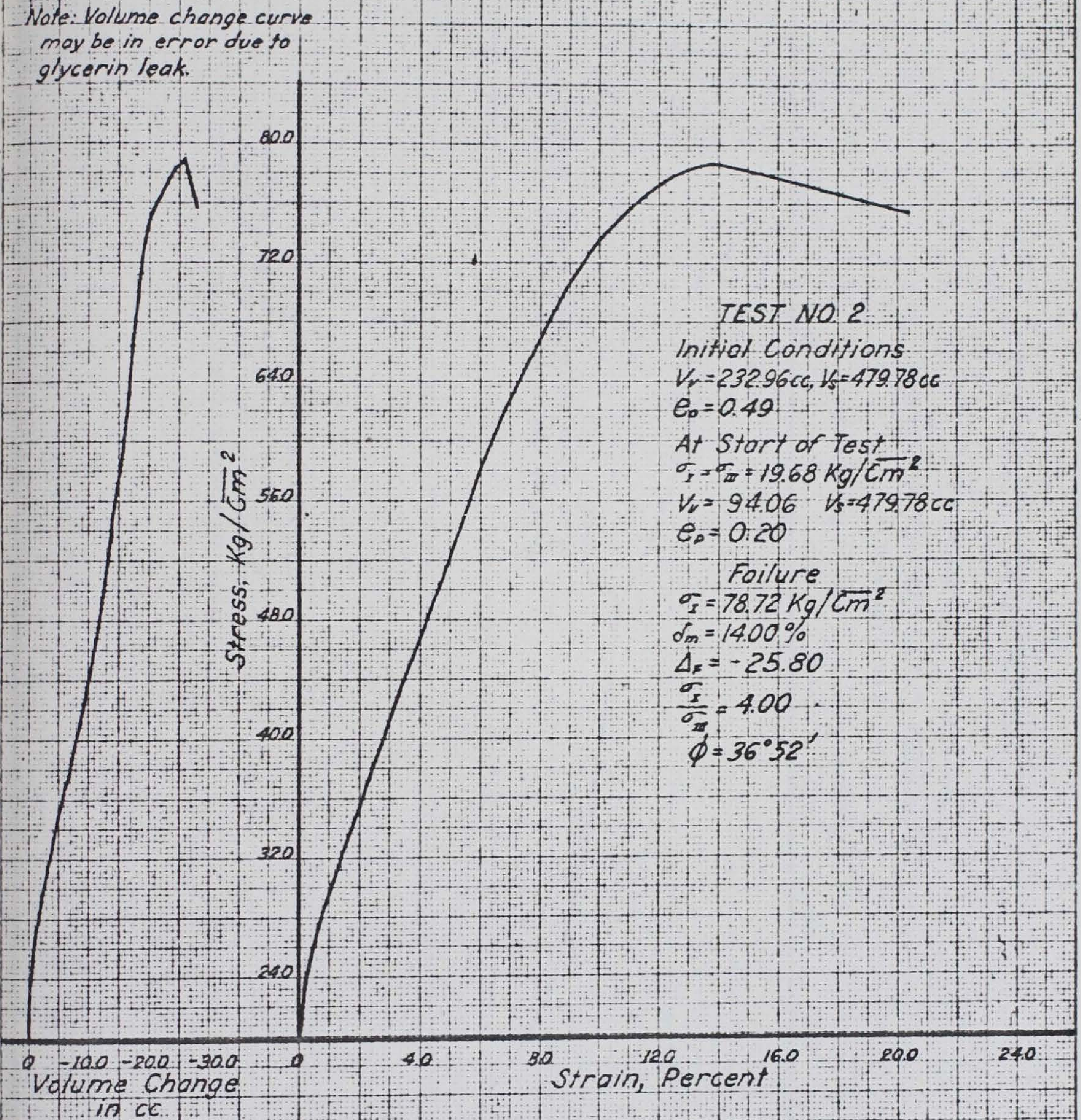
CORE MATERIAL

PROPOSED MUD MOUNTAIN DAM

Test Pit No. 1 Sample No. 2

TIME-CONSOLIDATION DIAGRAM

FIGURE 9



CORE MATERIAL

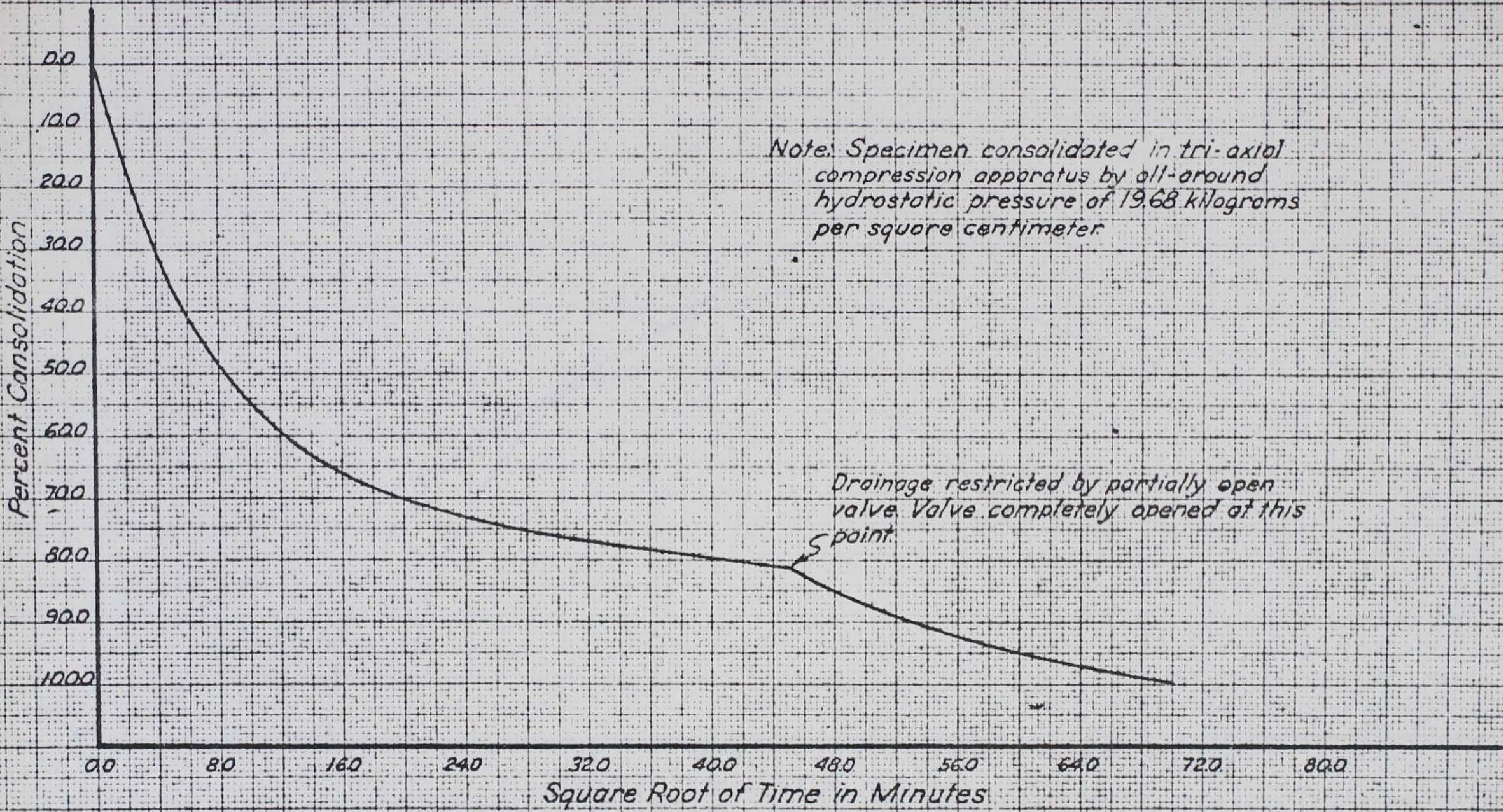
PROPOSED MUD MOUNTAIN DAM

Test Pit No. 1 Sample No. 2

STRESS STRAIN CURVE

TRI-AXIAL COMPRESSION TEST

FIGURE 10



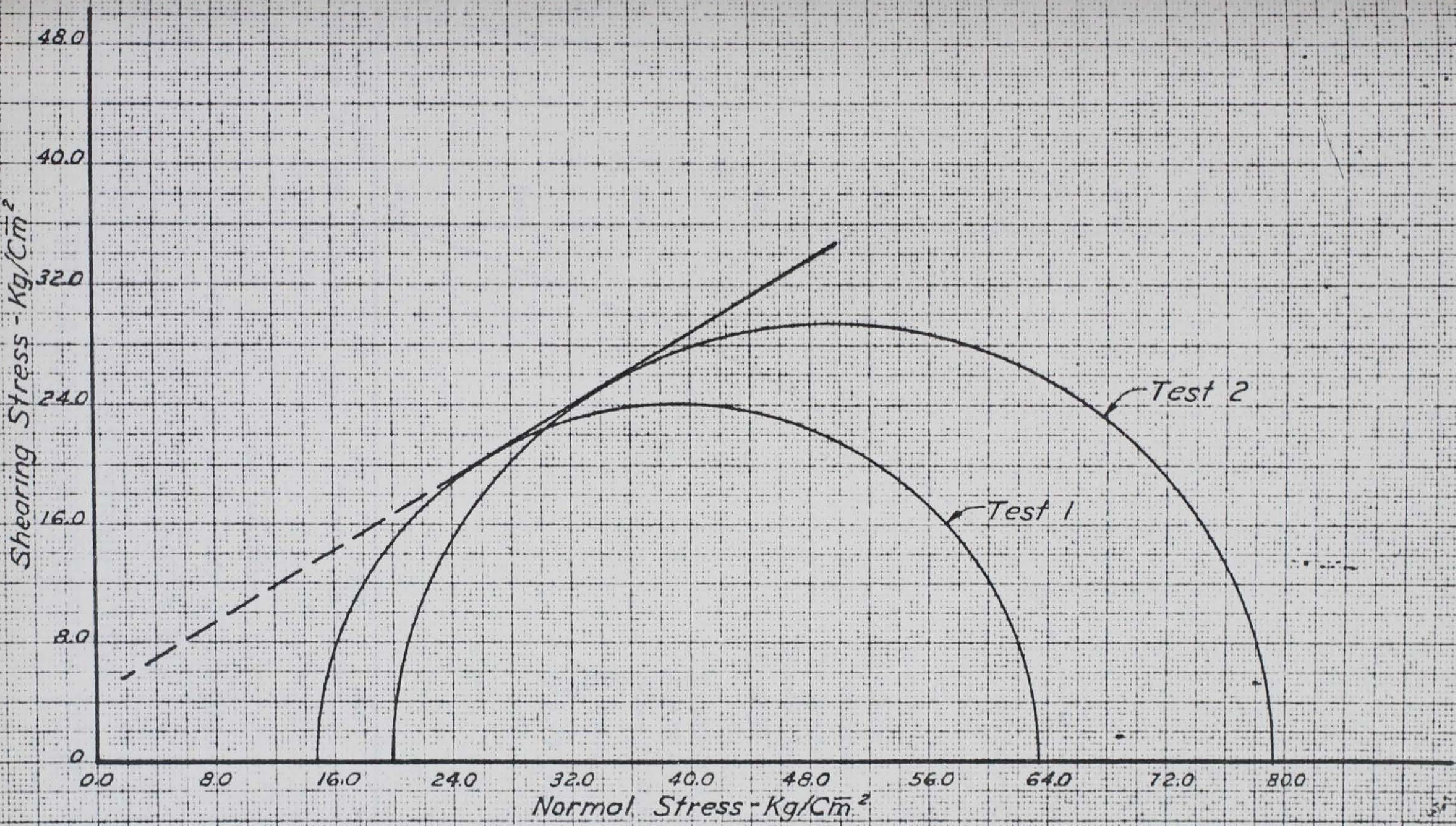
CORE MATERIAL

PROPOSED MUD MOUNTAIN DAM

Test Pit No. 1 Sample No. 2

TIME-CONSOLIDATION DIAGRAM

FIGURE 11

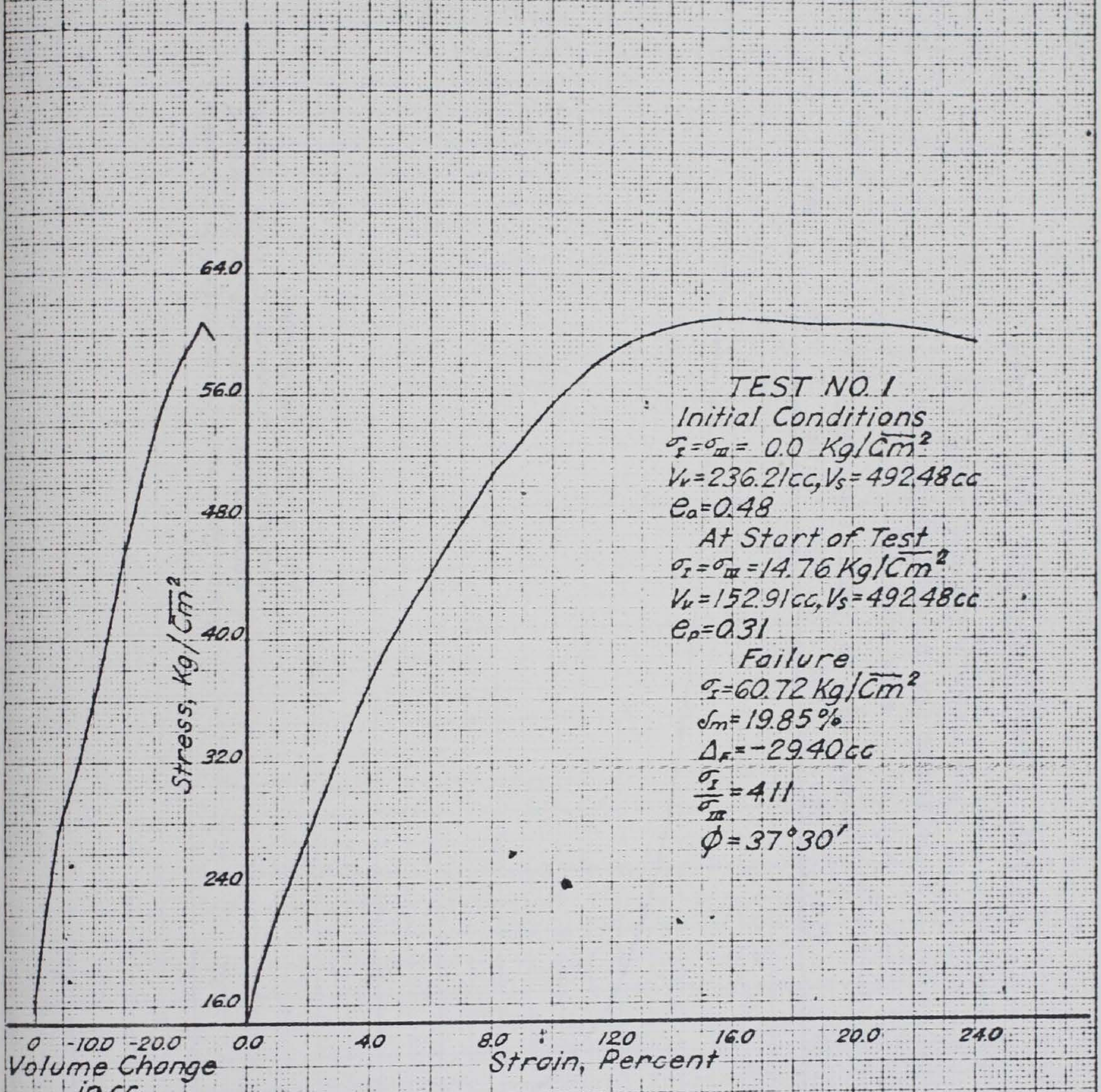


PROPOSED MUD MOUNTAIN DAM

Sample No. 2 - Test Pit No. 1

MOHR'S CIRCLES OF STRESS

FIGURE 12



CORE MATERIAL

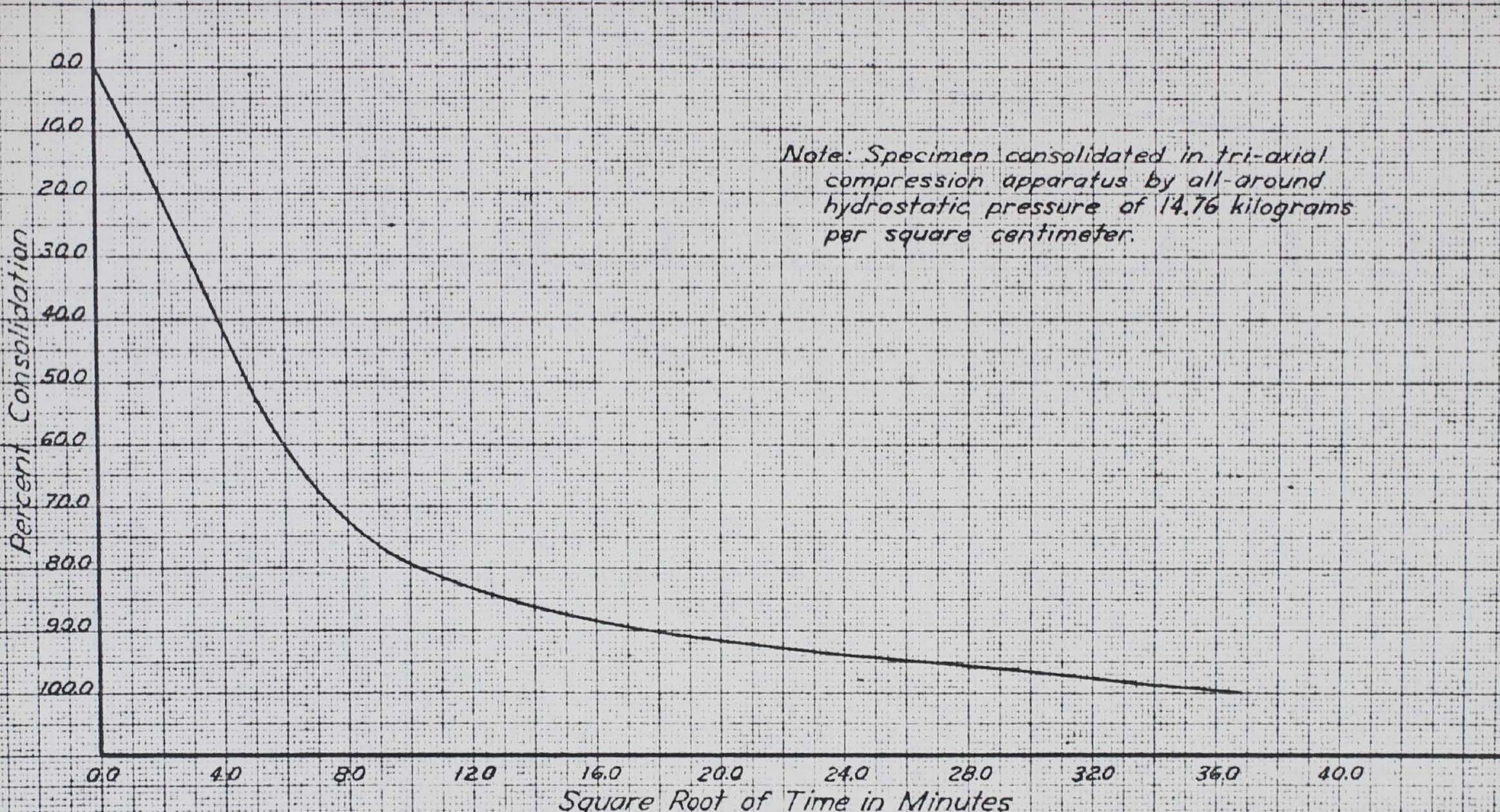
PROPOSED MUD MOUNTAIN DAM

Test Pit No. 3 Sample No. 2

STRESS STRAIN CURVE

TRI-AXIAL COMPRESSION TEST

FIGURE 13



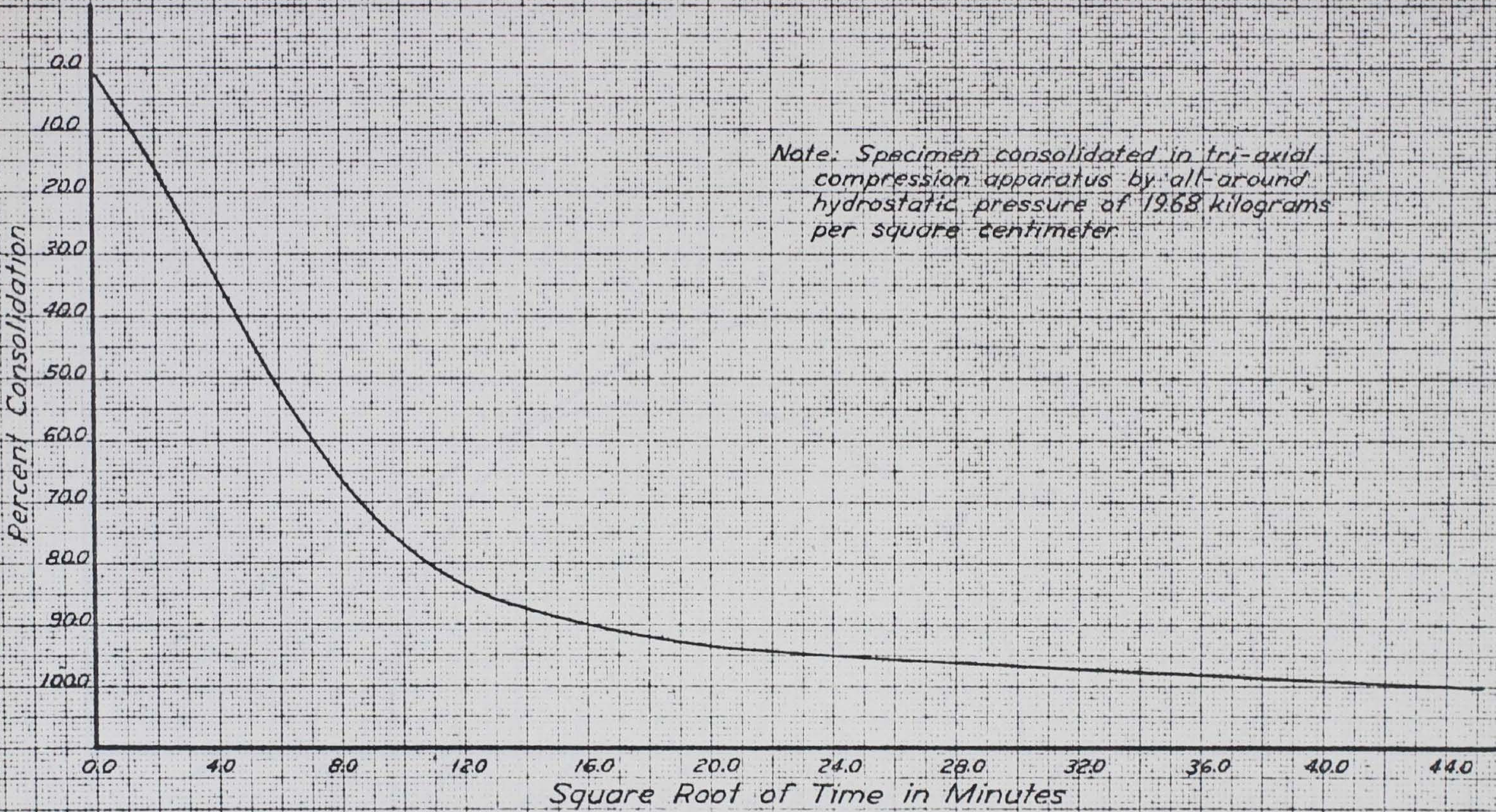
CORE MATERIAL

PROPOSED MUD MOUNTAIN DAM

Test Pit No. 3 Sample No. 2

TIME-CONSOLIDATION DIAGRAM

FIGURE 14



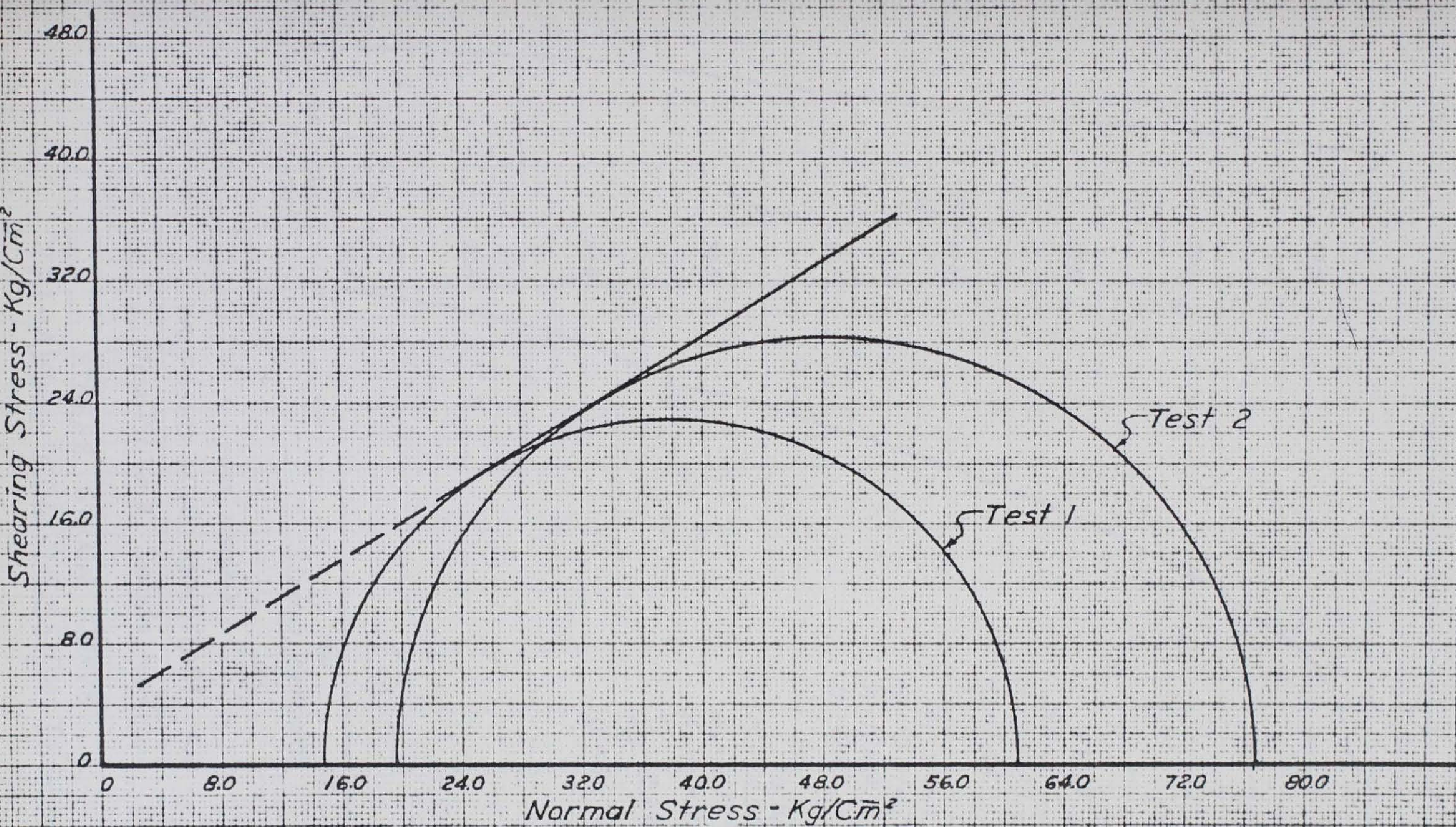
CORE MATERIAL

PROPOSED MUD MOUNTAIN DAM

Test Pit No. 3 Sample No. 2

TIME-CONSOLIDATION DIAGRAM

FIGURE 16

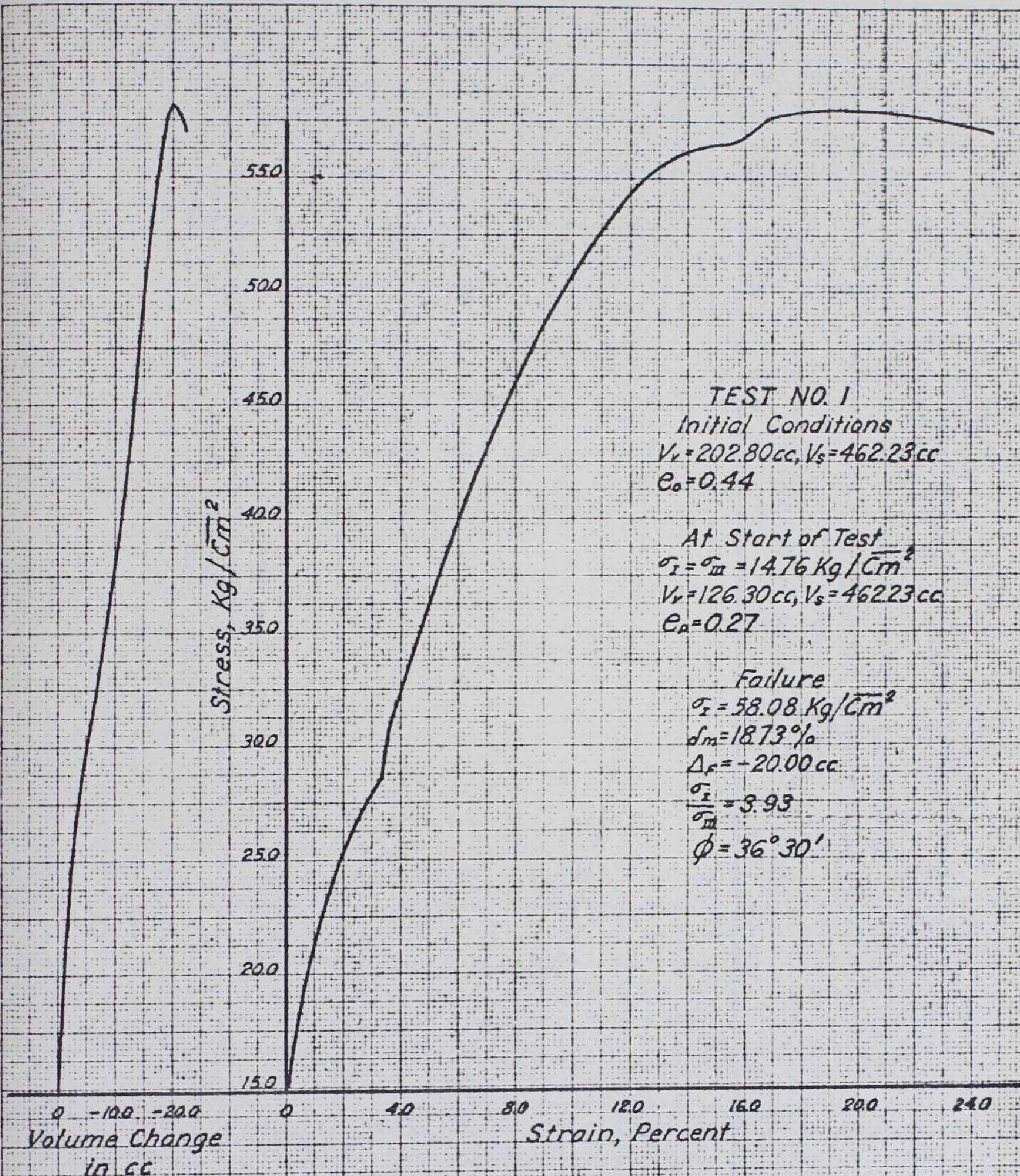


PROPOSED MUD MOUNTAIN DAM

Sample No. 2 - Test Pit No. 3

MOHR'S CIRCLES OF STRESS

FIGURE 17



CORE MATERIAL

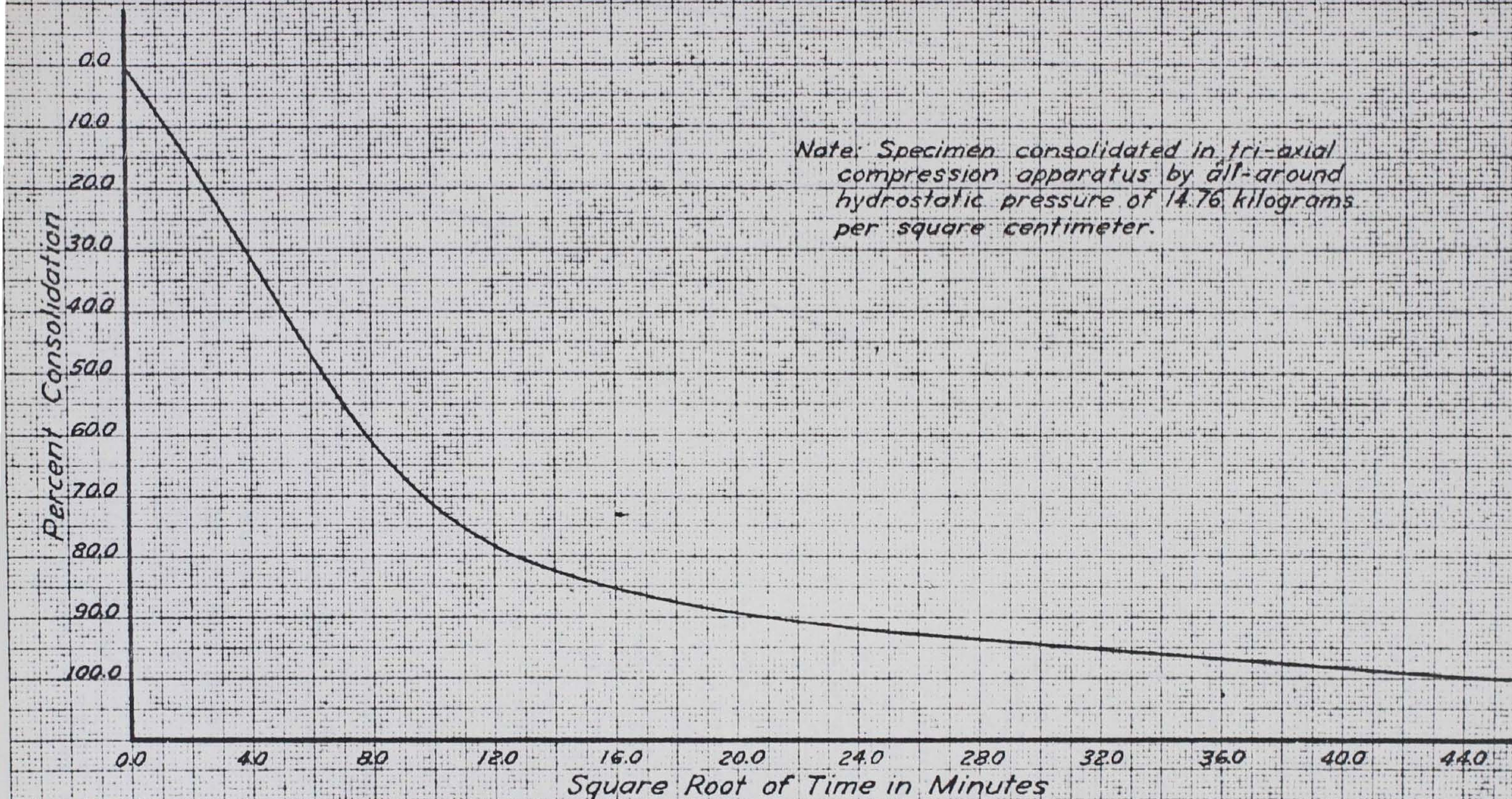
PROPOSED MUD MOUNTAIN DAM

Test Pit No. 8 Sample No. 2

STRESS STRAIN CURVE

TRI-AXIAL COMPRESSION TEST

FIGURE 18



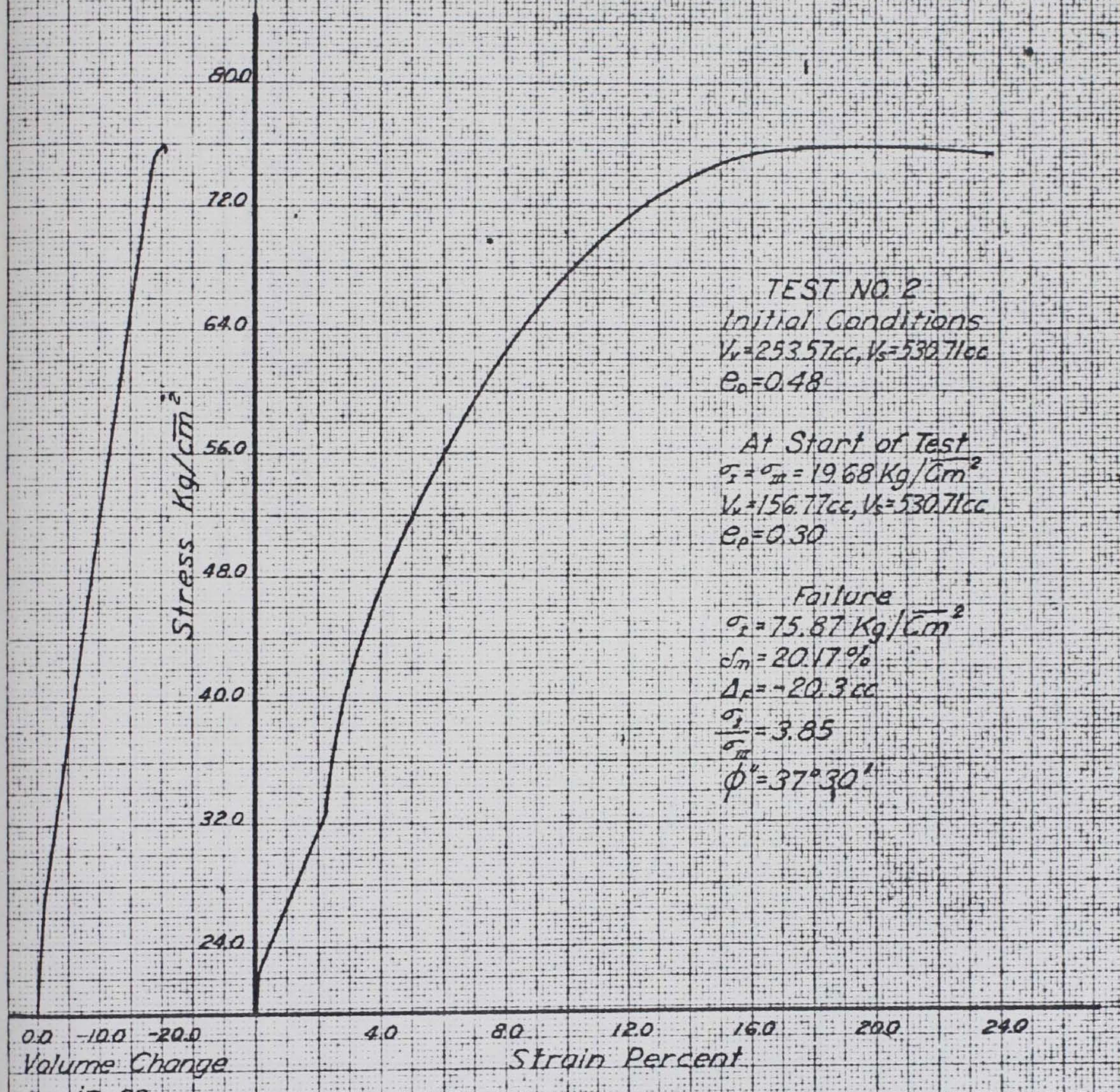
CORE MATERIAL

PROPOSED MUD MOUNTAIN DAM

Test Pit No. 8 Sample No. 2

TIME-CONSOLIDATION DIAGRAM

FIGURE 19



CORE MATERIAL

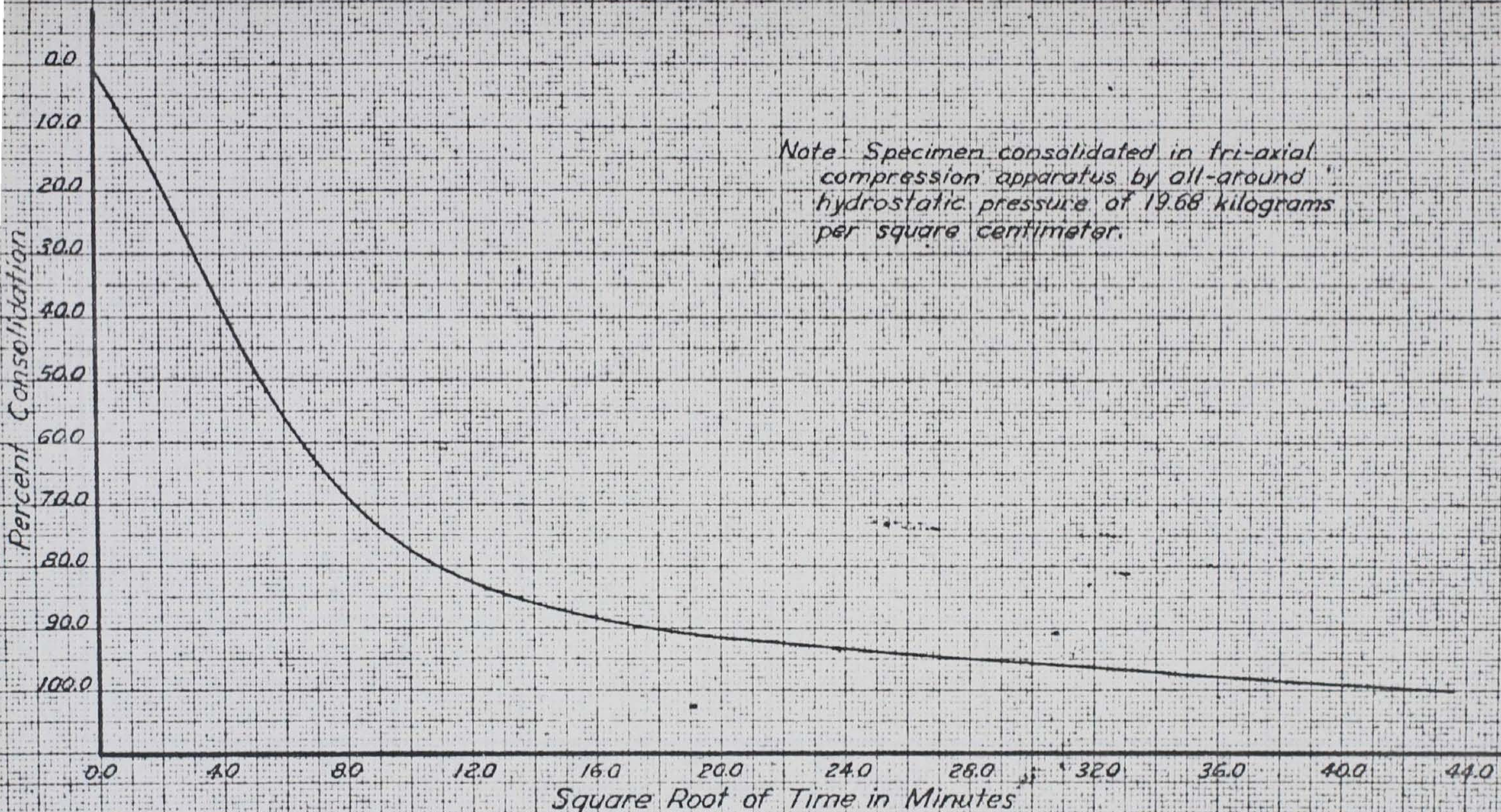
PROPOSED MUD MOUNTAIN DAM

Test Pit No. 8 Sample No. 2

STRESS STRAIN CURVE

TRI-AXIAL COMPRESSION TEST

FIGURE 20



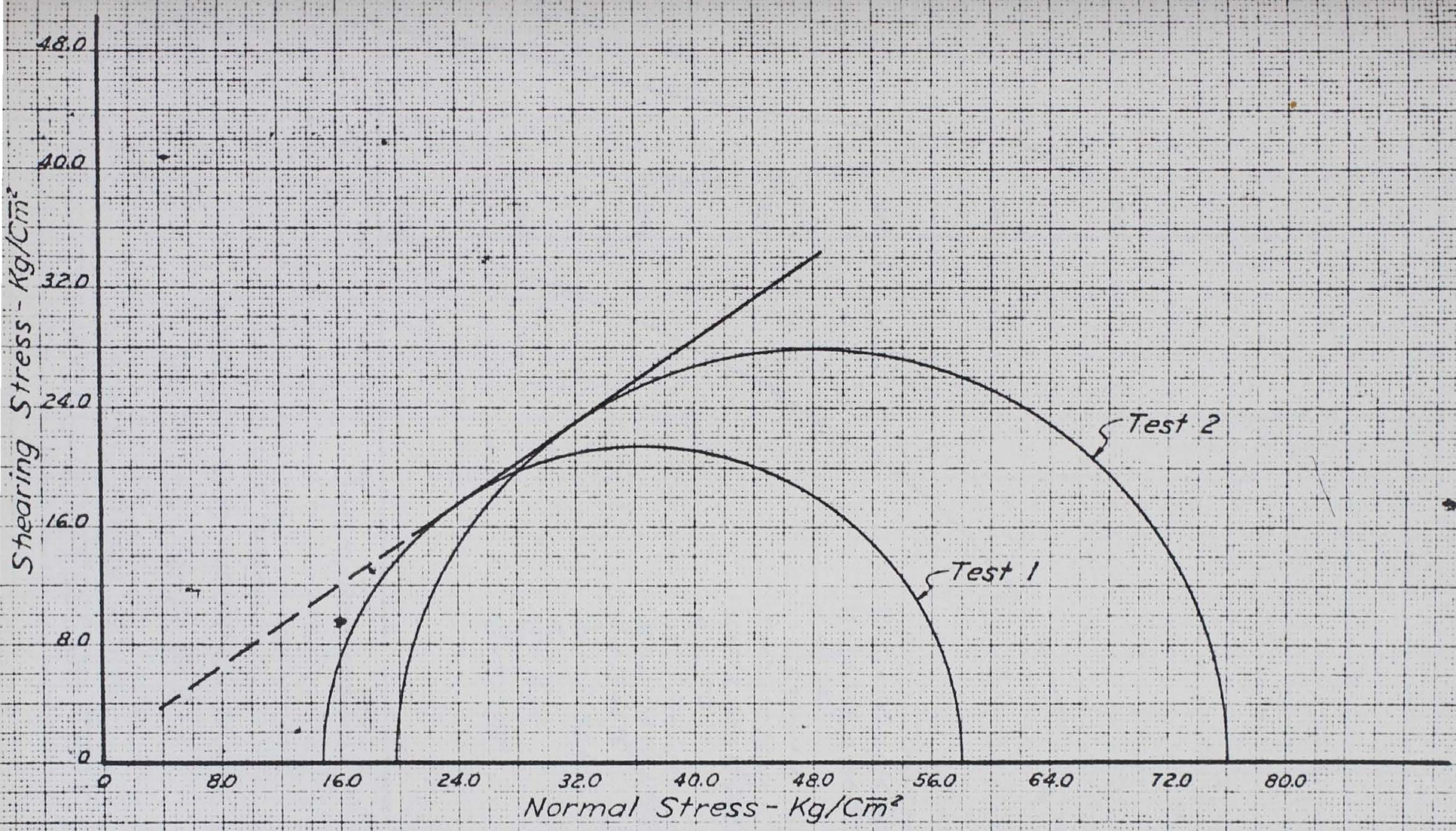
CORE MATERIAL

PROPOSED MUD MOUNTAIN DAM

Test Pit No. 8 Sample No. 2

TIME-CONSOLIDATION DIAGRAM

FIGURE 21

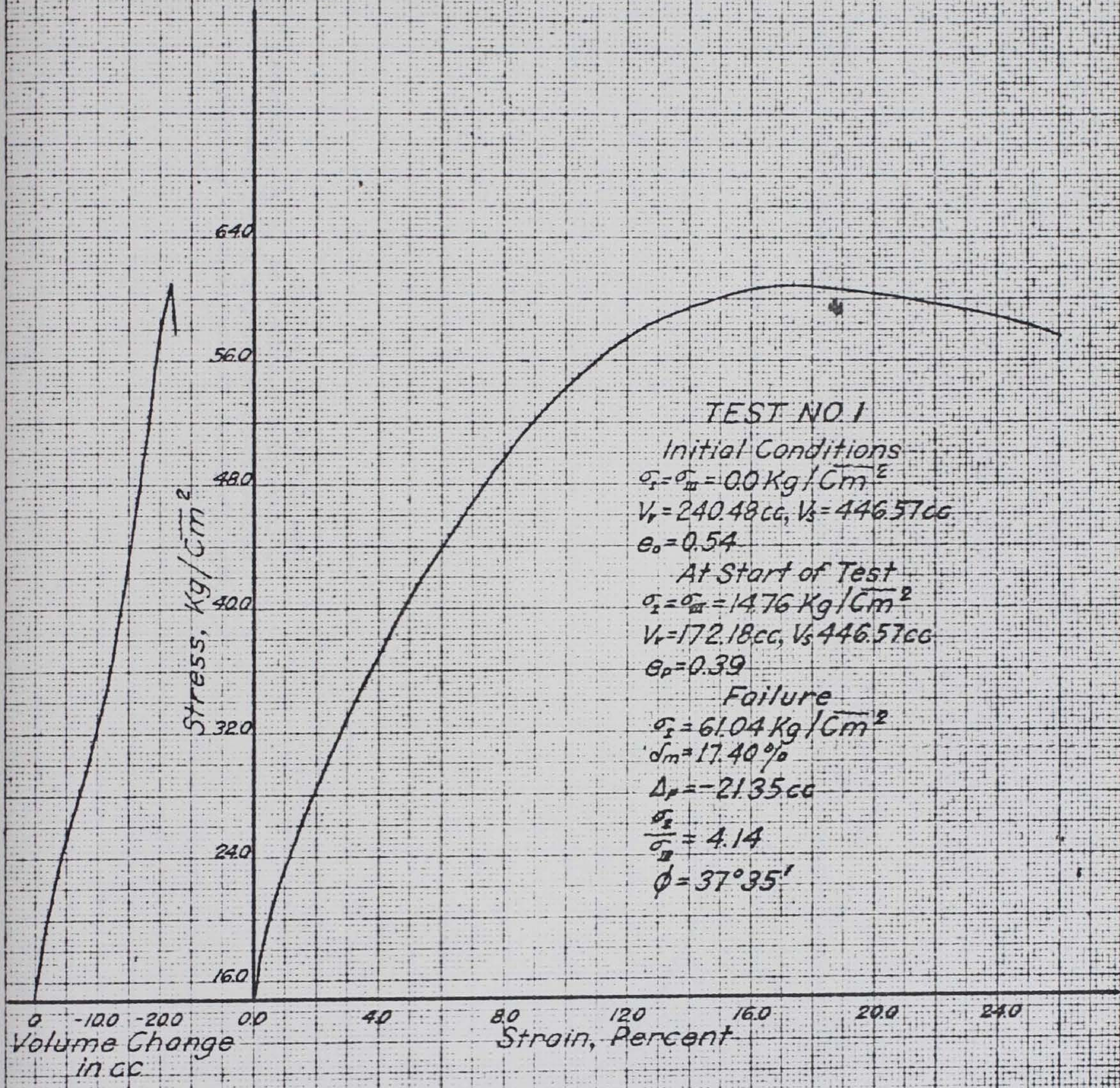


PROPOSED MUD MOUNTAIN DAM

Sample No. 2 - Test Pit No. 8

MOHR'S CIRCLES OF STRESS

FIGURE 22



CORE MATERIAL

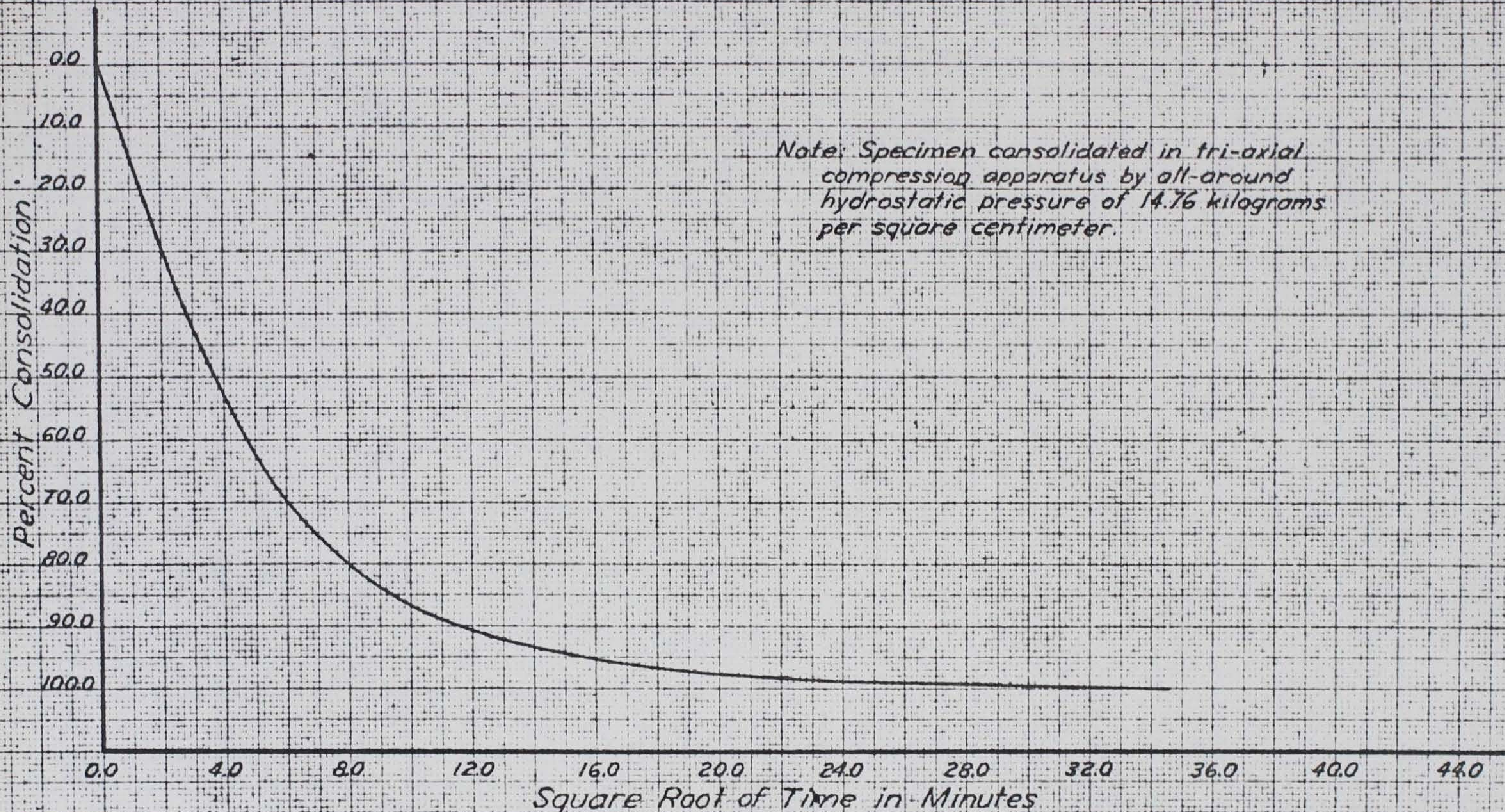
PROPOSED MUD MOUNTAIN DAM

Test Pit No. 9 Sample No. 2

STRESS STRAIN CURVE

TRI-AXIAL COMPRESSION TEST

FIGURE 23



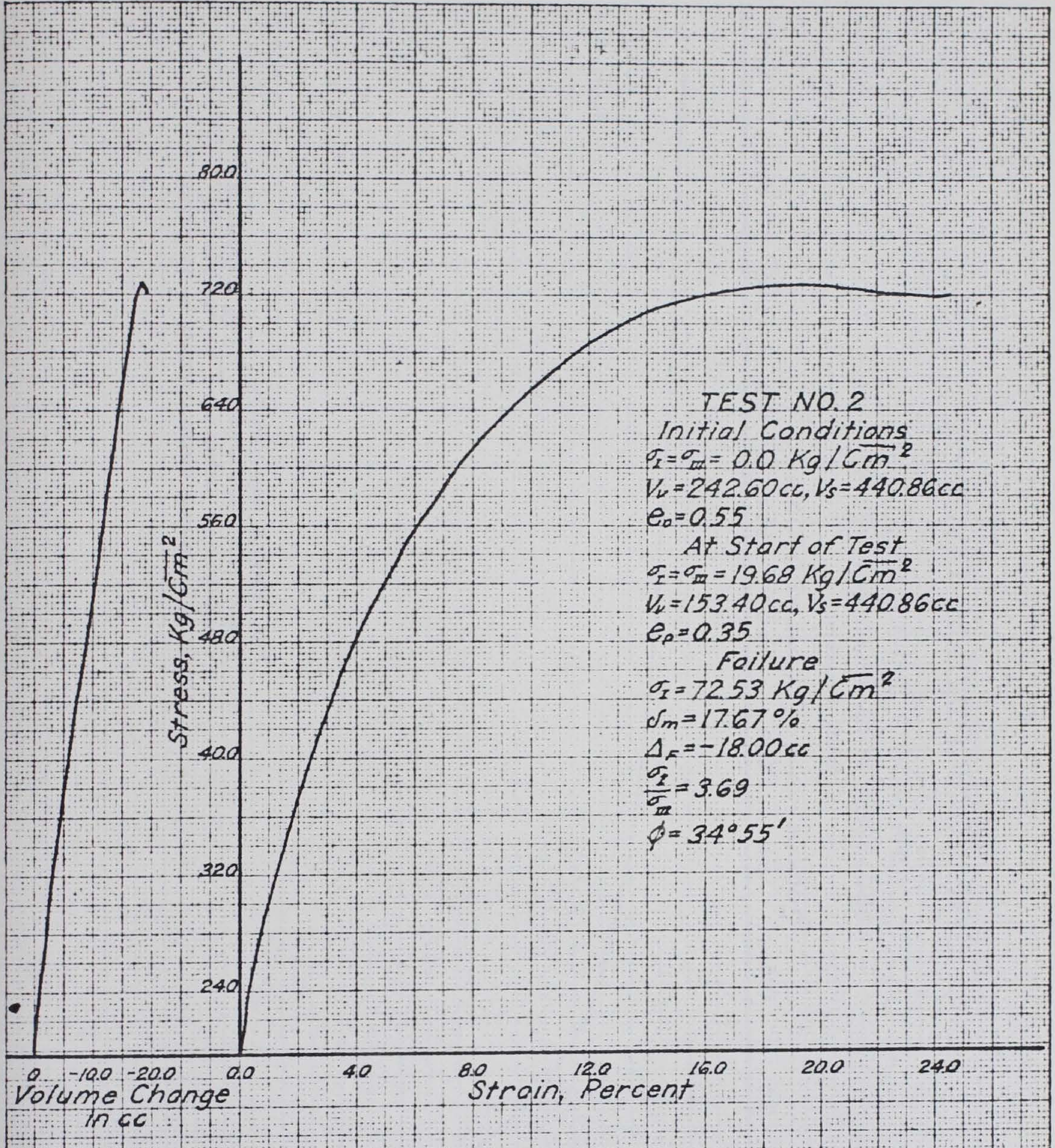
CORE MATERIAL

PROPOSED MUD MOUNTAIN DAM

Test Pit No. 9 - Sample No. 2

TIME-CONSOLIDATION DIAGRAM

FIGURE 24



CORE MATERIAL

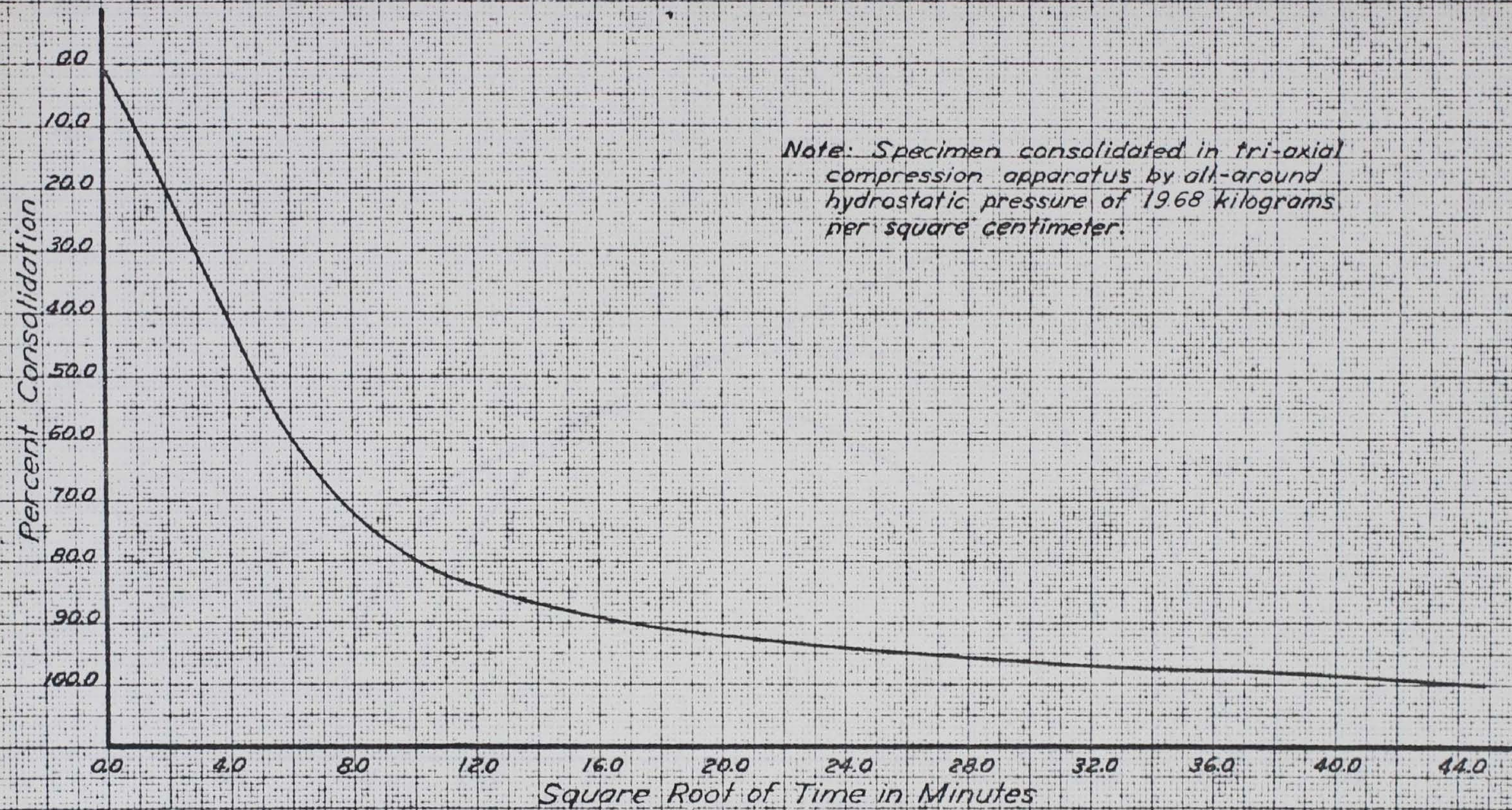
PROPOSED MUD MOUNTAIN DAM

Test Pit No. 9 Sample No. 2

STRESS STRAIN CURVE

TRI-AXIAL COMPRESSION TEST

FIGURE 25



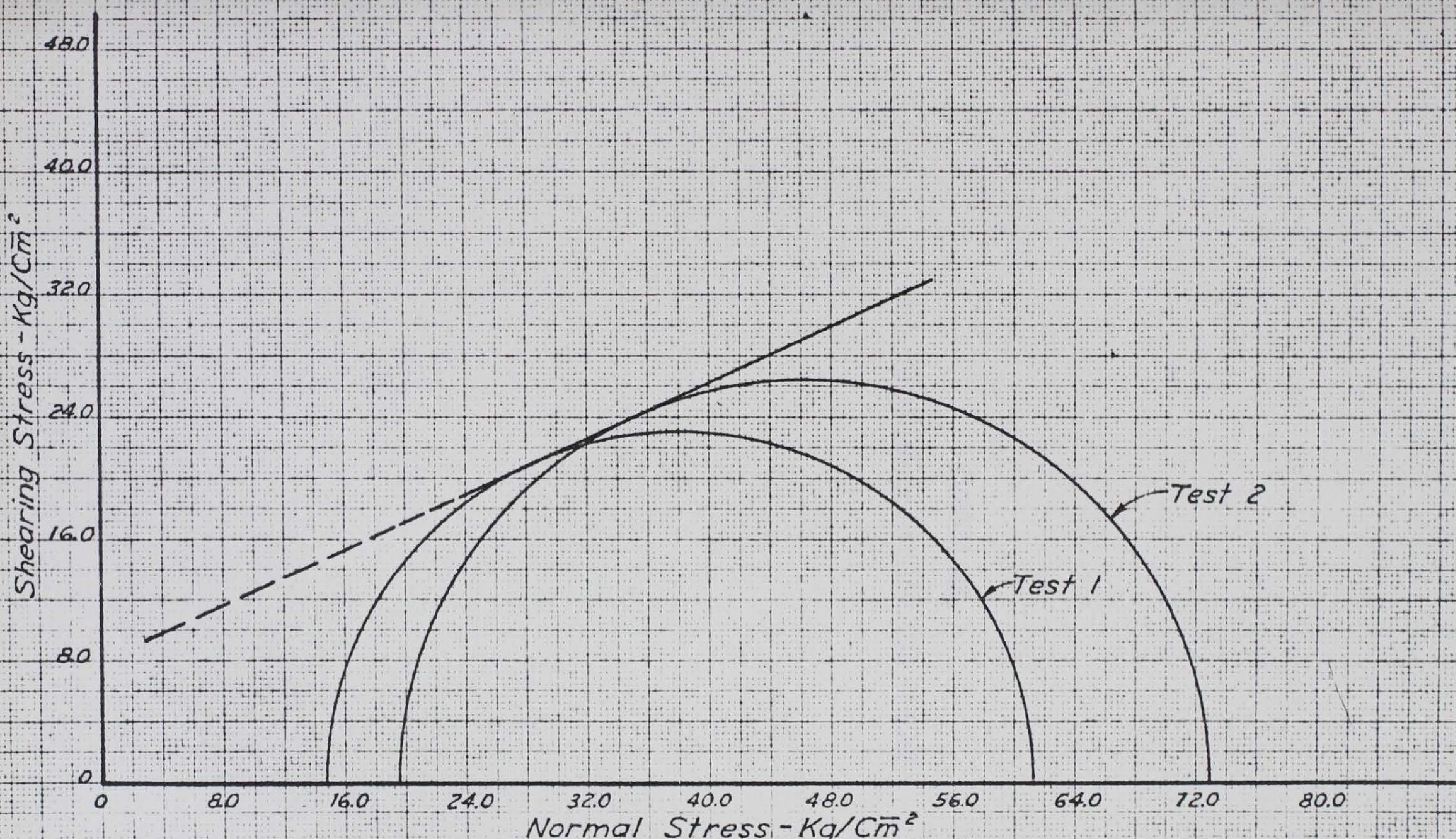
CORE MATERIAL

PROPOSED MUD MOUNTAIN DAM

Test Pit No. 9 Sample No. 2

TIME-CONSOLIDATION DIAGRAM

FIGURE 26



PROPOSED MUD MOUNTAIN DAM

Sample No. 2 - Test Pit No. 9

MOHR'S CIRCLES OF STRESS

FIGURE 27

FIGURES FOR

SAND AND GRAVEL - GLACIAL TILL SAMPLES

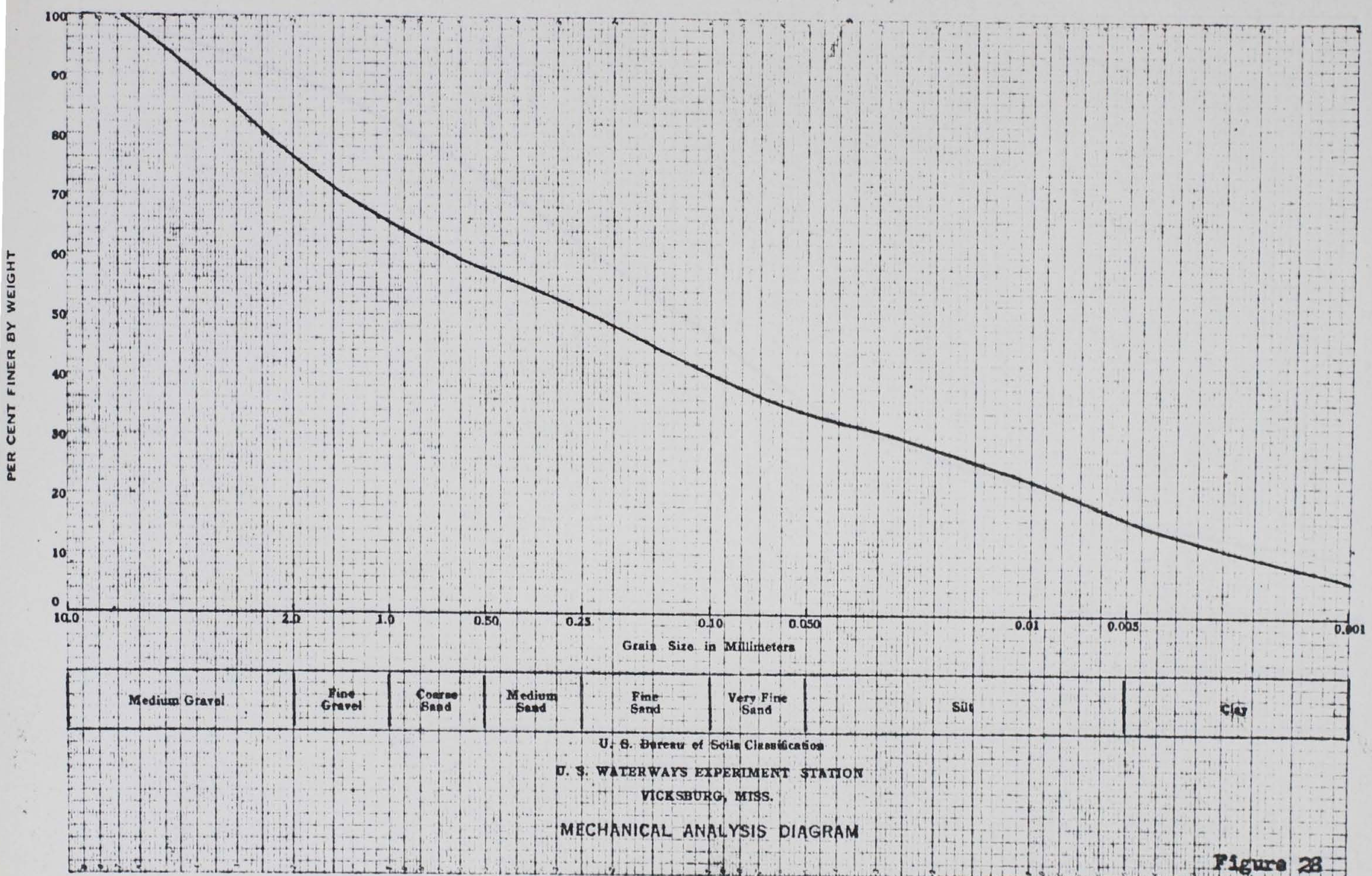


Figure 28

Sample No. 4 (sand and gravel)

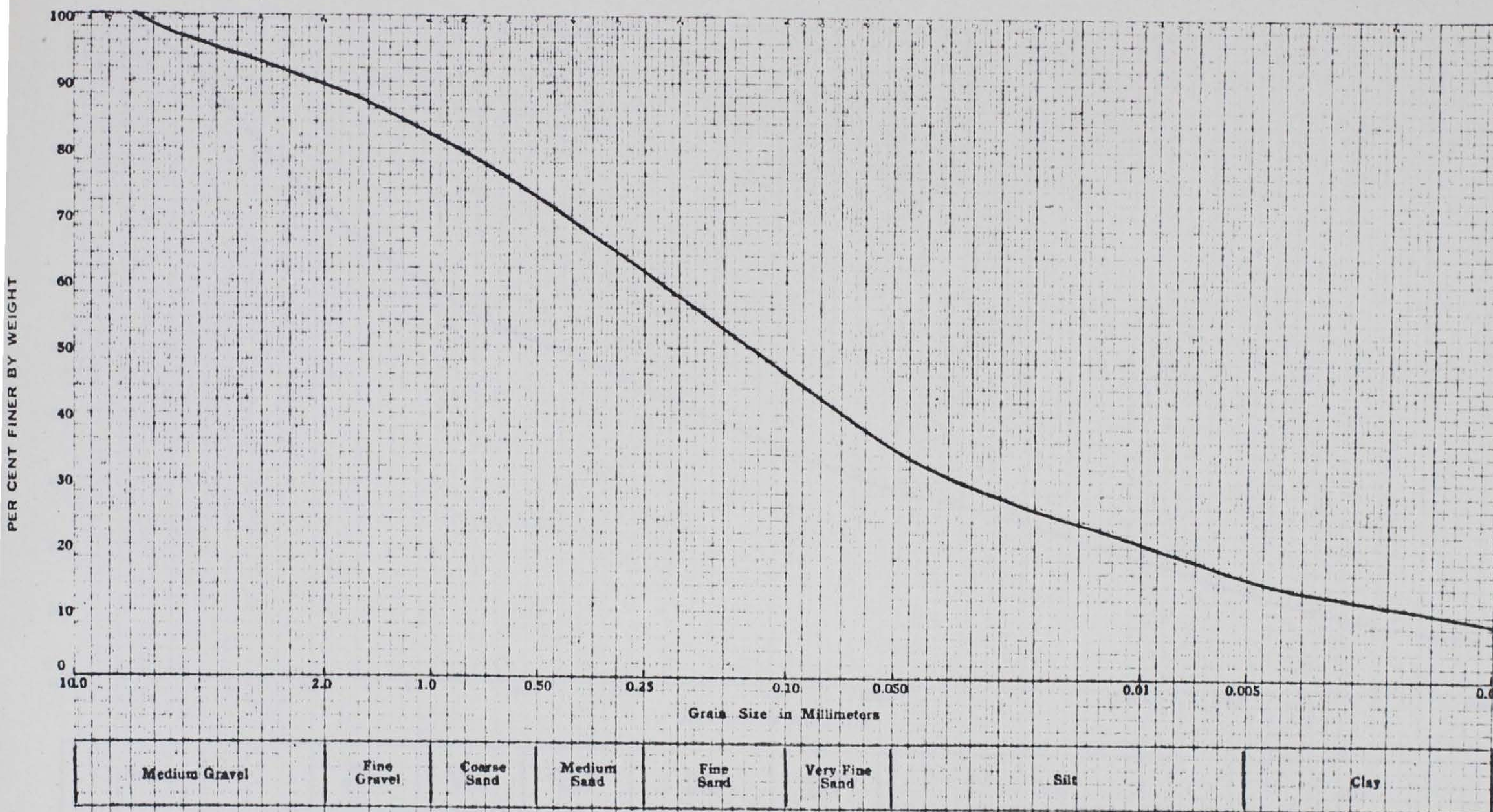
Location of Sample Proposed Mud Mountain Dam

Remarks Portion of Sample Passing 3 Mesh Sieve

Date Sample Taken

Date Sample Tested 7-19-39

Specific Gravity of Sample 2.75



U. S. WATERWAYS EXPERIMENT STATION
VICKSBURG, MISS.

MECHANICAL ANALYSIS DIAGRAM

Figure 29

Sample No. 1 (glacial till)

Location of Sample Proposed Mud Mountain Dam

Remarks Portion of Sample Passing 3 Mesh Sieve

Date Sample Taken

Date Sample Tested 7-19-39

Specific Gravity of Sample 2.68

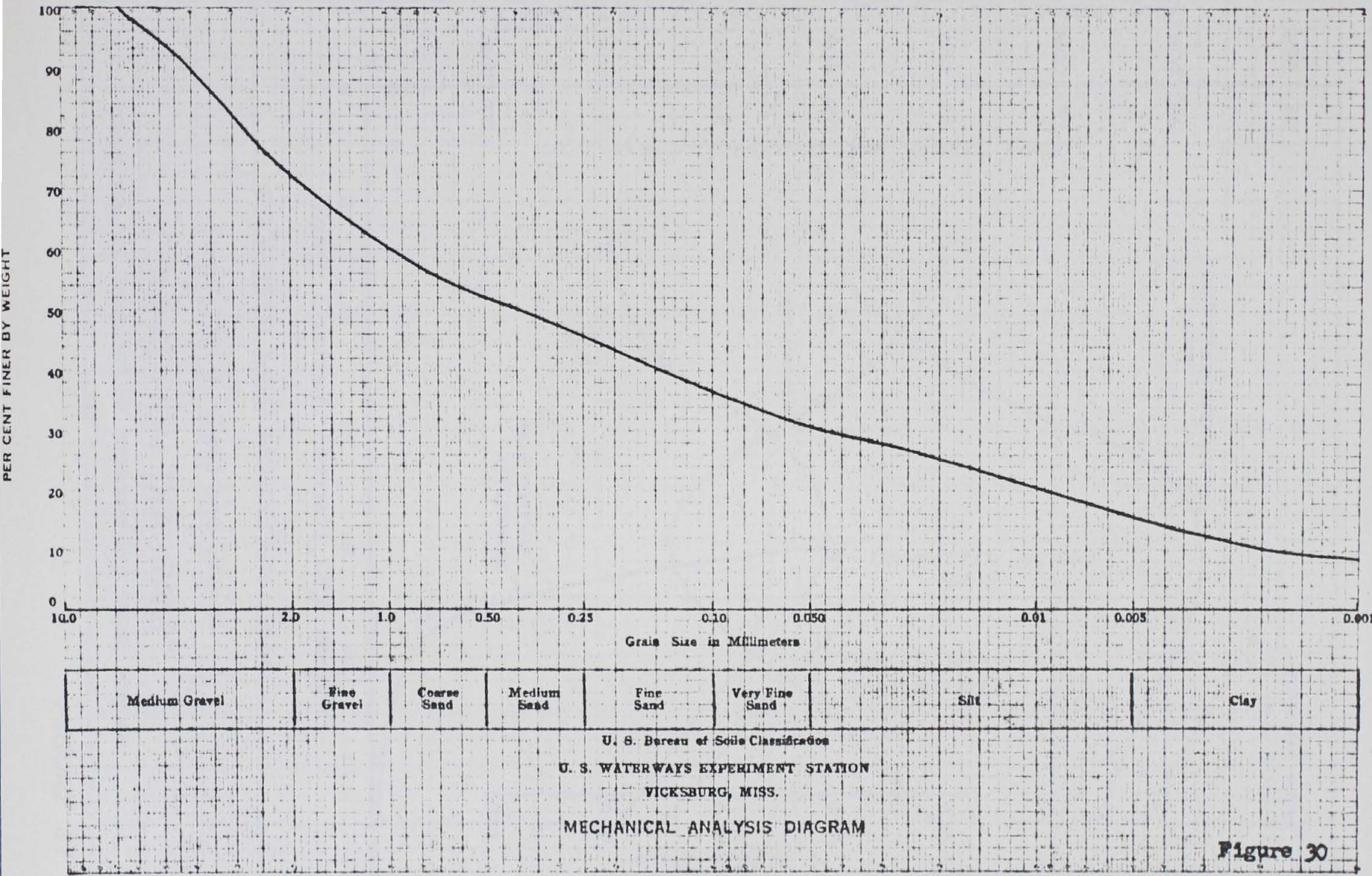
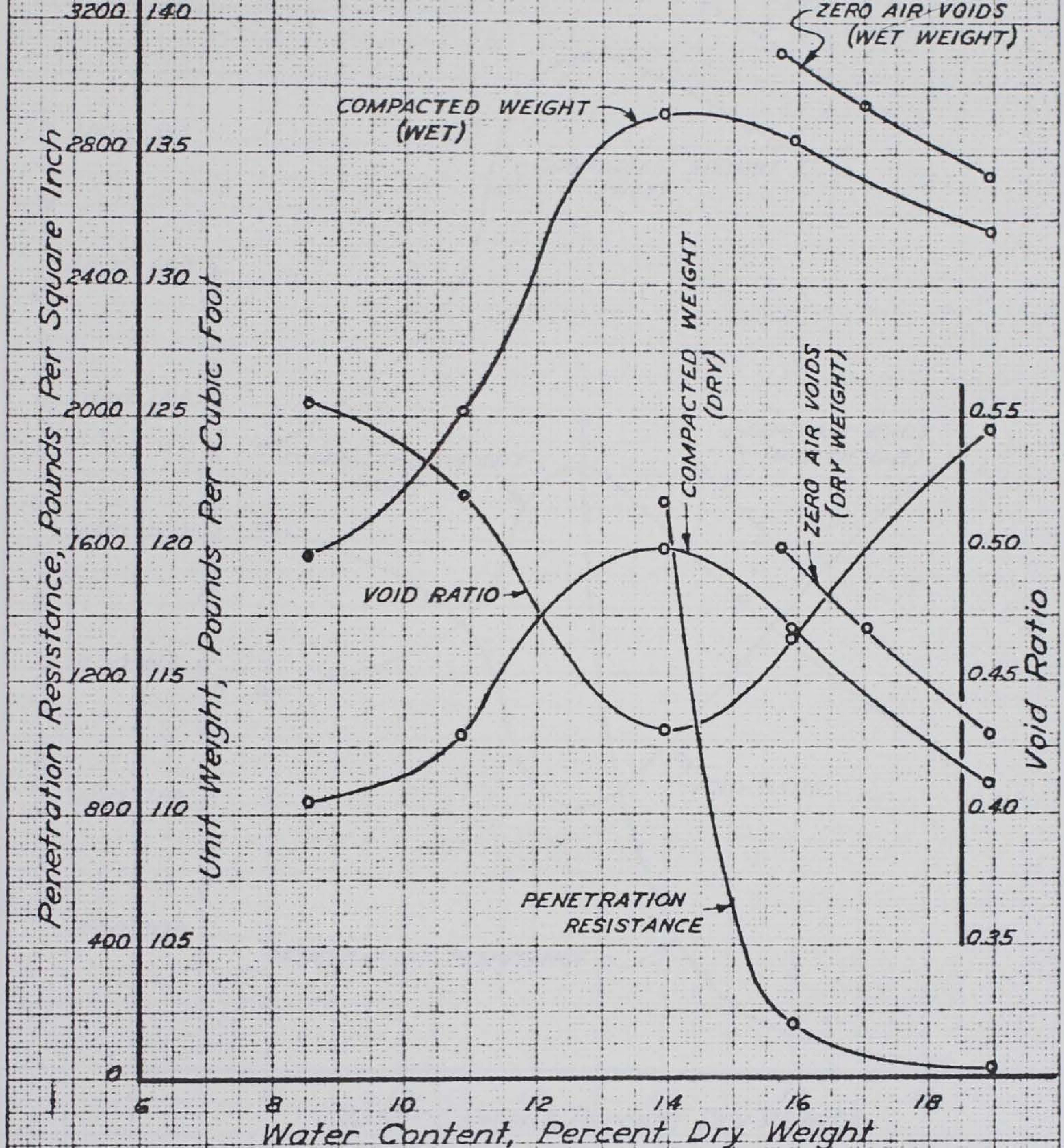


Figure 30

Sample No. Mixture - 80% Sample No. 4 and 20% Sample No. 1
Location of Sample. Proposed Mud Mountain Dam
Remarks. Portion of Sample Passing 3 Mesh Sieve

Date Sample Taken.
Date Sample Tested. 7-20-39
Specific Gravity of Sample. 2.72



PROPOSED MUD MOUNTAIN DAM

Sample No. 4 - Sand and Gravel

COMPACTION DIAGRAM

COMPACTED BY 25 BLOWS OF STANDARD $5\frac{1}{2}$ POUND HAMMER

FIGURE 31

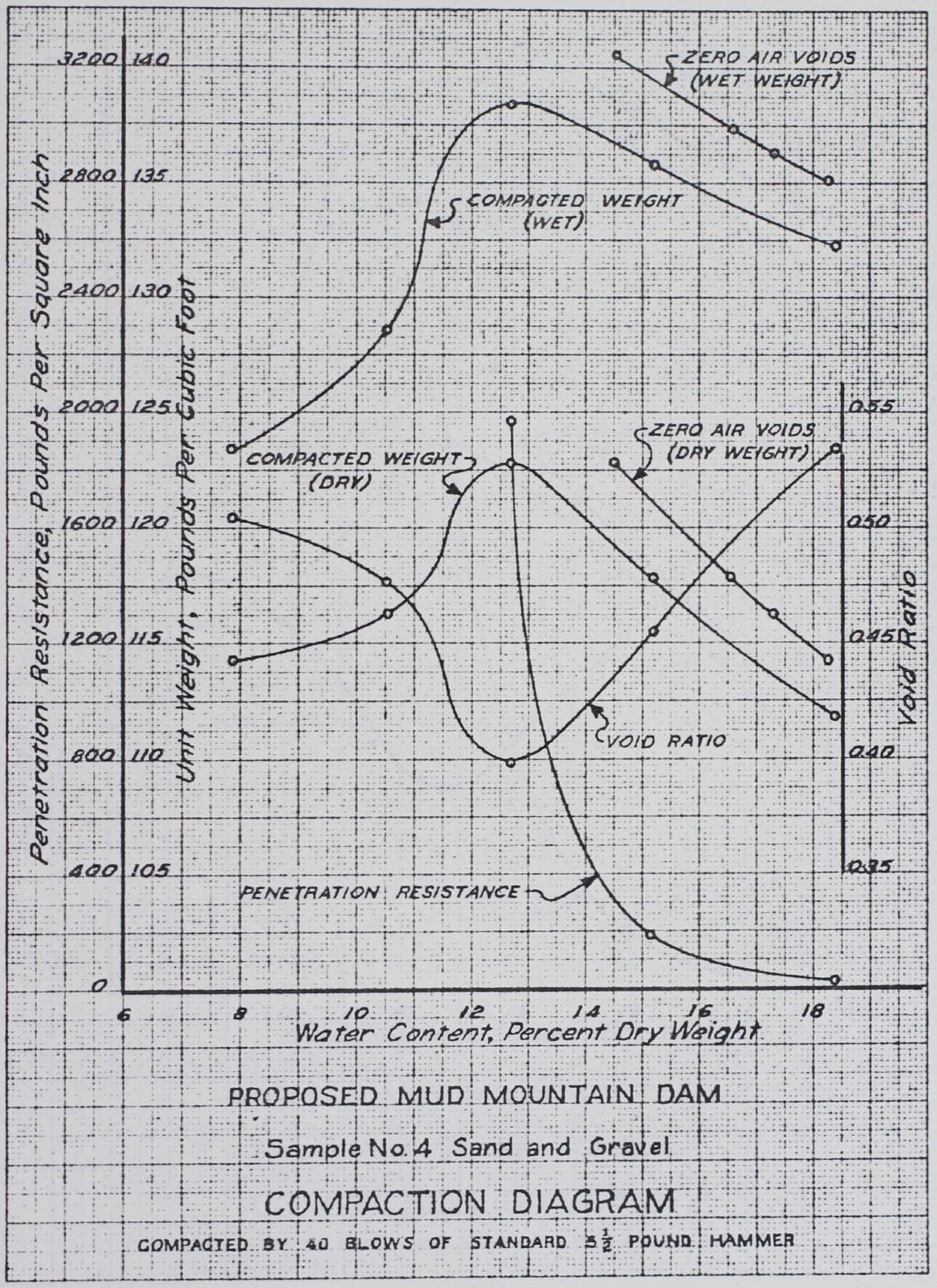
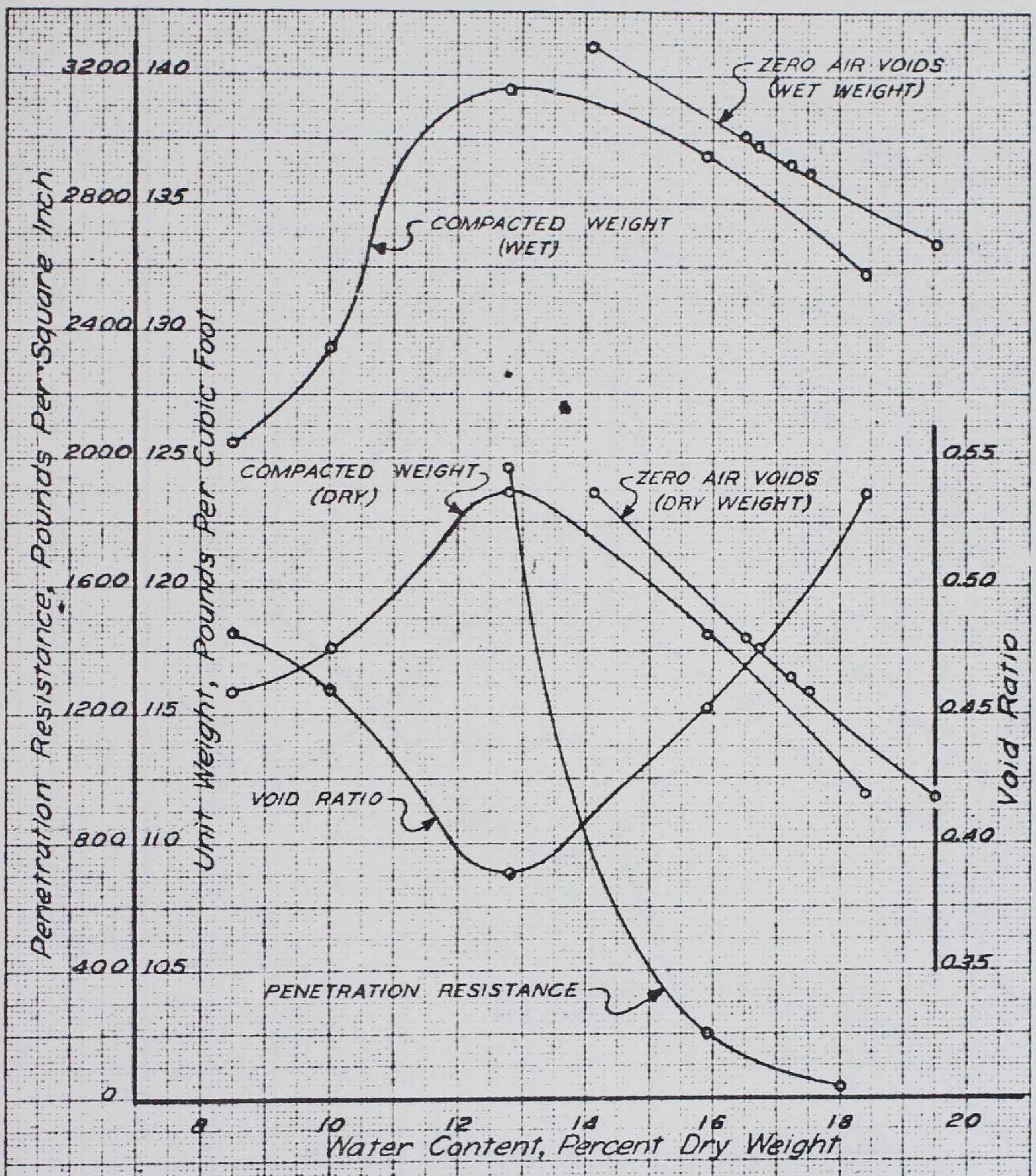

ZERO AIR VOIDS (WET WEIGHT)
COMPACTED WEIGHT (WET)
ZERO AIR VOIDS (DRY WEIGHT)
COMPACTED WEIGHT (DRY)
VOID RATIO
PENETRATION RESISTANCE
3200 2800 2400 2000 1600 1200 800 400 0
140 135 130 125 120 115 110 105
0.55 0.50 0.45 0.40 0.35
6 8 10 12 14 16 18
Penetration Resistance, Pounds Per Square Inch
Unit Weight, Pounds Per Cubic Foot
Void Ratio
Water Content, Percent Dry Weight
PROPOSED MUD MOUNTAIN DAM
Sample No. 4 Sand and Gravel
COMPACTION DIAGRAM
COMPACTED BY 40 BLOWS OF STANDARD 5½ POUND HAMMER

FIGURE 32



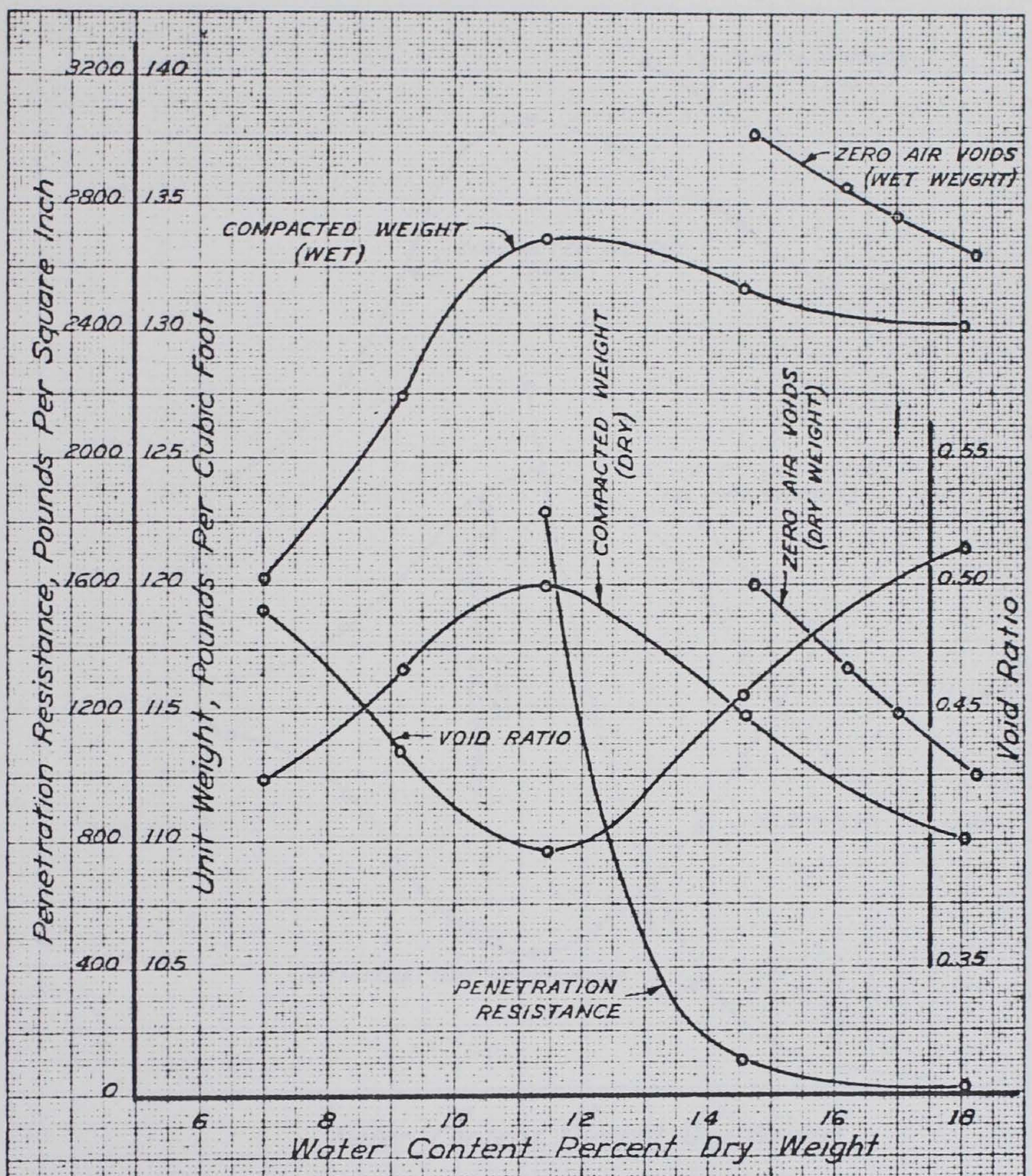
PROPOSED MUD MOUNTAIN DAM

Sample No. 4 - Sand and Gravel

COMPACTION DIAGRAM

COMPACTED BY 50 BLOWS OF STANDARD $5\frac{1}{2}$ POUND HAMMER

FIGURE 33



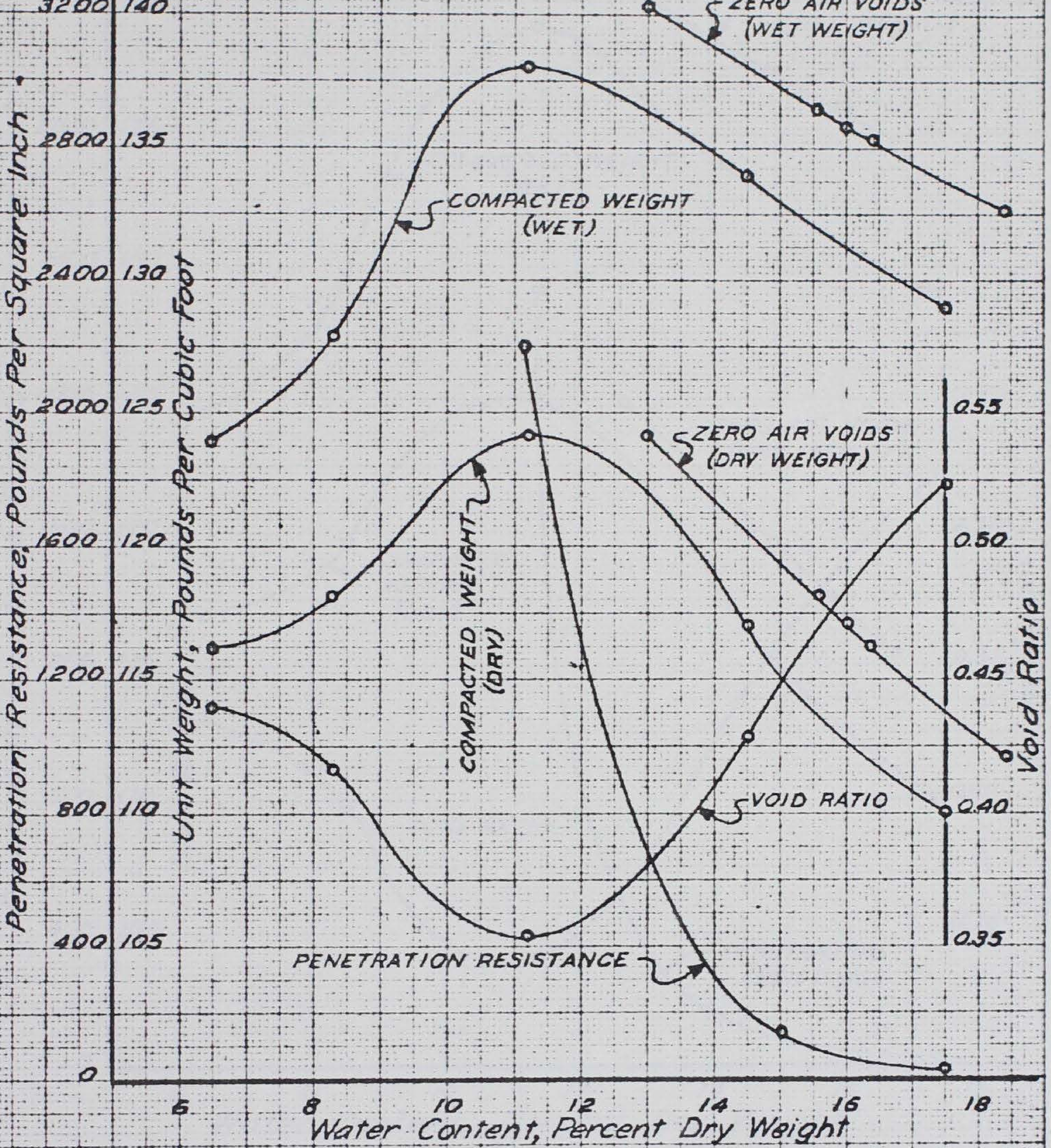
PROPOSED MUD MOUNTAIN DAM

Sample No. 1 - Glacial Till

COMPACTION DIAGRAM

COMPACTED BY 25 BLOWS OF STANDARD $5\frac{1}{2}$ POUND HAMMER

FIGURE 34



PROPOSED MUD MOUNTAIN DAM

Sample No. I Glacial Till

COMPACTION DIAGRAM

COMPACTED BY 40 BLOWS OF STANDARD 5½ POUND HAMMER

FIGURE 35

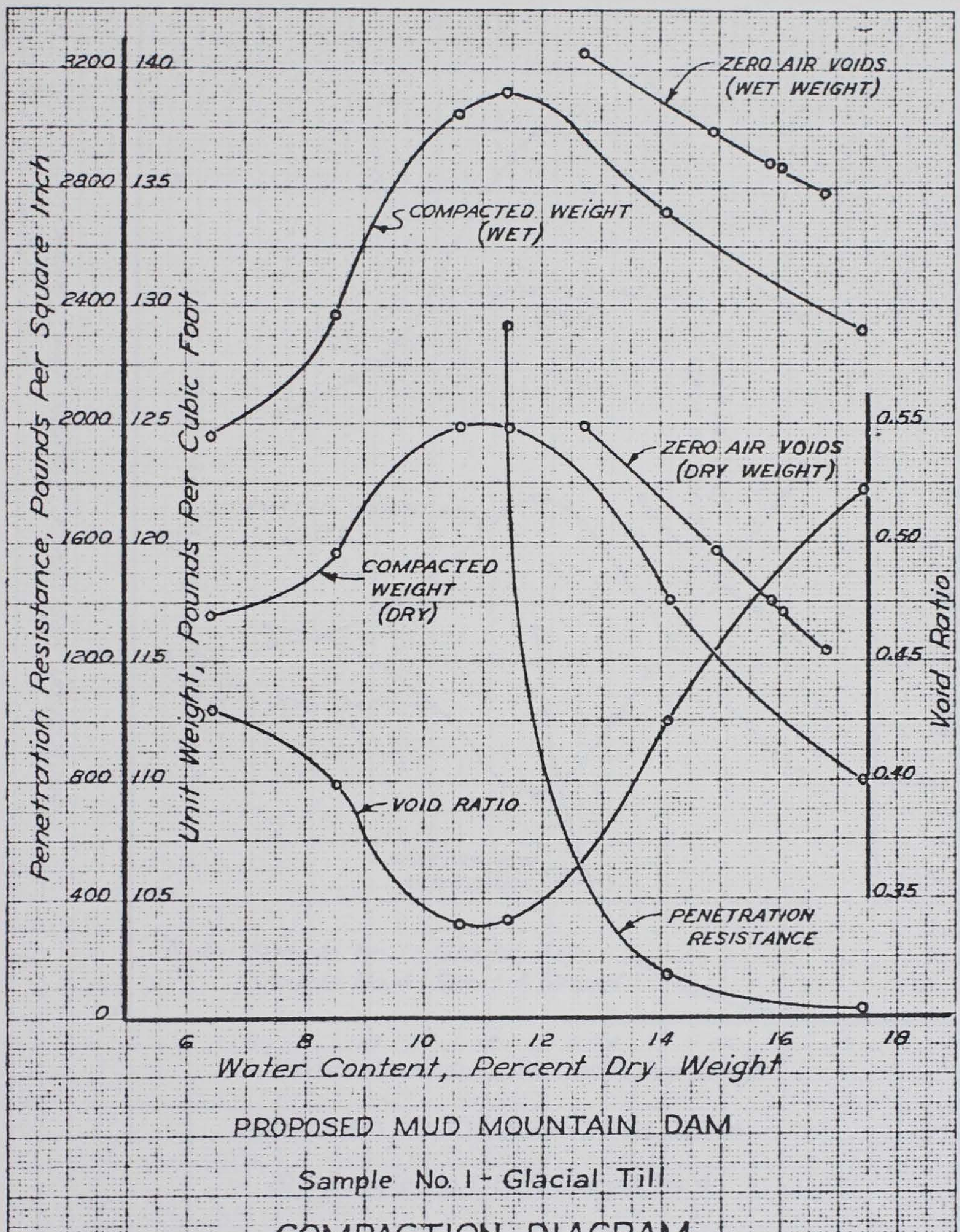

Penetration Resistance, Pounds Per Square Inch
Unit Weight, Pounds Per Cubic Foot
Void Ratio
3200
2800
2400
2000
1600
1200
800
400
0
140
135
130
125
120
115
110
105
0.55
0.50
0.45
0.40
0.35
ZERO AIR VOIDS
(WET WEIGHT)
COMPACTED WEIGHT
(WET)
ZERO AIR VOIDS
(DRY WEIGHT)
COMPACTED
WEIGHT
(DRY)
VOID RATIO
PENETRATION
RESISTANCE
6
8
10
12
14
16
18
Water Content, Percent Dry Weight
PROPOSED MUD MOUNTAIN DAM
Sample No. 1 - Glacial Till
COMPACTION DIAGRAM
COMPACTED BY 50 BLOWS OF STANDARD 5½ POUND HAMMER

FIGURE 36

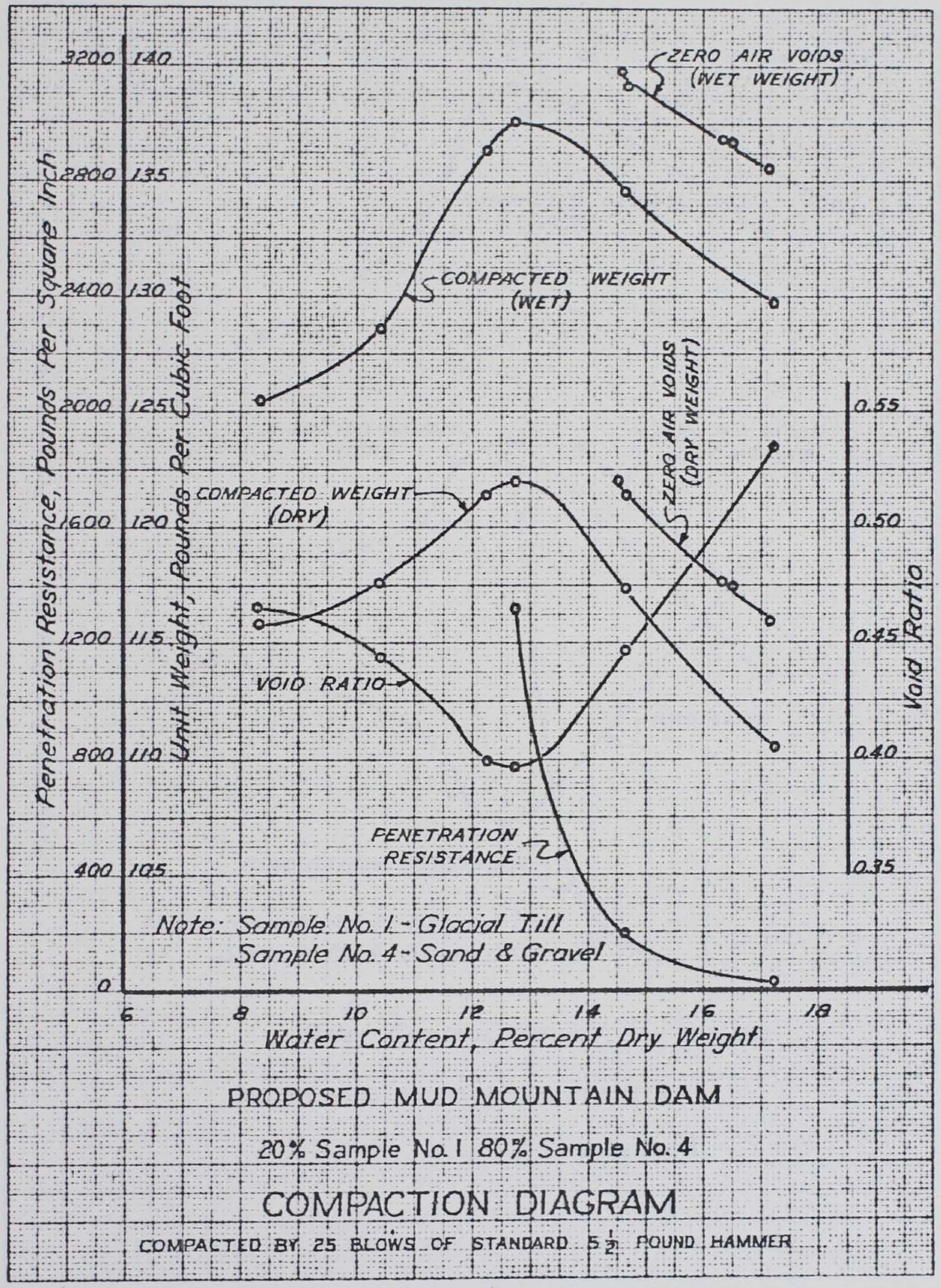
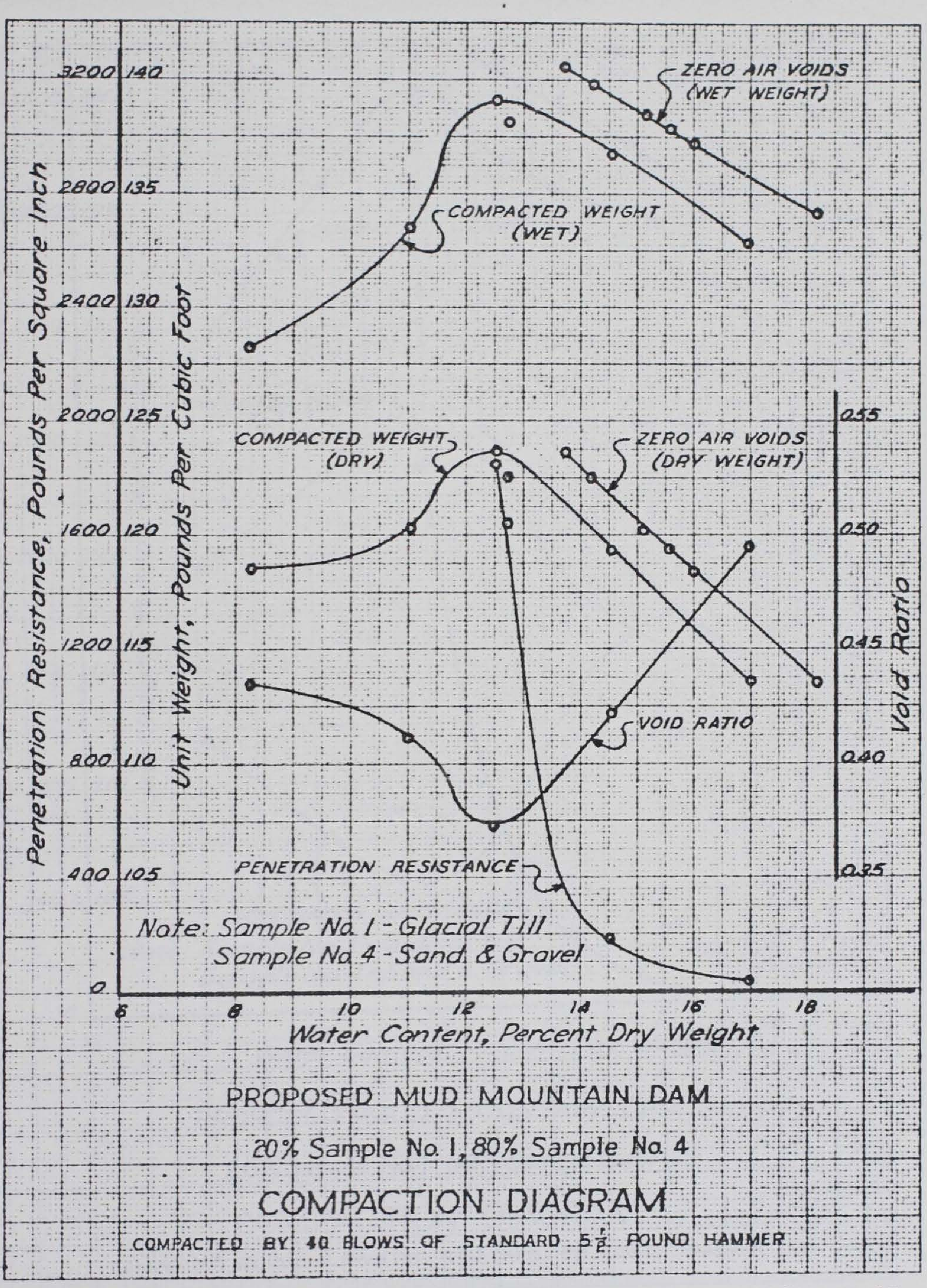
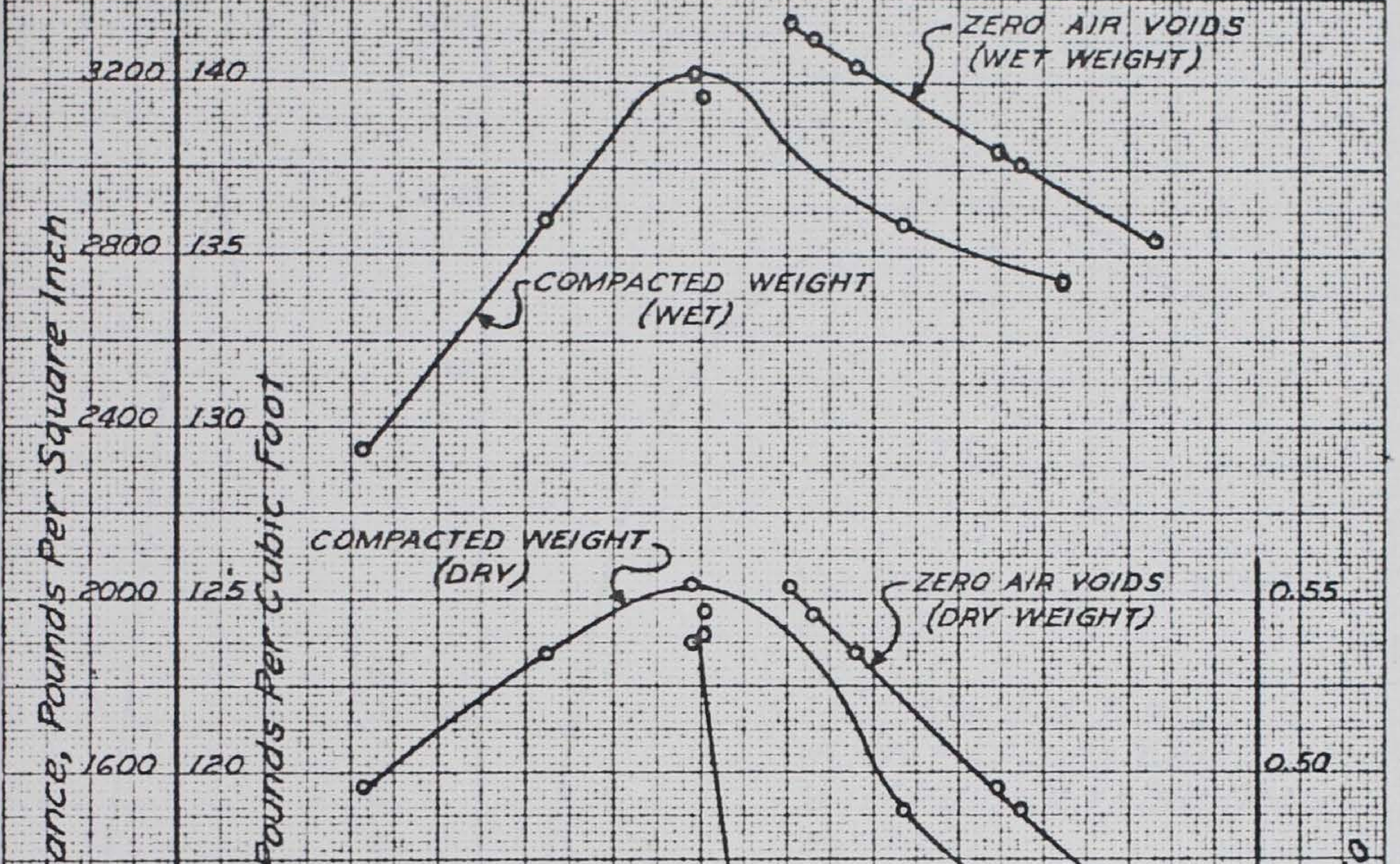

ZERO AIR VOIDS (WET WEIGHT)
COMPACTED WEIGHT (WET)
ZERO AIR VOIDS (DRY WEIGHT)
COMPACTED WEIGHT (DRY)
VOID RATIO
PENETRATION RESISTANCE
Penetration Resistance, Pounds Per Square Inch
Unit Weight, Pounds Per Cubic Foot
Void Ratio
3200 140
2800 135
2400 130
2000 125
1600 120
1200 115
800 110
400 105
0
0.55
0.50
0.45
0.40
0.35
6 8 10 12 14 16 18
Note: Sample No. 1 - Glacial Till
Sample No. 4 - Sand & Gravel
Water Content, Percent Dry Weight
PROPOSED MUD MOUNTAIN DAM
20% Sample No. I 80% Sample No. 4
COMPACTION DIAGRAM
COMPACTED BY 25 BLOWS OF STANDARD 5 ½ POUND HAMMER

FIGURE 37



ZERO AIR VOIDS (WET WEIGHT)
COMPACTED WEIGHT (WET)
COMPACTED WEIGHT (DRY)
ZERO AIR VOIDS (DRY WEIGHT)
VOID RATIO
PENETRATION RESISTANCE
Note: Sample No. 1 - Glacial Till
Sample No. 4 - Sand & Gravel
Penetration Resistance, Pounds Per Square Inch
Unit Weight, Pounds Per Cubic Foot
Void Ratio
Water Content, Percent Dry Weight
3200 140
2800 135
2400 130
2000 125
1600 120
1200 115
800 110
400 105
0
0.55
0.50
0.45
0.40
0.35
6
8
10
12
14
16
18
PROPOSED MUD MOUNTAIN DAM
20% Sample No. 1, 80% Sample No. 4
COMPACTION DIAGRAM
COMPACTED BY 40 BLOWS OF STANDARD 5 1/2 POUND HAMMER

FIGURE 38



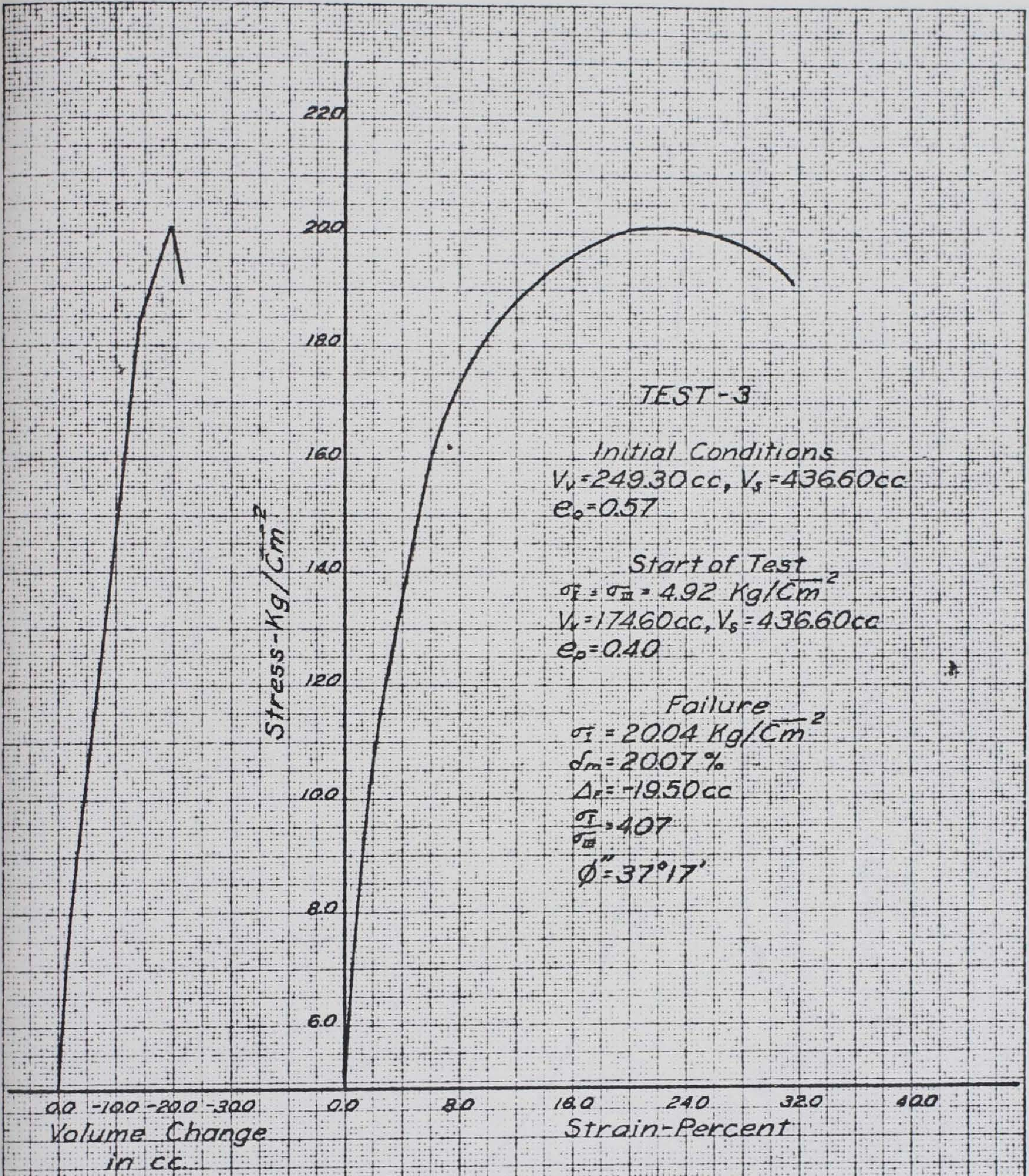
PROPOSED MUD MOUNTAIN DAM

20% Sample No. 1 80% Sample No. 4

COMPACTION DIAGRAM

COMPACTED BY 50 BLOWS OF STANDARD $5\frac{1}{2}$ POUND HAMMER

FIGURE 39



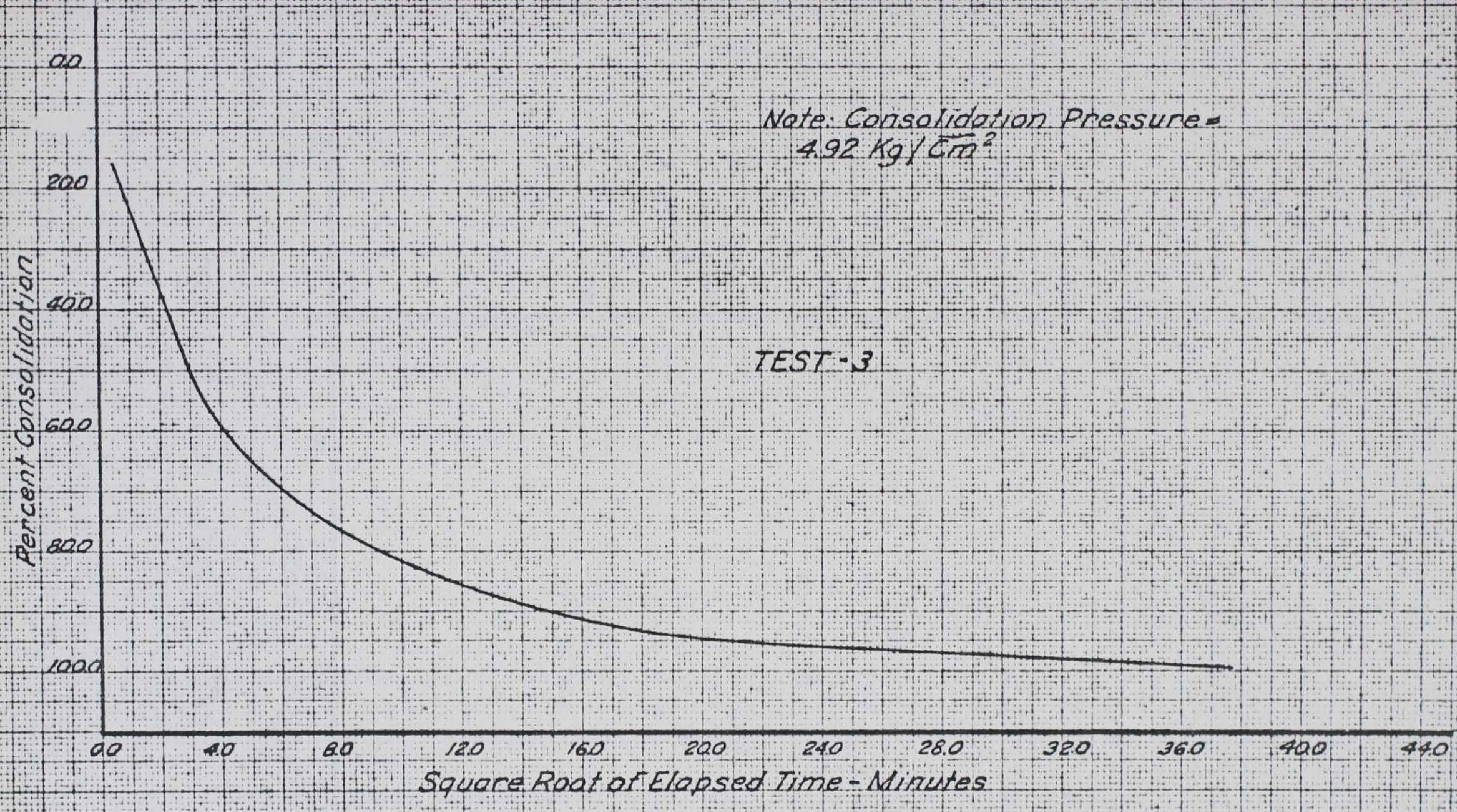
PROPOSED MUD MOUNTAIN DAM

Sample No. 4-Sand and Gravel

STRESS STRAIN CURVE

TRI-AXIAL COMPRESSION TEST

Figure 40

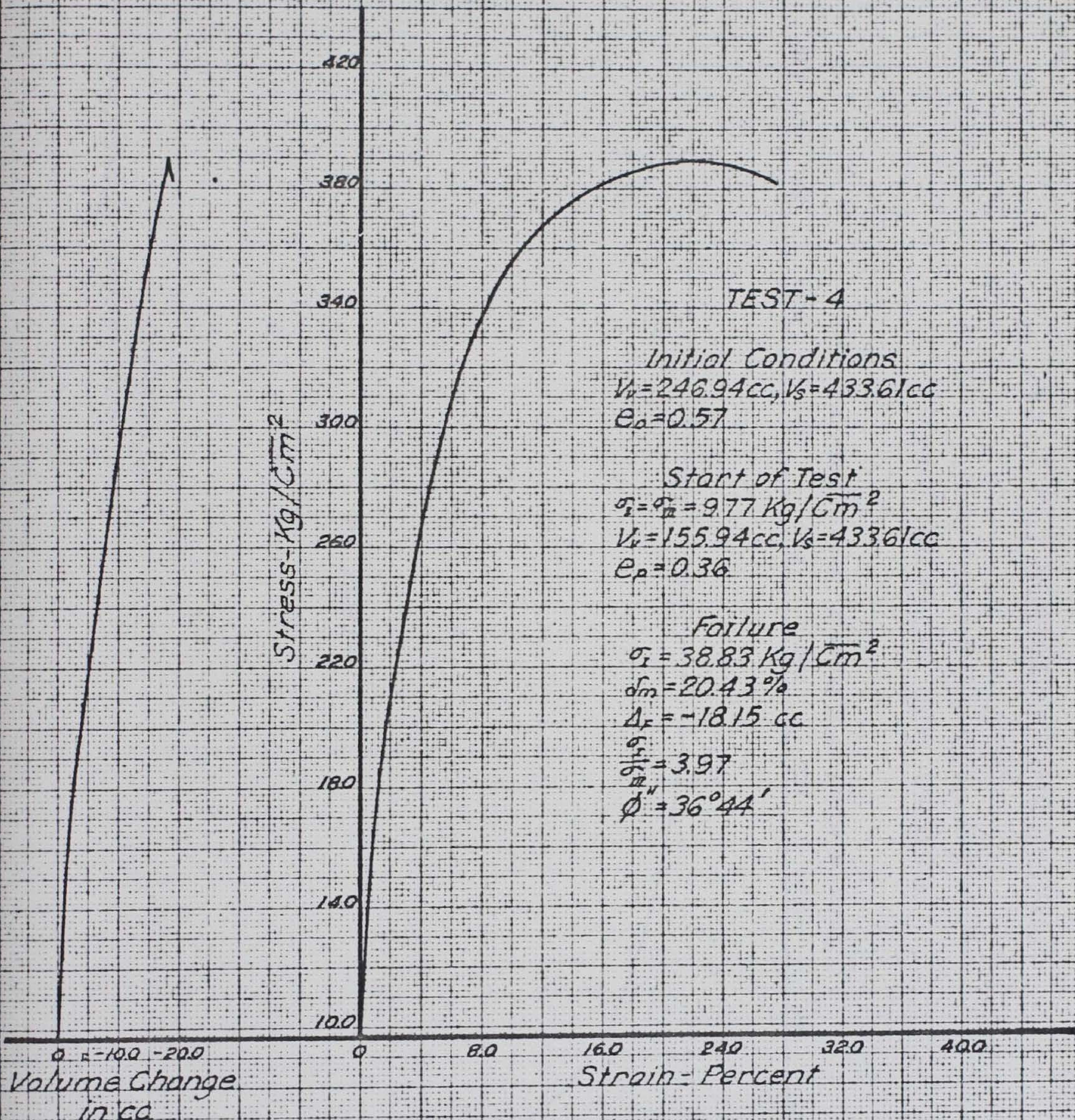


PROPOSED MUD MOUNTAIN DAM

Sample No. 4 - Sand and Gravel

TIME-CONSOLIDATION DIAGRAM

Figure 41



PROPOSED MUD MOUNTAIN DAM

Sample No.4 - Sand and Gravel

STRESS STRAIN CURVE

TRI-AXIAL COMPRESSION TEST

Figure 42

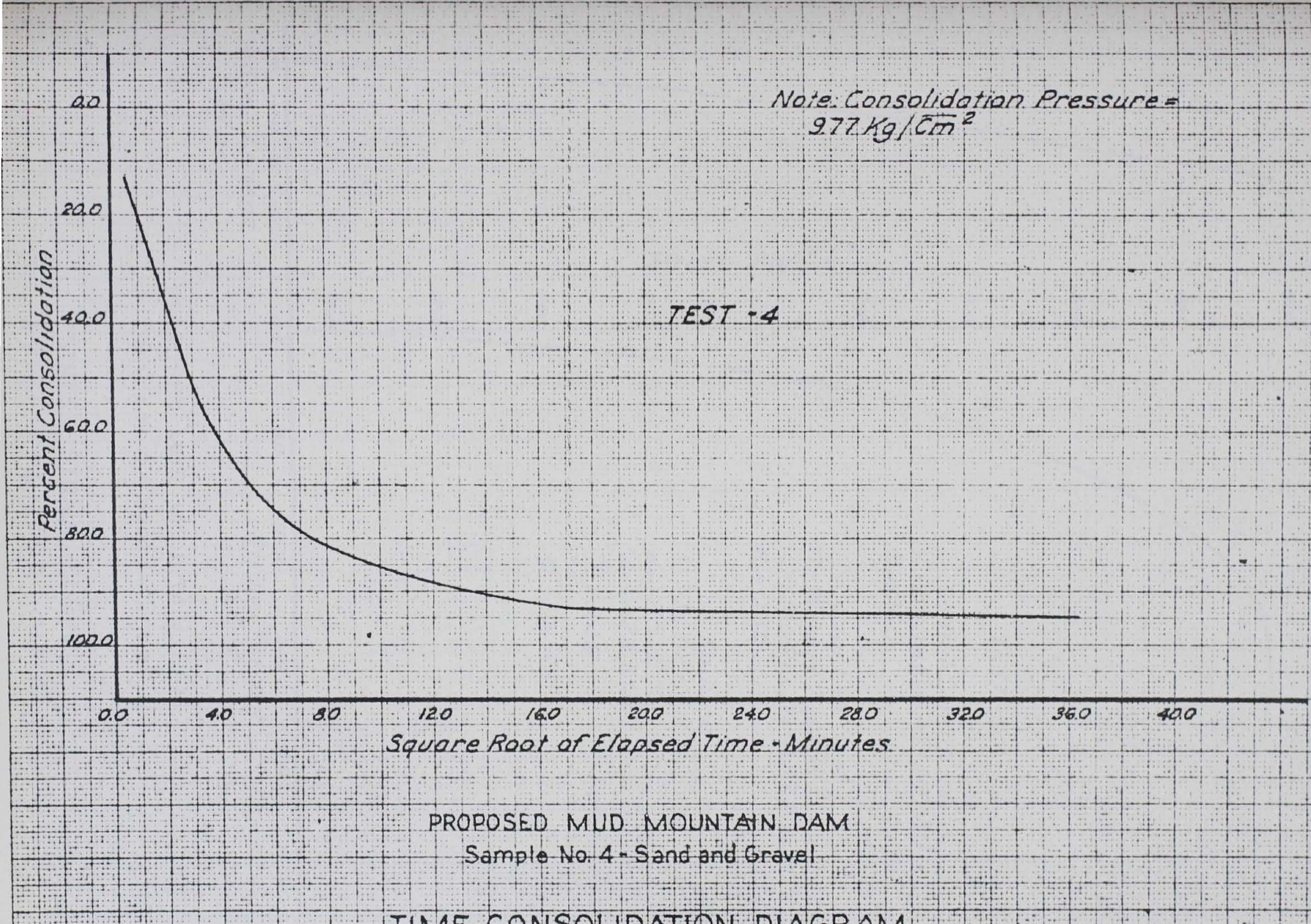
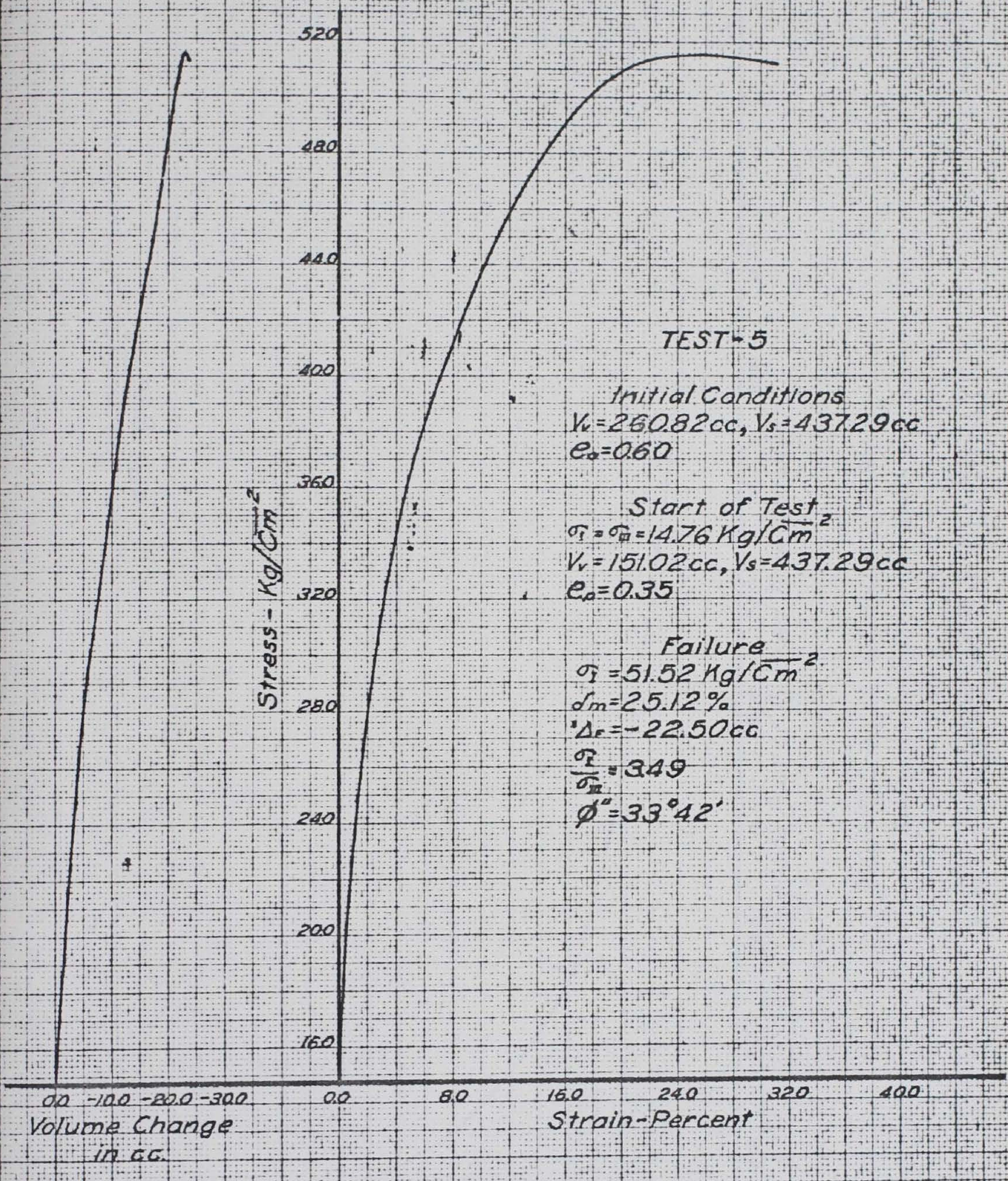

Note: Consolidation Pressure = 9.77 Kg/Cm 2
TEST - 4
Percent Consolidation
0.0
20.0
40.0
60.0
80.0
100.0
0.0
4.0
8.0
12.0
16.0
20.0
24.0
28.0
32.0
36.0
40.0
Square Root of Elapsed Time - Minutes
PROPOSED MUD MOUNTAIN DAM
Sample No. 4 - Sand and Gravel
TIME-CONSOLIDATION DIAGRAM

Figure 43



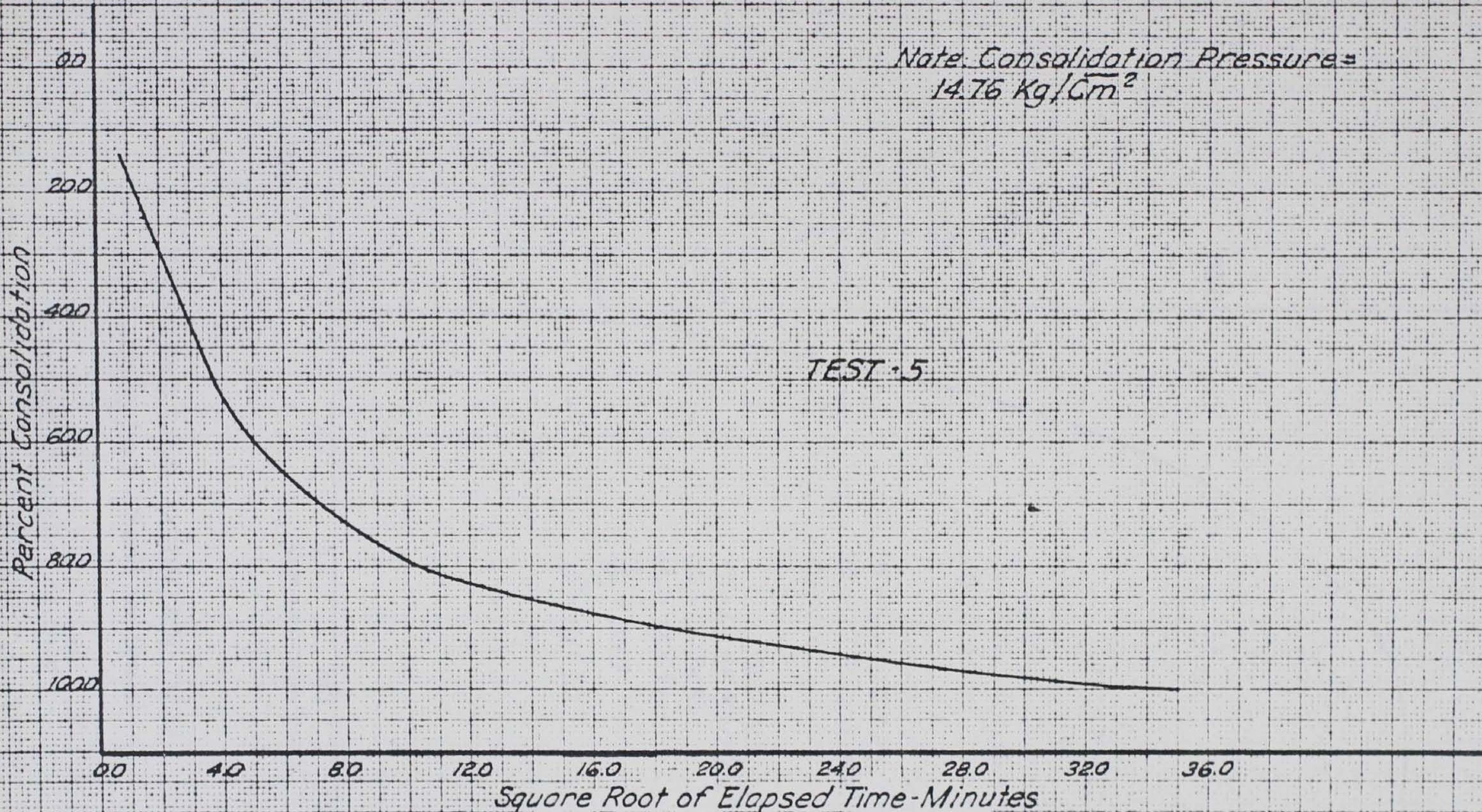
PROPOSED MUD MOUNTAIN DAM

Sample No 4 - Sand and Gravel

STRESS STRAIN CURVE

TRI-AXIAL COMPRESSION TEST

Figure 44

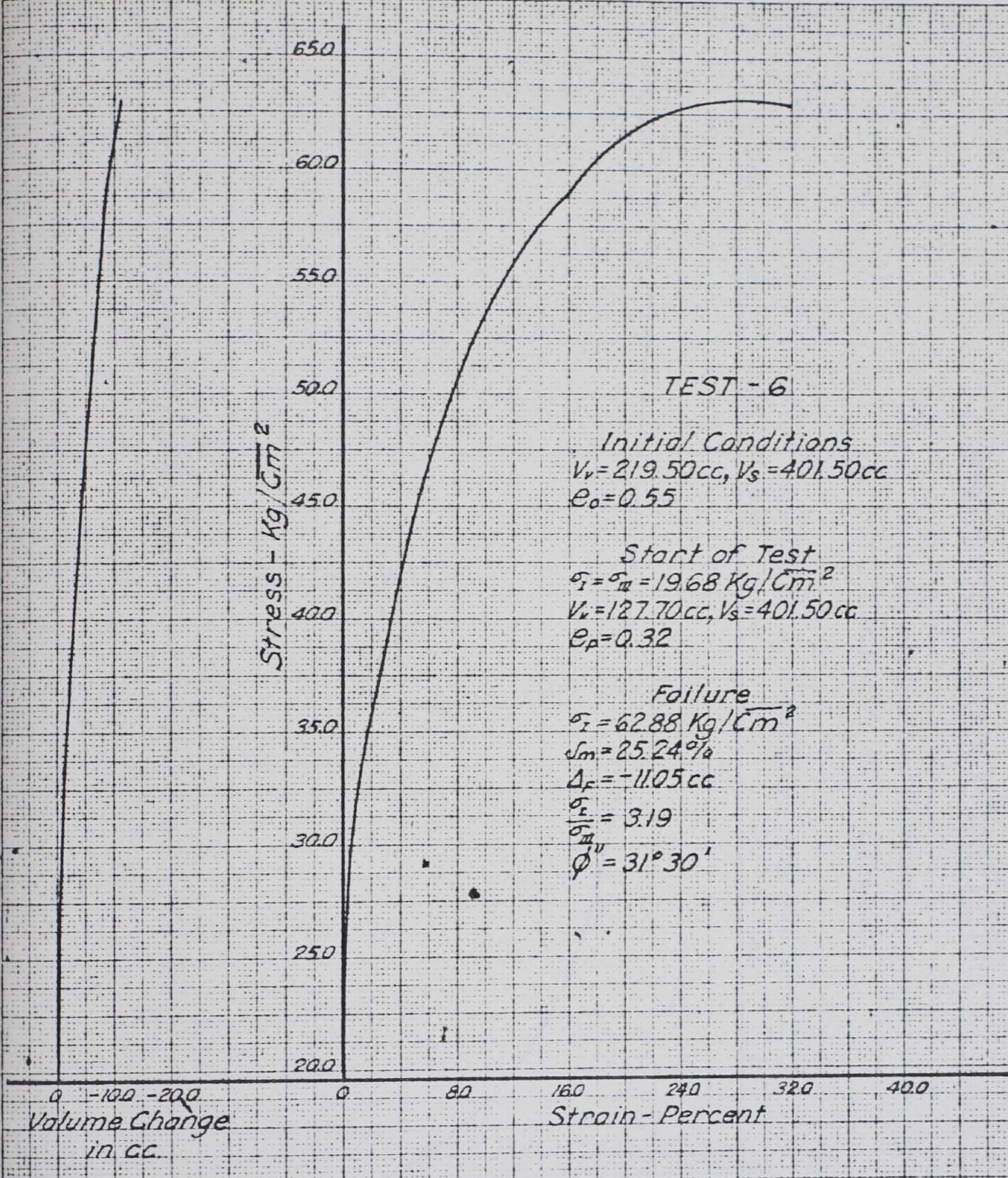


PROPOSED MUD MOUNTAIN DAM

Sample No. 4 - Sand and Gravel

TIME-CONSOLIDATION DIAGRAM

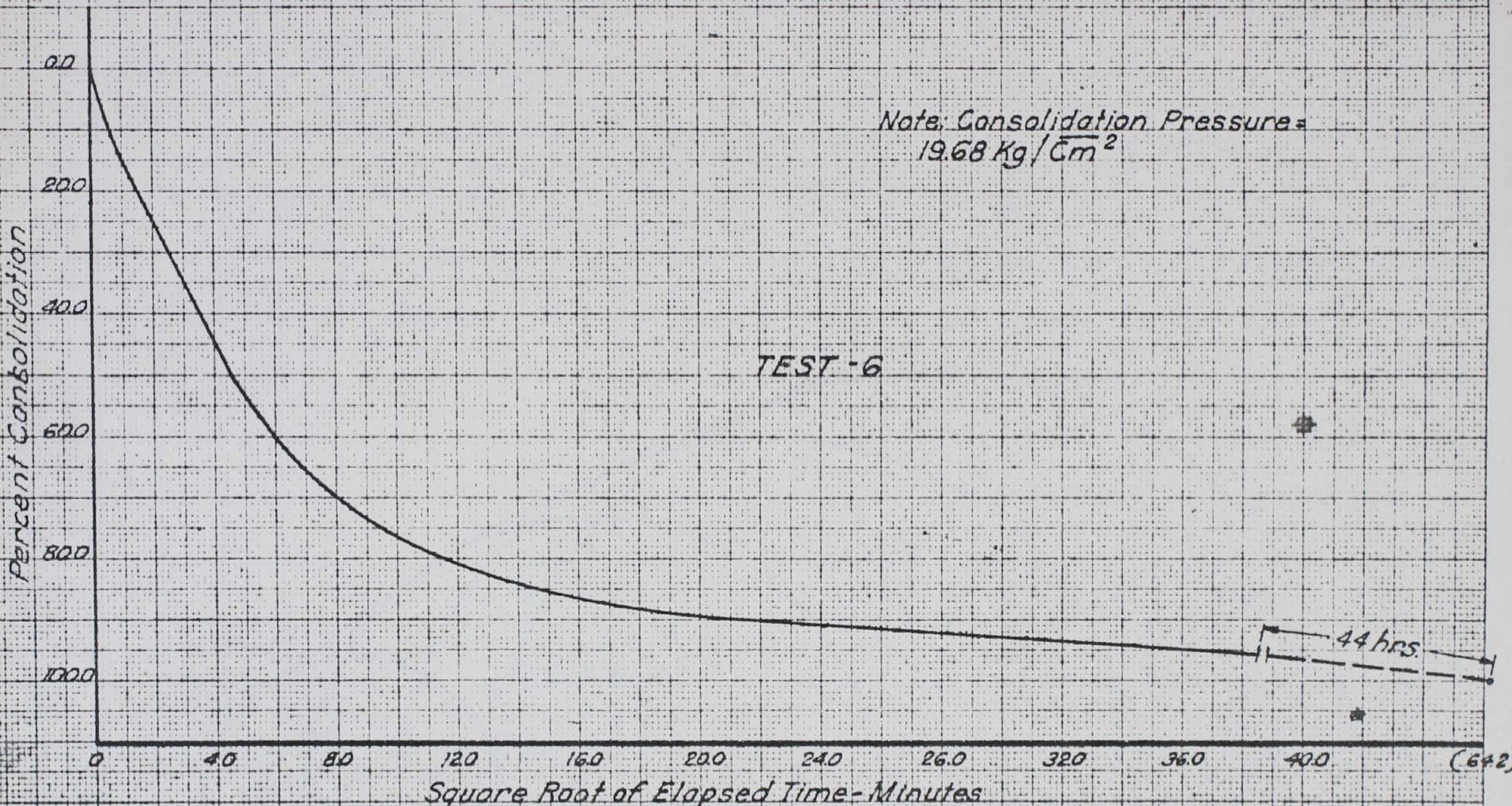
Figure 45



PROPOSED MUD MOUNTAIN DAM
Sample No. 4 - Sand and Gravel

STRESS STRAIN CURVE
TRI-AXIAL COMPRESSION TEST

Figure 46

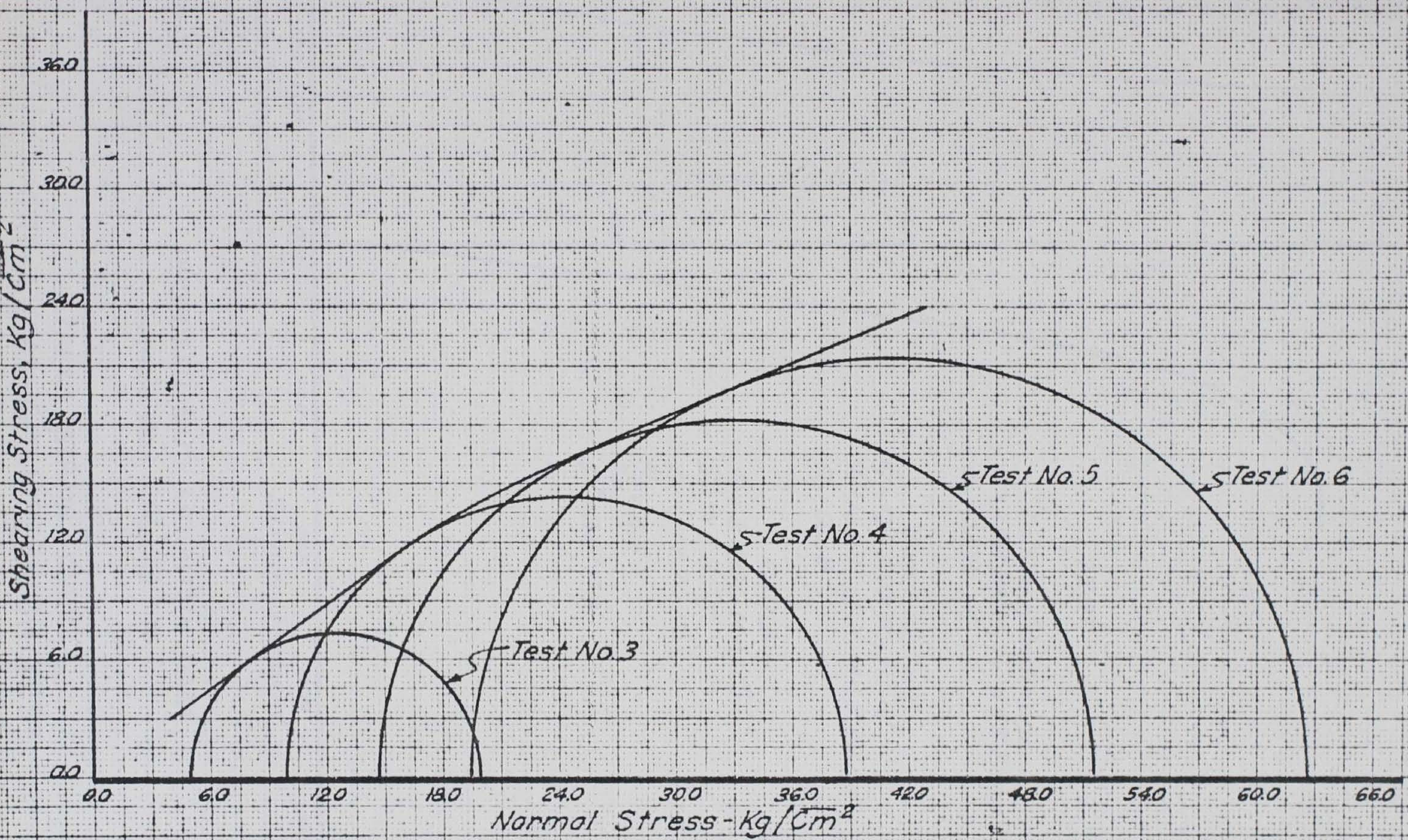


PROPOSED MUD MOUNTAIN DAM

Sample No. 4 - Sand and Gravel

TIME-CONSOLIDATION DIAGRAM

Figure 47

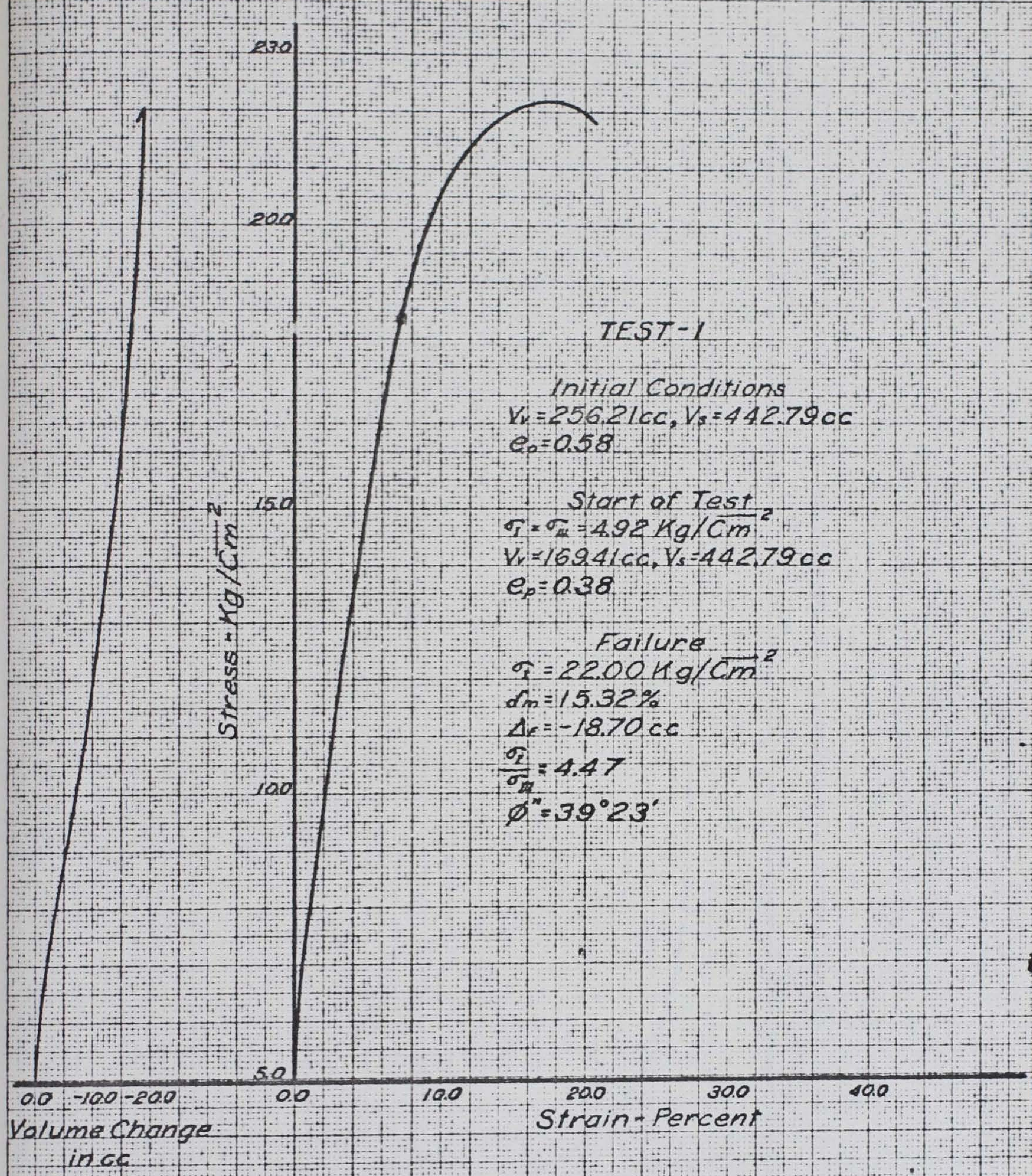


PROPOSED MUD MOUNTAIN DAM

Sample No. 4 - Sand and Gravel

MOHR'S CIRCLES OF STRESS

Figure 48



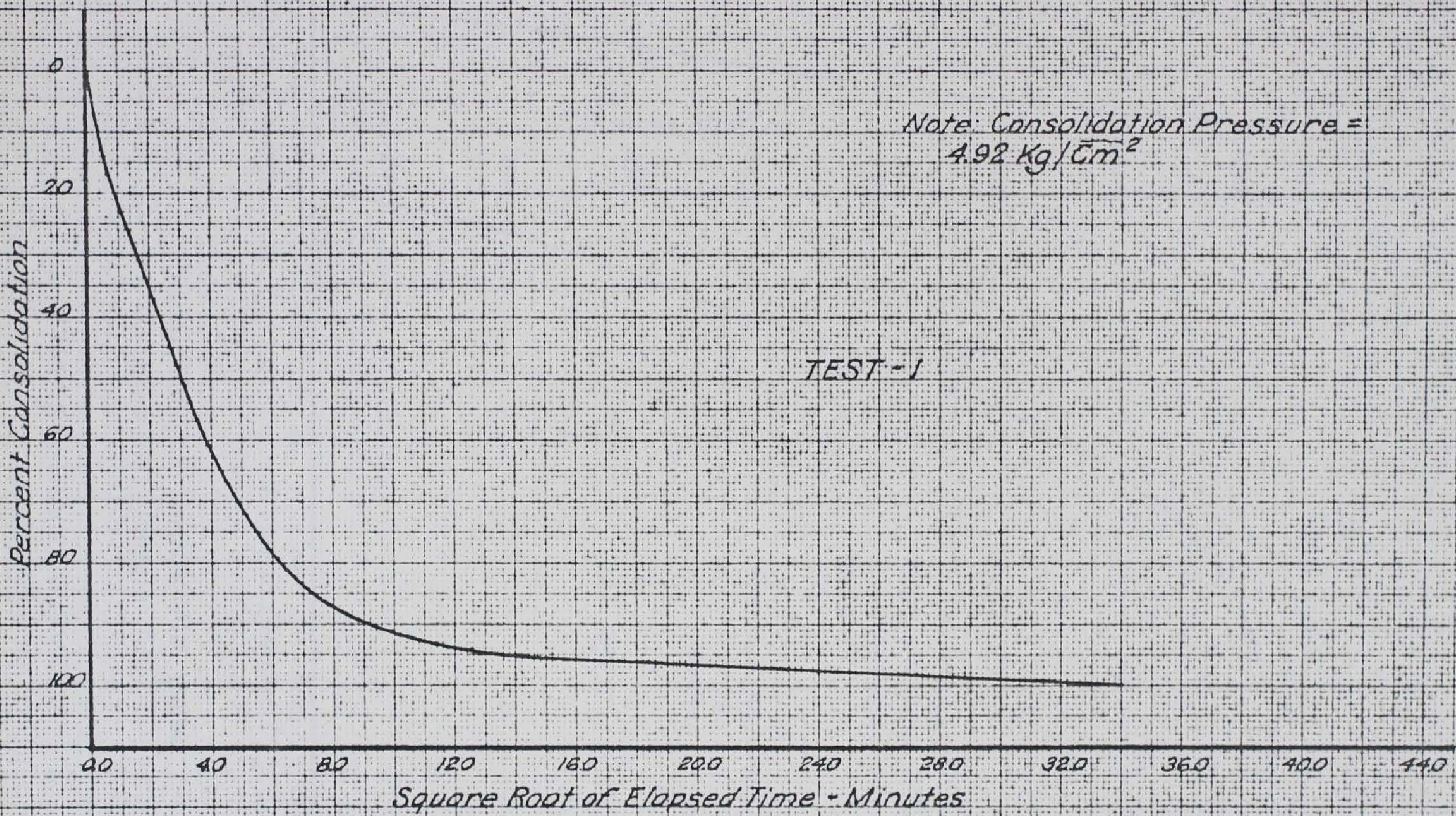
PROPOSED MUD MOUNTAIN DAM

Sample No. 1 - Glacial Till

STRESS STRAIN CURVE

TRI-AXIAL COMPRESSION TEST

Figure 49

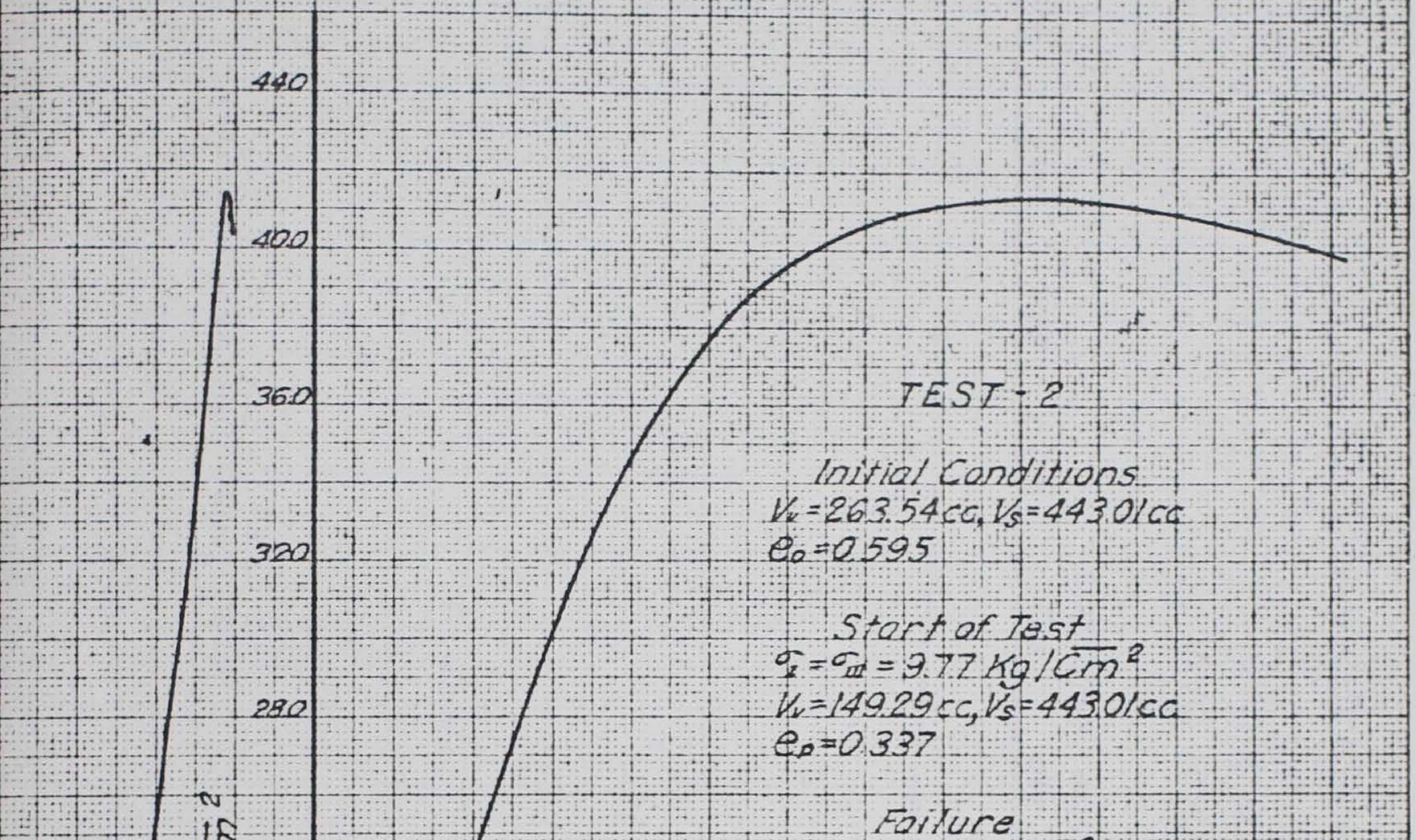


PROPOSED MUD MOUNTAIN DAM

Sample No. I - Glacial Till

TIME-CONSOLIDATION DIAGRAM

Figure 50



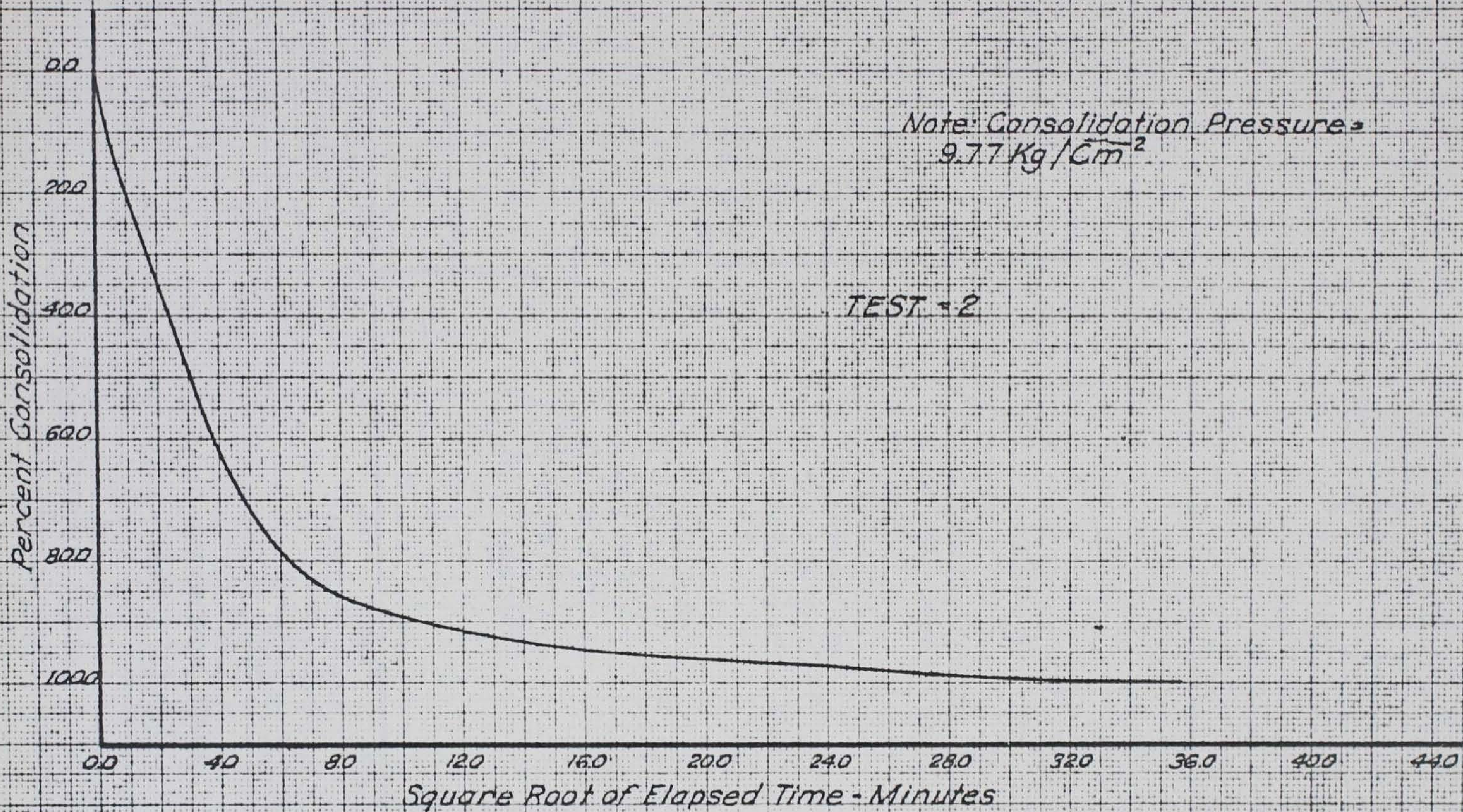
PROPOSED MUD MOUNTAIN DAM

Sample No. I - Glacial Till

STRESS STRAIN CURVE

TRI-AXIAL COMPRESSION TEST

Figure 51

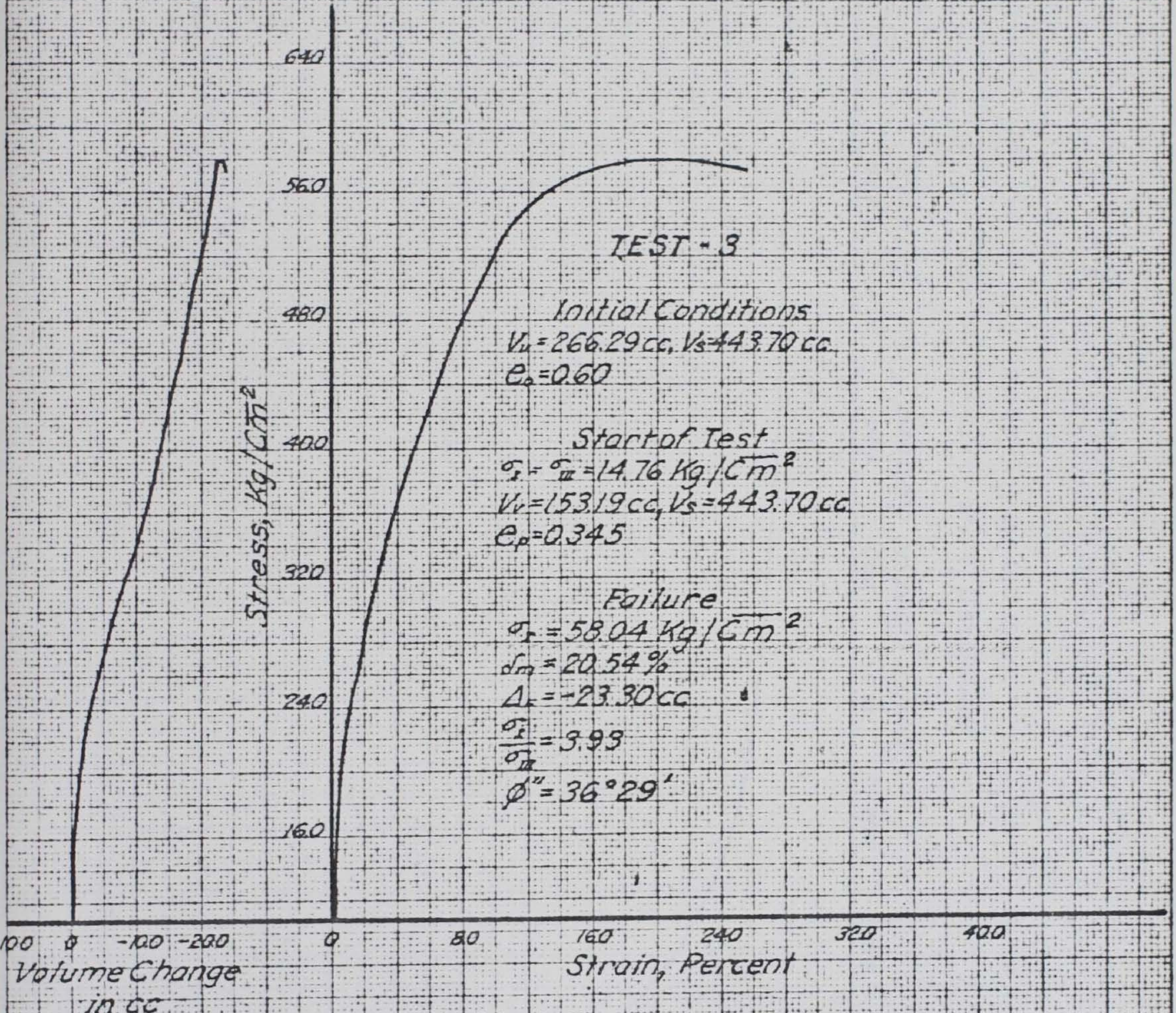


PROPOSED MUD MOUNTAIN DAM

Sample No. 1 - Glacial Till

TIME-CONSOLIDATION DIAGRAM

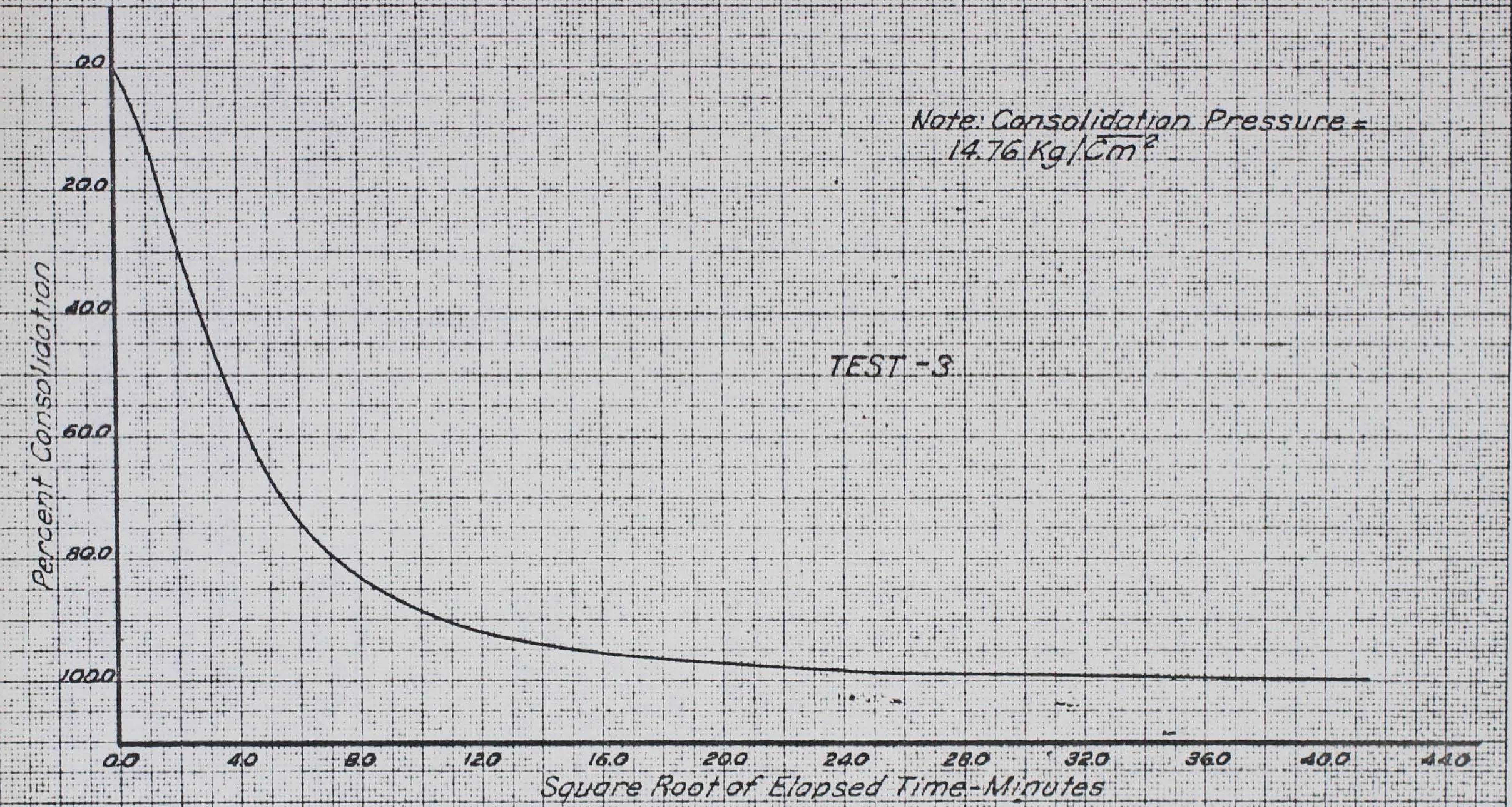
Figure 52



PROPOSED MUD MOUNTAIN DAM
Sample No. I - Glacial Till

STRESS STRAIN CURVE
TRI-AXIAL COMPRESSION TEST

Figure 53

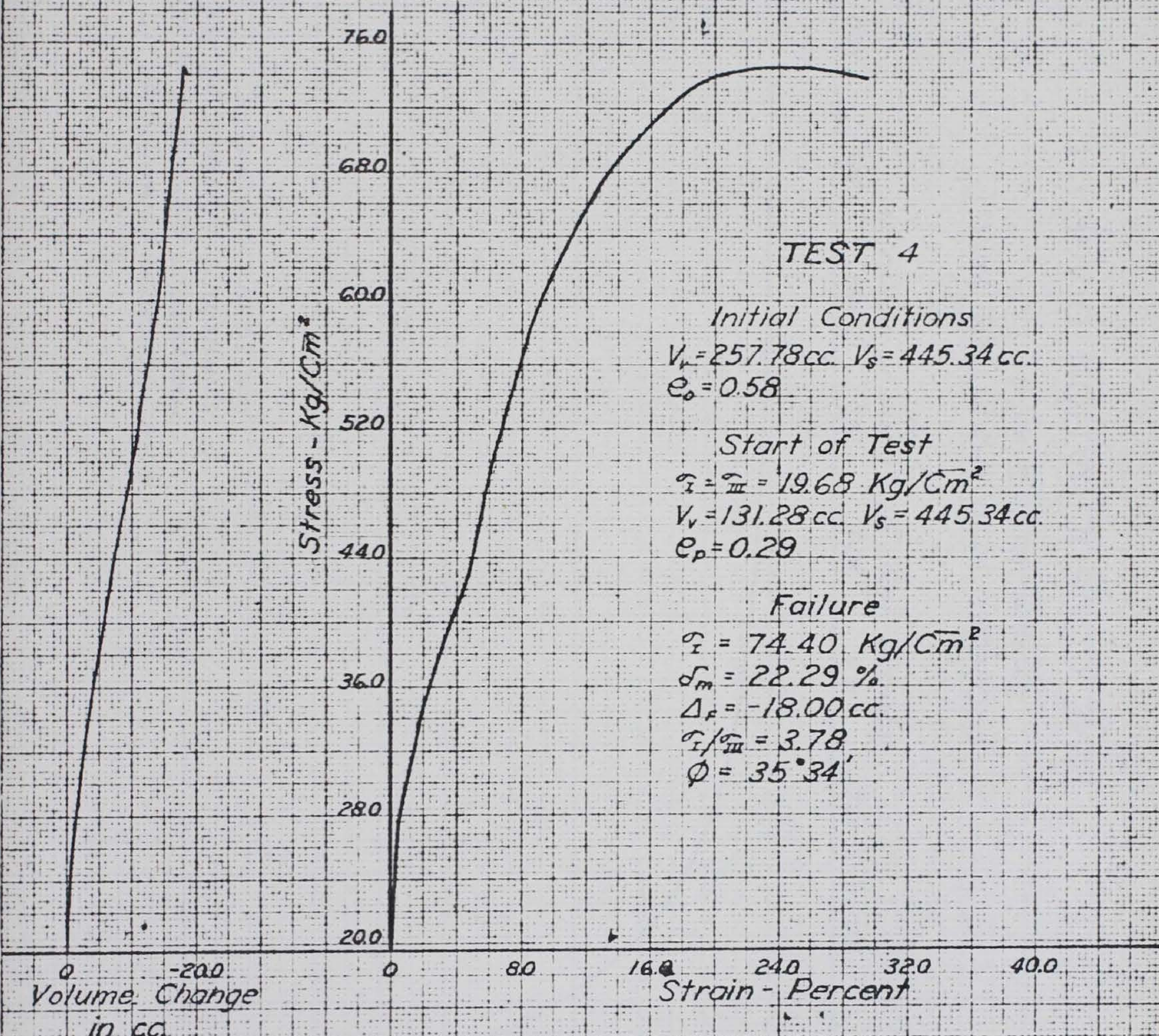


PROPOSED MUD MOUNTAIN DAM

Sample No. I - Glacial Till

TIME-CONSOLIDATION DIAGRAM

Figure 54



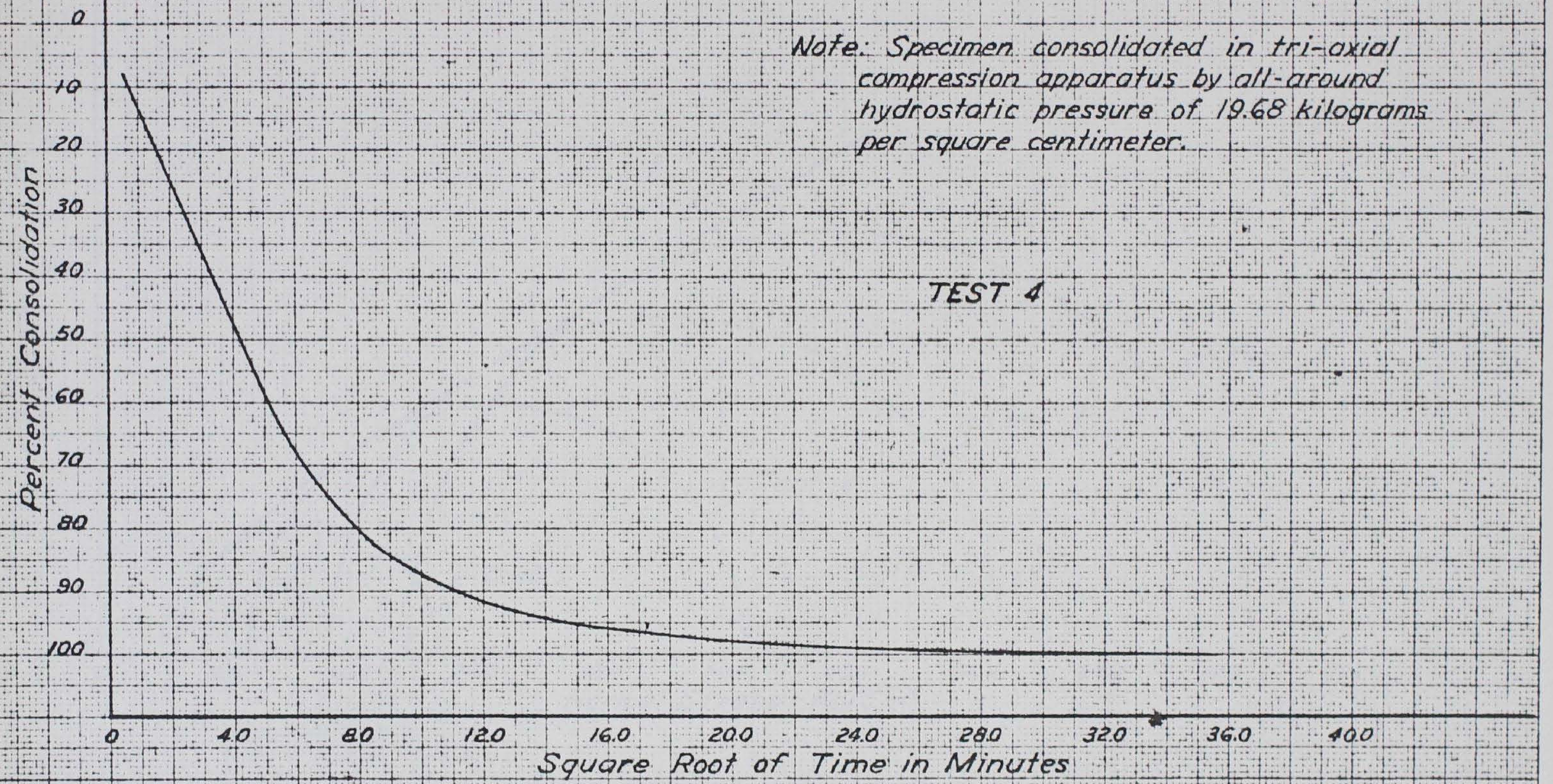
PROPOSED MUD MOUNTAIN DAM

Sample No. I - Glacial Till

STRESS STRAIN CURVE

TRI-AXIAL COMPRESSION TEST

FIGURE 55

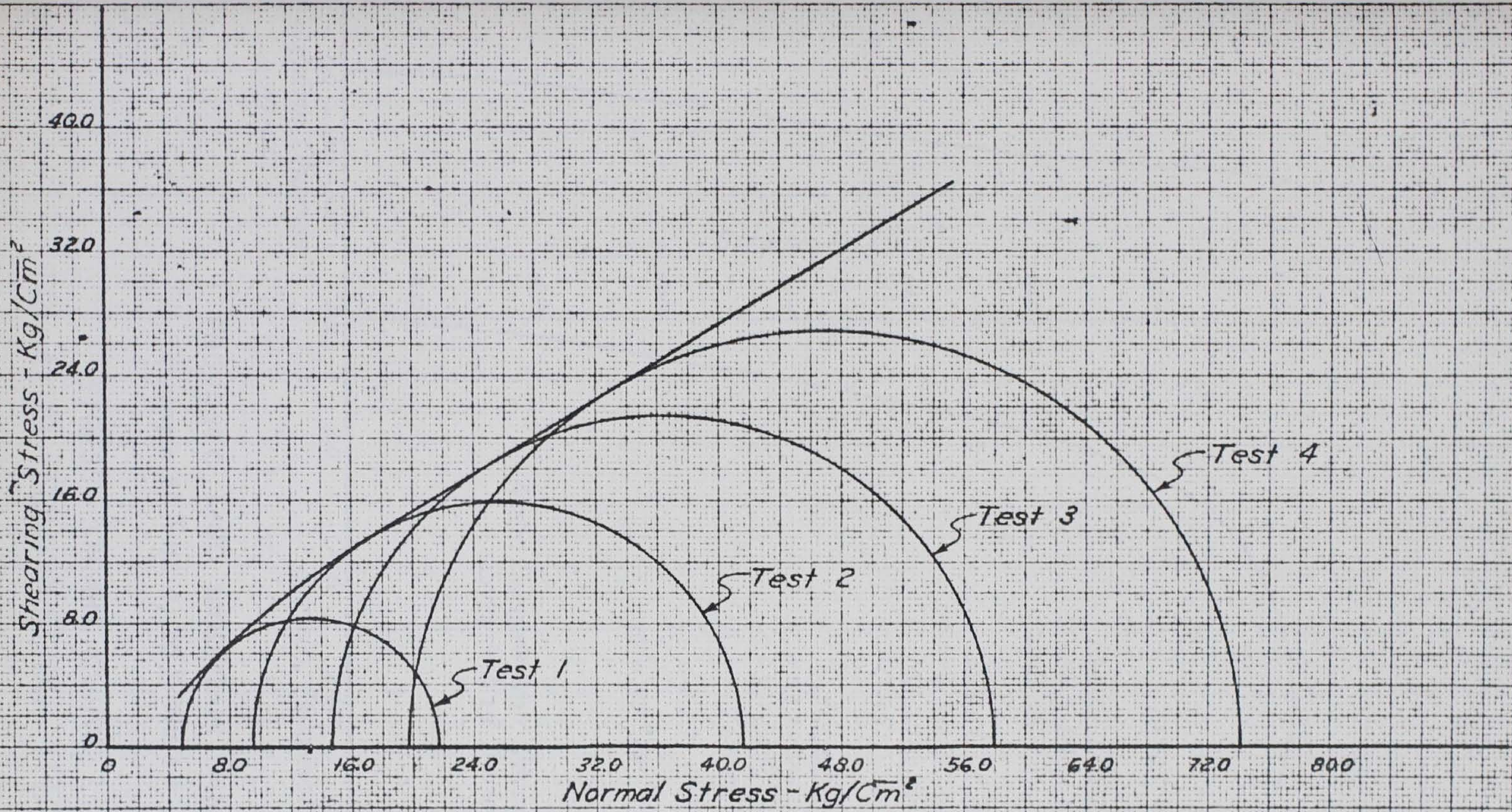


PROPOSED MUD MOUNTAIN DAM

Sample No. I - Glacial Till

TIME CONSOLIDATION DIAGRAM

FIGURE 56

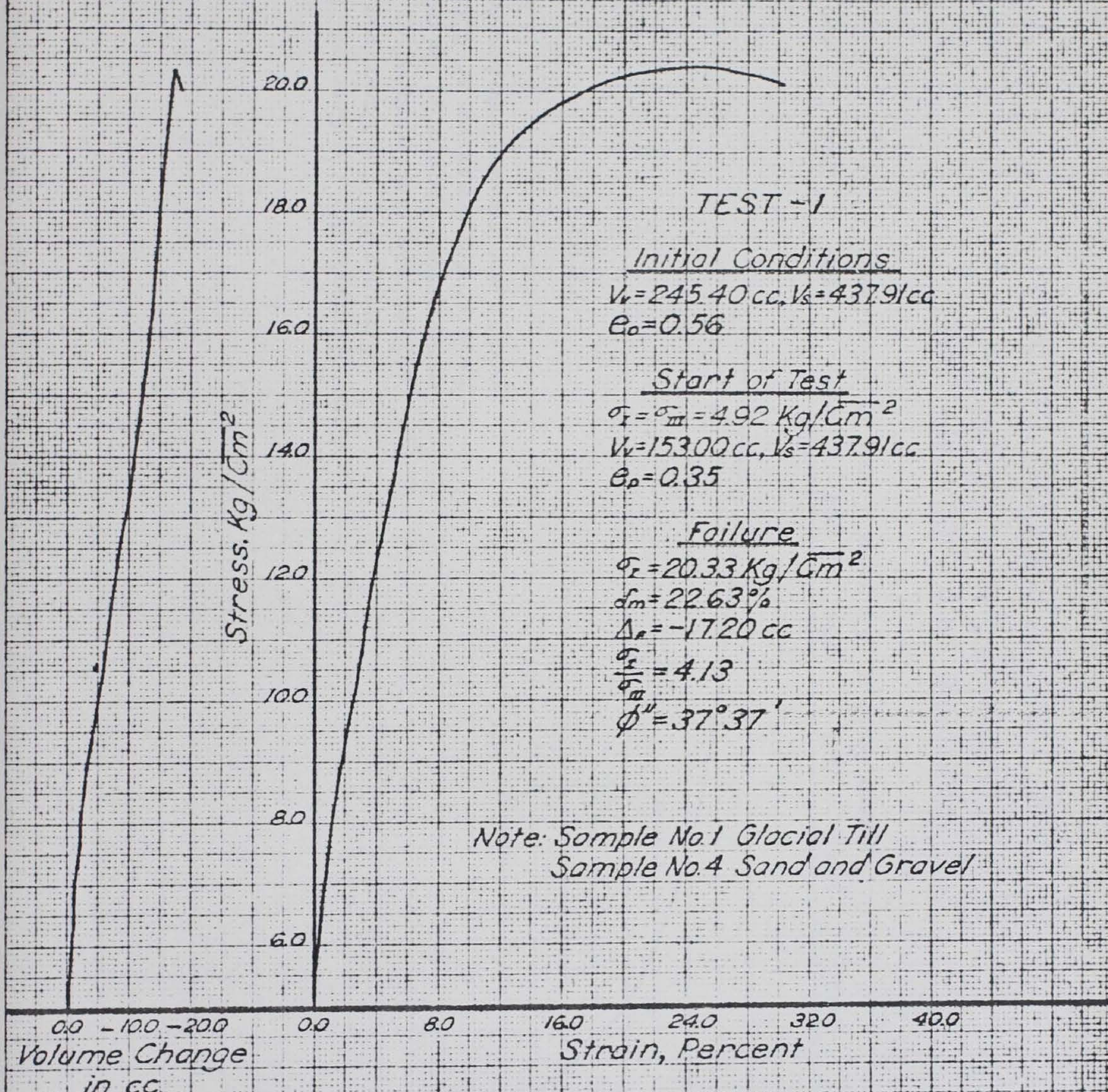


PROPOSED MUD MOUNTAIN DAM

Sample No. 1 - Glacial Till

MOHR'S CIRCLES OF STRESS

FIGURE 57



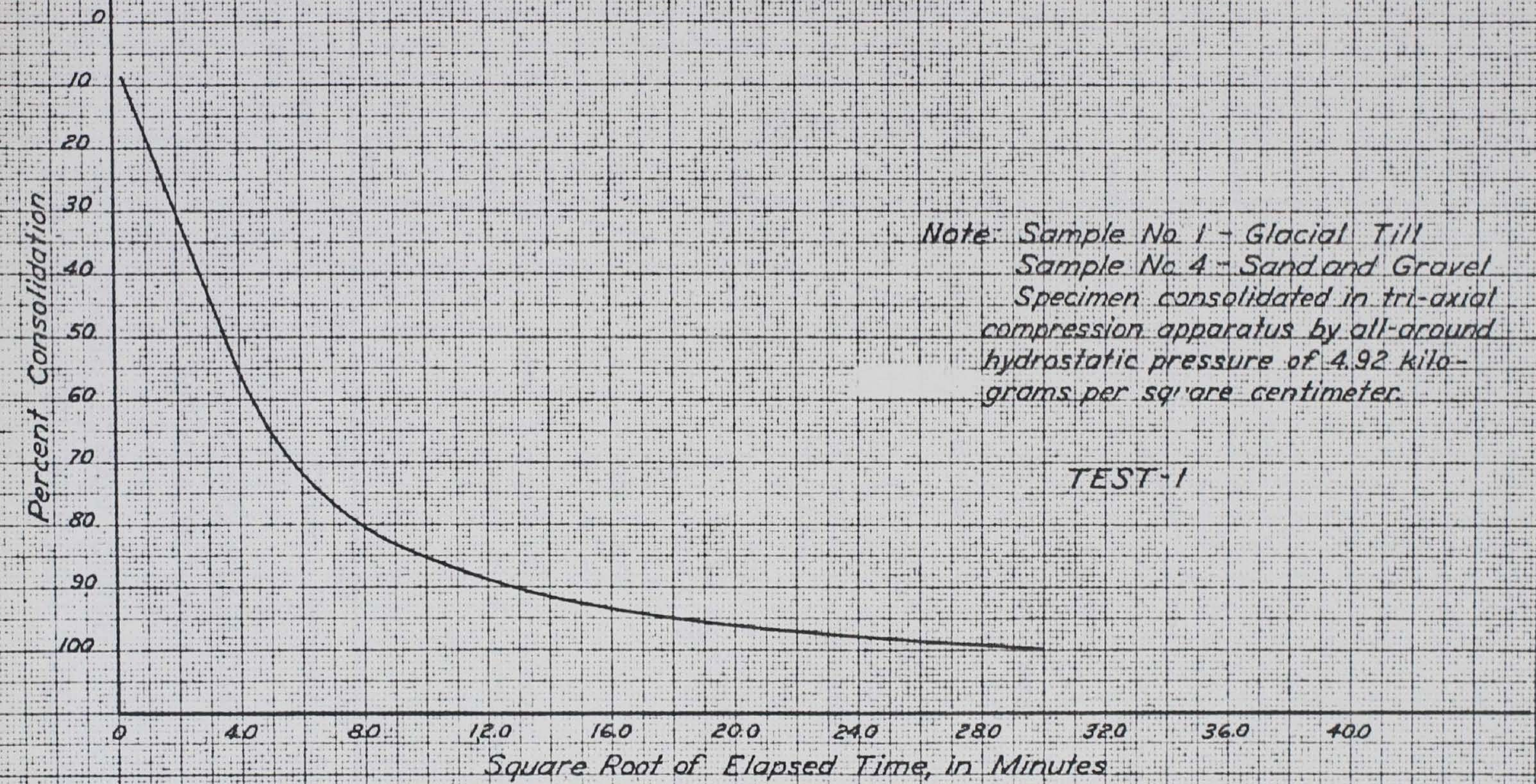
PROPOSED MUD MOUNTAIN DAM

Sample: 80% No. 4, 20% No. 1

STRESS - STRAIN CURVE

TRI-AXIAL COMPRESSION TEST

FIGURE 58

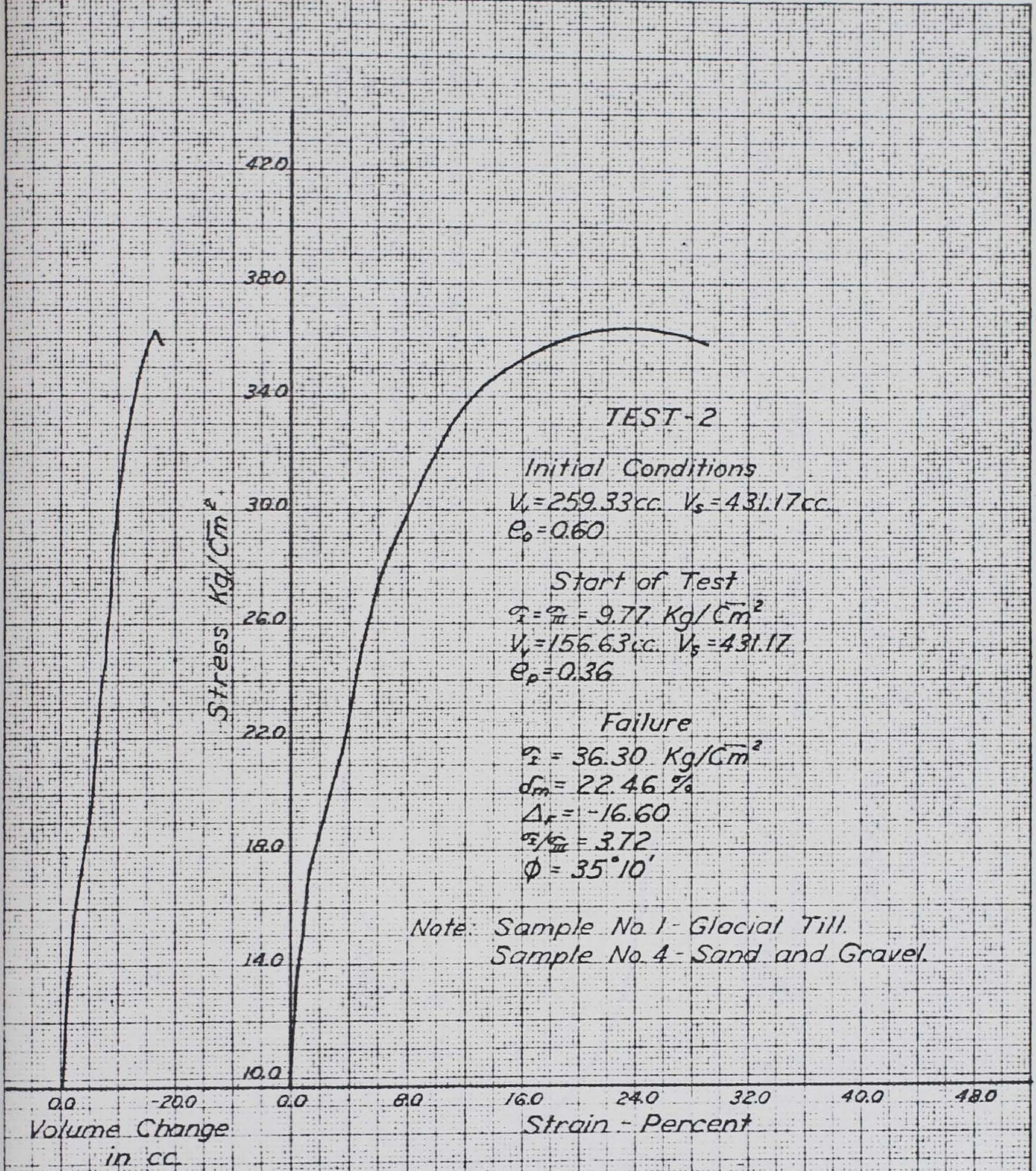


PROPOSED MUD MOUNTAIN DAM

Sample 80% No 4, 20% No 1

TIME CONSOLIDATION DIAGRAM

FIGURE 59



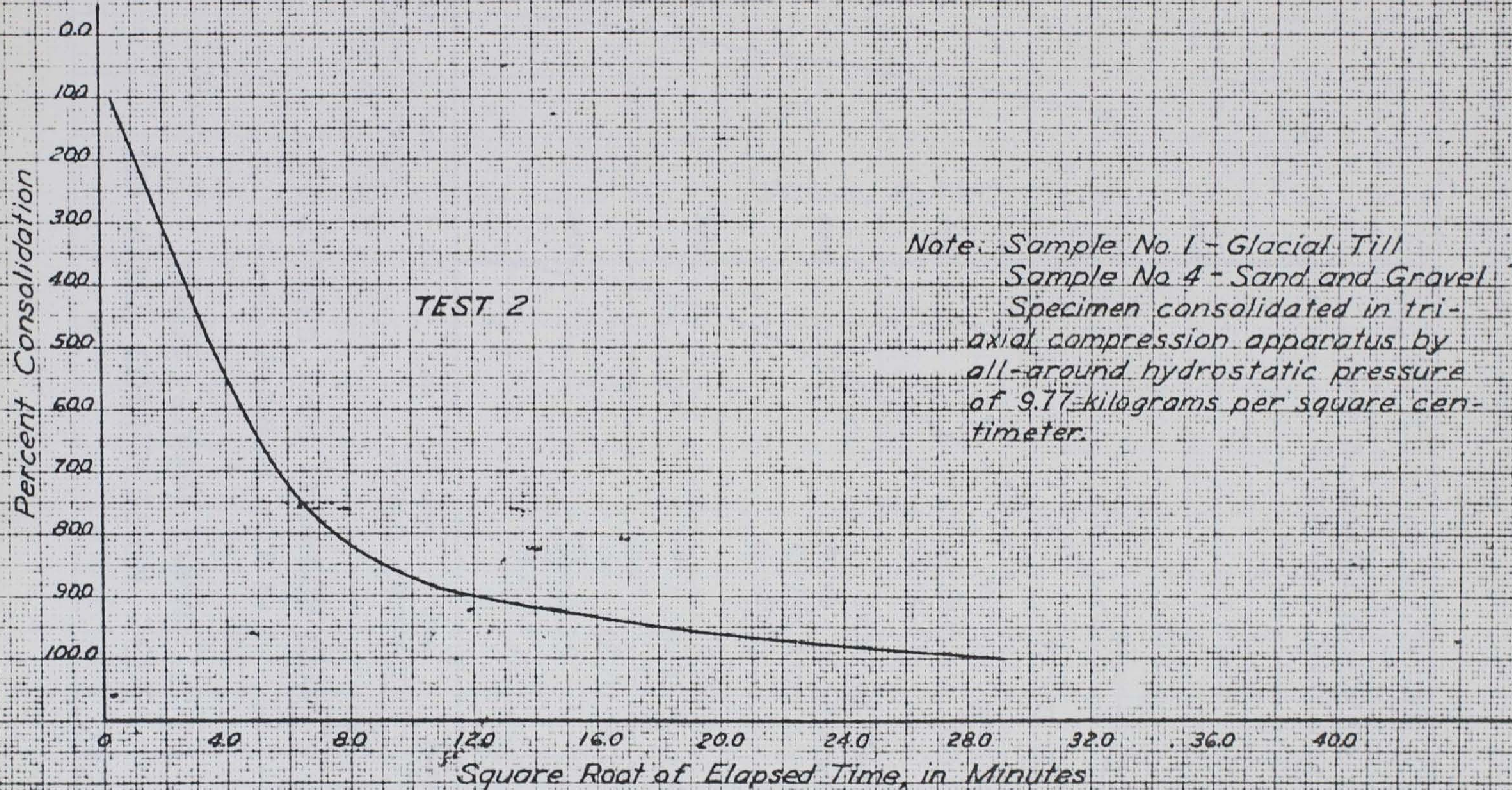
PROPOSED MUD MOUNTAIN DAM

Sample 80% No. 4, 20% No. I

STRESS - STRAIN CURVE

TRI AXIAL COMPRESSION TEST

FIGURE 60B

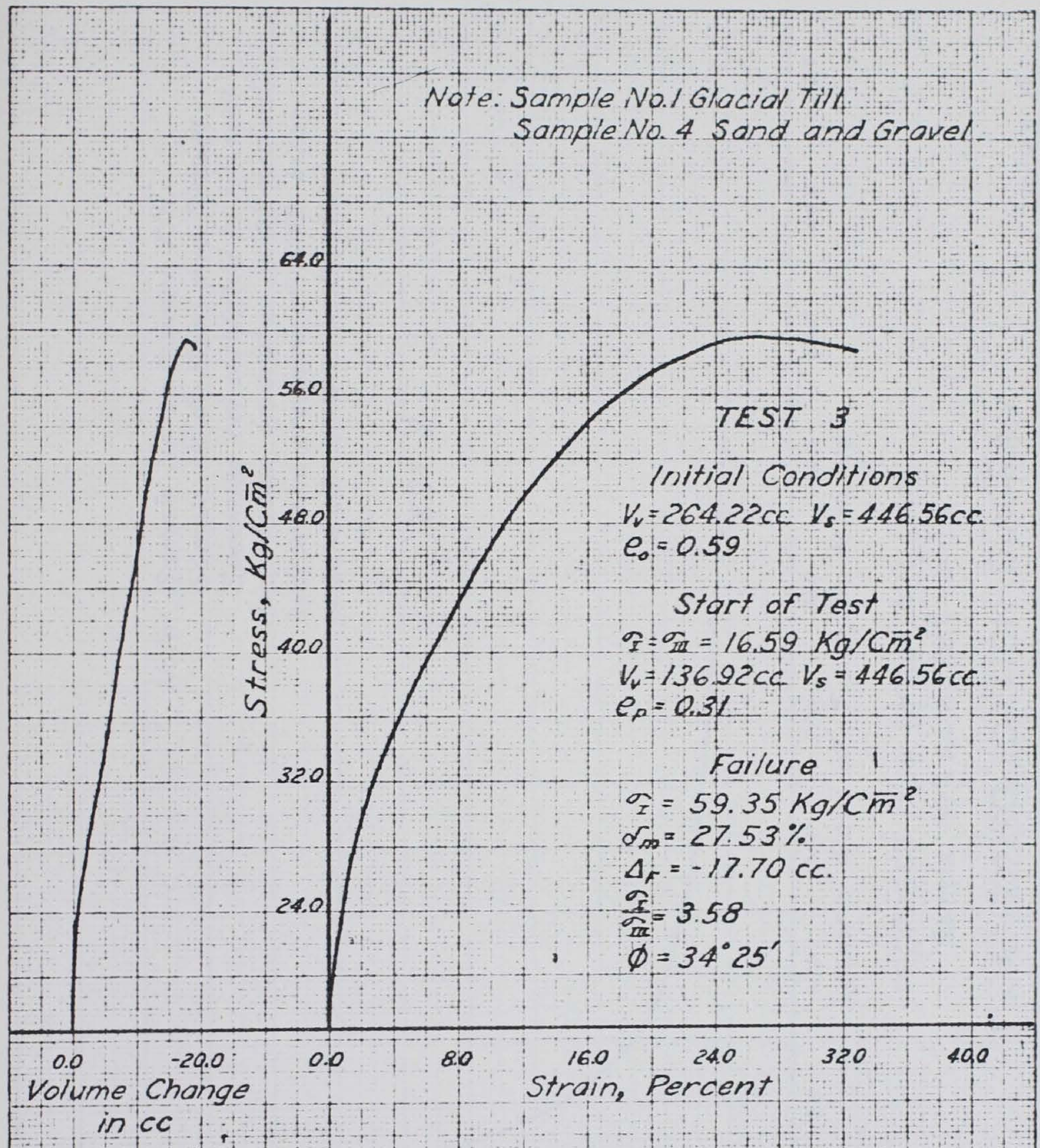


PROPOSED MUD MOUNTAIN DAM

Sample 80% No. 4, 20% No. 1

TIME CONSOLIDATION DIAGRAM

FIGURE 61



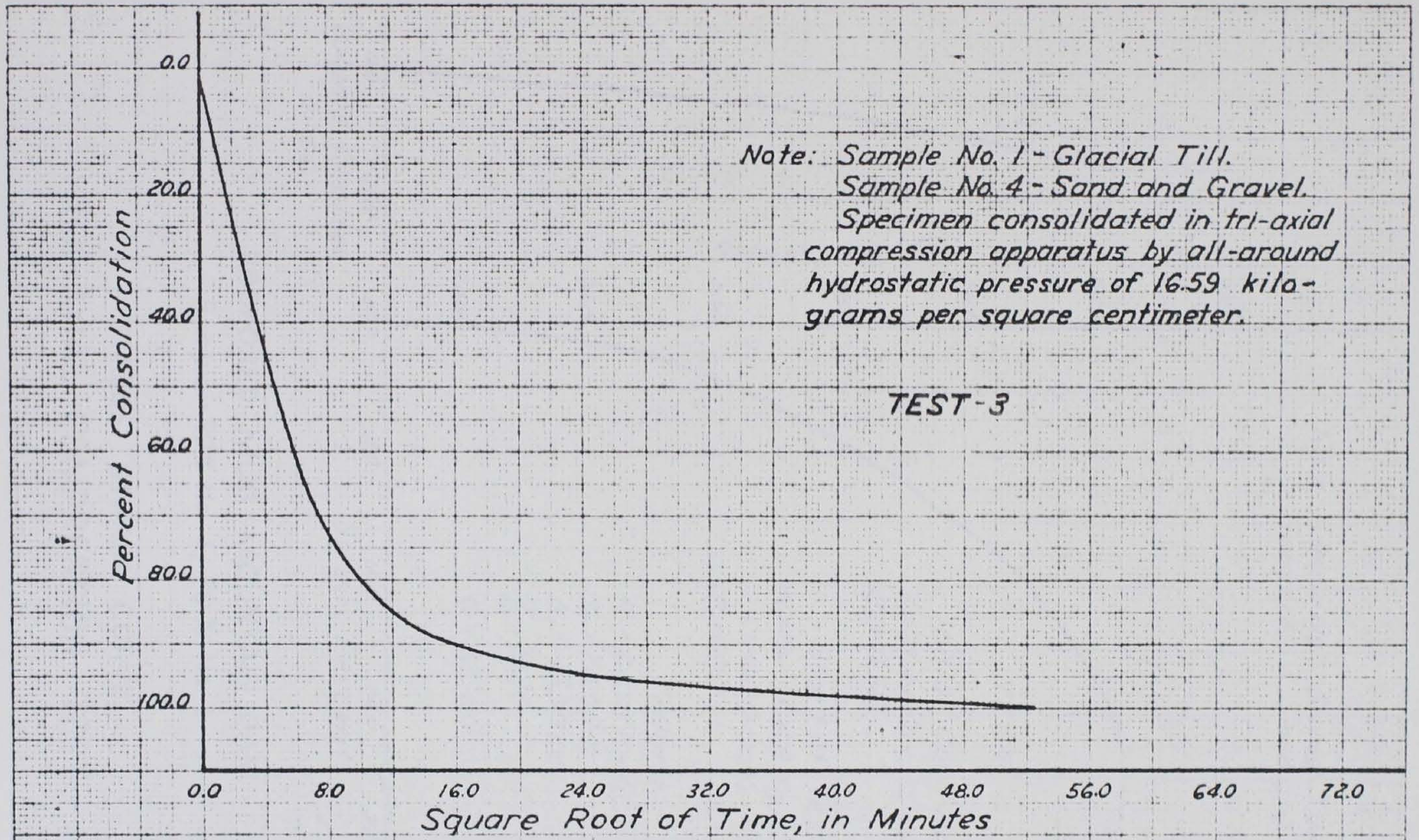
PROPOSED MUD MOUNTAIN DAM

Sample: 80% No. 4, 20 % No. 1

STRESS STRAIN CURVE

TRI-AXIAL COMPRESSION TEST

FIGURE 62

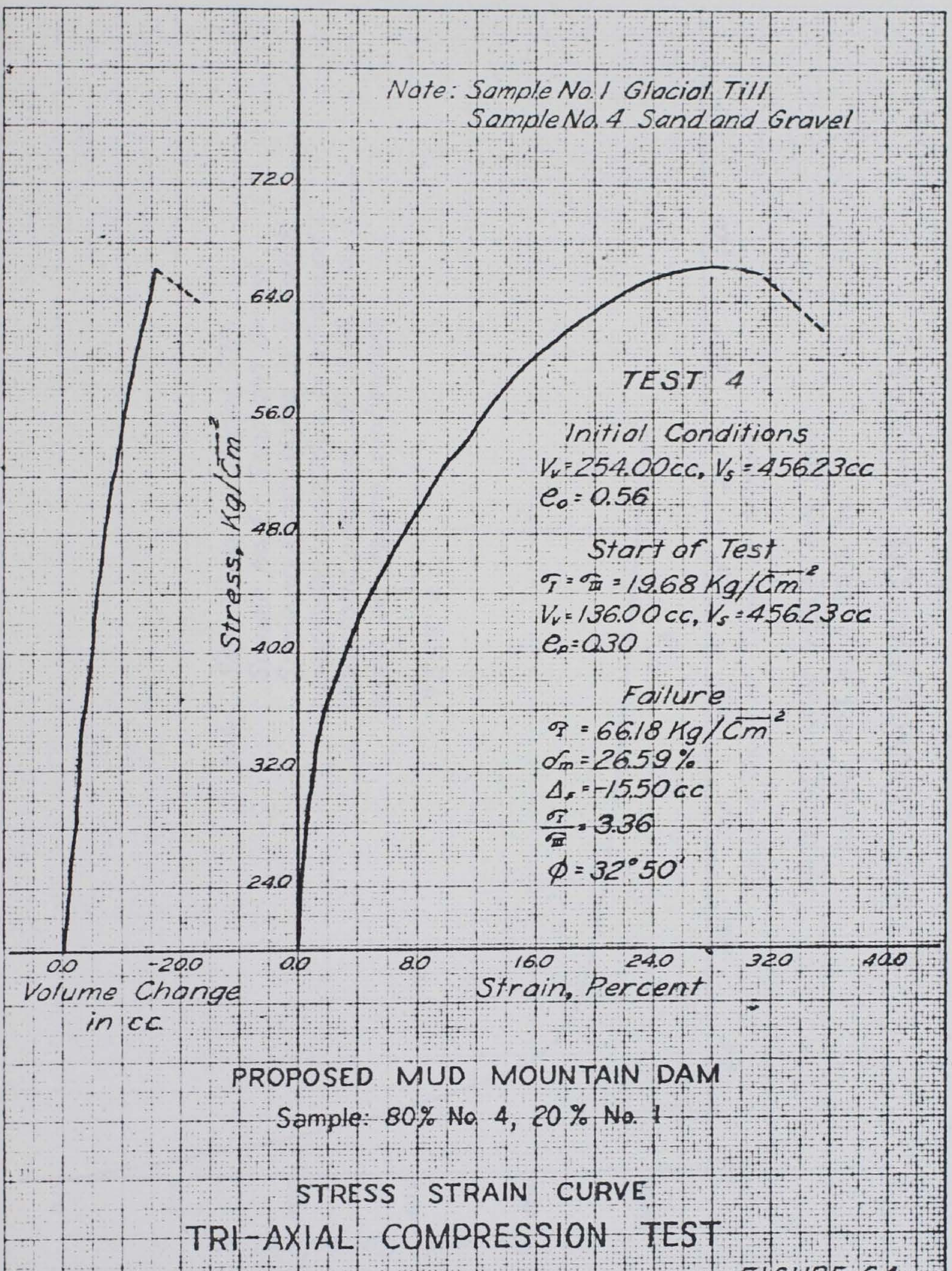


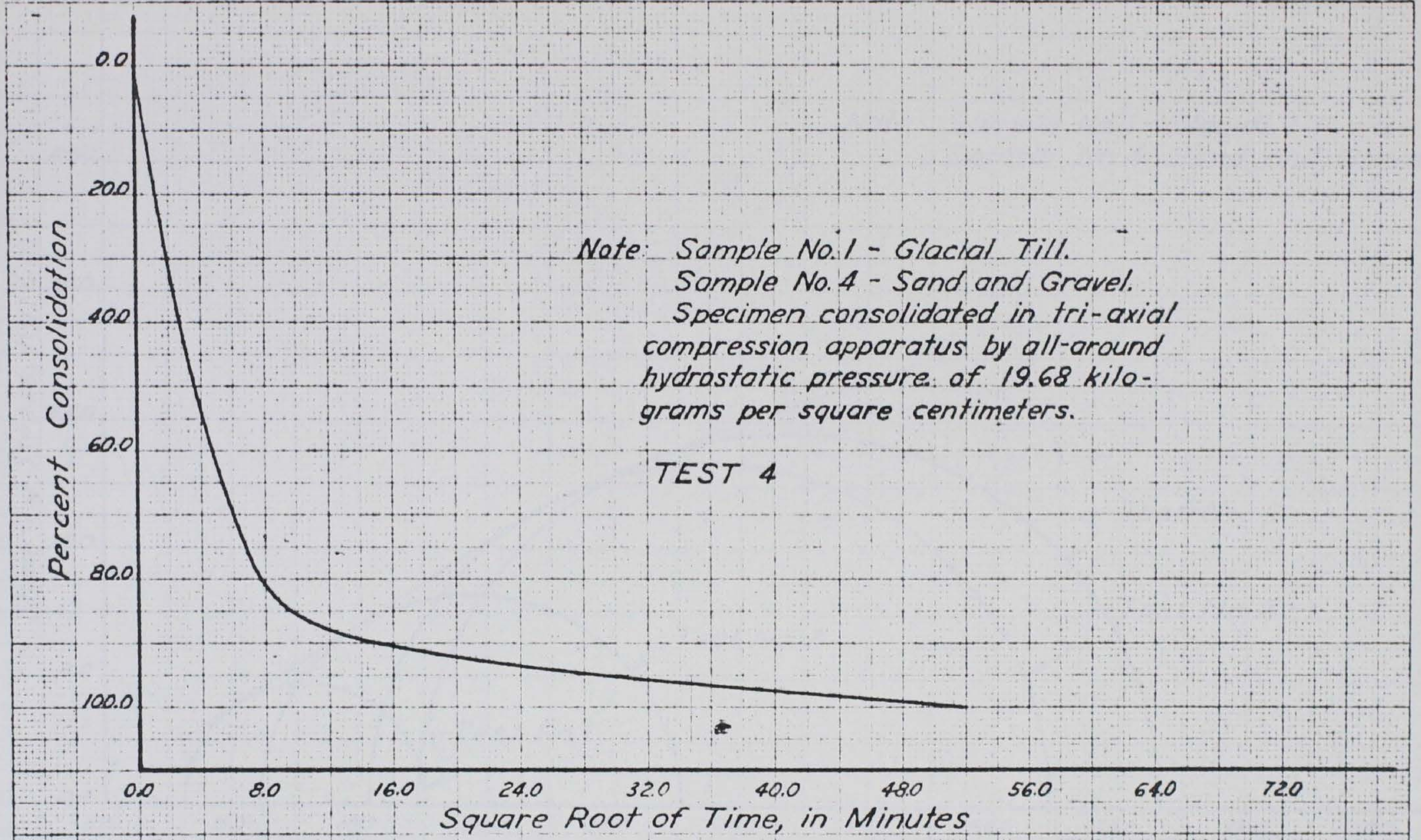
PROPOSED MUD MOUNTAIN DAM

Sample: 80% No. 4, 20% No. 1

TIME CONSOLIDATION DIAGRAM

FIGURE 63


Note: Sample No. 1 Glacial Till
Sample No. 4 Sand and Gravel
72.0
64.0
56.0
48.0
40.0
32.0
24.0
Stress, Kg/Cm²
TEST 4
Initial Conditions
Vv=254.00cc, Vs=456.23cc
e₀=0.56
Start of Test
σI=σIII=19.68 Kg/Cm²
Vv=136.00cc, Vs=456.23cc
ef=0.30
Failure
σI=66.18 Kg/Cm²
δm=26.59%
Δf=-15.50cc
σI/σIII=3.36
φ=32°50'
0.0
-20.0
Volume Change in cc.
0.0
8.0
16.0
24.0
32.0
40.0
Strain, Percent
PROPOSED MUD MOUNTAIN DAM
Sample: 80% No. 4, 20% No. 1
STRESS STRAIN CURVE
TRI-AXIAL COMPRESSION TEST
FIGURE 64

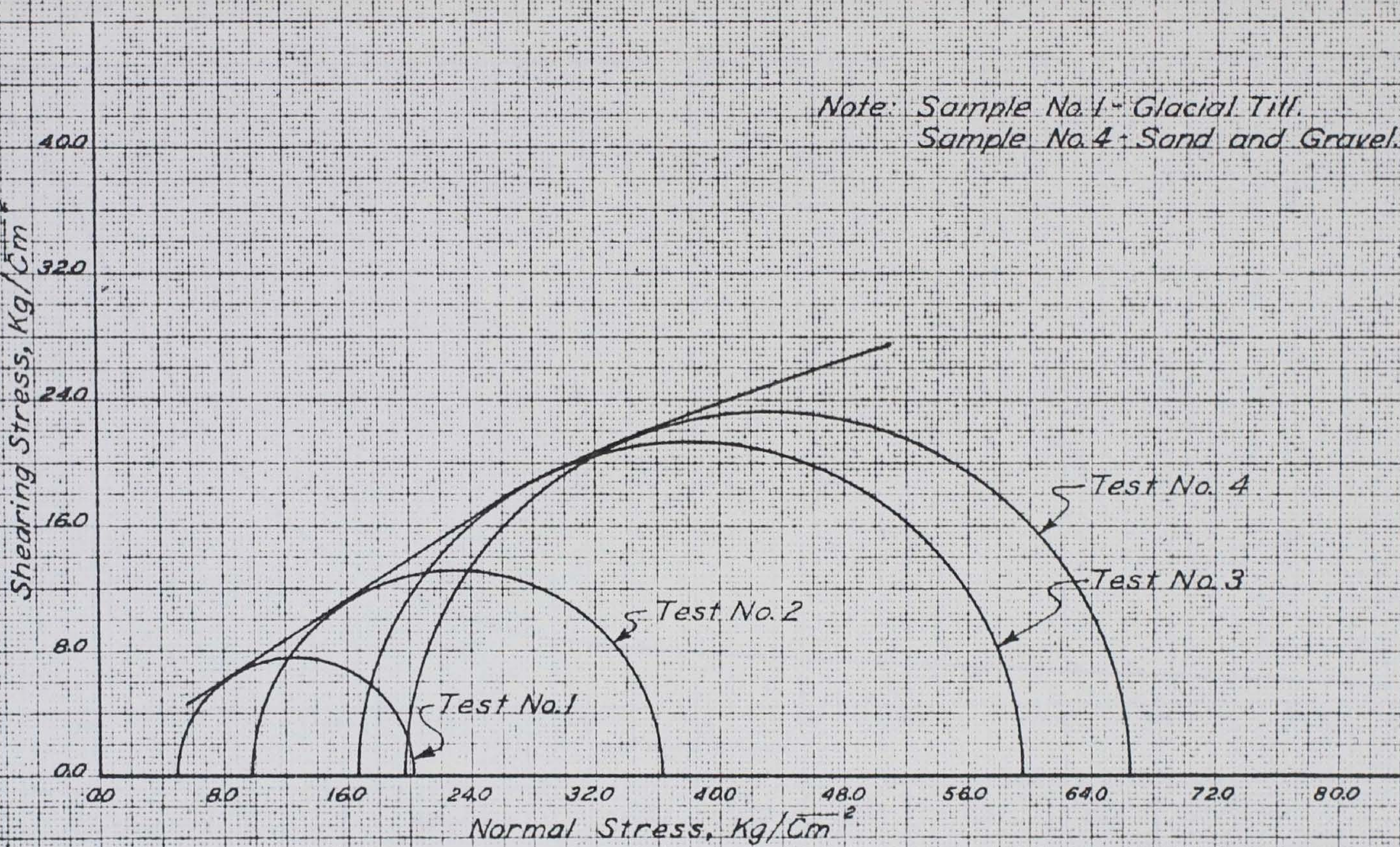


PROPOSED MUD MOUNTAIN DAM

Sample: 80% No. 4, 20% No. 1

TIME CONSOLIDATION DIAGRAM

FIGURE 65



PROPOSED MUD MOUNTAIN DAM

Sample: 80% No. 4, 20% No. 1

MOHR'S CIRCLES OF STRESS

FIGURE 66

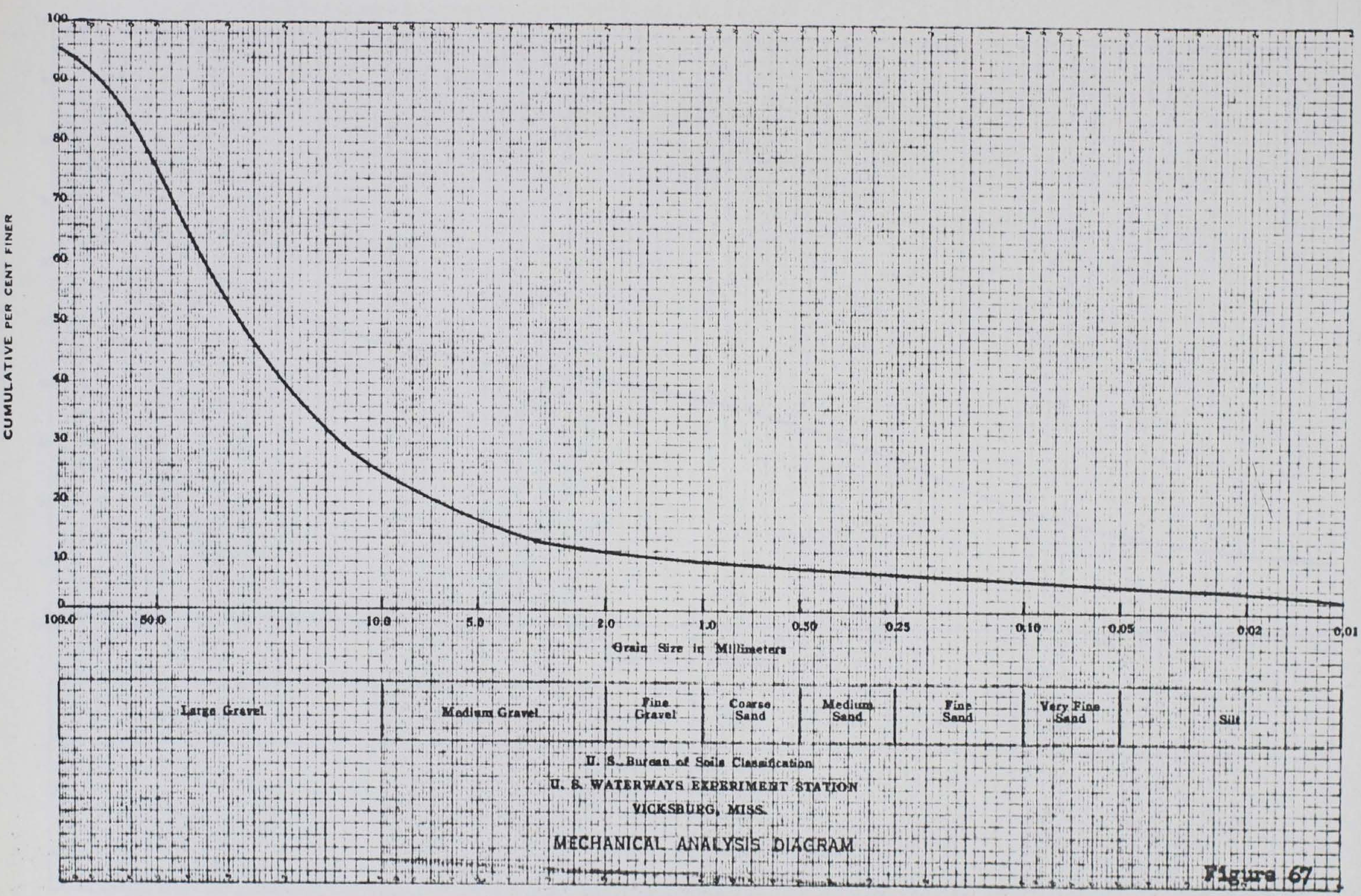


Figure 67

Sample No. 3 - Sand and gravel

Location of Sample. Proposed Mud Mountain Dam

Remarks. Sample as received

Date Sample Taken.

Date Sample Tested. 7-8-39

Specific Gravity of Sample.

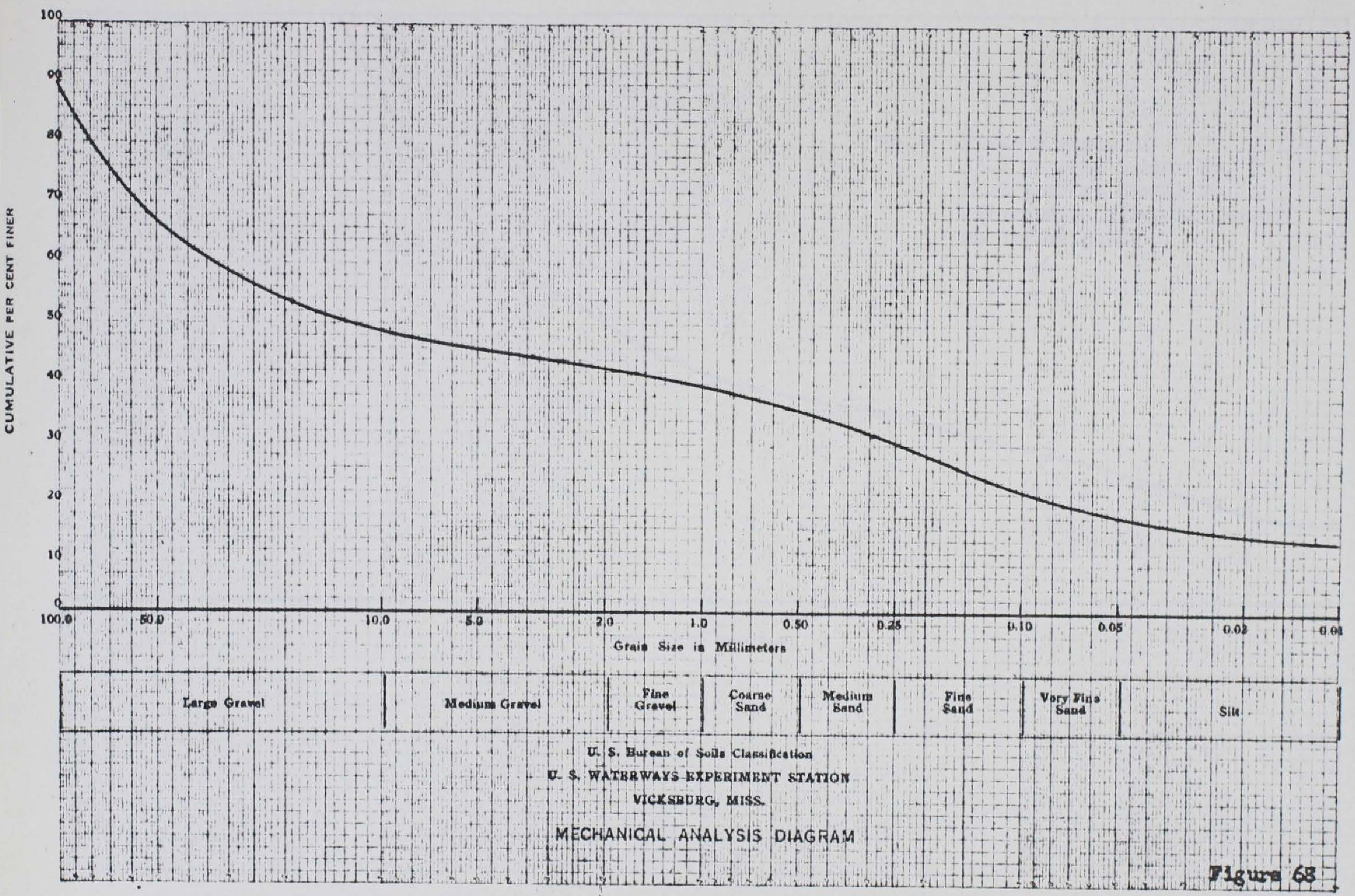


Figure 68

Sample No. 1 - Unaltered glacial till

Location of Sample Proposed Mud Mountain Dam

Remarks Sample as-received

Date Sample Taken

Date Sample Tested 7-13-39

Specific Gravity of Sample

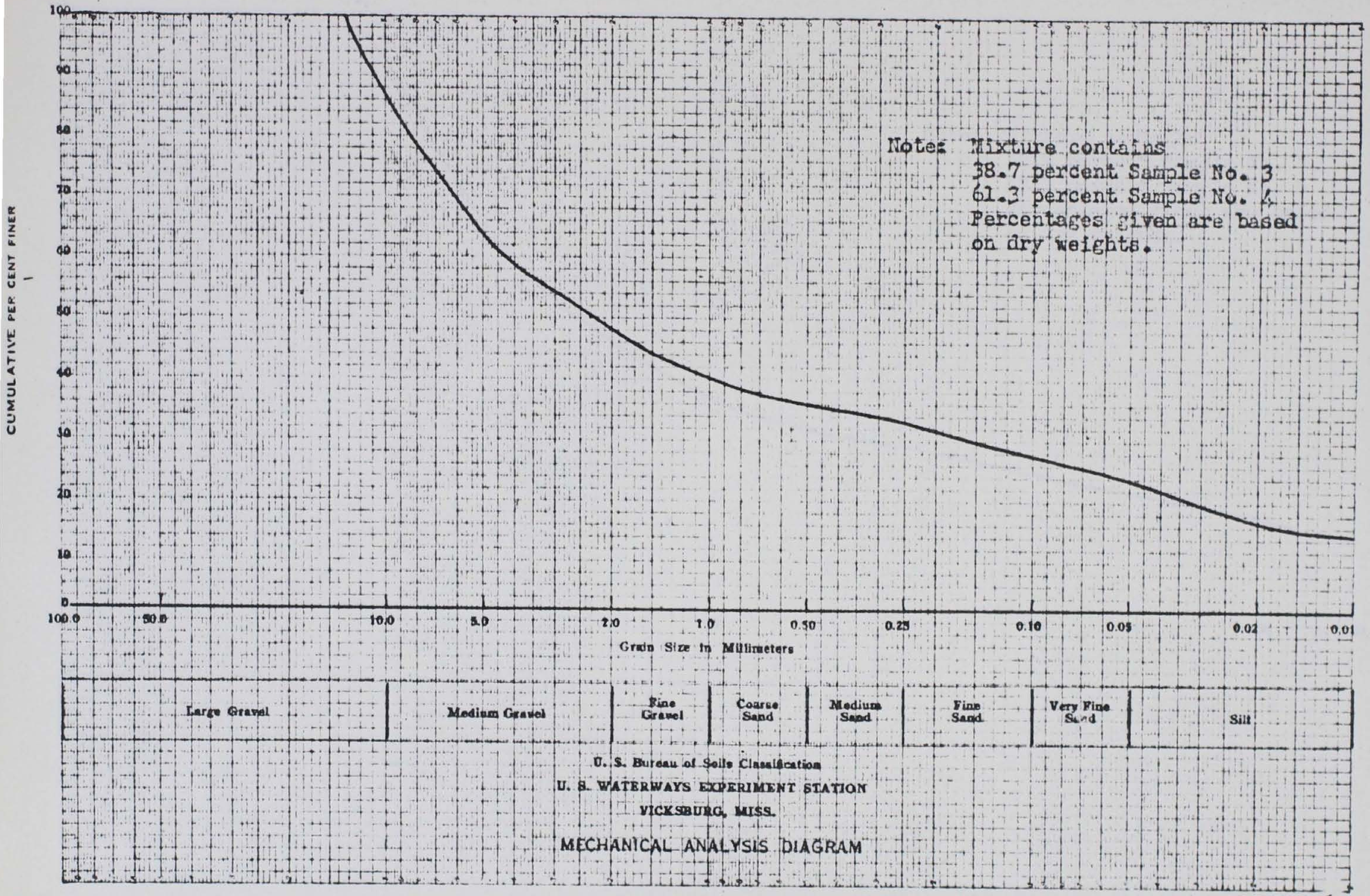


Figure 69

Sample No. 3 and 4 (Sand and Gravel)

Location of Sample Proposed Mud Mountain Dam

Remarks Mixture of Samples 3 and 4 passing $\frac{1}{2}$-in. sieve opening.

Date Sample Taken

Date Sample Tested 8-15-39

Specific Gravity of Sample 2.74

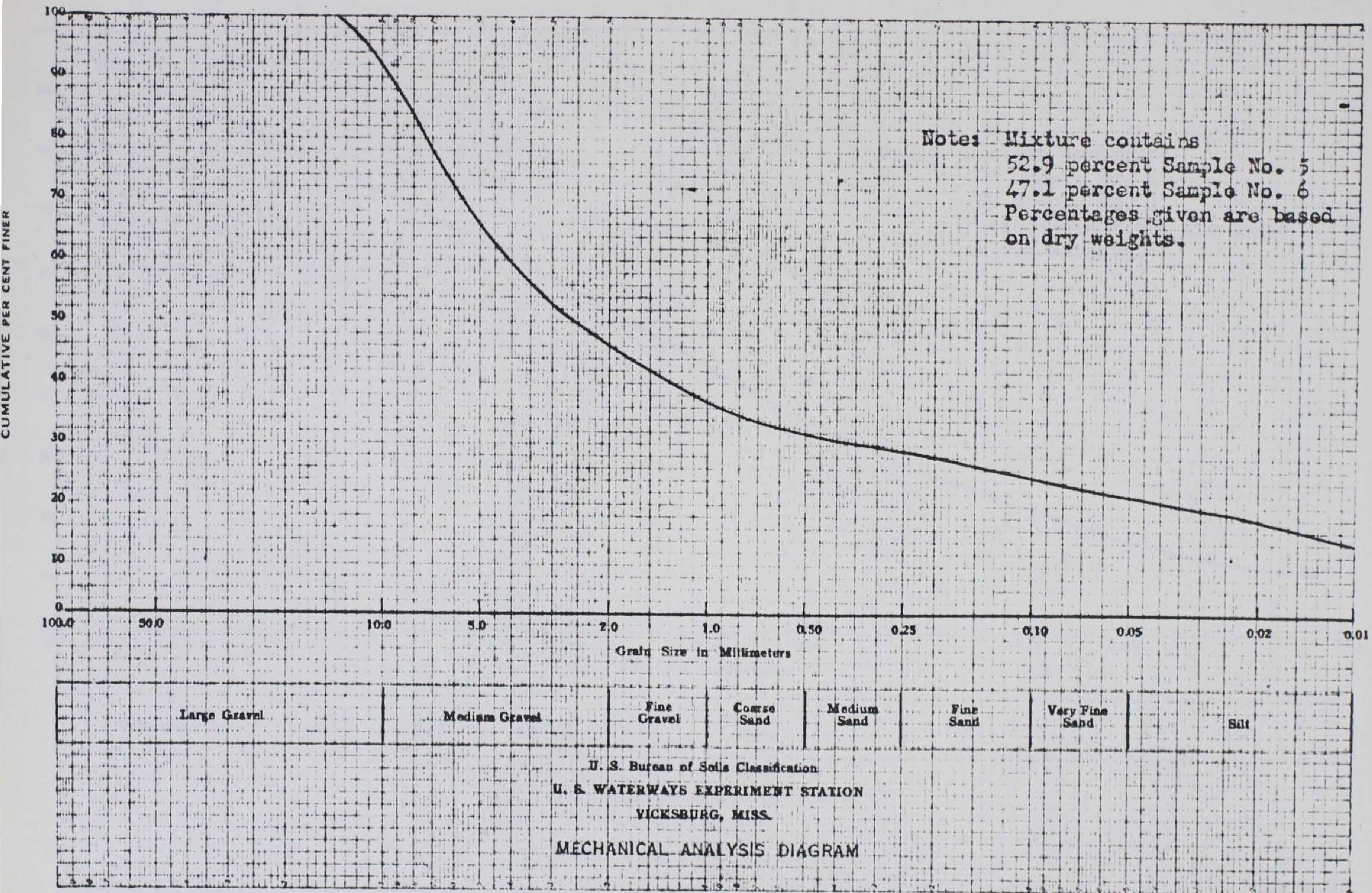


Figure 70

Sample No. 5 and 6 (Sand and Gravel)

Location of Sample Proposed Mud Mountain Dam

Remarks Mixture of Samples 5 and 6 passing 1/2-in. sieve opening.

Date Sample Taken

Date Sample Tested 9-14-39

Specific Gravity of Sample 2.74

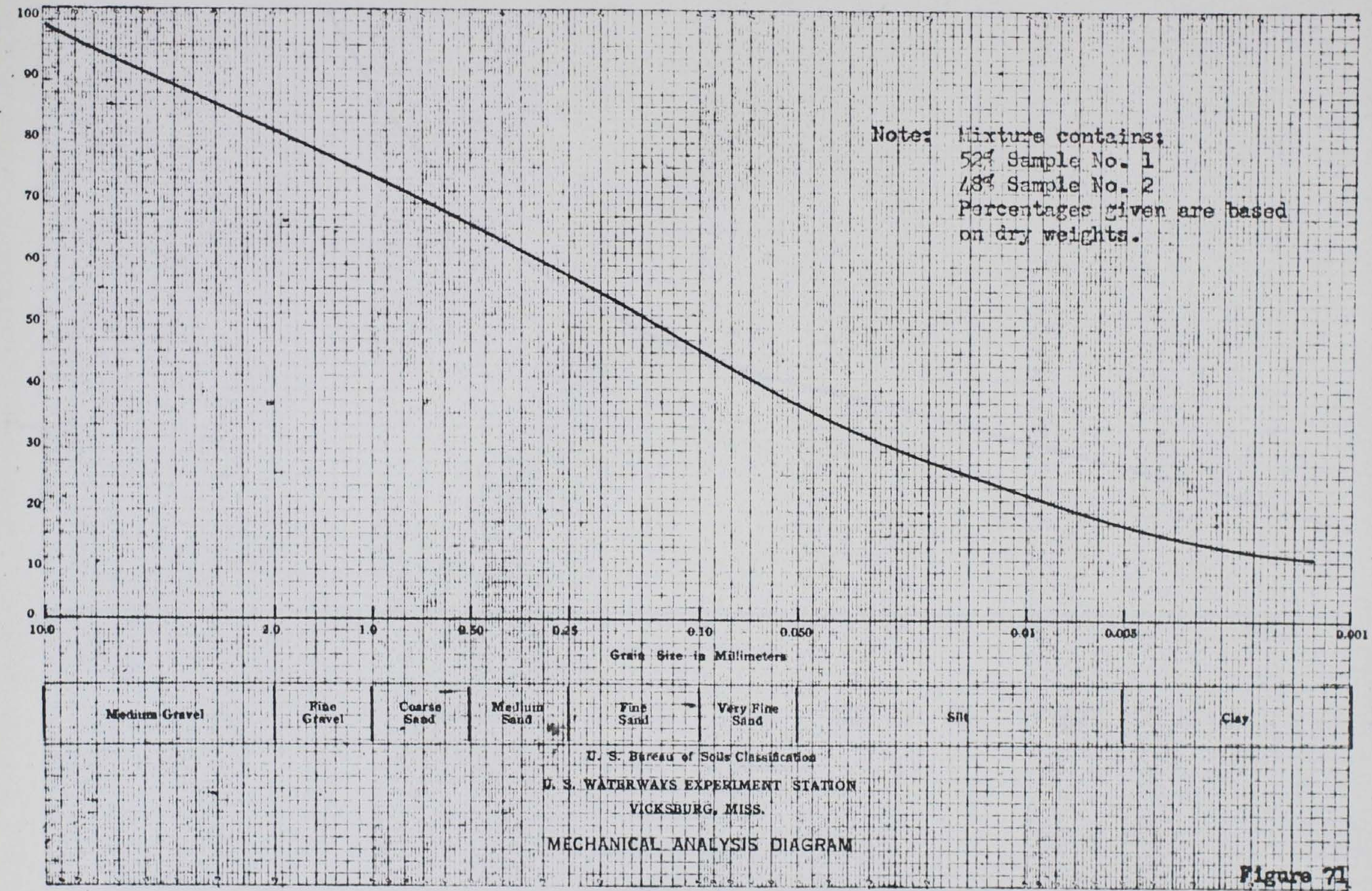


Figure 71

Sample No. 1 and 2 (Glacial Till)

Location of Sample Proposed Mud Mountain Dam

Remarks Mixture of Samples 1 and 2 passing 1/2-in. sieve opening

Date Sample Taken

Date Sample Tested 9-29-39

Specific Gravity of Sample 2.69

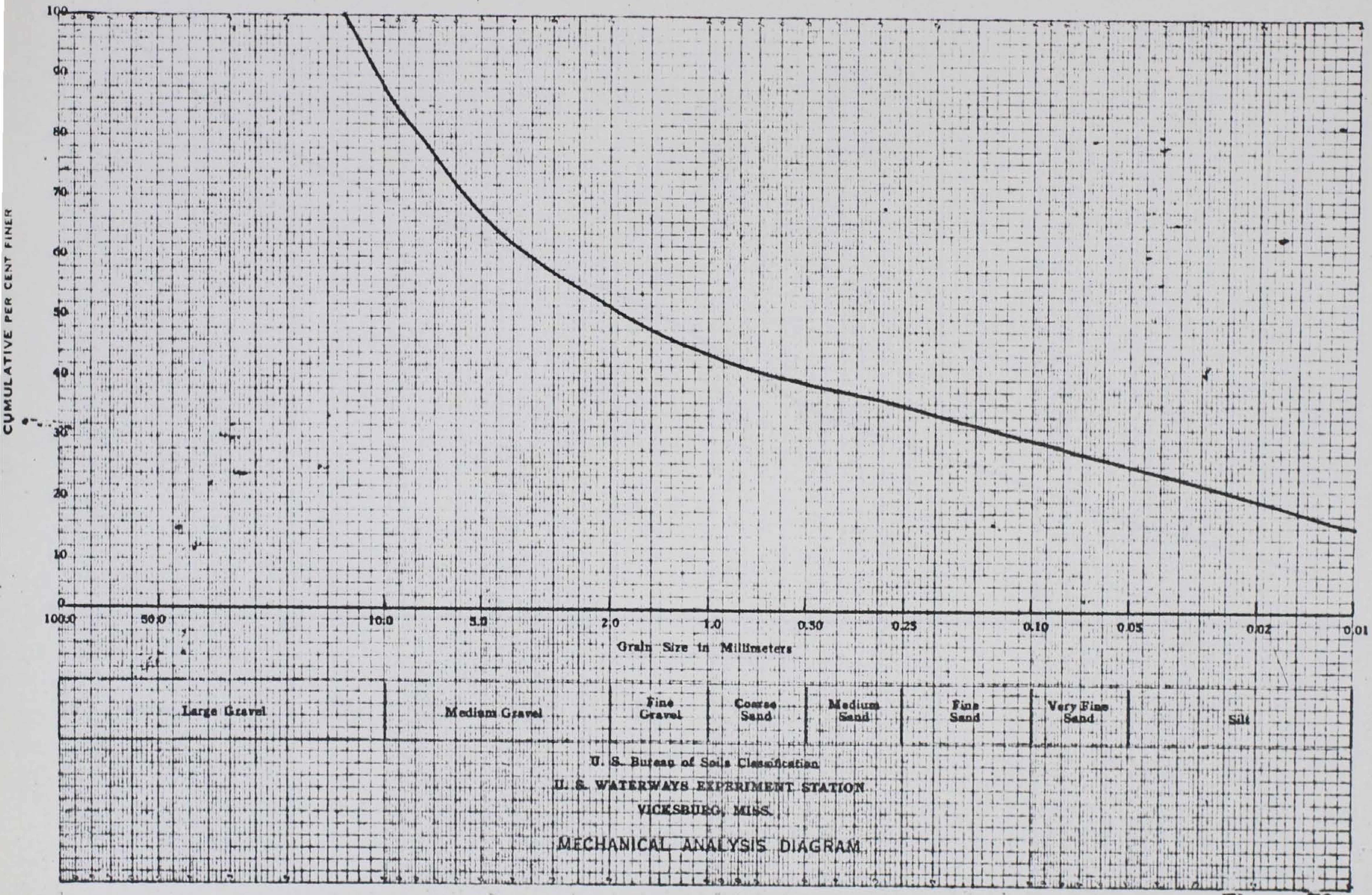


Figure 72

Sample No. Mixture 80% sand and gravel, 20% till

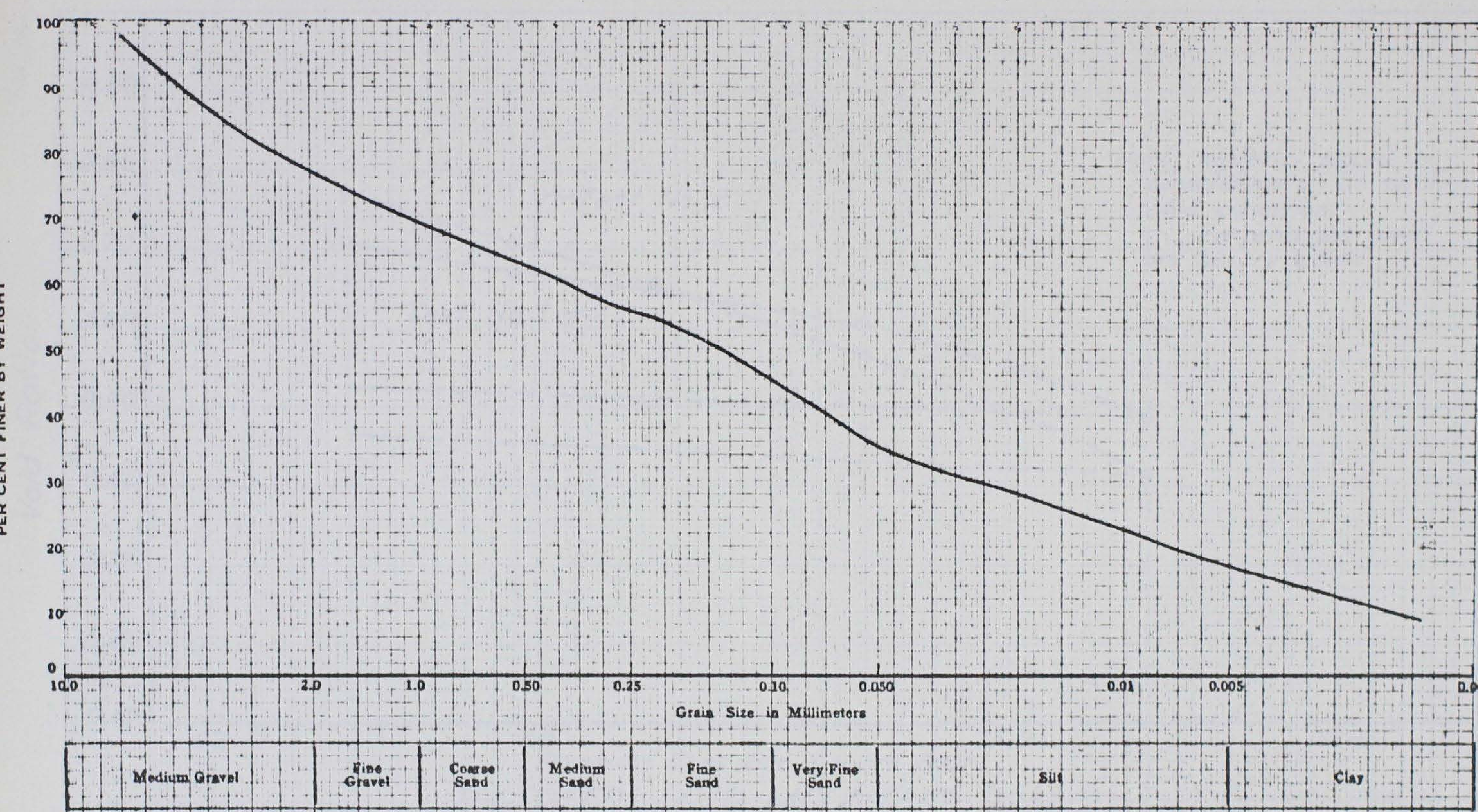
Location of Sample Proposed Mud Mountain Dam

Remarks

Date Sample Taken

Date Sample Tested 9-11-39

Specific Gravity of Sample 2.74



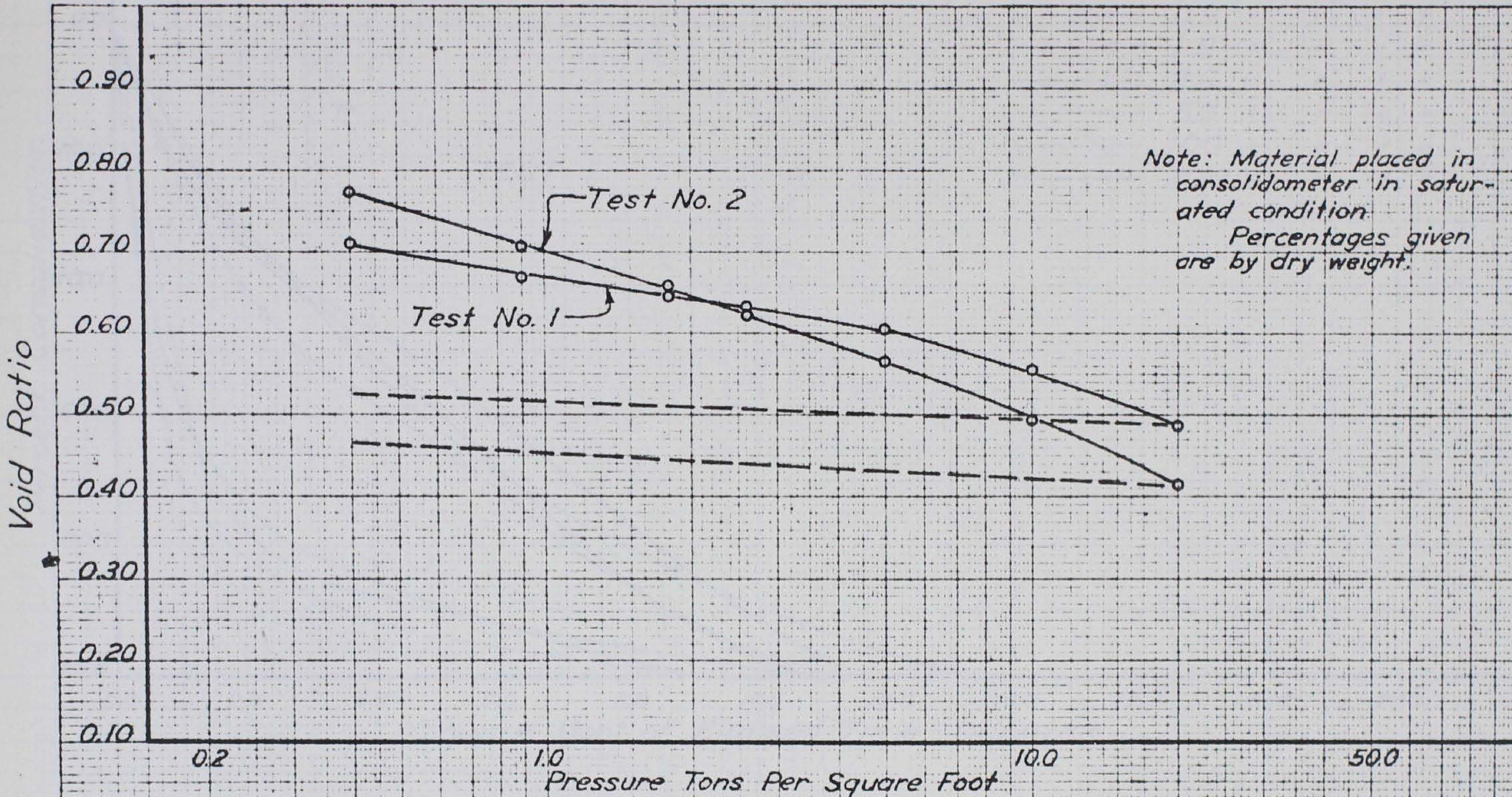
U. S. WATERWAYS EXPERIMENT STATION
VICKSBURG, MISS.

MECHANICAL ANALYSIS DIAGRAM

Figure 73

Sample No. Mixture-60% sand and gravel (Samples Nos. 3 and 4)
40% glacial till (Samples Nos. 1 and 2)
Location of Sample Proposed Mud Mountain Dam
Remarks All material passing 0.525-in. sieve

Date Sample Taken
Date Sample Tested 11-16-39
Specific Gravity of Sample



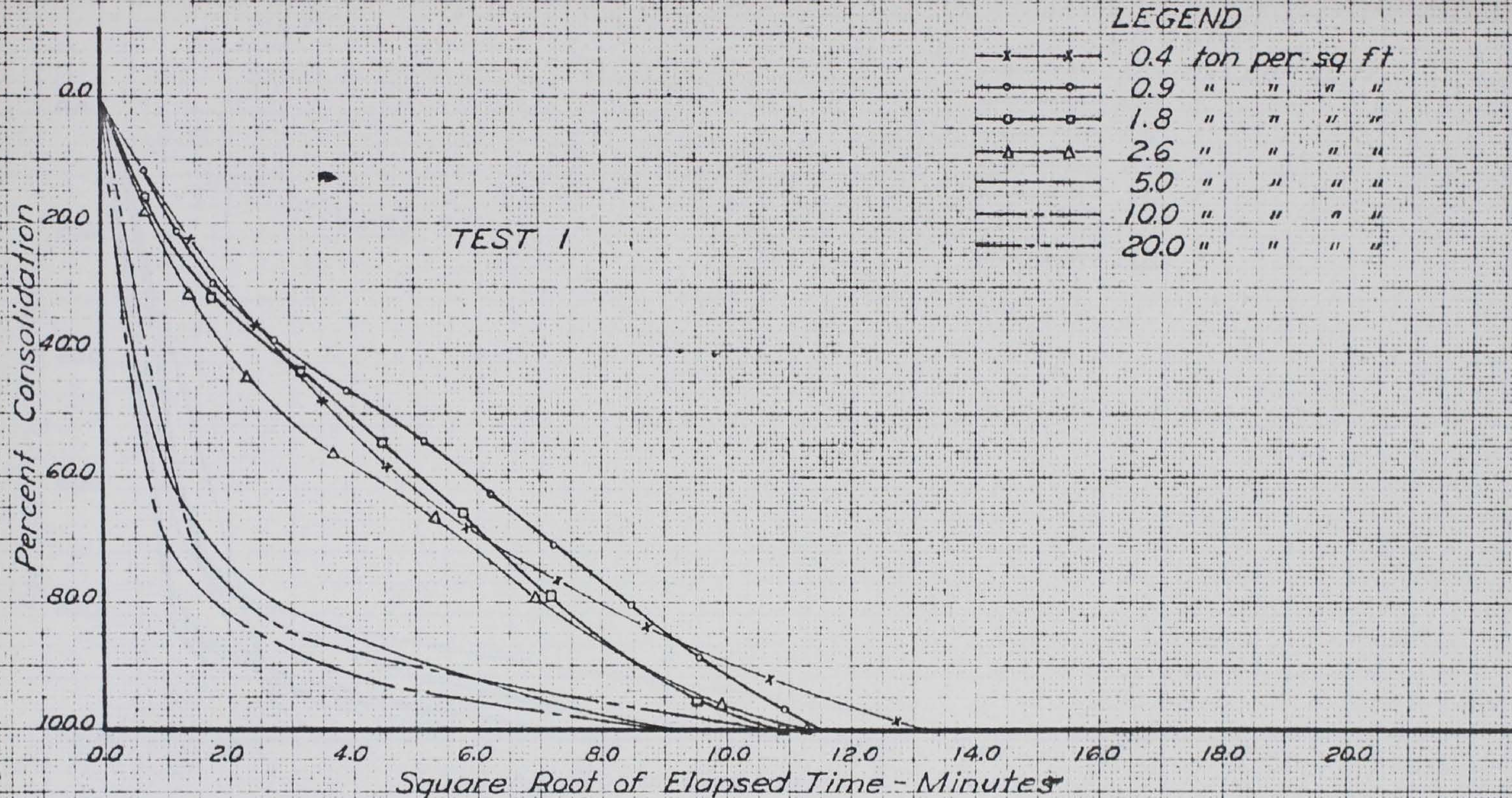
PROPOSED MUD MOUNTAIN DAM

Sand and Gravel

52.9 Percent Sample No. 5, 47.1 Percent Sample No. 6

VOID RATIO - PRESSURE DIAGRAM

FIGURE 74



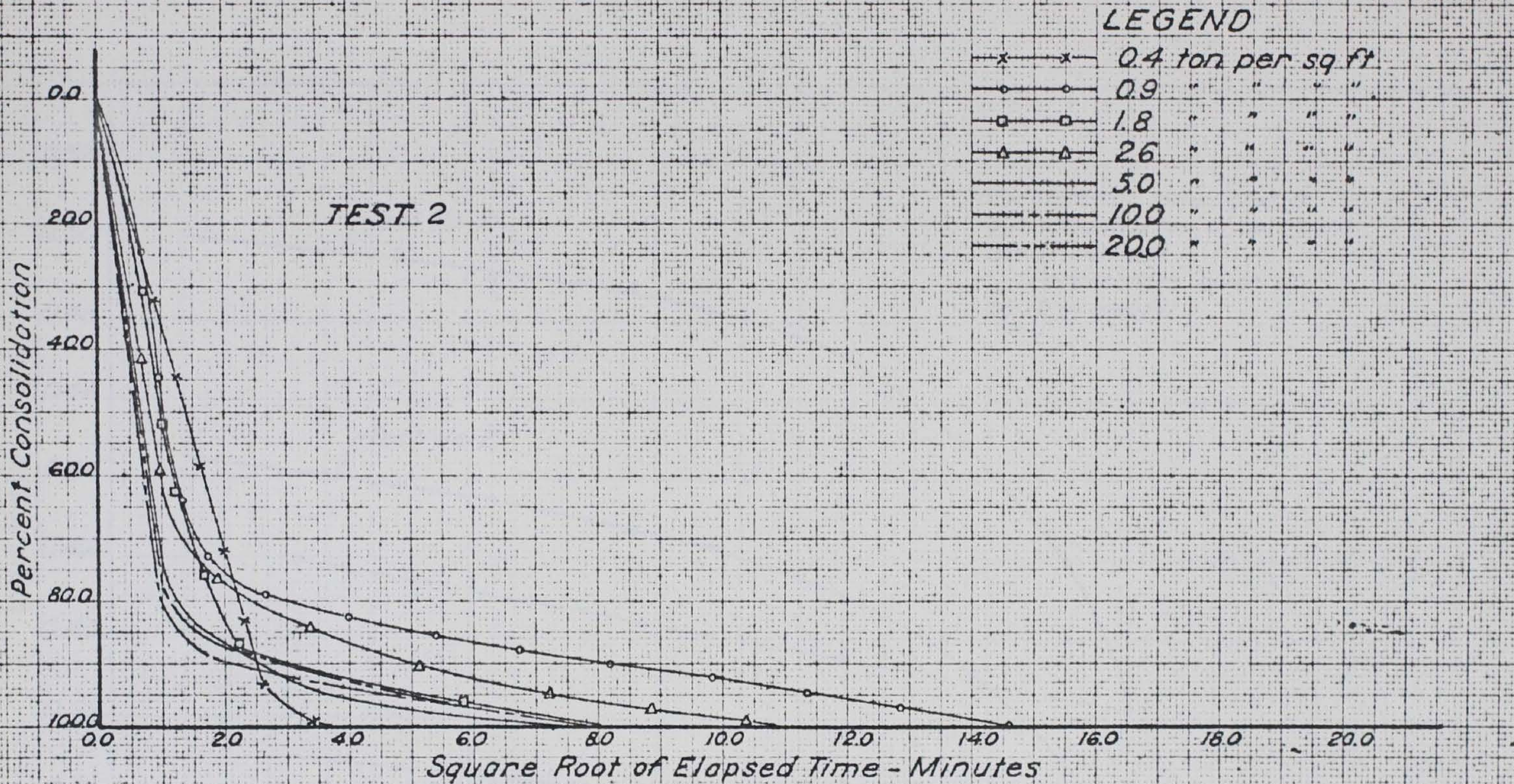
PROPOSED MUD MOUNTAIN DAM

SAND AND GRAVEL

52.9 Percent Sample No. 5; 47.1 Percent Sample No. 6

TIME-CONSOLIDATION DIAGRAM

FIGURE-75



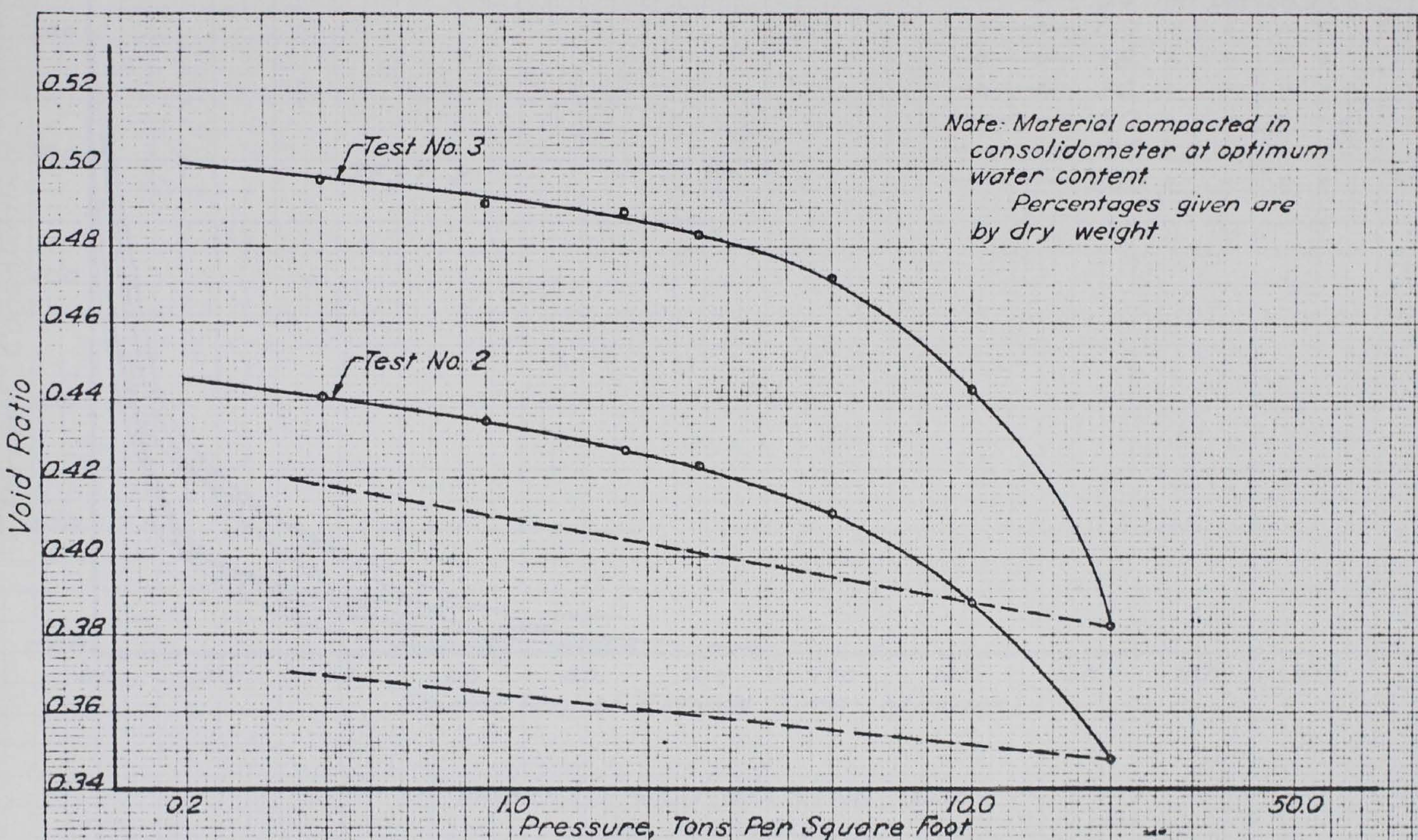
PROPOSED MUD MOUNTAIN DAM

SAND AND GRAVEL

52.9 Percent Sample No. 5; 47.1 Percent Sample No. 6

TIME-CONSOLIDATION DIAGRAM

FIGURE 76



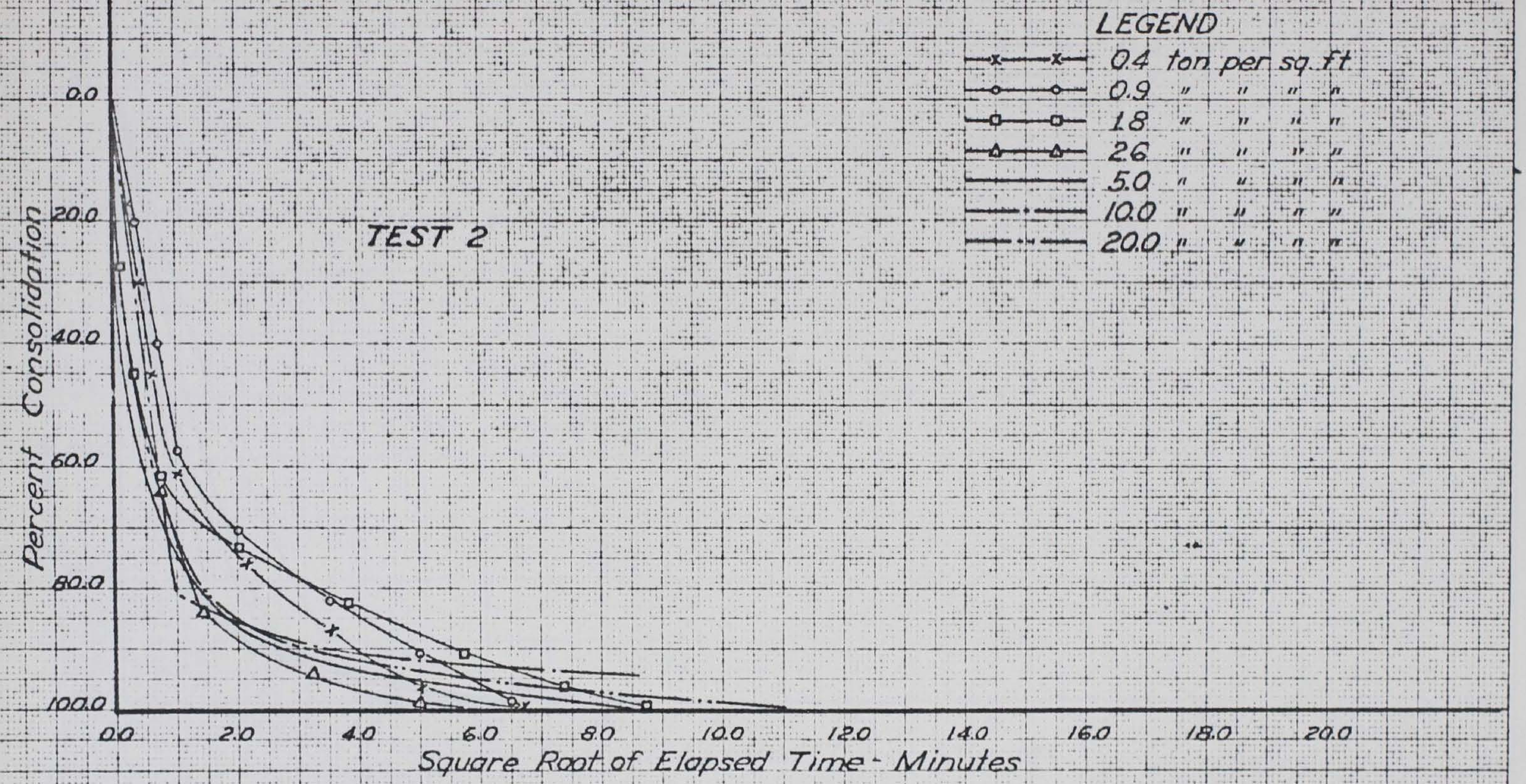
PROPOSED MUD MOUNTAIN DAM

SAND AND GRAVEL

38.7 Percent Sample No. 3; 61.3 Percent Sample No. 4

FIGURE 77

VOID RATIO - PRESSURE DIAGRAM



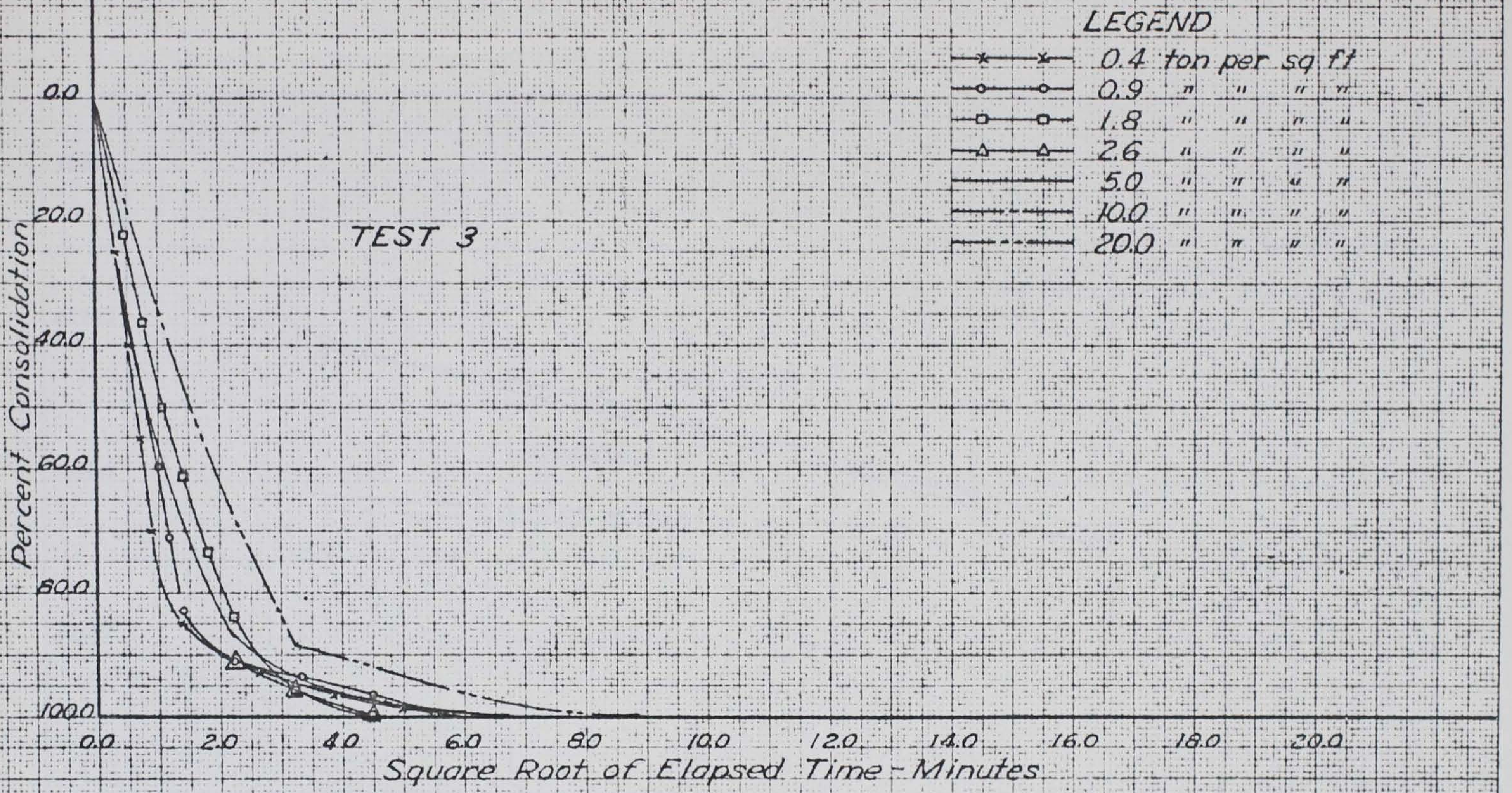
PROPOSED MUD MOUNTAIN DAM

SAND AND GRAVEL

38.7 Percent Sample No. 3, 61.3 Percent Sample No. 4

TIME CONSOLIDATION DIAGRAM

FIGURE 78



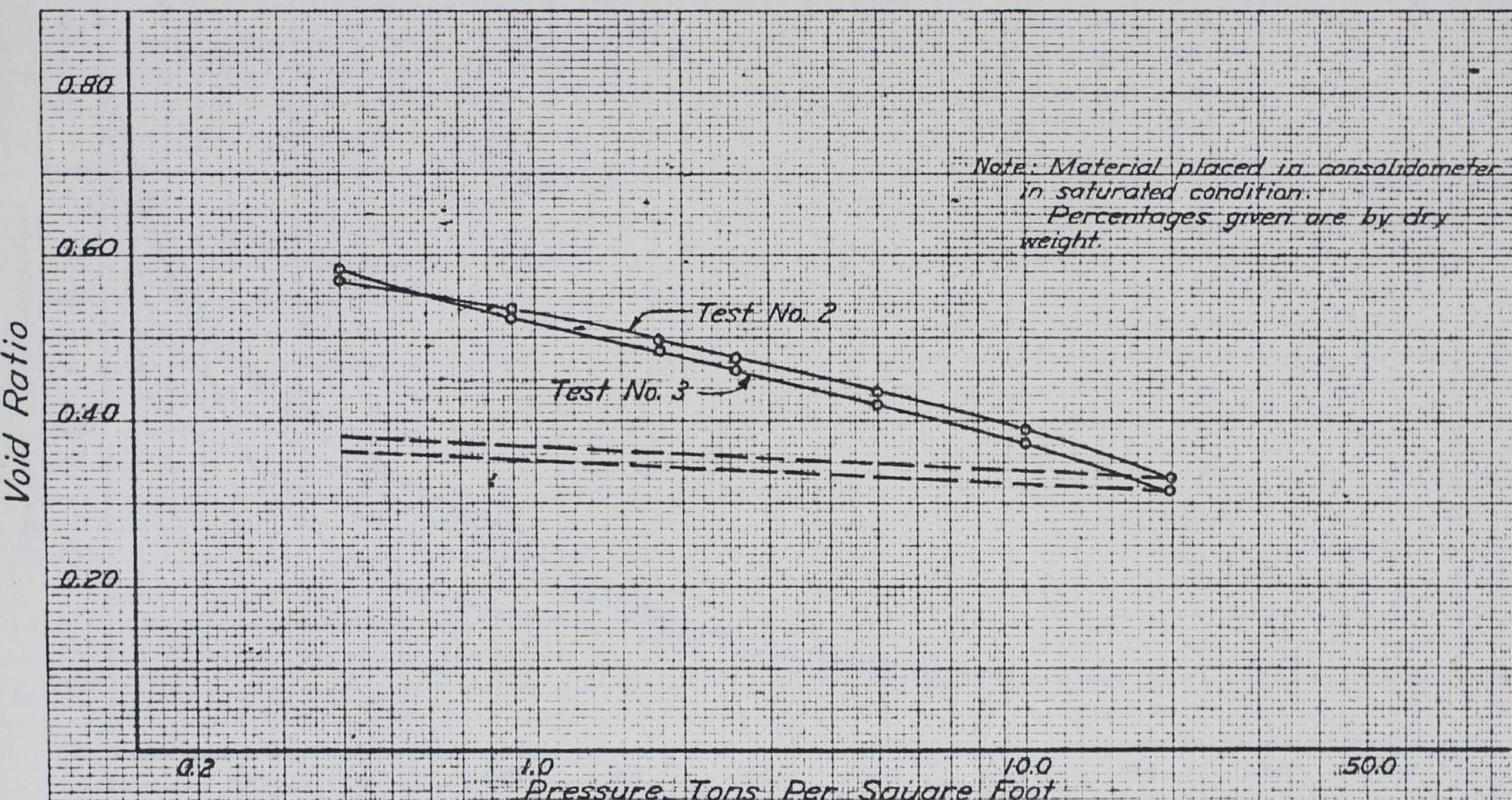
PROPOSED MUD MOUNTAIN DAM

SAND AND GRAVEL

38.7 Percent Sample No. 3, 61.3 Percent Sample No. 4

TIME-CONSOLIDATION DIAGRAM

FIGURE 79



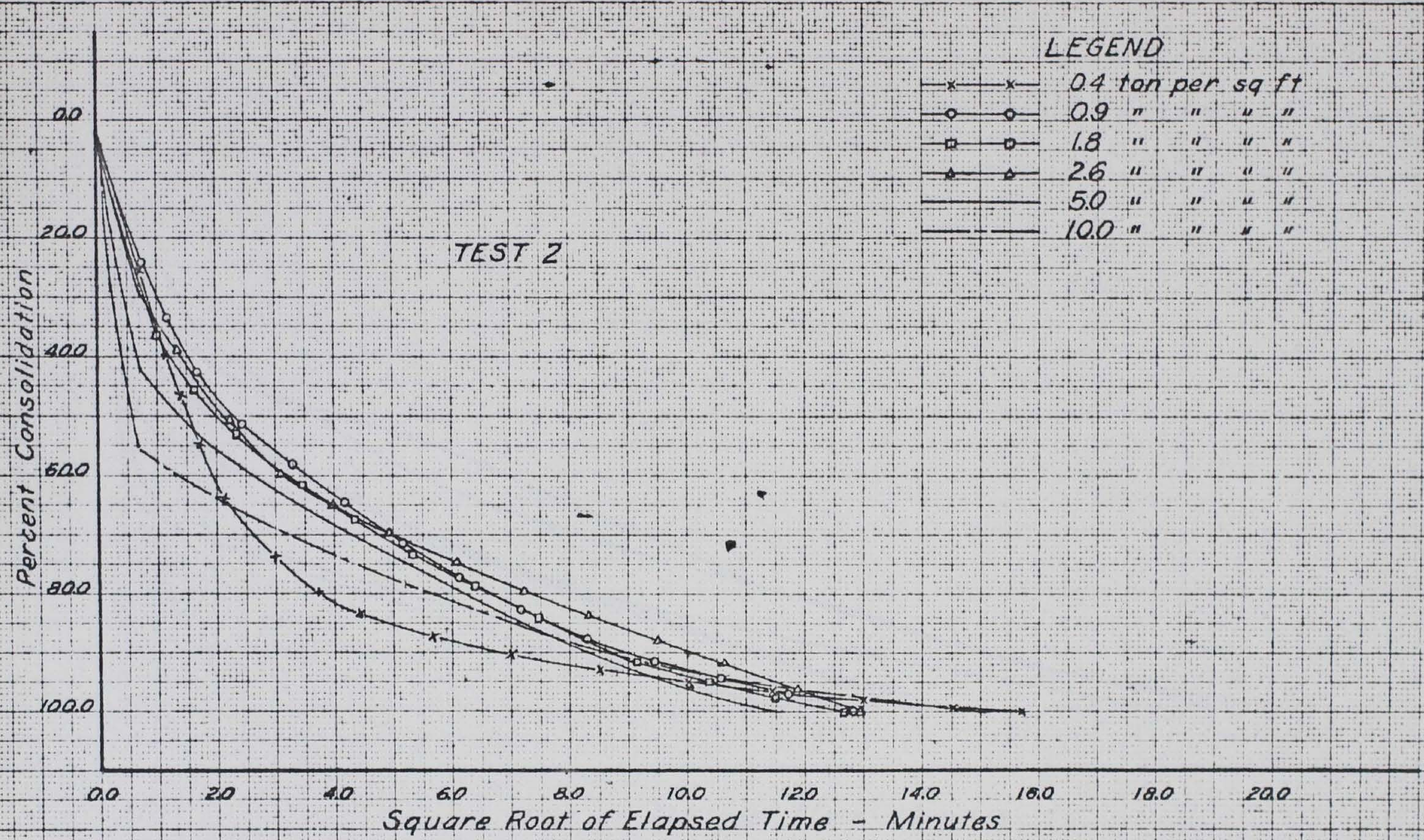
PROPOSED MUD MOUNTAIN DAM

Glacial Till

52 Percent Sample No. 1; 48 Percent Sample No. 2

VOID RATIO - PRESSURE DIAGRAM

FIGURE 80



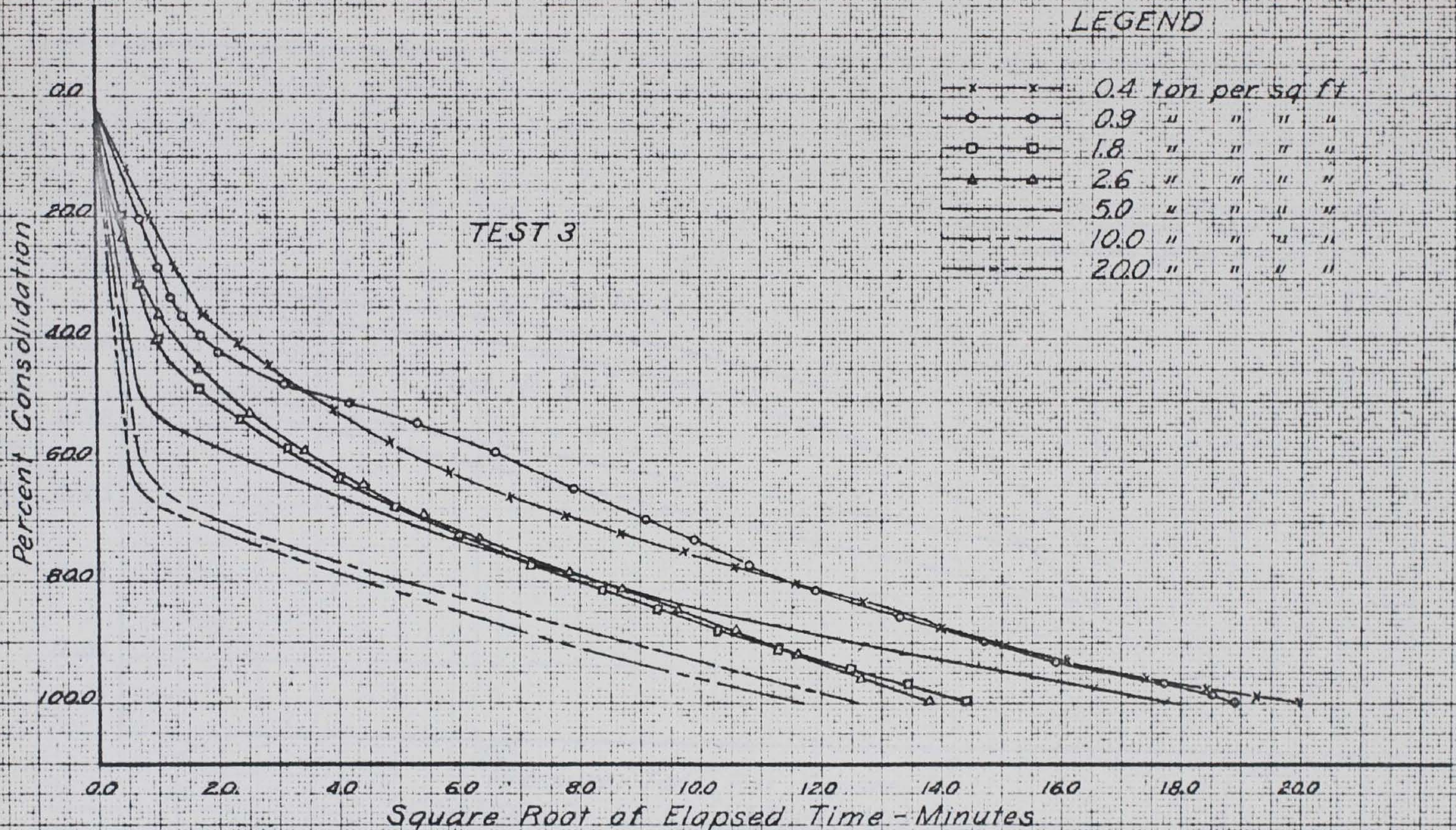
PROPOSED MUD MOUNTAIN DAM

Glacial Till

52 Percent Sample No. 1, 48 Percent Sample No. 2

TIME-CONSOLIDATION DIAGRAM

FIGURE 81



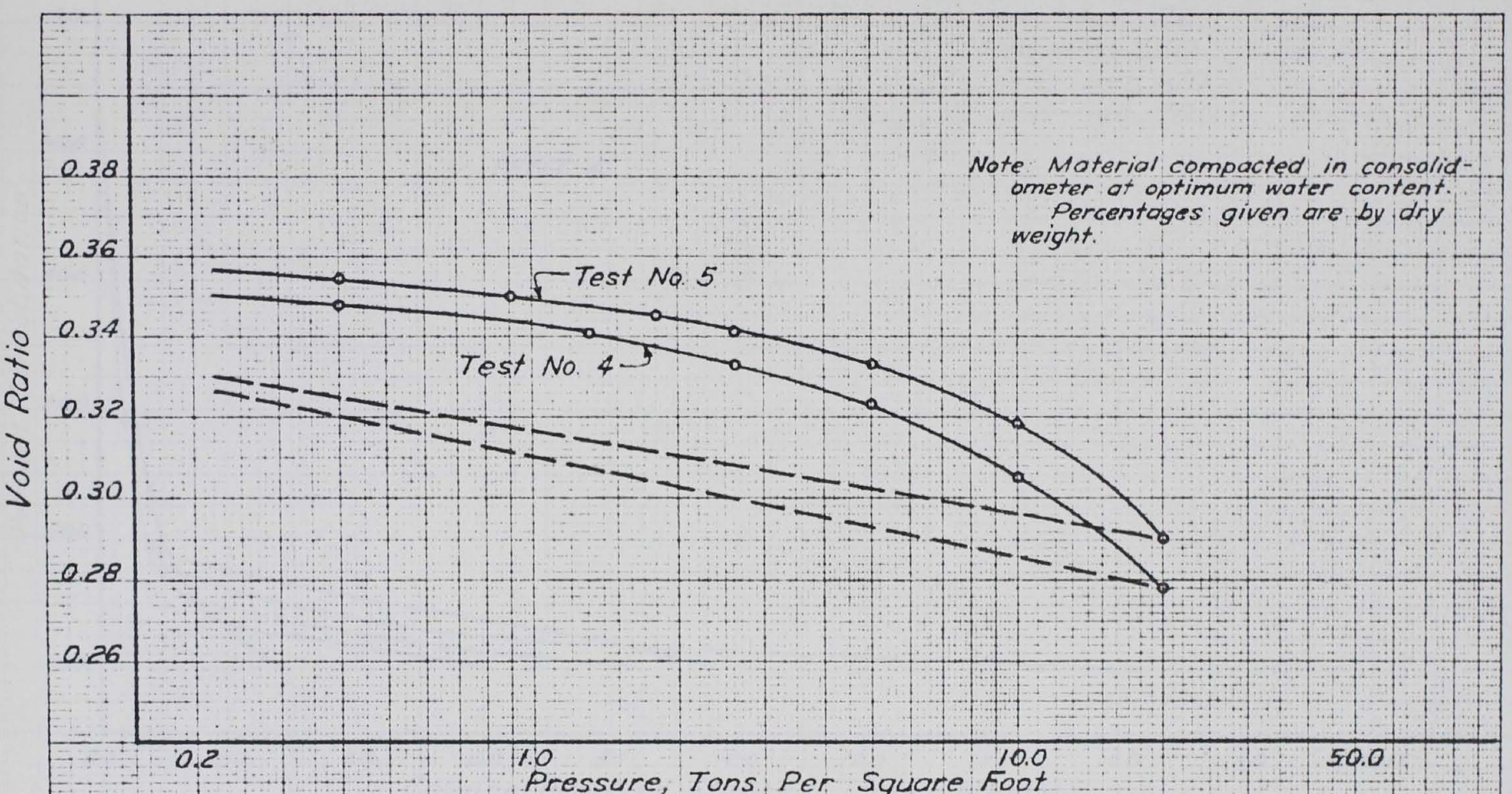
PROPOSED MUD MOUNTAIN DAM

Glacial Till

52 Percent Sample No. 1, 48 Percent Sample No. 2

TIME-CONSOLIDATION DIAGRAM

FIGURE 82



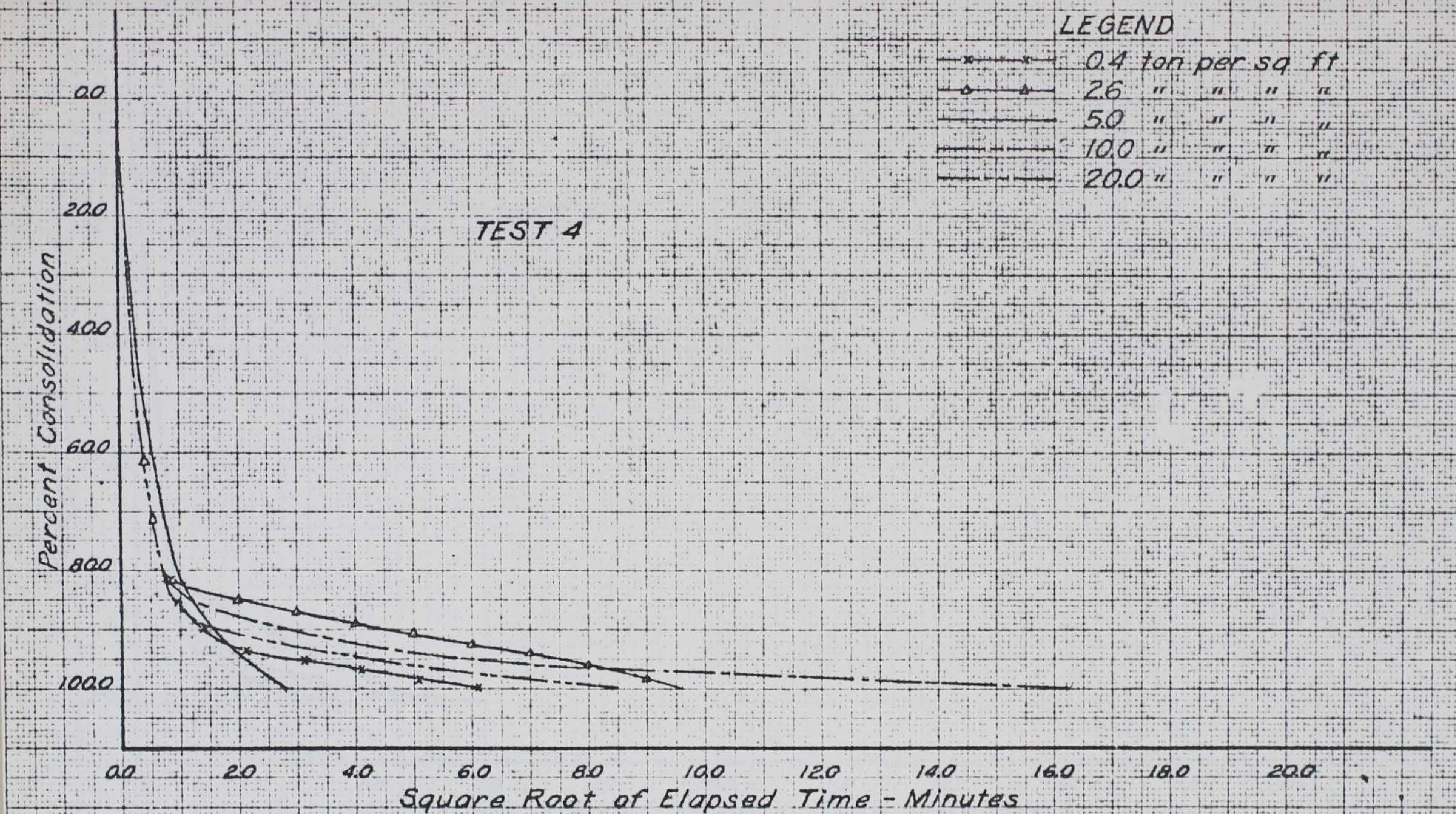
PROPOSED MUD MOUNTAIN DAM

Glacial Till

52 Percent Sample No. 1; 48 Percent Sample No. 2

VOID RATIO-PRESSURE DIAGRAM

FIGURE 83



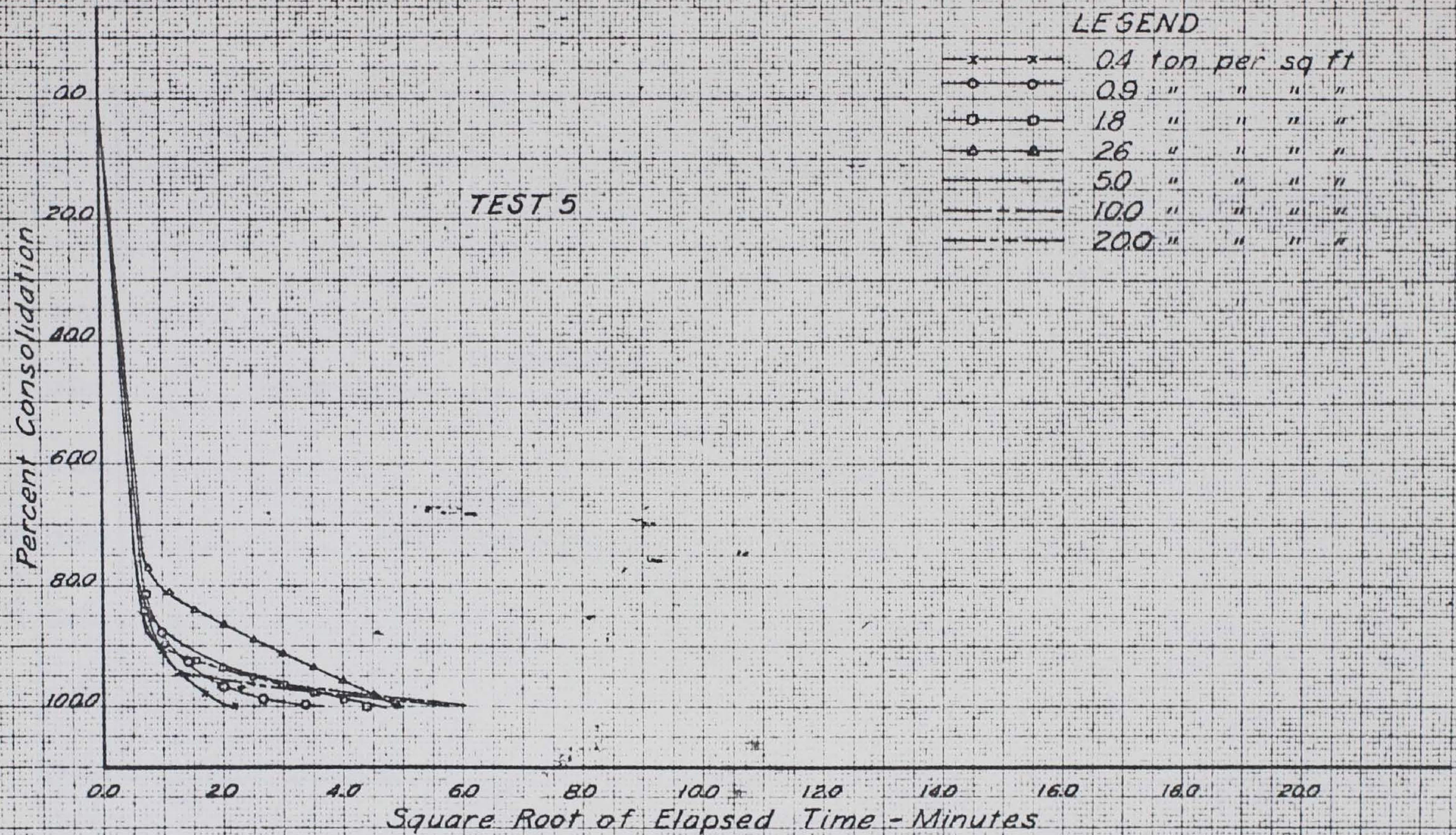
PROPOSED MUD MOUNTAIN DAM

Glacial Till

52 Percent Sample No. 1, 48 Percent Sample No. 2

TIME-CONSOLIDATION DIAGRAM

FIGURE 84



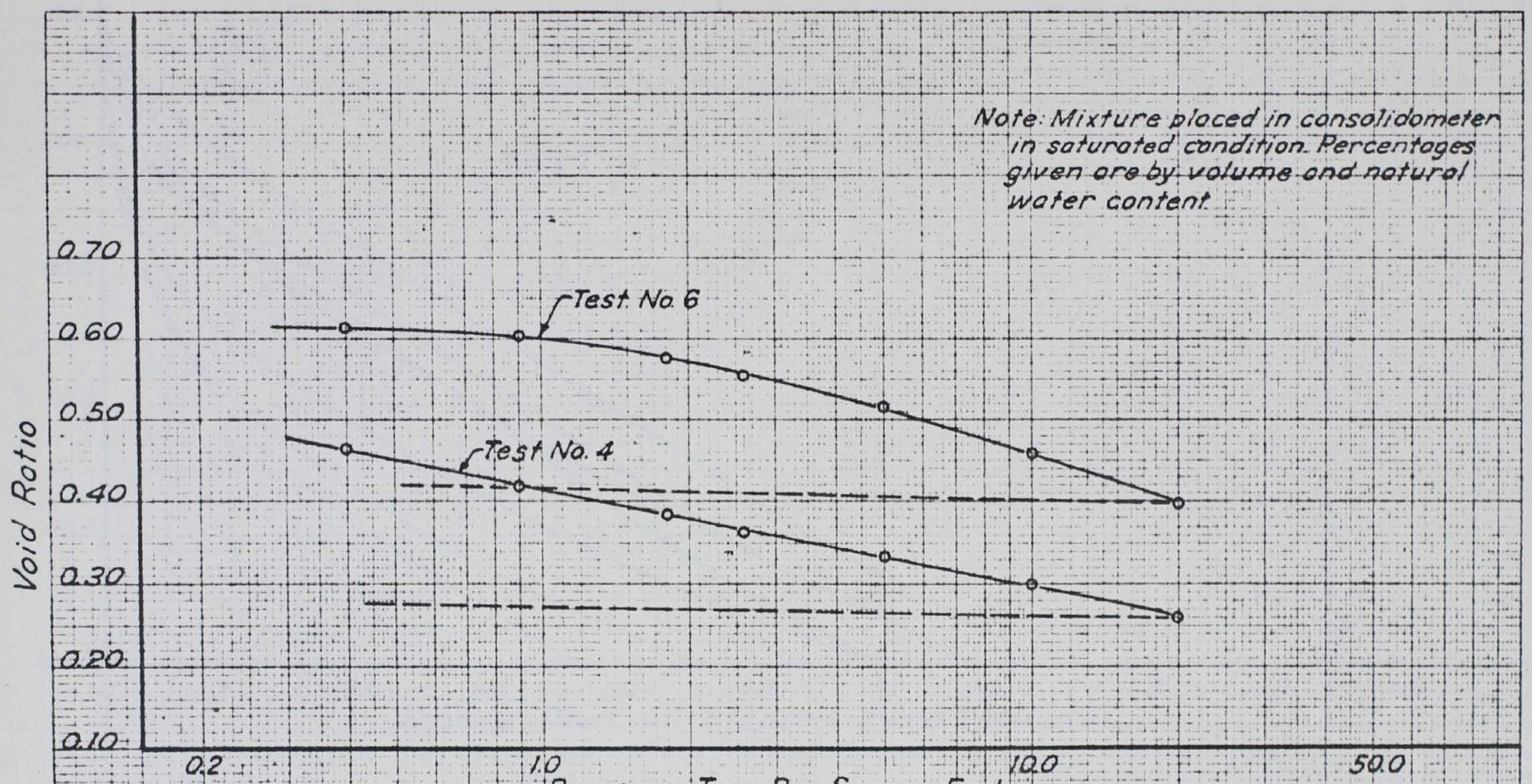
PROPOSED MUD MOUNTAIN DAM

Glacial Till

52 Percent Sample No. 1, 48 Percent Sample No. 2

TIME-CONSOLIDATION DIAGRAM

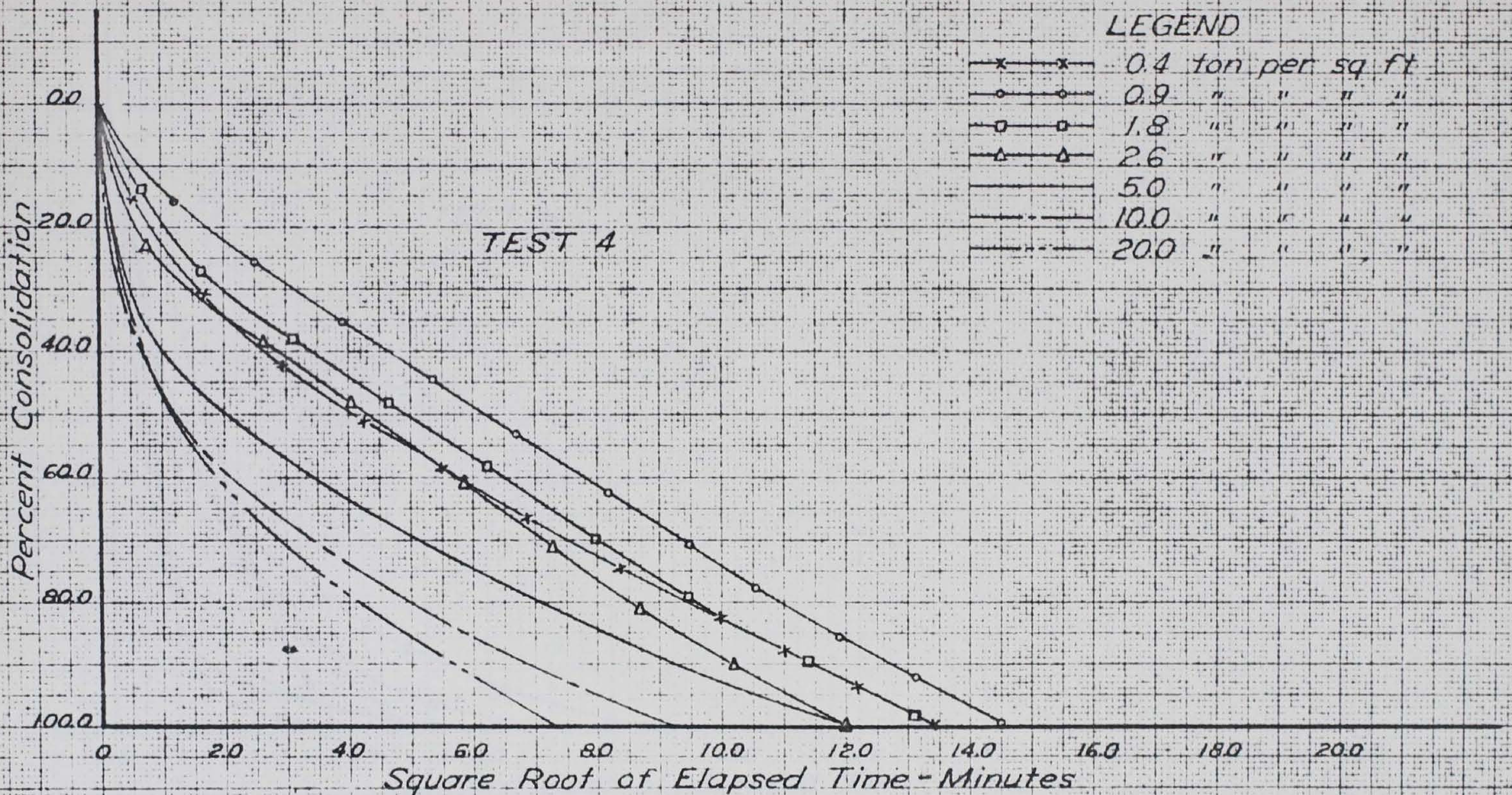
FIGURE 85



PROPOSED MUD MOUNTAIN DAM
Mixture- 80 Percent Sand and Gravel (Samples No. 3 and 4)
20 Percent Glacial Till (Sample No. 1)

VOID RATIO—PRESSURE DIAGRAM

FIGURE 86

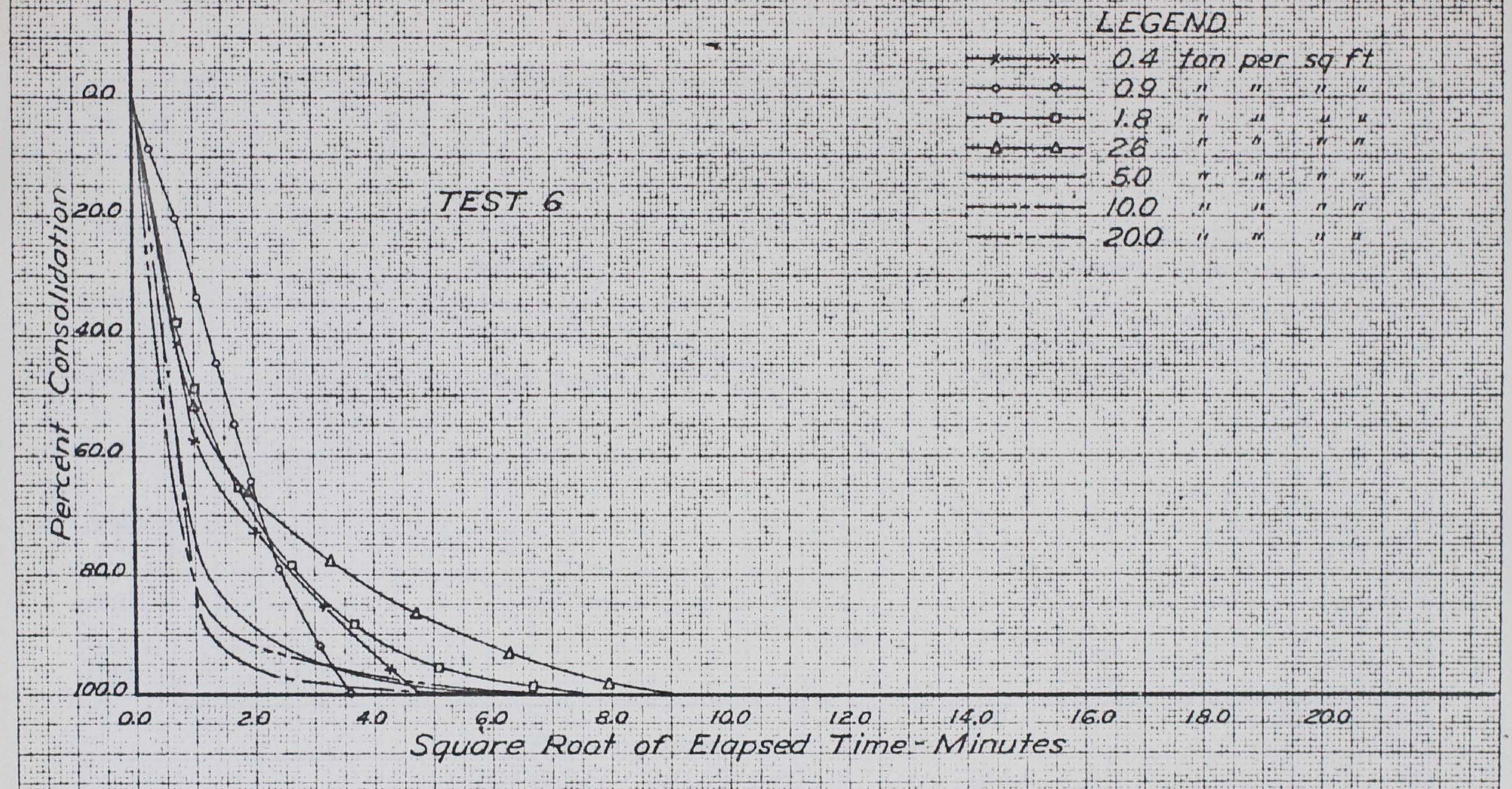


PROPOSED MUD MOUNTAIN DAM

Mixture – 80 Percent Sand and Gravel (Samples No. 3 and 4)
20 Percent Glacial Till (Sample No. 1)

TIME-CONSOLIDATION DIAGRAM

FIGURE 87

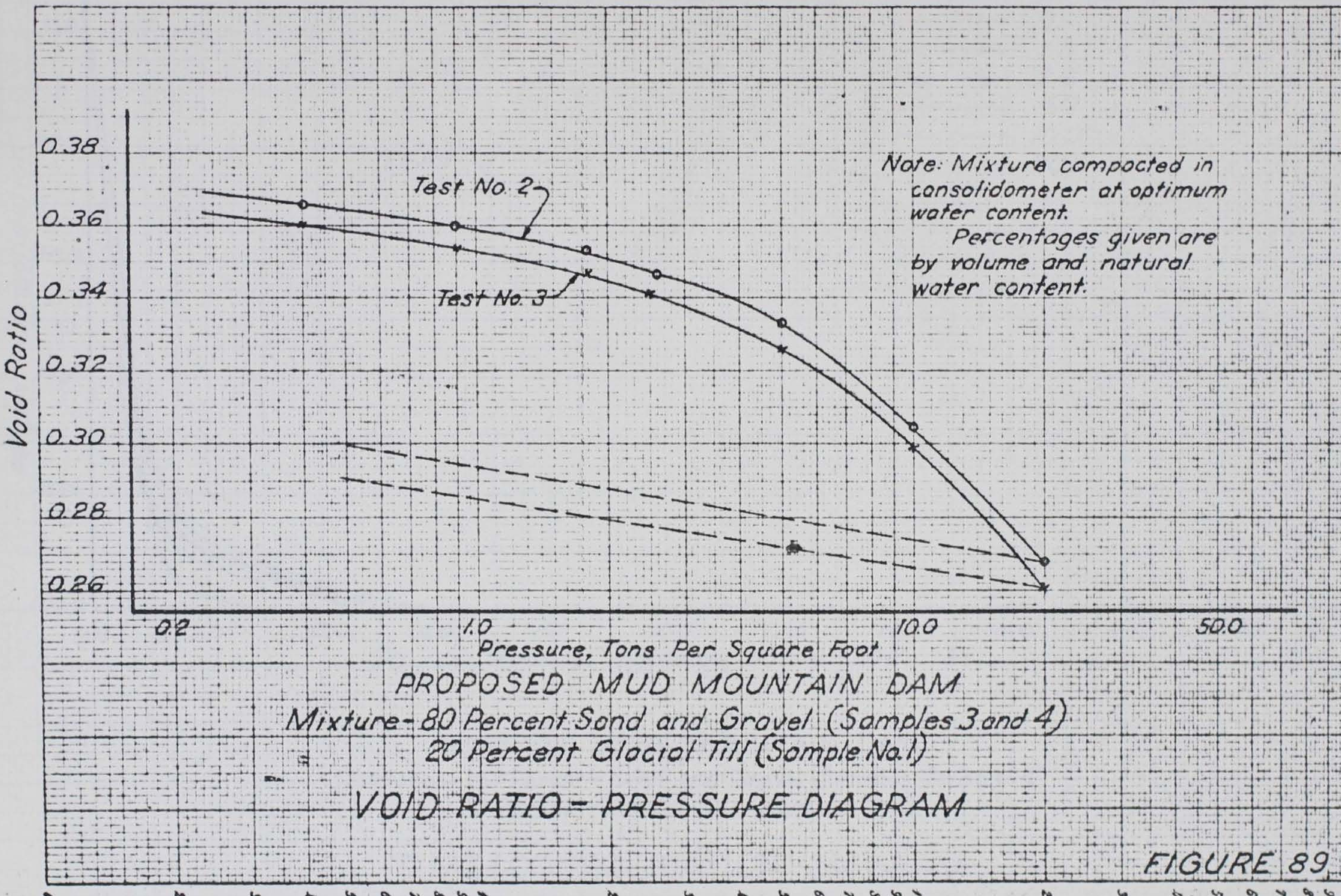


PROPOSED MUD MOUNTAIN DAM

Mixture - 80 Percent Sand and Gravel (Samples No. 3 and 4)
20 Percent Glacial Till (Sample No. 1)

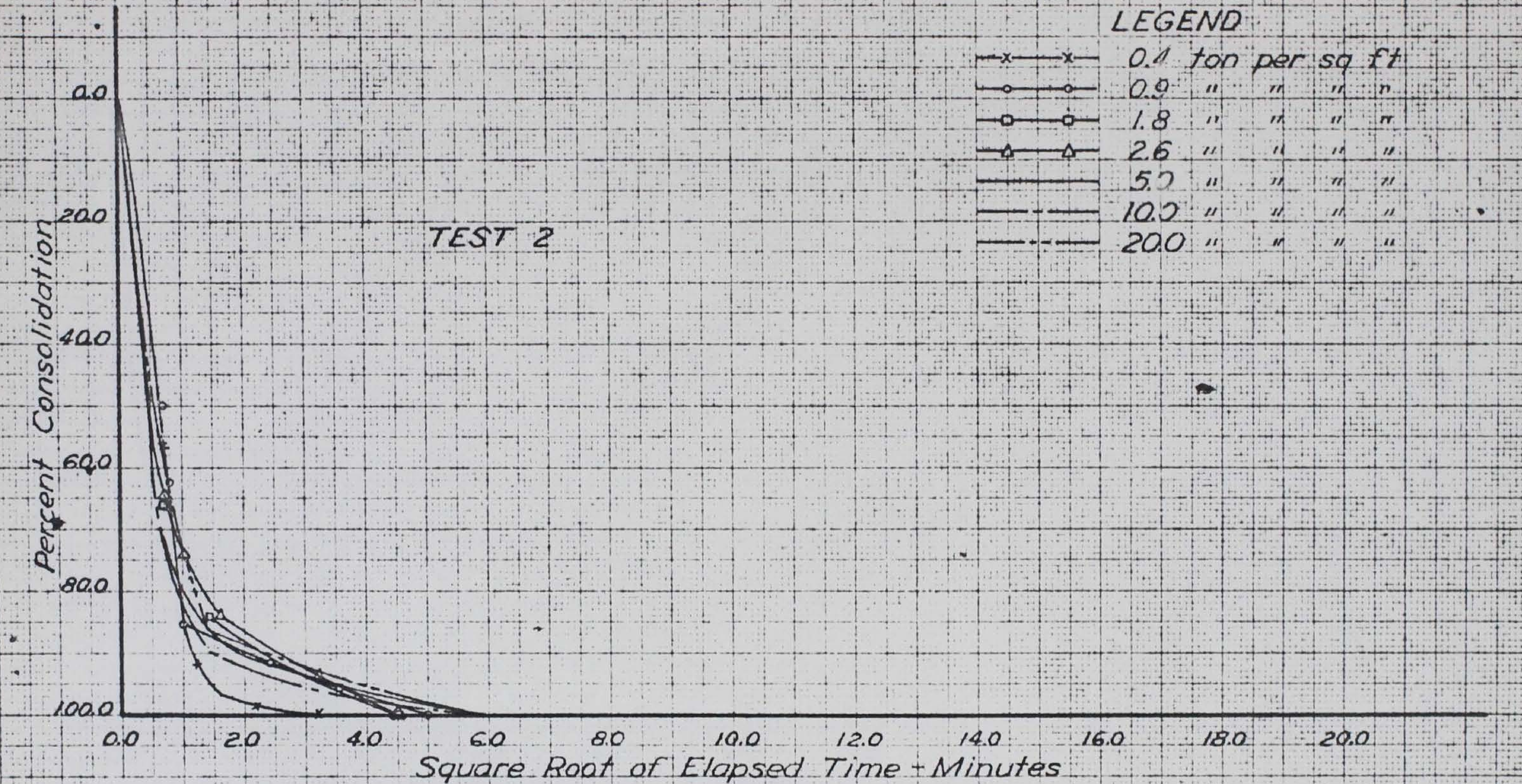
TIME-CONSOLIDATION DIAGRAM

FIGURE 88



Void Ratio
0.38
0.36
0.34
0.32
0.30
0.28
0.26
Test No. 2
Test No. 3
Note: Mixture compacted in consolidometer at optimum water content.
Percentages given are by volume and natural water content.
0.2
1.0
10.0
50.0
Pressure, Tons Per Square Foot
PROPOSED MUD MOUNTAIN DAM
Mixture- 80 Percent Sand and Gravel (Samples 3 and 4)
20 Percent Glacial Till (Sample No. 1)
VOID RATIO - PRESSURE DIAGRAM

FIGURE 89

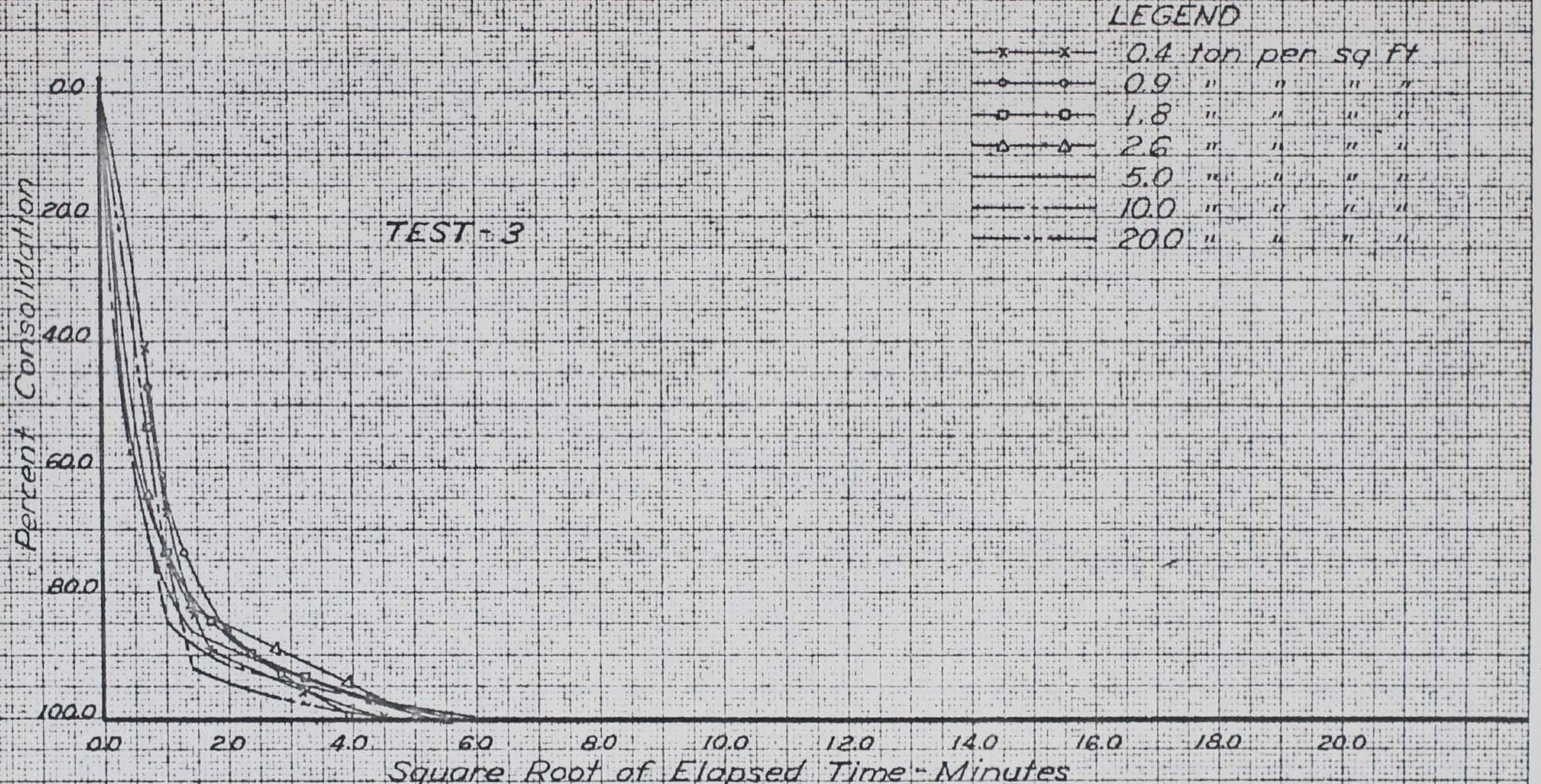


PROPOSED MUD MOUNTAIN DAM

Mixture – 80 Percent Sand and Gravel (Samples No. 3 and 4)
20 Percent Glacial Till (Sample No. 1)

TIME-CONSOLIDATION DIAGRAM

FIGURE 90

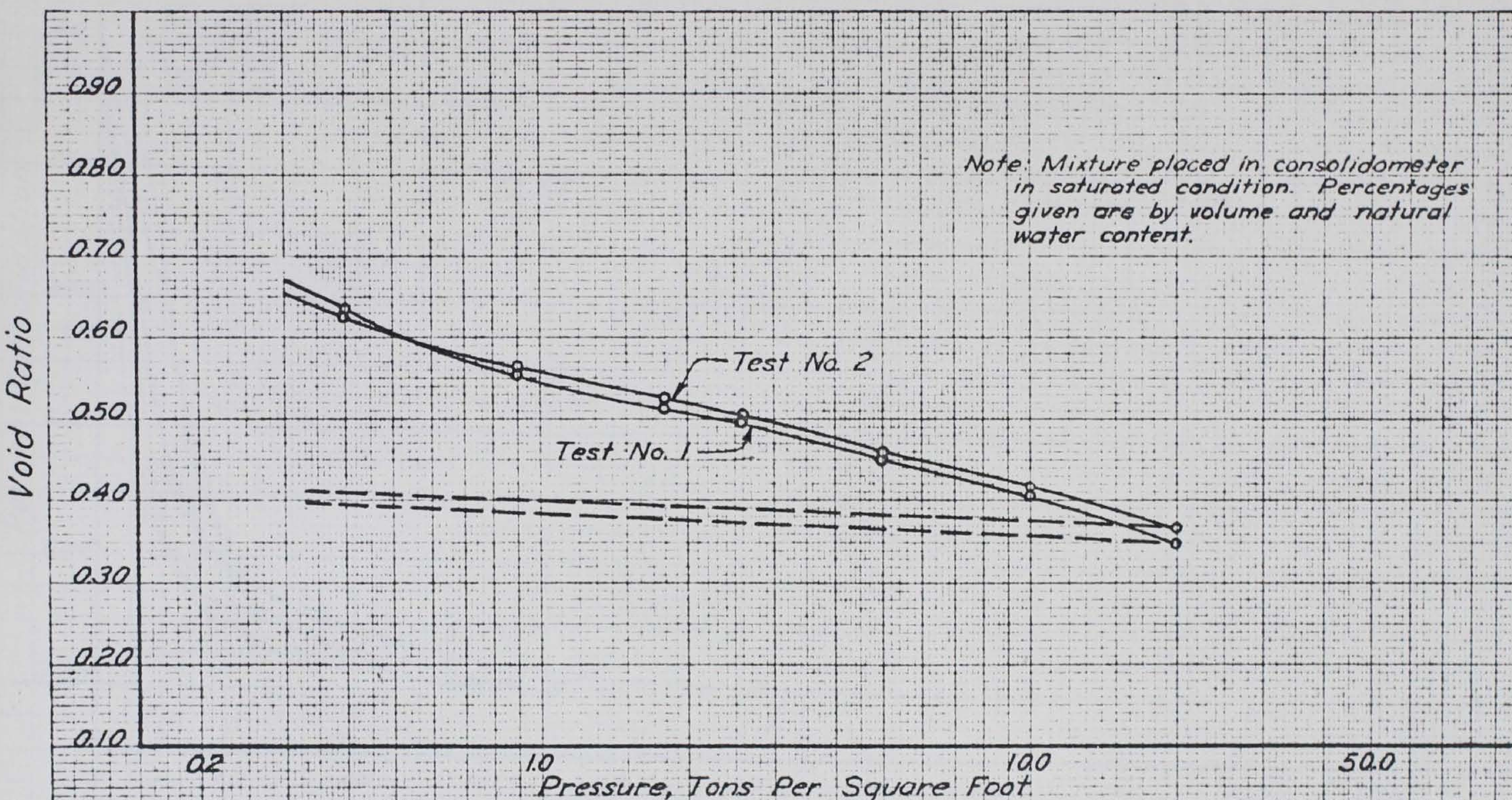


PROPOSED MUD MOUNTAIN DAM

Mixture - 80 Percent Sand and Gravel (Samples No. 3 and 4)
20 Percent Glacial Till (Sample No. 1)

TIME-CONSOLIDATION DIAGRAM

FIGURE 91



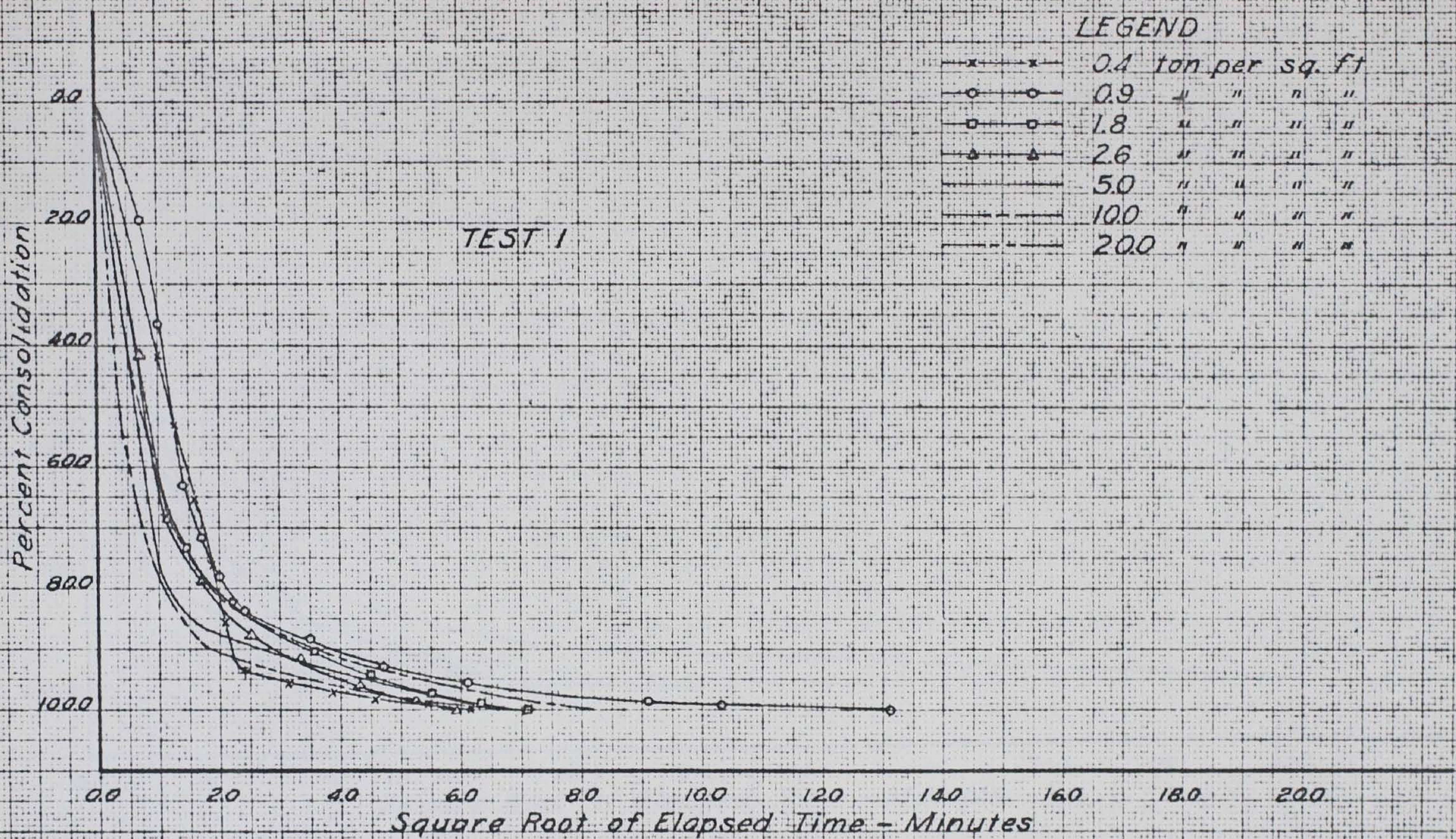
PROPOSED MUD MOUNTAIN DAM

Mixture - 60 Percent Sand and Gravel (Samples No. 3 and 4)

40 Percent Glacial Till (Sample No. 1)

VOID RATIO - PRESSURE DIAGRAM

FIGURE 92

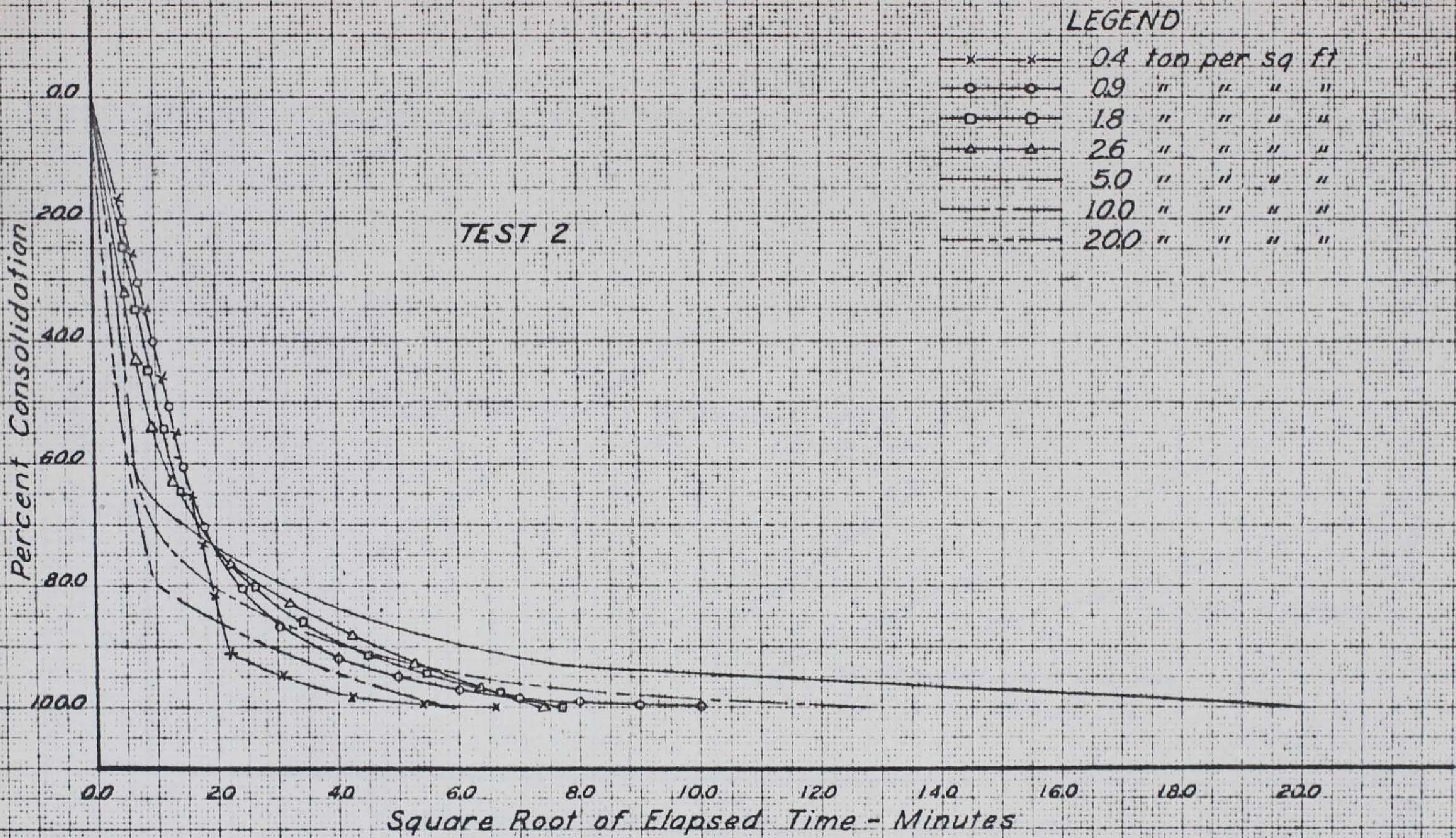


PROPOSED MUD MOUNTAIN DAM

Mixture - 60 Percent Sand and Gravel (Samples No. 3 and 4)
40 Percent Glacial Till (Sample No. 1)

TIME-CONSOLIDATION DIAGRAM

FIGURE 93

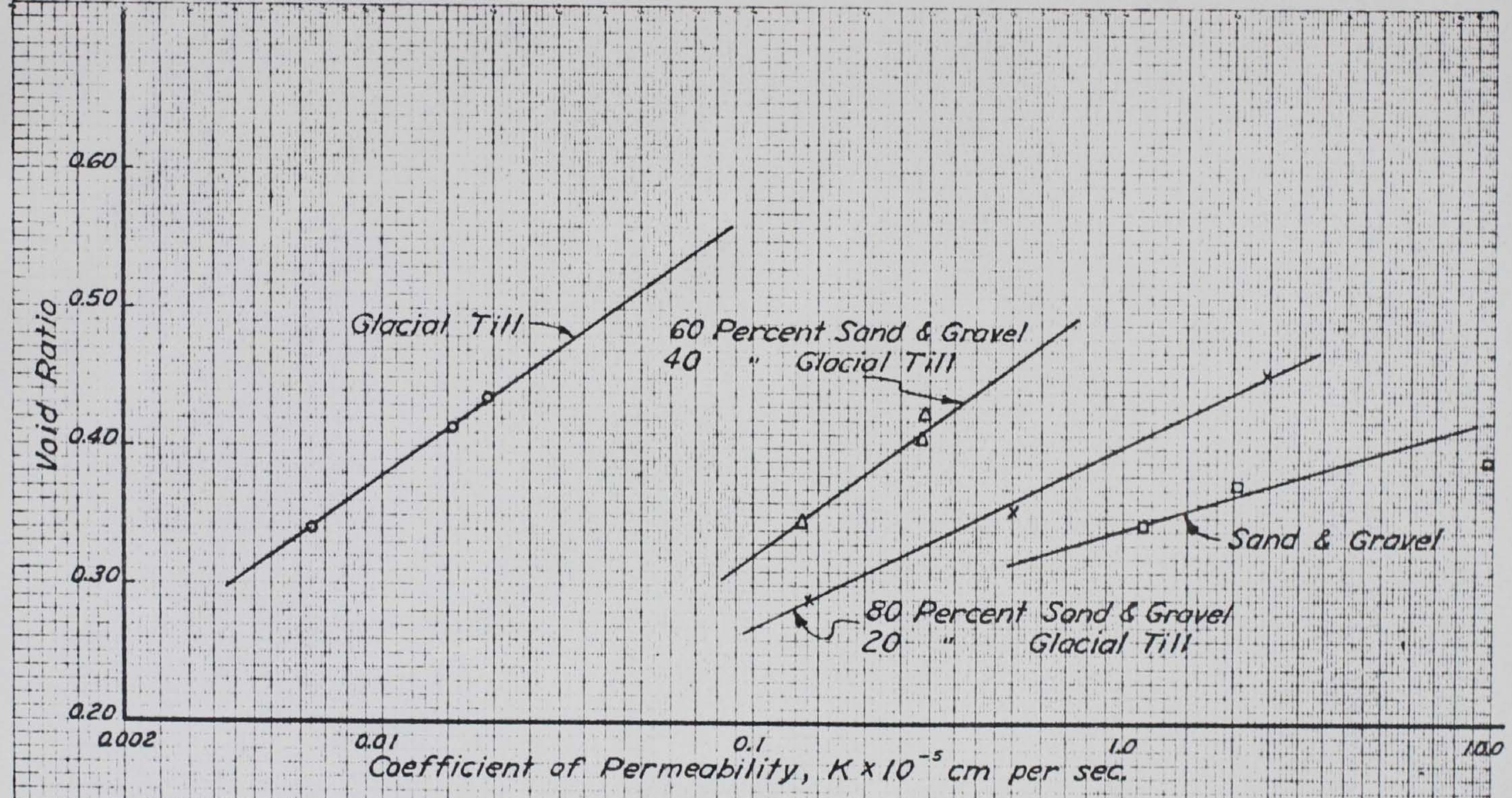


PROPOSED MUD MOUNTAIN DAM

Mixture - 60 Percent Sand and Gravel (Samples No. 3 and 4)
40 Percent Glacial Till (Sample No. 1)

TIME-CONSOLIDATION DIAGRAM

FIGURE 94



PROPOSED MUD MOUNTAIN DAM

PERMEABILITY DIAGRAM

FIGURE 95