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TECHNICAL MEMORANDUM NO. 138-1

A Report of Soils Tests of Foundation Material for a
Dam on the Warrior River, Tuscaloosa, Alabama.

August 1, 1938

U. S. Waterways Experiment Station
Vicksburg, Mississippi

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INDEX

Text

	Page
Introduction	1
Scope	1
Authority	1-2
Purpose	2
Materials Tested	2
Table 1	3
Tests	3
Table 2	3
Test Procedures	4-5
Results of Tests	5-7
Table 3	5
Table 4	6
Table 5	6
Table 6	7
Discussion of Results	7-10

Figures

Figures

Stress-Strain Diagram (Compression).....	1
Void Ratio-Pressure Curves (Consolidation)	2-9
Shear Diagrams (Shear Tests)	10-13
Shear Diagrams (Bond Tests)	14-19
Photographs showing results of Wetting and Drying Tests (Deterioration)	20-25

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Subject: A Report of Soils Tests of Foundation Material for a Dam on the Warrior River, Tuscaloosa, Alabama.

To: The District Engineer, U. S. Engineer Office, Mobile, Alabama.

Introduction

1. This memorandum is a report of tests performed on samples of the foundation materials that underlie the dam now under construction on the Warrior River at Tuscaloosa, Alabama. The dam is an integral part of a new lock that is being built in connection with the general improvement of the river.

Scope

2. In accordance with the specific requests of the U. S. Engineer Office, Mobile, Alabama, as contained in an inclosure accompanying a letter from the District Engineer to this Station, dated January 24, 1938, Subject: "Tests of Foundation Material, Tuscaloosa Dam," this report is concerned only with a concise description of tests and results of tests.

Authority

3. Authority for the performance of these tests at this Station was requested by the Mobile District in a letter dated April 2, 1938,

Subject: "Special Laboratory Investigations." Approval for the investigation by the Chief of Engineers is contained in the 2nd Indorsement dated April 11, 1938, to the above-mentioned letter.

Purpose

4. The tests reported in this memorandum were made to determine strength factors of the foundation media that are directly concerned with the determination of its adequacy for supporting the proposed structure.

Materials Tested

5. The foundation material represented by the samples consists of shale, and shale streaked with sandstone and coal lenses. Samples of the material, obtained by the field forces of the Mobile District, were of the undisturbed type, 4.87 and 6.00 inches in diameter. The samples were taken with a core drill, using a special bit developed by that District. Immediately after being withdrawn from the boring, the samples were sealed in watertight jackets formed of paraffin. Eight samples were delivered to this Station for testing. The elevations at which the samples were taken are shown in Table 1.

Table 1
Locations and Elevations of Samples

Boring Number	Sample Number	Elevation of Sample in Feet, H. S. L.
S-7	1	69.6 to 68.5
	2	67.6 to 66.7
	3	66.2 to 65.0
	4	65.0 to 64.0
	5	64.0 to 63.3
38	6	55.2 to 54.5
	7	54.5 to 53.8
	8	52.2 to 50.7

Tests

6. The tests made using these samples are summarized in Table 2.
The test procedures are described in paragraph 7 below.

Table 2
Tests Performed

Type of Test	Sample No.
Water Content	1-8, incl.
Absolute Sp. Gravity	2, 4-8, incl.
Unconfined Compression	1, 3, 8
Consolidation, submerged	2, 4-7, incl.
Consolidation, dry*	5, 6, 7
Shear	2, 4, 5, 6
Bond	1, 2, 4, 6, 7, 8
Wetting and Drying	1-8, incl.

*Condition of specimens during test
same as in nature - no water added.

Test Procedures

7. Procedures for the tests summarized in Table 2 follow:

a. General Tests. Procedures for water content, absolute specific gravity, consolidation and shear tests are described in a manual of this Station, "Laboratory Procedure in Testing Soils and Sediment", a copy of which is on file in the Mobile District Office. This manual contains descriptions of all the standard tests, as conducted in the Soils Laboratory of this Station.

b. Unconfined Compression Tests. Cylindrical specimens for the unconfined compression tests were cut from the samples with a carborundum grinding wheel and faced in a machine lathe to provide parallel faces at the ends. To conform to American Society of Testing Materials specifications for concrete cylinders, Designation C-42-31, the length of the specimens was made to equal approximately twice their diameter (see Table 4). The tests were conducted with a Southwick-Emery hydraulic compression-tension machine, Bureau of Standards calibrated, having a capacity of 300,000 lbs. The American Society of Testing Materials procedure referred to above, was found satisfactory in connection with the investigation of the foundation materials for the following structures: Norris Dam, Boulder Dam, and the Grand Coules Dam.

c. Consolidation Tests. The specimens for the consolidation tests were shaped by machine lathe to the exact dimensions of the standard consolidation device. Specimens were consolidated in both the submerged and dried conditions so that the effects of saturation and of exposure might be ascertained. The standard procedure for the consolidation tests referred to in a above, was used.

d. Shear and Bond Tests. The specimens for the shear tests were cut to approximate dimensions with a band saw and sandpapered to the exact dimensions of the standard shear box. The standard procedure for the shear tests referred to in a above, was used.

To determine the bond strength developed between the shale and cement mortar, and in addition, to determine the coefficient of friction between these materials, specimens of the shale one-half the thickness of the standard shear specimens were placed in a form of the same dimensions as the shear box. A mortar composed of one part cement and two parts sand was then cast on top of the specimens and allowed to cure for three days. The conventional constant-stress shear apparatus was used for the shear and bond tests, procedures for which are given in the manual referred to in a, above. Each bond test consisted of two phases:

(1) shearing was produced with the bond between the shale and the cement mortar intact; (2) shearing was produced with the bond broken. For the second phase, the segments of the shale and mortar were fitted together in their original positions prior to the application of the shearing force.

e. Wetting and Drying Tests. For the wetting and drying (deterioration) tests, duplicate specimens from each sample were obtained. Each test was divided into phases. Each phase consisted of the following: (1) the specimens were saturated with distilled water; (2) the excess free water was drained from the specimens; and (3) one set of specimens (the "A" set) was air-dried for 22 hours, and the duplicate set (the "B" set) was oven-dried at 105° C. for 22 hours. This procedure was repeated for 10 phases for Samples Nos. 1 to 5, and for 13 phases for Samples Nos. 6, 7, and 8.

Results of Tests

8. Data obtained from the detailed tests are shown graphically by the figures accompanying this memorandum. Data from all tests, both general and detailed, are summarized in the following subparagraphs.

a. General Tests. The results of the water content and absolute specific gravity determinations are tabulated below.

Table 3

Results of General Tests

Sample Number	Natural Water Content Per Cent	Absolute Specific Gravity
1	4.1	—
2	1.0	2.76
3	2.0	—
4	3.0	2.76
5	3.6	2.76
6	3.0	2.71
7	2.4	2.71
8	2.1	2.71

b. Unconfined Compression Tests. The results of the unconfined compression tests are contained in Table 4. A typical stress-strain diagram is shown by Figure 1.

Table 4
Results of Unconfined Compression Tests

Sample Number	Approx. Elev. of Sample Ft.	Dimensions of Samples Tested		Ratio Length to Diameter	Ultimate Crushing Strength Tons Per Sq. Ft.
		Length In.	Diameter In.		
1	69.3-68.5	8.82	4.52	1.95	55.2
3	65.8-65.0	8.80	4.60	1.92	106.9
8	51.3-50.7	6.80	5.86	1.16	389.5*

*A.S.T.M. correction factor applied since ratio of length to diameter was less than 2. (See Paragraph 11.)

c. Consolidation Tests. Consolidation tests data are shown by Figures 2 to 9, inclusive. Table 5 indicates the conditions of each test; that is, whether the specimens were submerged or dry.

Table 5
Conditions for Consolidation Tests

Sample Number	Submerged Specimen Figure No.	*Dry Specimen Figure No.
2	2	—
4	3	—
5	4	5
6	6	7
7	8	9

*Condition of specimens during test same as in nature - no water added.

d. Shear and Bond Tests. Data from the shear and bond tests are summarized in Table 6 and shown by Figures 10 to 19, inclusive.

Table 6
Results of Shear and Bond Tests

Shear Tests				Bond Tests		
Sample Number	Shear Strength Tons per Sq. Ft.	Angle of Internal Friction	Figure No.	Strength of Bond Tons per Sq. Ft.	Coefficient of Friction Cement on Shale	Figure No.
1	—	—	—	1.28	0.50	14
2	1.85	70°00'	10	1.01	0.50	15
4	2.80	79°30'	11	0.54	0.80	16
5	3.50	76°00'	12	—	—	—
6	4.45	82°20'	13	7.45	0.83	17
7	—	—	—	5.28	0.63	18
8	—	—	—	7.02	0.67	19

e. Wetting and Drying Tests. The various phases of the wetting and drying (deterioration) tests, and the results of the tests are shown by Figures 20 to 25, inclusive.

Discussion of Results

9. General Tests. The data obtained from the water content and absolute specific gravity tests as presented in Table 3, are self-explanatory.

10. Unconfined Compression Tests. As pointed out in paragraph 7 b, above, these tests conformed to American Society of Testing Materials Specifications. If ratio of height of specimen to diameter is less than 2, it is necessary to apply a correction factor to obtain the crushing strength comparable with that obtained, using a cylinder having the standard ratio. It may be noted that in the case of Samples Nos. 1 and 3 (See Table 4), these ratios were so close to 2 that no corrections were applied to the results of the tests. However, Sample No. 8 (See Table 4 and Figure 1) had a ratio of only 1.16, and failed at a vertical stress of 425.0 tons per square foot.

Application of the correction factor 0.916, for the ratio of 1.16 gives an ultimate strength of 389.5 tons per square foot. This application may be questioned inasmuch as factors suitable for concrete may not be suitable for stone. However, a deviation of 50% (the maximum that seems reasonable to expect) in the correction factor would result in a relatively abnormal crushing strength.

II. The ultimate crushing strengths of the samples tested vary considerably. The number of samples received, and their size limited the number of unconfined compression tests that could be made. The results, for which possible explanation of their variation is given herein, were obtained from samples selected as representative of the material. A possible explanation follows:

a. Sample No. 1, with a comparatively low ultimate crushing strength of 55.2 tons per square foot, may have been obtained from relatively near the bottom of the excavation. (See Table 1) Hence, it may have disintegrated to some extent before being obtained. This explanation is borne out by its relatively high water content. (See Table 3).

b. Sample No. 3, with an ultimate crushing strength of 106.9 tons per square foot, appears to be representative of the group, and the results obtained therefrom appear to be in accord with an average value for the ultimate crushing strength of this type of material.

c. Sample No. 8, with an ultimate crushing strength of 389.5 tons per square foot, did not meet the criterion established by the American Society of Testing Materials insofar as the ratio (1:2) of length to diameter is concerned, as pointed out above. Visual examination of the specimen prior to testing and review of the results of the shear and bond tests of (See Table 6) both indicate the material to be more dense and stronger than that represented by Samples Nos. 1 and 3. Consequently, use of a value of 195 tons per square foot is believed to be conservative.

12. At the time that Samples Nos. 1 and 3 were tested, the equipment necessary to measure actual deformation resulting from application of load was not available; consequently, the stress-strain characteristics for these samples could not be ascertained. When Sample No. 8 was tested, an extensometer for measuring deformations to 0.001 inch was available. Figure 1 shows the stress-strain characteristics of this specimen. The small deformation occurring at no load was caused by the machine adjusting itself to the face of the sample.

13. Consolidation Tests. The results of the consolidation tests reveal that the material represented by the samples is practically incompressible for loads of 13 to 20 tons per square foot. This is shown by the very small change in void ratio (ratio of volume of voids to volume of solids) that was observed upon application of these loads. Hence, the material in situ is very well consolidated under its present load.

The relative position of the rebound curve with respect to the compression curve is interesting, particularly for Samples Nos. 5, 6, and 7. Specimens from these samples were tested in their natural state, both submerged, and dry, as indicated in Table 5. It is to be noted that the rebound curve is in much closer proximity to the compression curve for the submerged specimens than for the dry specimens. Some change in the physical condition of the shale appears to occur when this material is not completely submerged. The usual time-consolidation curves are not shown, since in all cases complete consolidation occurred almost immediately after application of the load.

14. Shear and Bond Tests. The values for the frictional strength of the material, as indicated by the angles of internal friction shown

in Table 6, are in accordance with those which would be expected for such highly consolidated materials. The close agreement between the angles not only indicates that the tests are reliable, but also supports the conclusion that the material is uniform. For the bond tests it is interesting to note that the friction angle with the bond between the shale and the cement intact, was found to be the same as with the bond broken. The vertical displacement between the two curves represents the shearing strength due to the bond between the cement mortar and the shale. The strength of the bond (See Table 6), naturally depends upon the water-cement ratio, the condition of the shale surface, the curing conditions, and other variables. The strength of the bond between the structure and the material in situ may vary considerably from the values given.

15. Wetting and Drying Tests. The results of the deterioration tests, as shown by the photographs, Figures 20 to 25, inclusive, indicate that the material represented by Samples Nos. 1 to 5 (from Boring No. S-7) are much more susceptible to weathering than is the material represented by Samples Nos. 6, 7, and 8 (from Boring No. 38).

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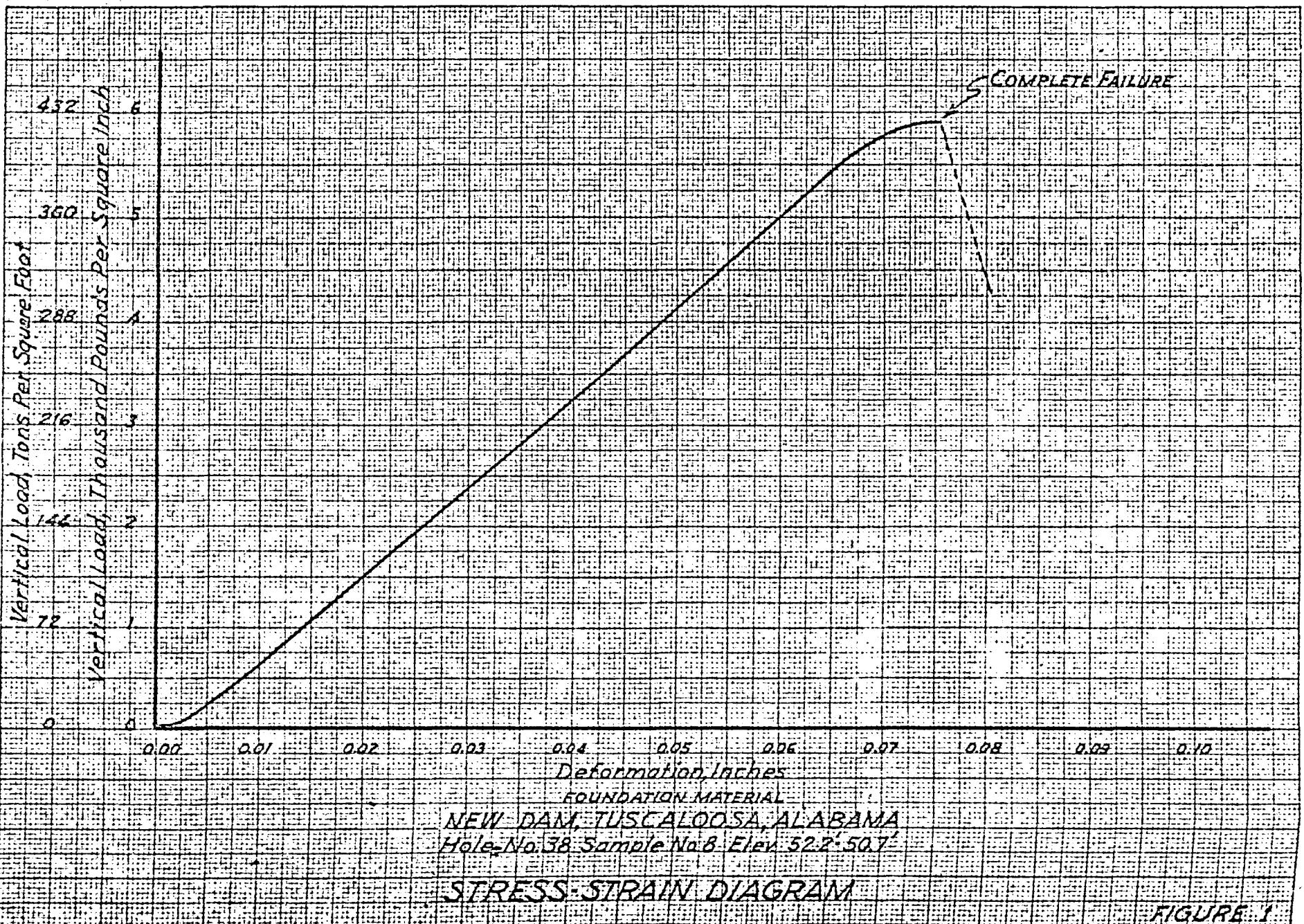


FIGURE 1

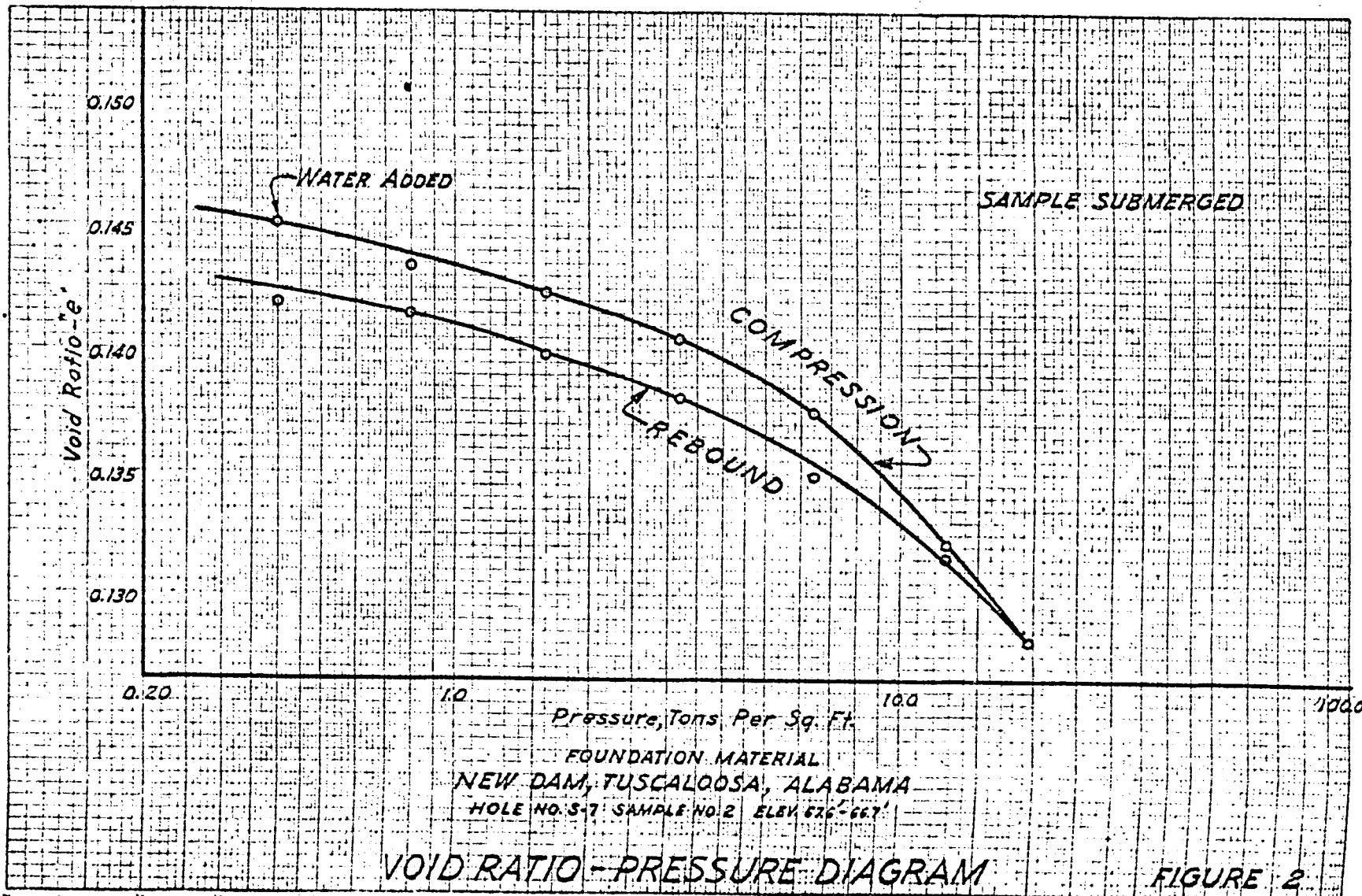


FIGURE 2

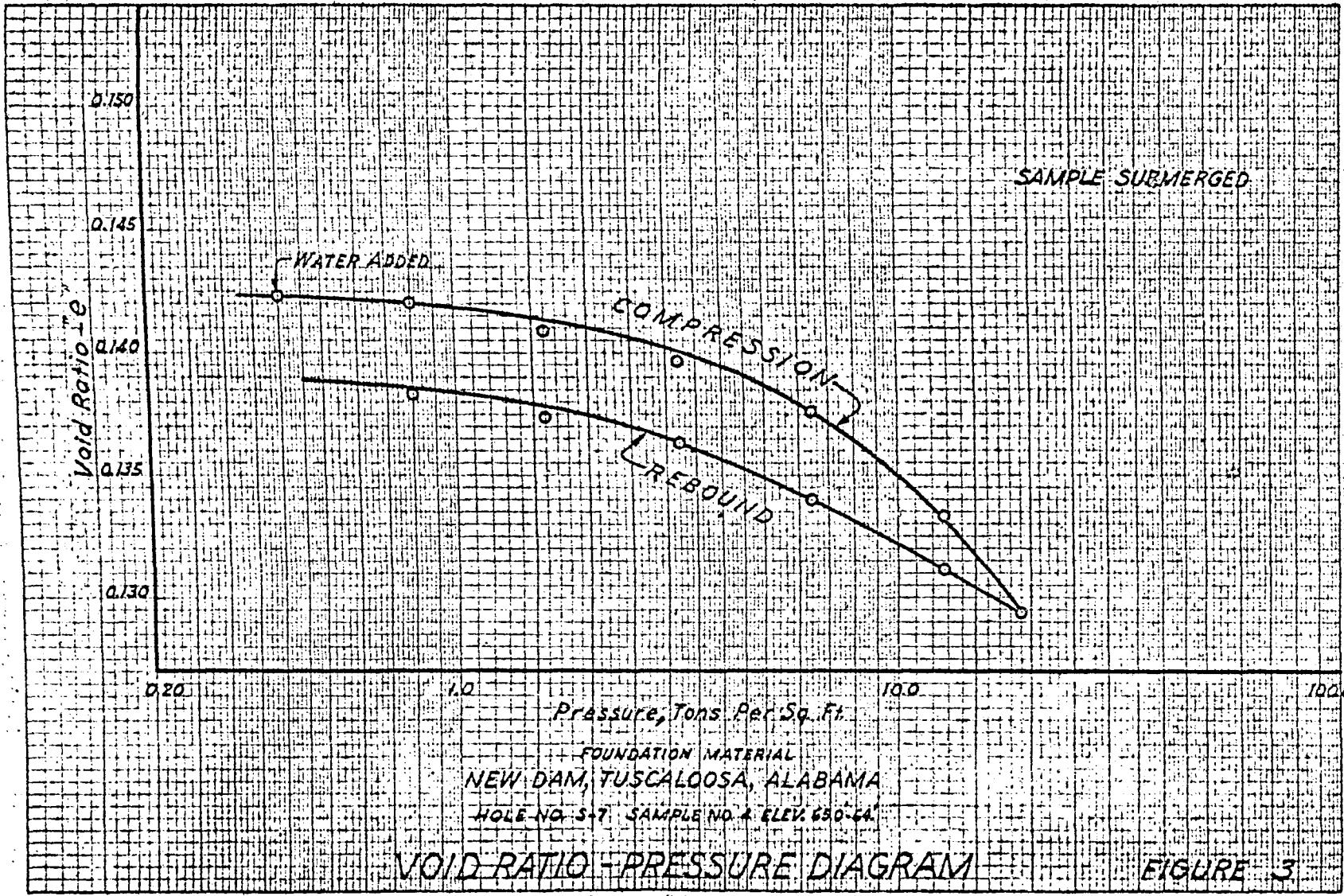


FIGURE 3

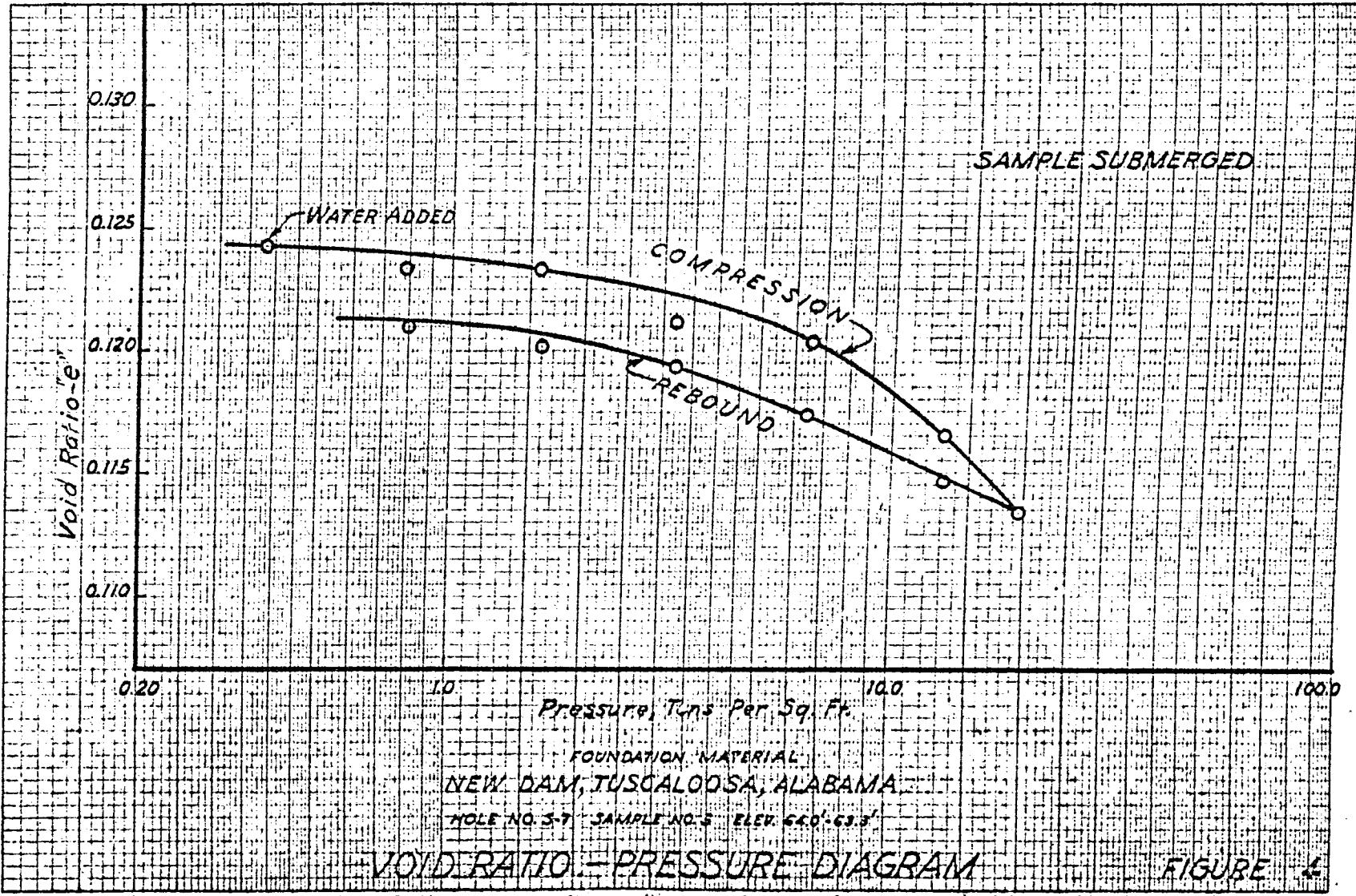


FIGURE 4

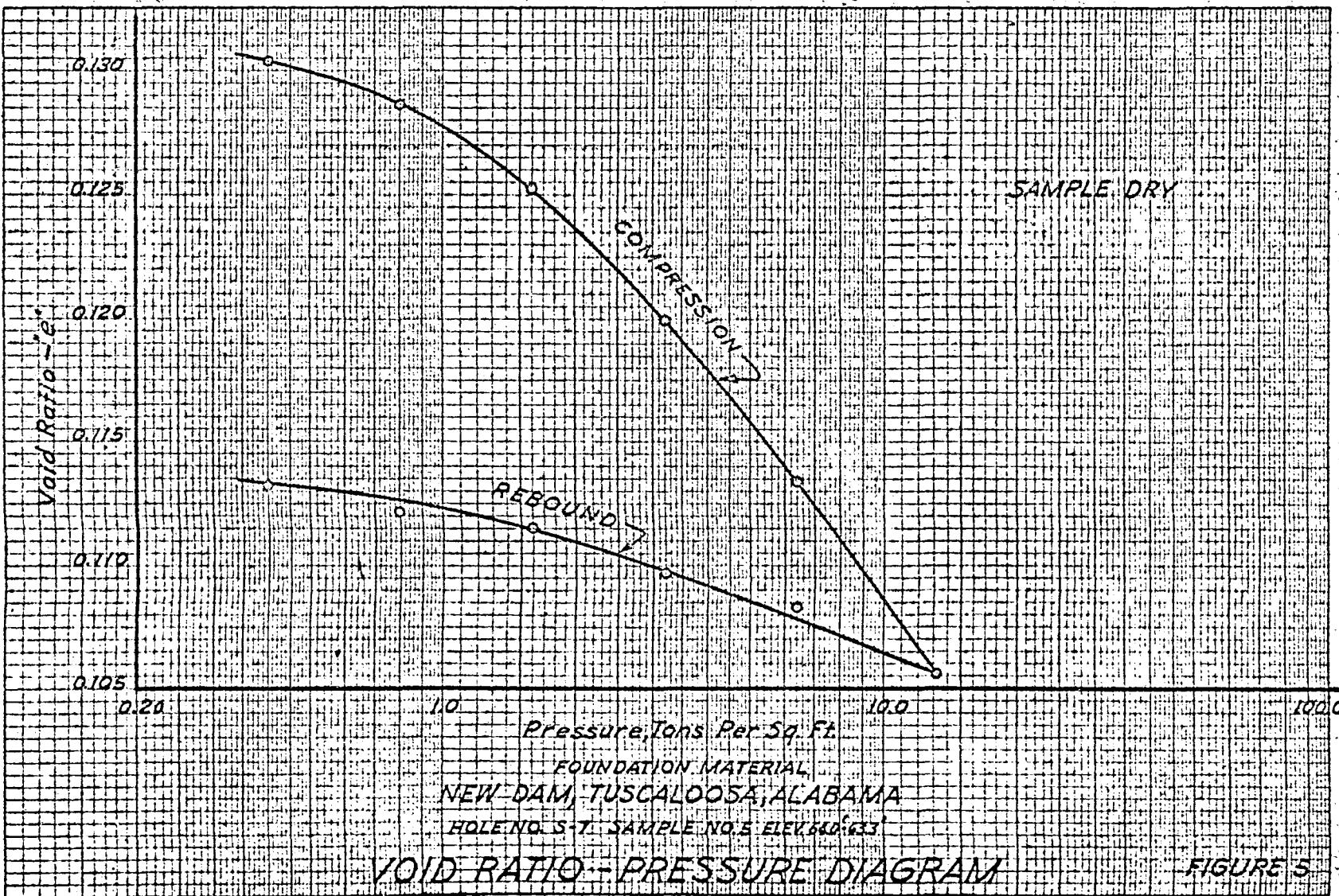


FIGURE 5

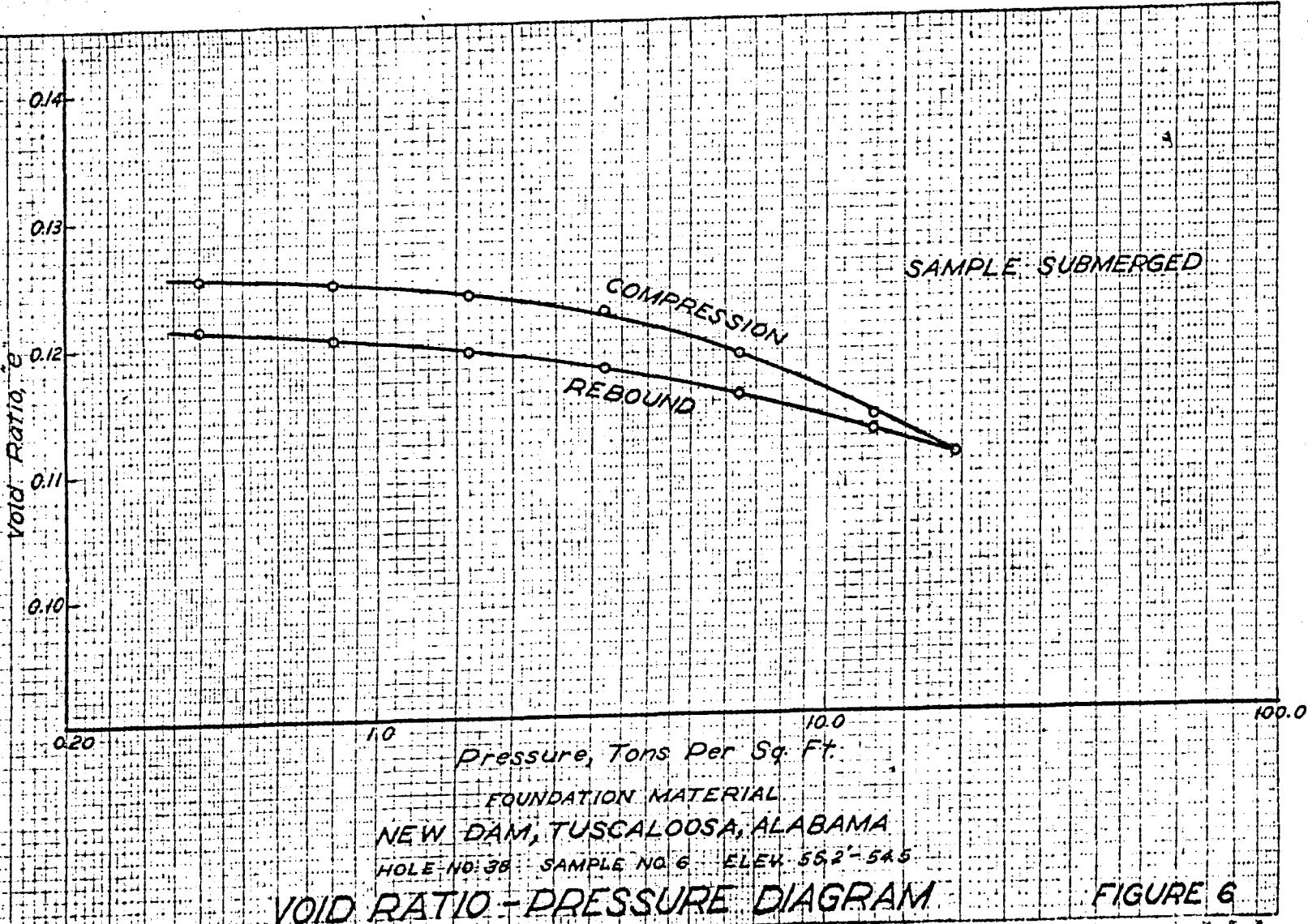


FIGURE 6

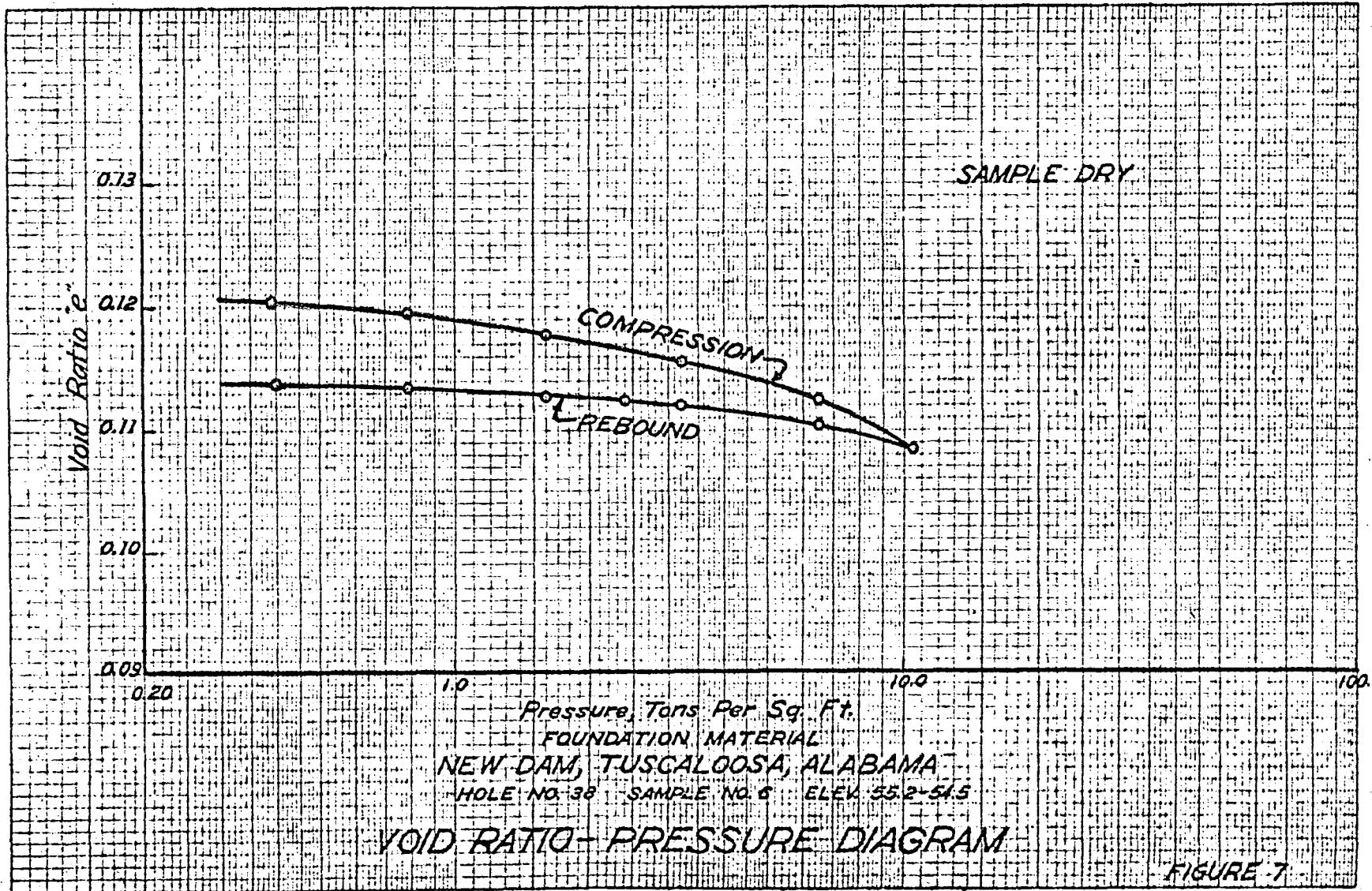


FIGURE 7

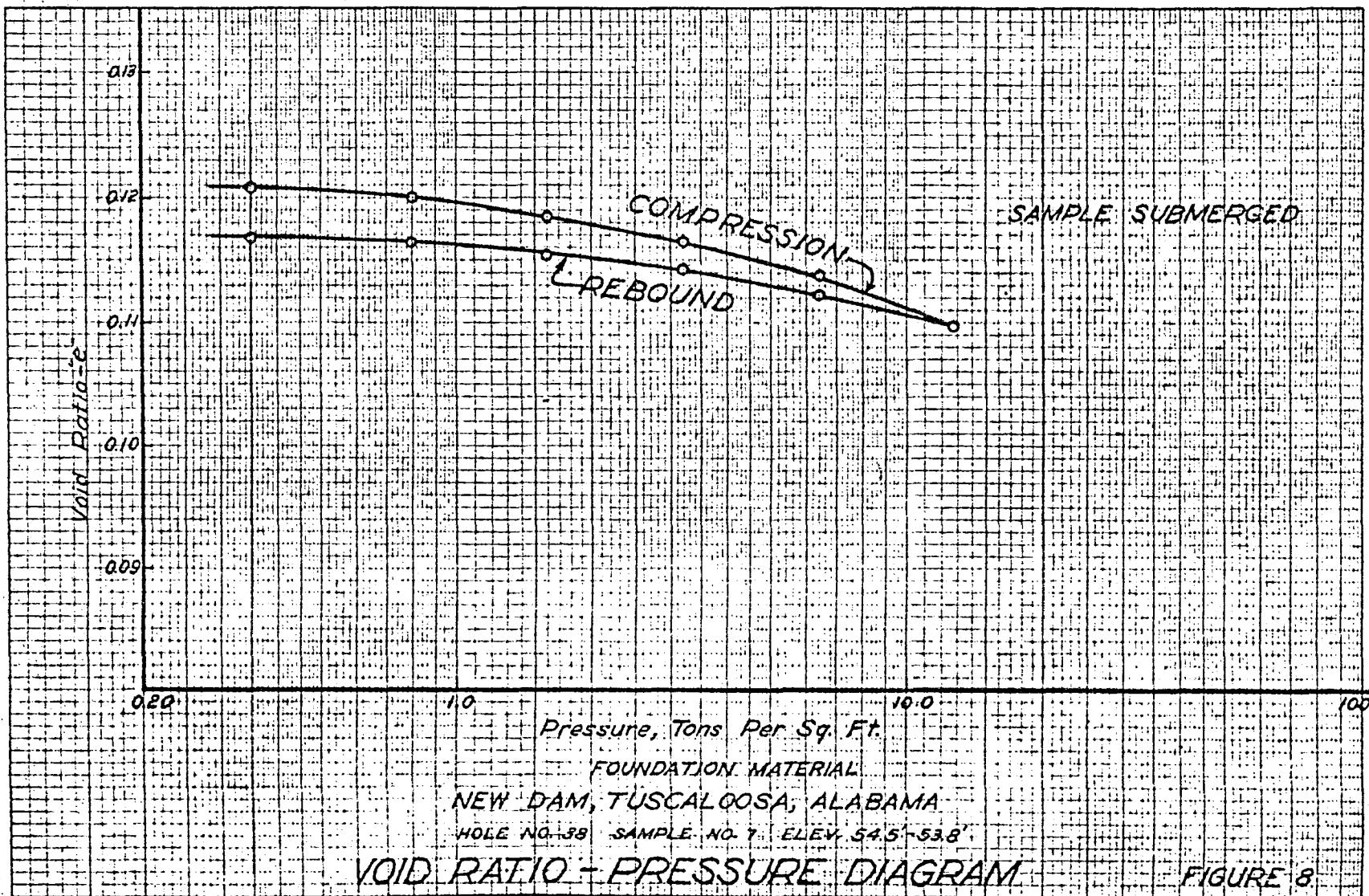


FIGURE 8

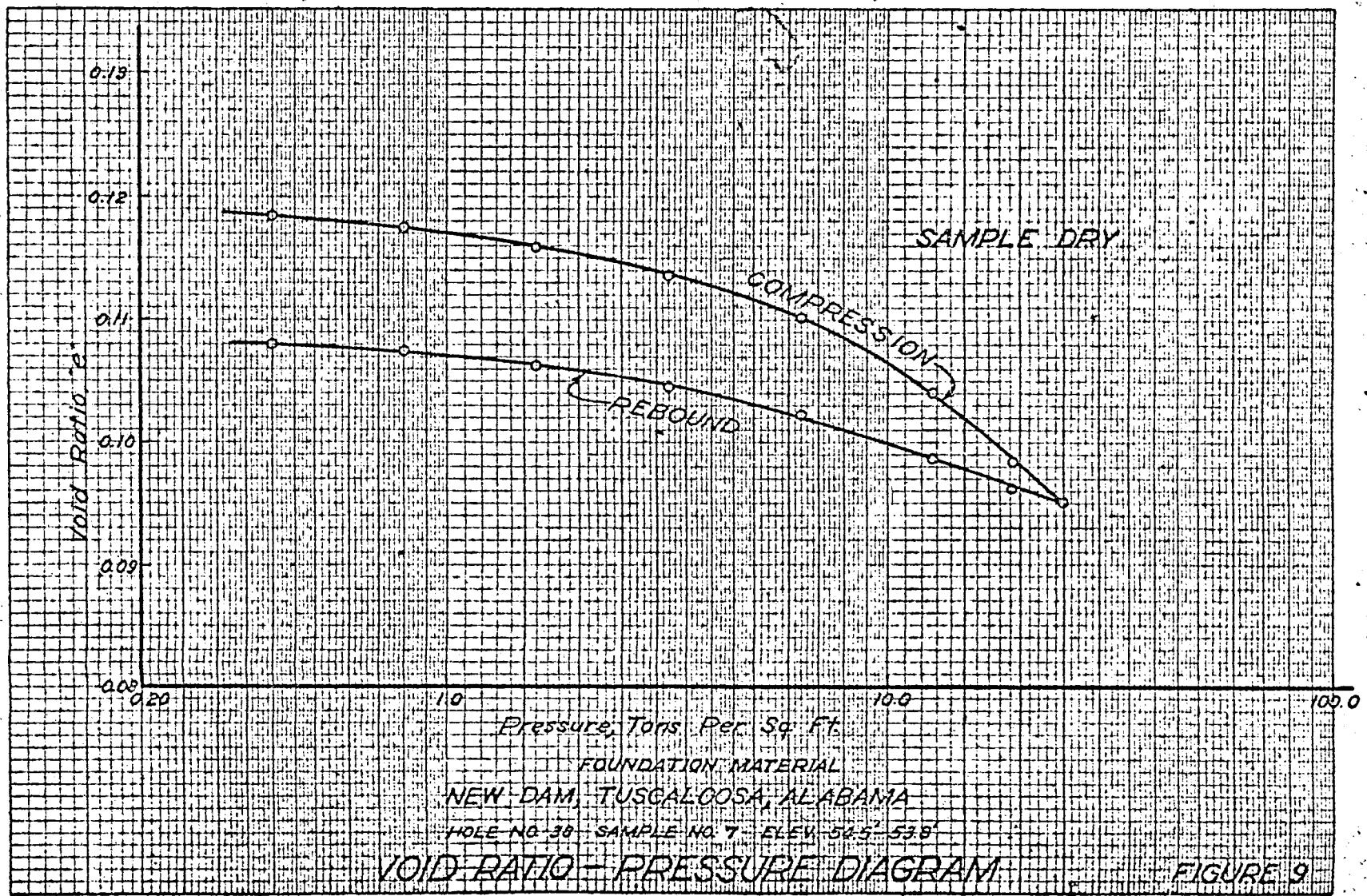


FIGURE 9

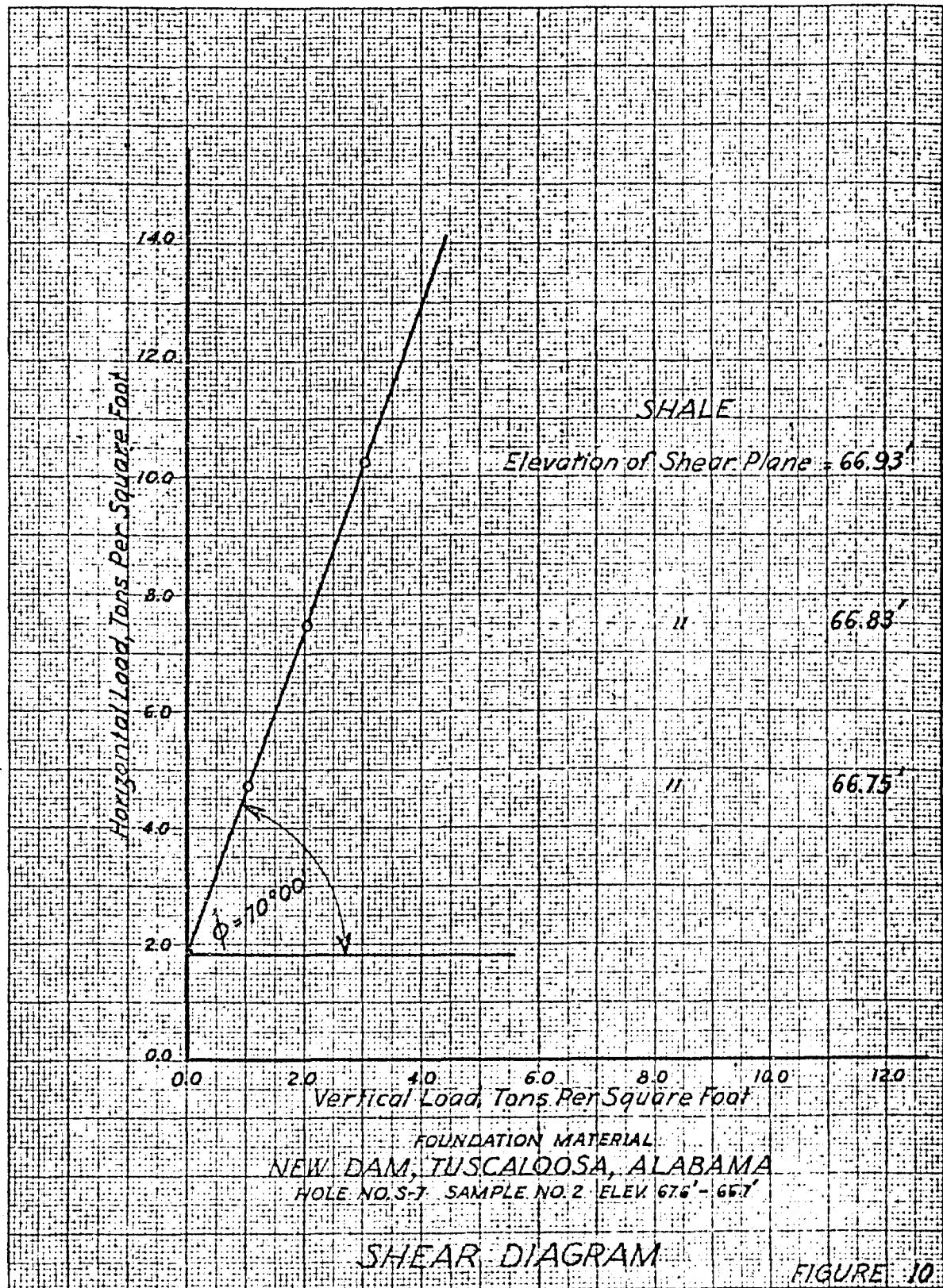


FIGURE 10

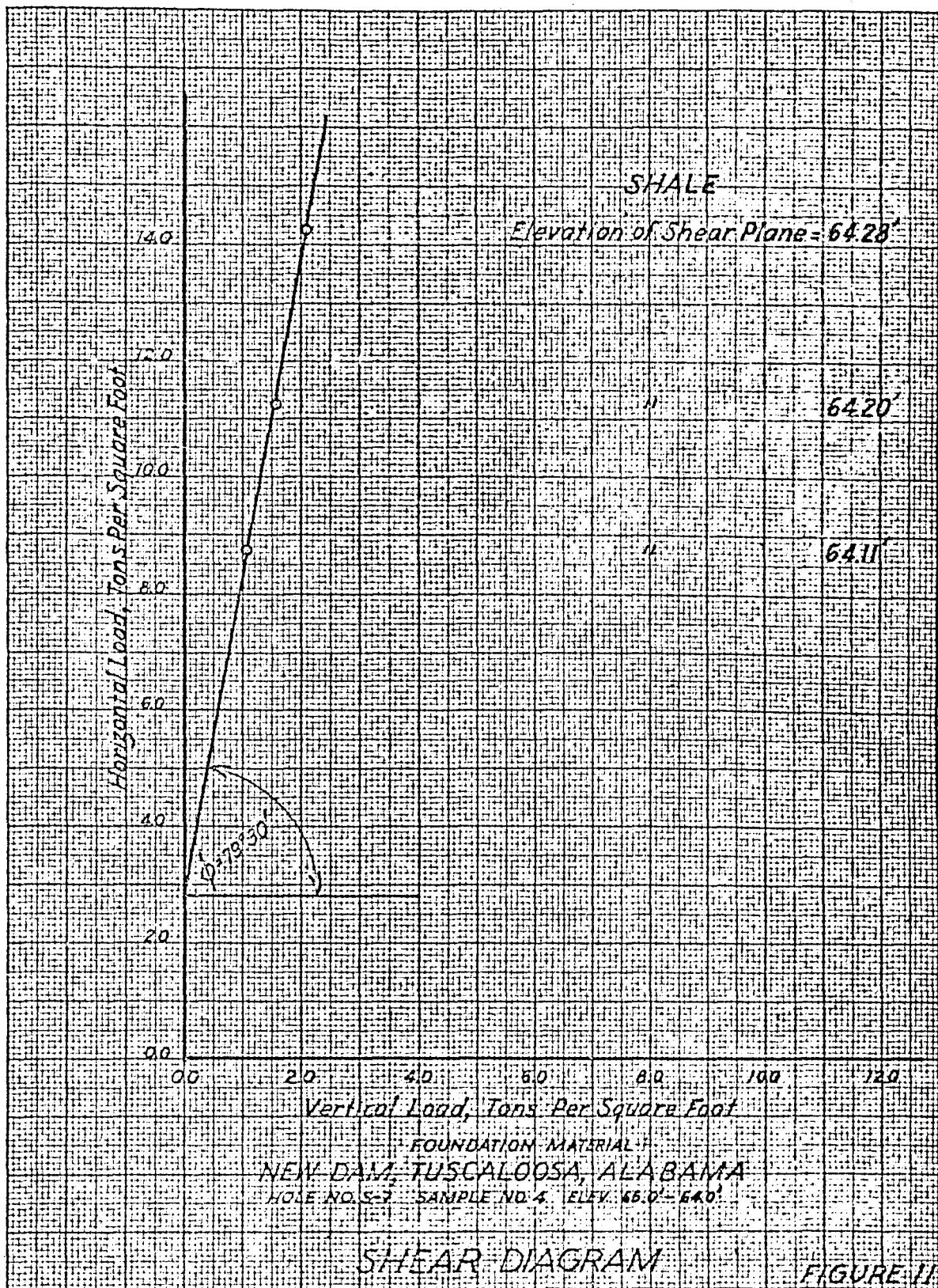


FIGURE II

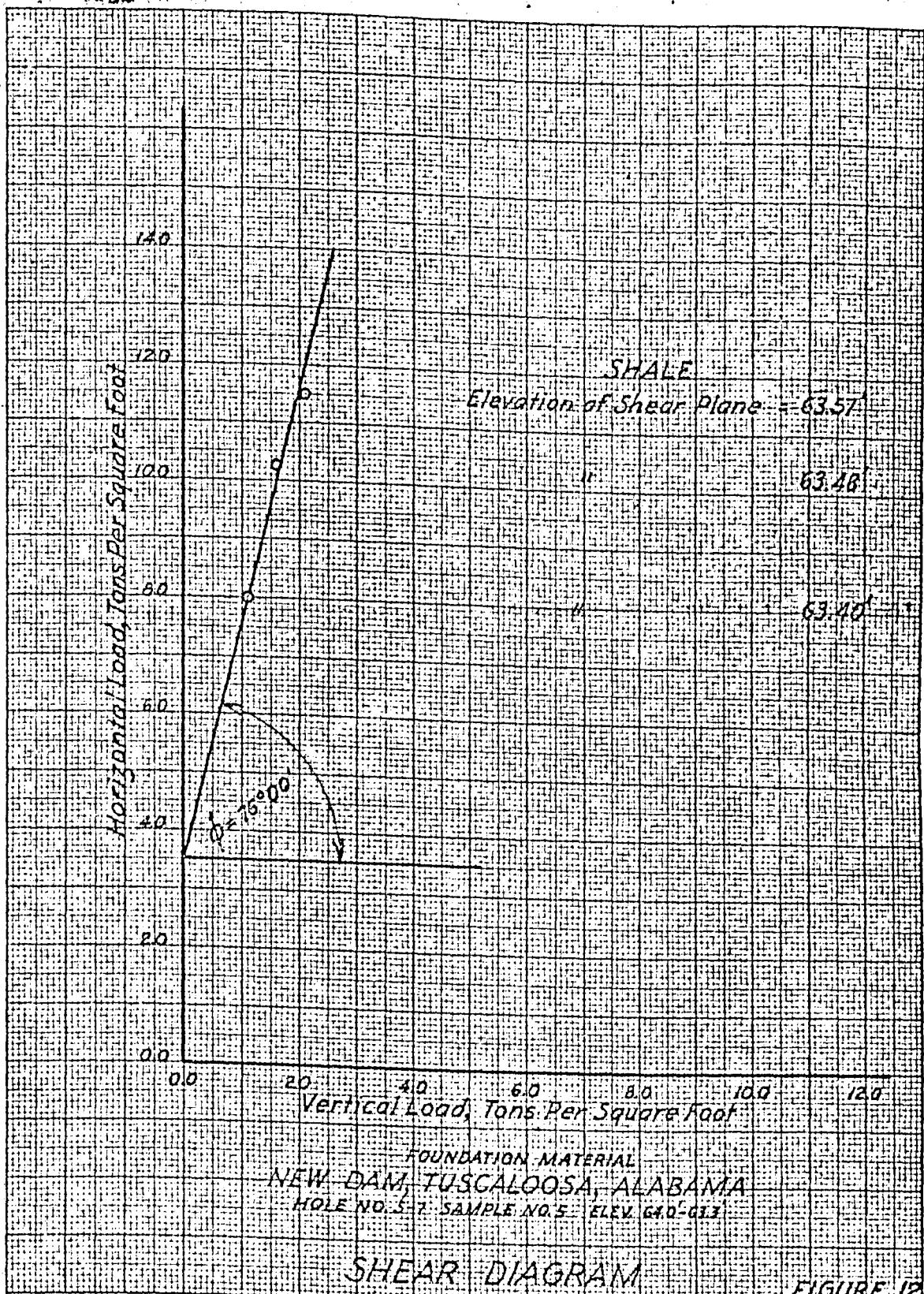
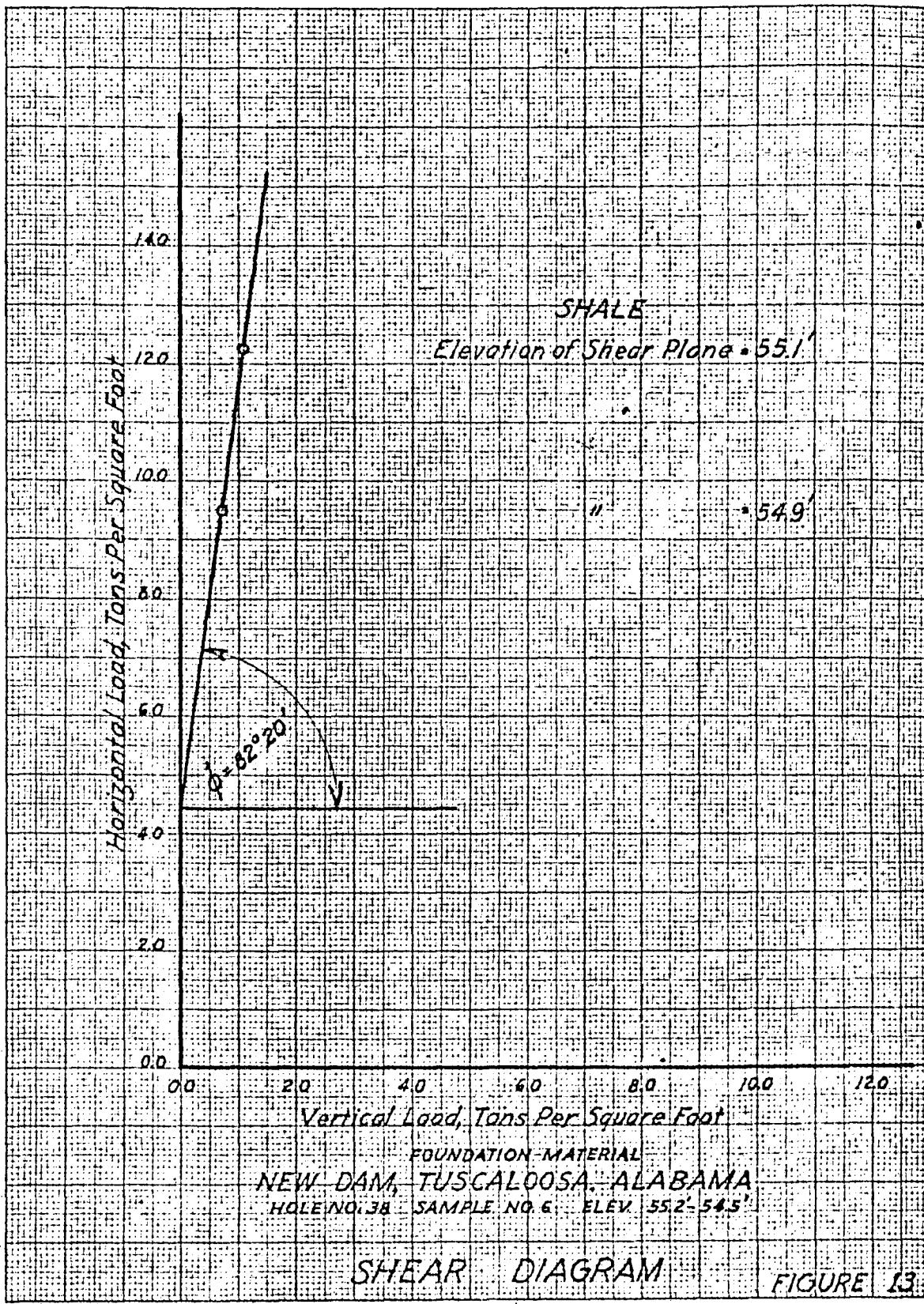


FIGURE 12



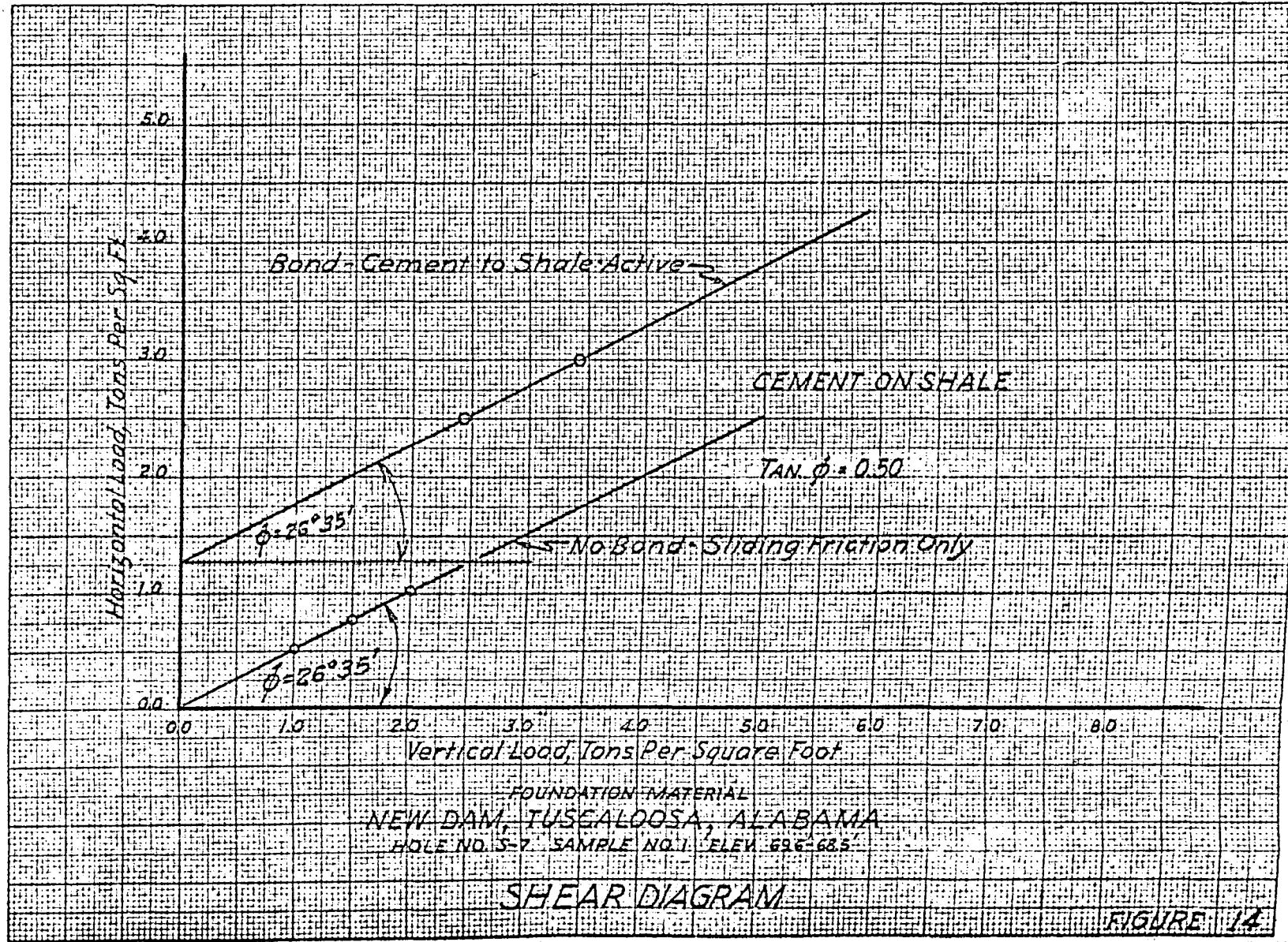


FIGURE 14

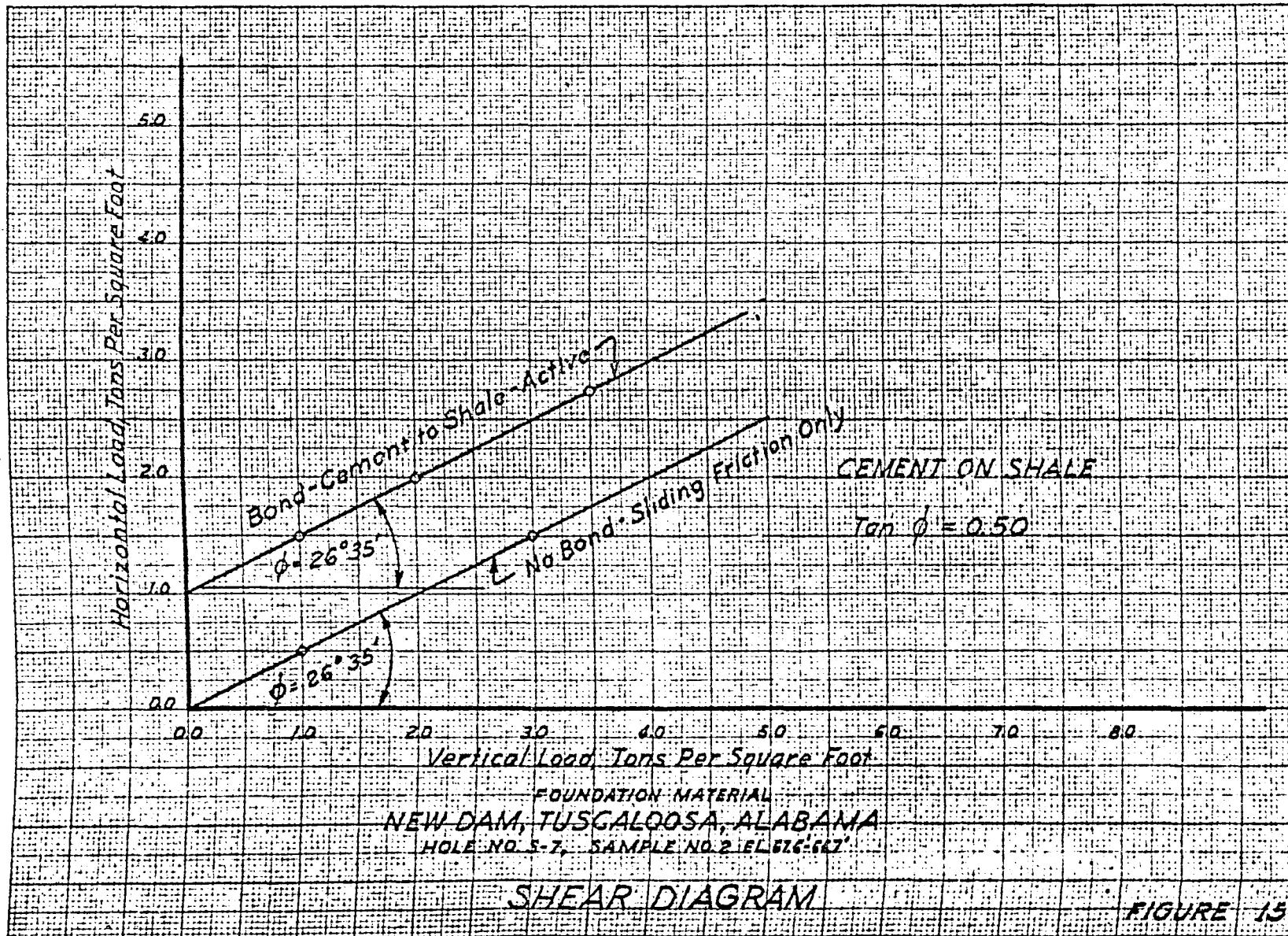
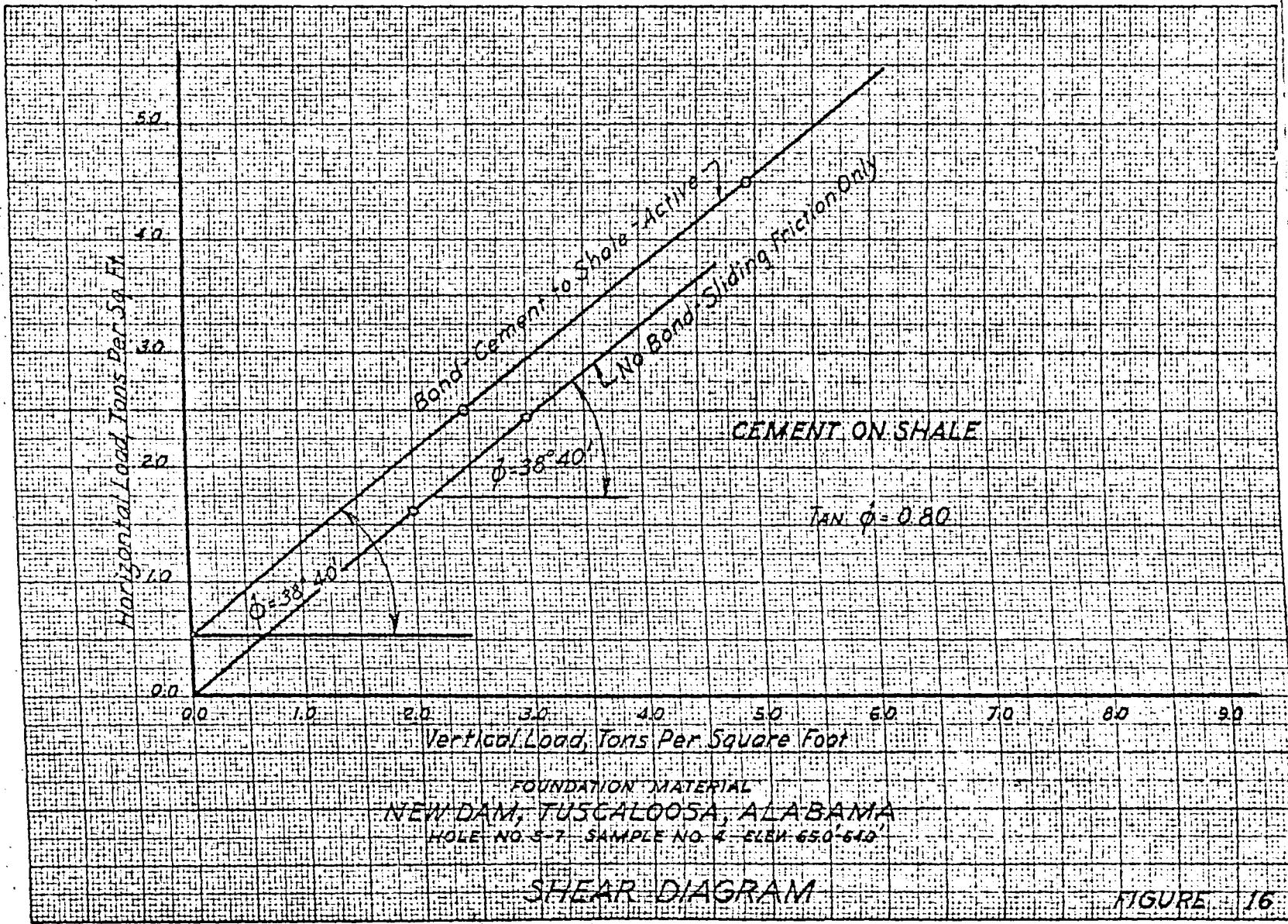
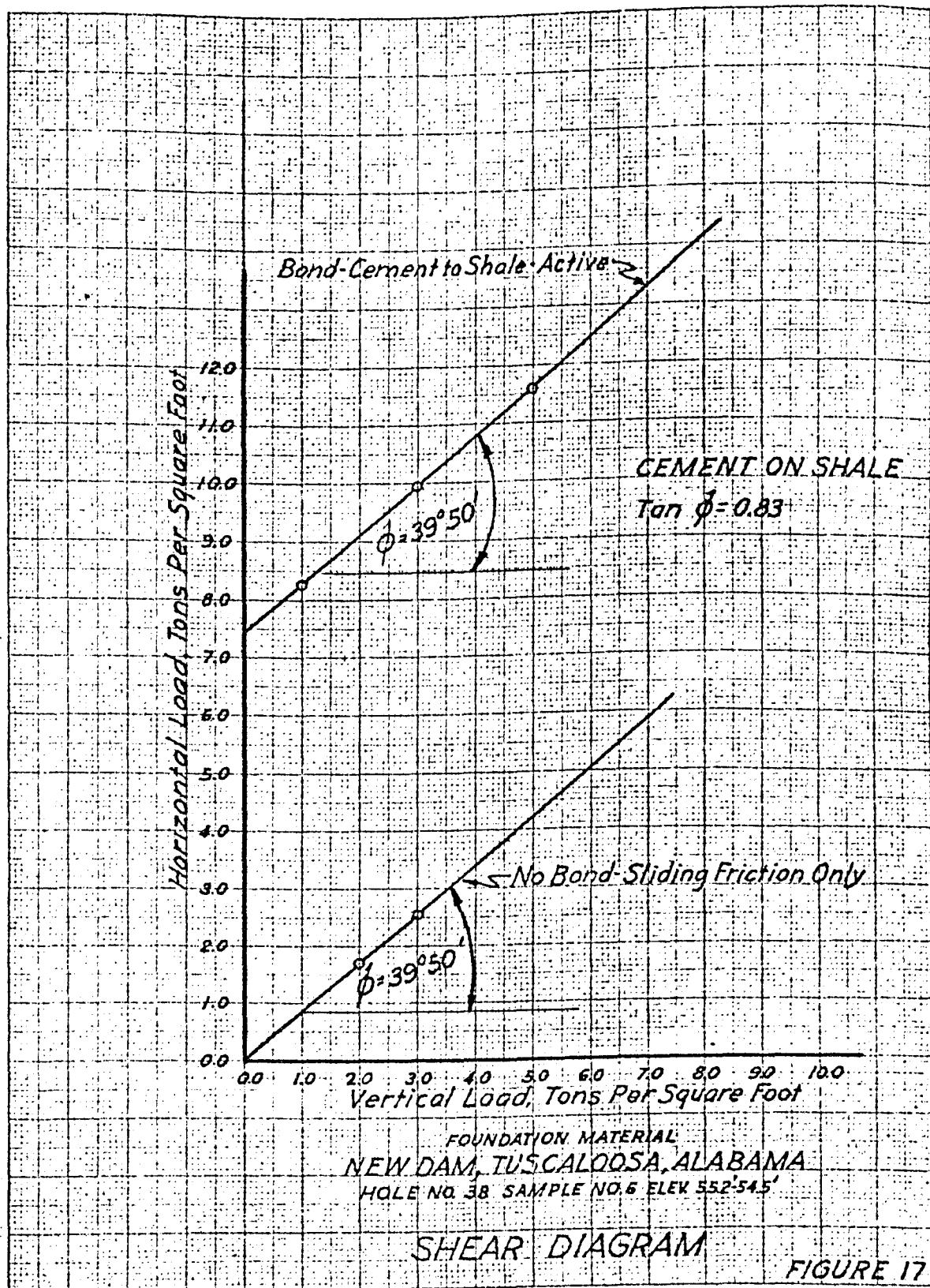
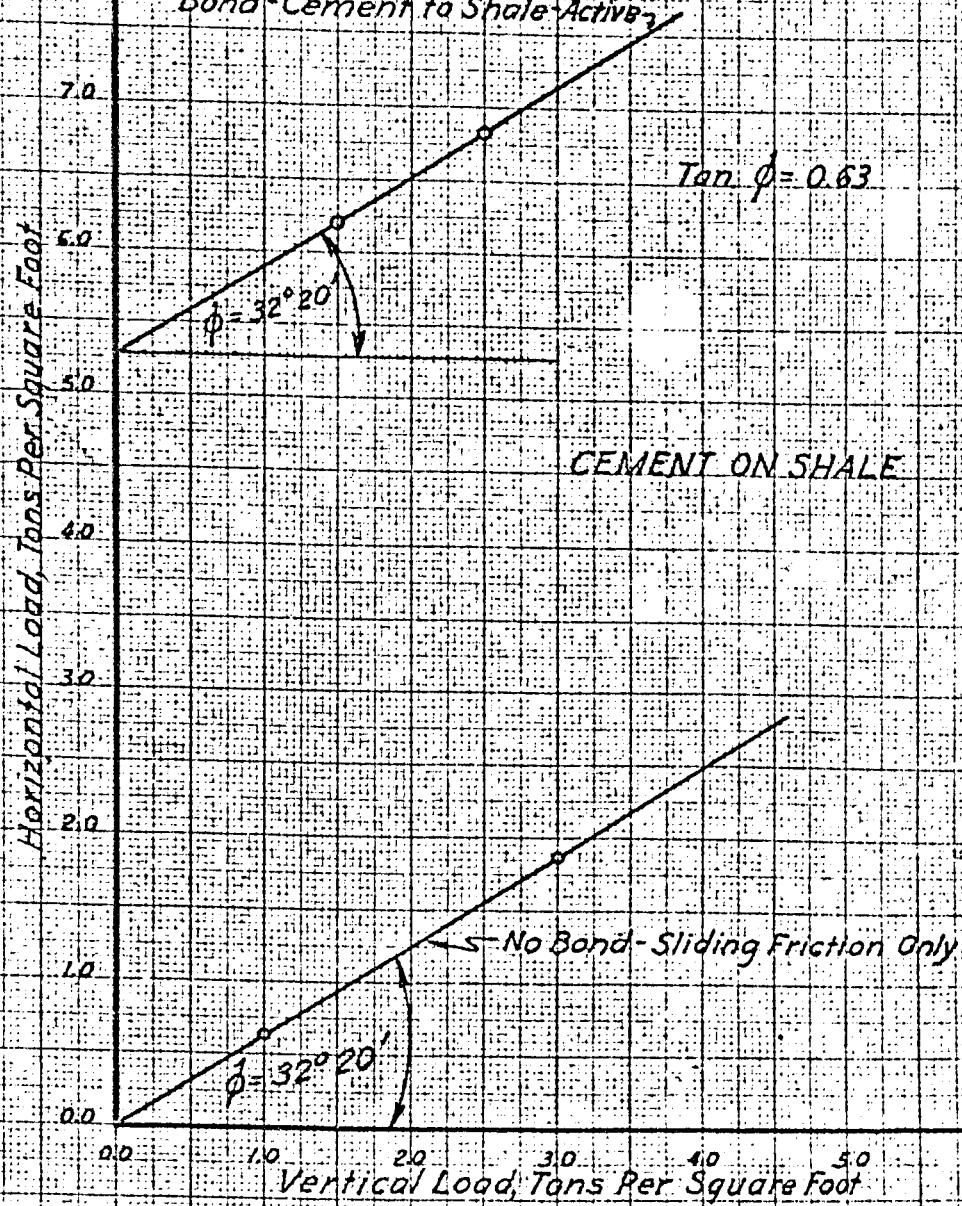


FIGURE 15







SHEAR DIAGRAM

FIGURE 18

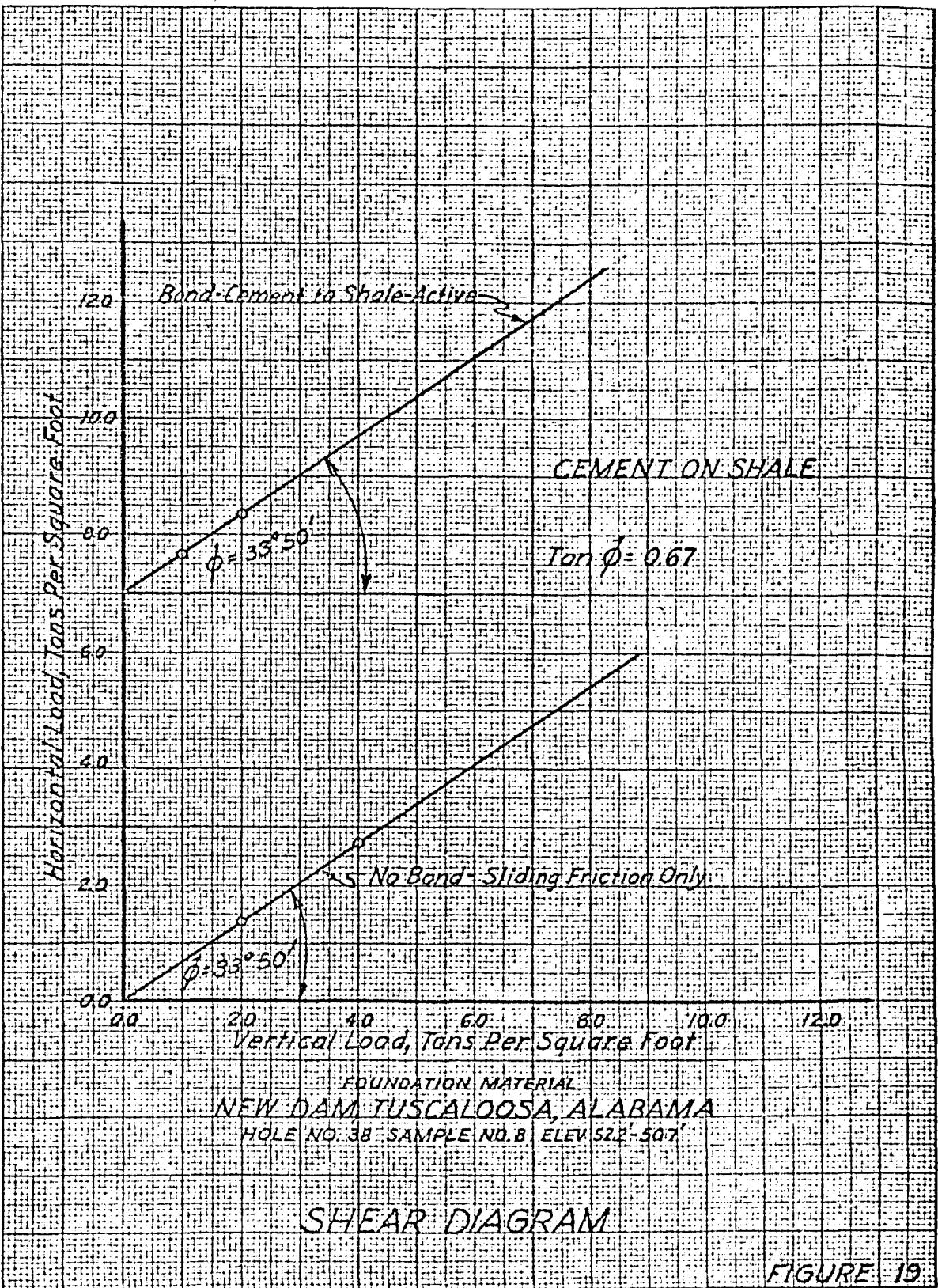
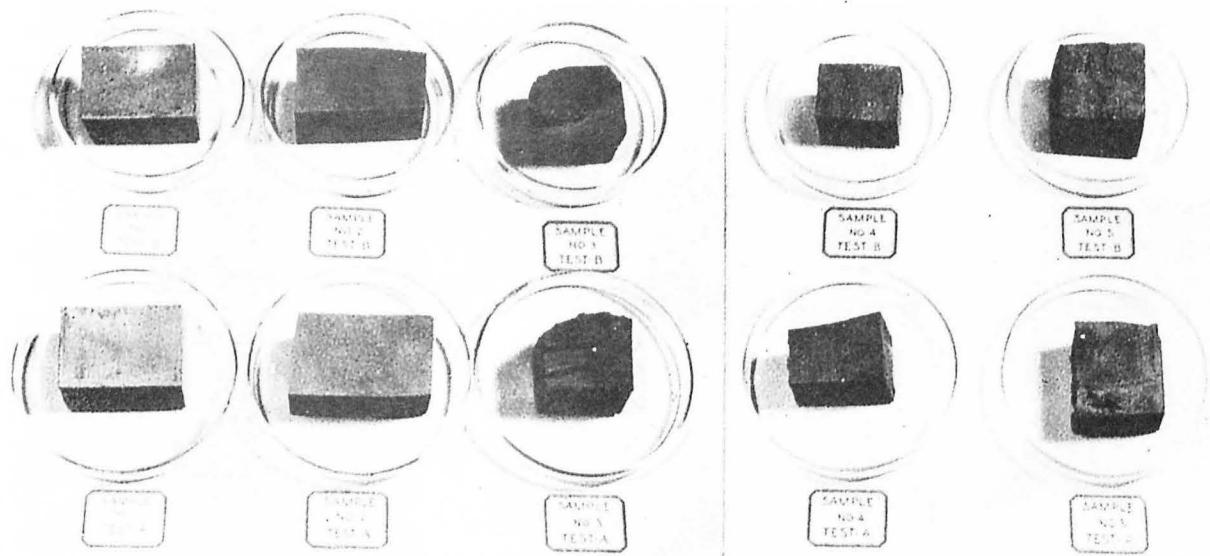
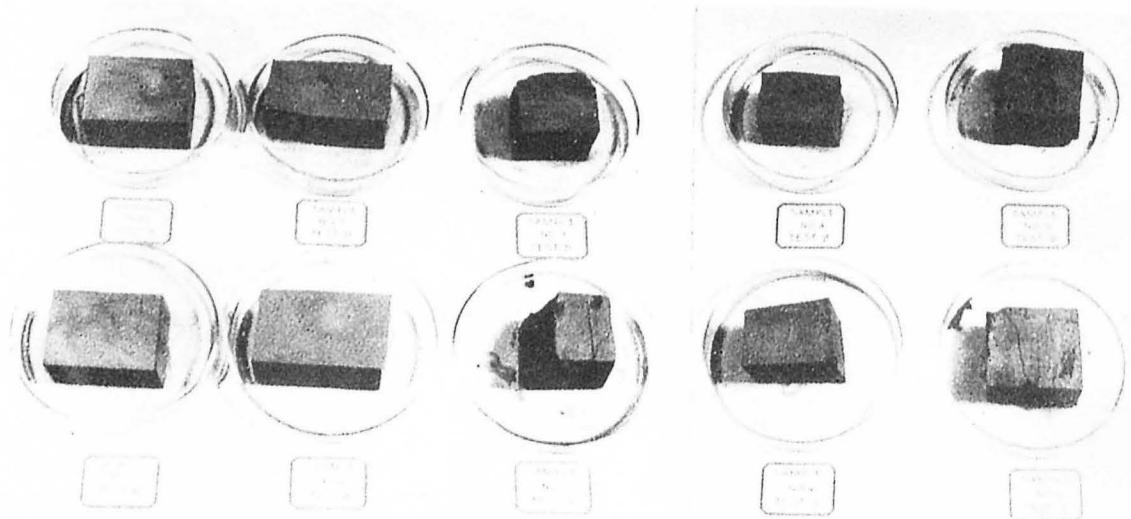


FIGURE 19

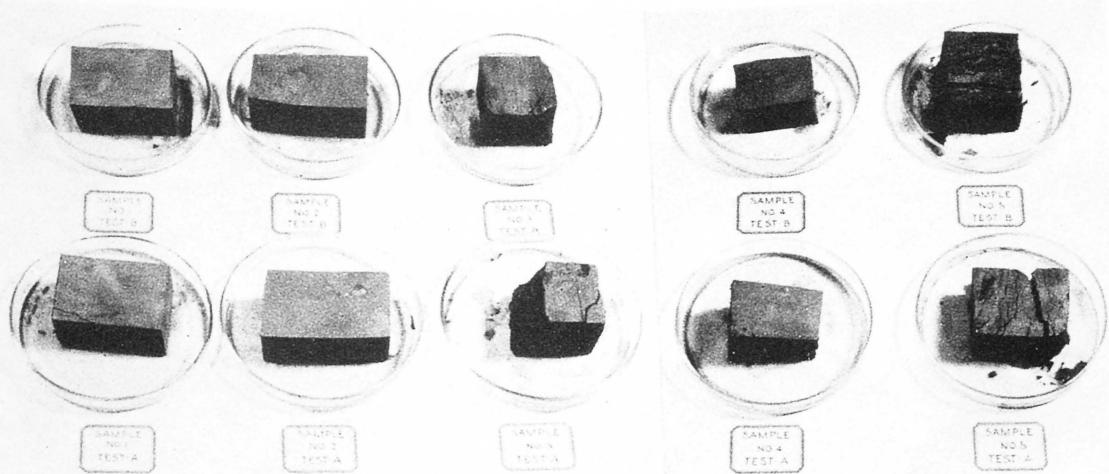


Photograph 1
before beginning of Tests
All samples in Natural State

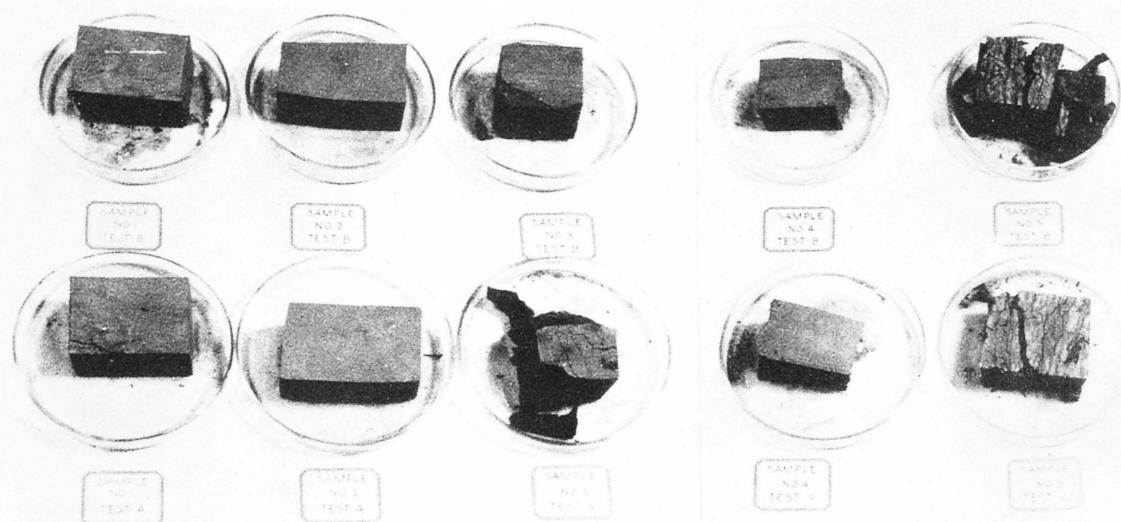


Photograph 2
after first tests
Testing Temperature - 100° C., oven dried

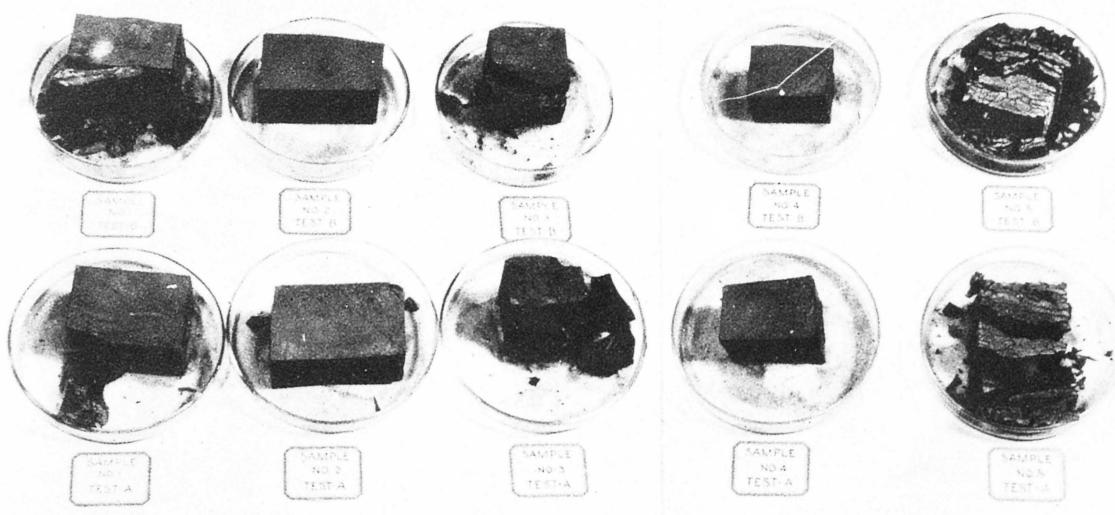
Figure 20



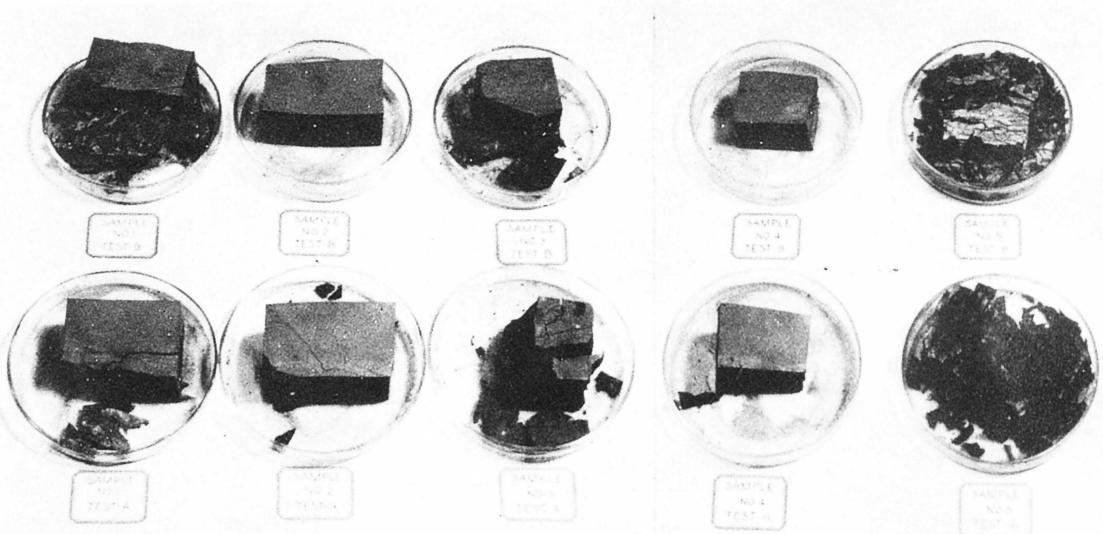
Photograph 3
After Second Phase



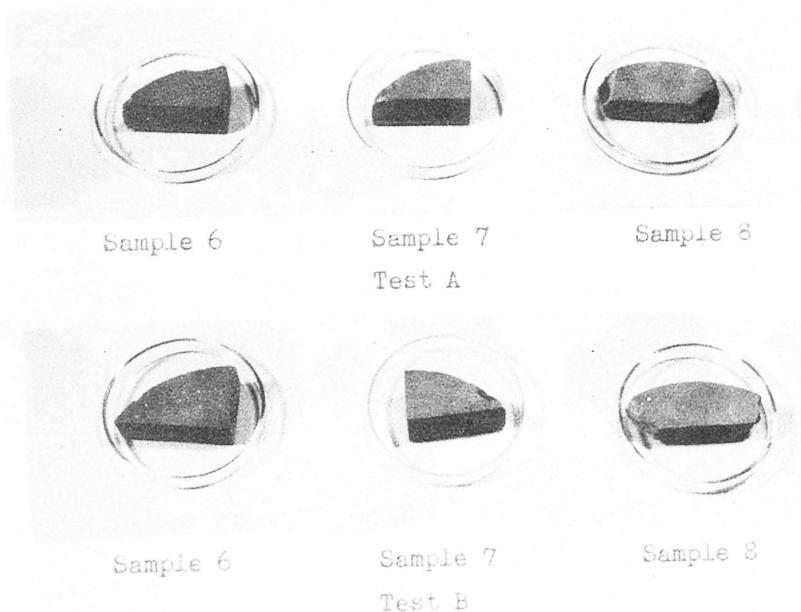
Photograph 4
After Fourth Phase



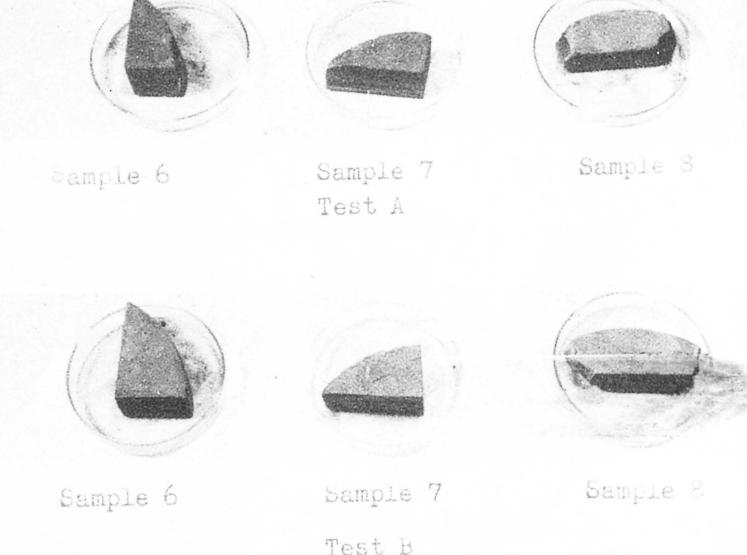
Photograph 5
After Eighth Phase



Photograph 6
After Tenth Phase

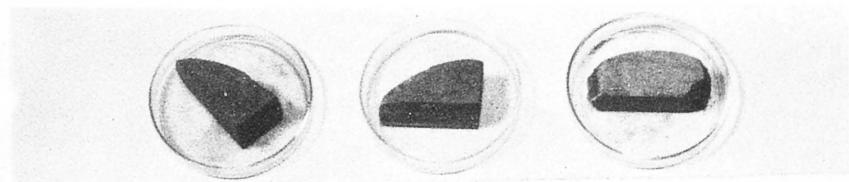


Photograph 7
Before Beginning of Tests
All Samples in Natural State

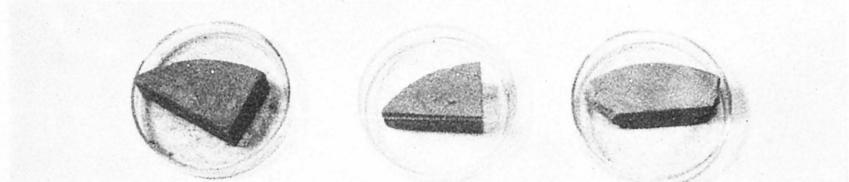


Photograph 8
After Fourth Phase
Test A, Air-dried - Test B, Oven-dried

Figure 23

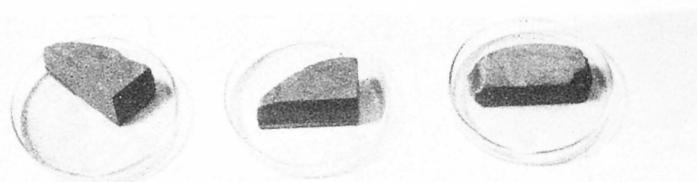


Sample 6 Sample 7 Sample 8
Test A

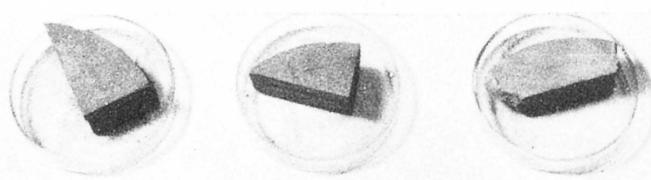


Sample 6 Sample 7 Sample 8
Test B

Photograph 9
After Fifth Phase

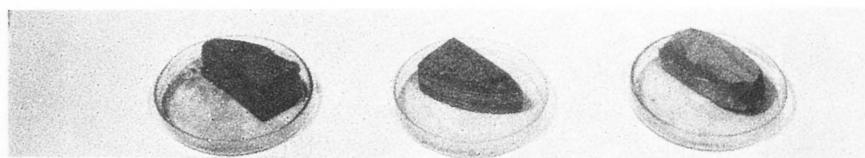


Sample 6 Sample 7 Sample 8
Test A

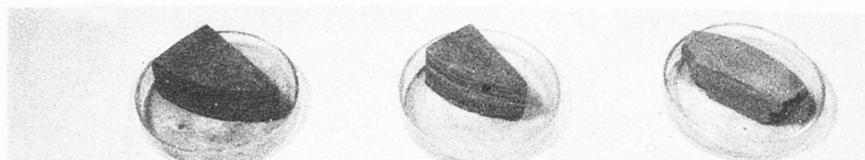


Sample 6 Sample 7 Sample 8
Test B

Photograph 10
After Seventh Phase



Sample 6 Sample 7 Sample 8
Test A



Sample 6 Sample 7 Sample 8
Test B

Photograph 11

After Eleventh Phase



Sample 6 Sample 7 Sample 8
Test A



Sample 6 Sample 7 Sample 8
Test B

Photograph 12
After Thirteenth Phase

Figure 25