THE STATE OF TEXAS

SOIL-LIME STABILIZATION STRENGTH RESEARCH

MATERIALS AND TESTS DIVISION

MCMXVII

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STATE DEPARTMENT OF HIGHWAYS
AND PUBLIC TRANSPORTATION

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PREFACE

This report is the result of laboratory and field studies made on six subgrade soil samples from a section of FM 71 in Hopkins and Delta Counties, District 1, State Department of Highways and Public Transportation. These studies were begun because of discussions between District 1 and Materials and Tests Division personnel concerning the validity of Test Method Tex-121-E for determining lime requirements in a subgrade soil which could be translated into good road serviceability.

In addition, District 1 personnel desired an investigation of the tendency of some soil-lime mixtures to show a decrease in strength after a period of more than a year.

ABSTRACT

Subgrade soil samples from FM 71 in District 1 were studied in the laboratory and in the field to determine if the serviceability of lime-treated soil could be adequately predicted by Test Method Tex-121-E (moist room capillarity test). Samples were exposed to capillarity in the lab and in field burial for up to three years.

Chemical and petrographic analysis of the original samples failed to reveal any characteristics of the soils that were adverse to lime stabilization. Visual examination of the subject section of roadway showed it to be in excellent condition.

Results obtained from Tex-121-E showed that all six samples passed the 50 psi criterion for subbase soils, thus confirming the requirements suggested in the test. However, when the test conditions were modified to include specimens with one-half the specified lime content and exposures to more than ten days of capillarity, most samples showed only fair strength and some showed a decrease in strength with time.

SUMMARY

At the suggestion of District 1, laboratory and field studies were made on six subgrade soil samples from FM 71 to determine the predictability of Test Method Tex-121-E (capillarity test) relative to the serviceability of soil-lime mixtures.

Duplicate samples of varying lime contents were exposed to capillarity tests in the moist room and to weathering while buried. Petrographic and chemical examination revealed no characteristics of the soils that were adverse to lime stabilization.

The high quality of the subgrade soil-lime mixtures was borne out by the excellent condition of the 3-1/2 mile section of the 12-year old FM 71 roadway that was examined.

Capillarity test (Tex-121-E) results showed that all six samples passed the 50 psi criterion for subbase soils, thus confirming the design requirements for lime of the test. When modified by using only half the designated lime contents or exposing samples to more than ten days of capillarity, the samples generally showed only fair initial strength and a decrease of strength with time.

Because of widely varying moisture contents, results from the buried samples were so erratic as to be of marginal value. It was apparent that rainfall runoff was the dominant factor in moisture content rather than capillarity. Soil piled around the specimens did not nearly duplicate conditions that would exist with a cored sample.

I. SUBJECT

Lime stabilization of flexible bases and subgrade soils has had increasing use in Texas since 1938. Several of the State Department of Highways and Public Transportation Districts pioneered the use of lime stabilization of soils with success. Limited research work in District 1 had shown that some soils showed increased strengths with time after a period of one year. It was also noted that some soils showed a decrease in strength with time, after initial strengthening with lime. These findings caused the District to question the use of Tex-121-E results for predicting long-term serviceability of lime-stabilized subgrade soil.

II. PURPOSE

The purpose of this investigation was to determine the reliability of Test Method Tex-121-E in predicting the serviceability of certain lime-soil mixtures for subgrade soils.

III. CONCLUSIONS AND RECOMMENDATIONS

It is concluded that the standard Test Method Tex-121-E is a reliable test for predicting the serviceability of lime-stabilized subgrade soils. Test results correlated very well with petrographic and chemical analyses and with the observed excellent condition of the roadway.

Modifying the test by using only half the designated lime content and exposing samples to long-term capillarity gave results that ranged from excellent to poor for long-term prediction of serviceability. These data tended to confirm that strength regression is possible in cases where insufficient amounts of lime for stabilization are used.

It was concluded that, in the plot of land available for burying these particular test specimens, capillarity occurred on a very limited basis, if at all, and that the strength of these buried samples varied with rainfall rather than capillarity and; further, that the strength prediction was erroneous. This procedure pointed out a second way that strength regression in stabilized materials is possible and, that is, abuse or failure to follow good stabilization practices.

Since there was some evidence in the roadway of a thin layer of friable to plastic material at the interface of the flexible base and lime-soil stabilization, it was concluded that this could be avoided either by blading off the retempered material at the final grading prior to placing the base material, or by adding an additional bit of lime slurry to this retempered material prior to compaction. This practice is recommended.

In view of the good relationship between the test results and the performance of this excellent stabilized subgrade, over a period of 12 years or more, it was concluded that no change in Test Method Tex-121-E was justified at this time.

IV. PROCEDURE

Laboratory and field studies on six subgrade soil samples from FM 71 in Hopkins and Delta counties were conducted in order to secure triaxial classifications and unconfined compressive strengths over a period of three years. Following determination of soil constants and selection of the lime contents to be used, moisture-density curves were run to select the optimum moisture to be used in molding specimens.

A set of six specimens was molded at optimum moisture and density to determine the triaxial classification of the soil-lime mixture. Thirty-two additional specimens were then molded under the same conditions for the aging test. Half of these were placed in the wet room for capillary wetting, while the other half were buried in the plot at District 14.

All the above operations were repeated using one-half the amount of lime recommended by the AASHTO T-220 chart.

Test methods used are as follows:

A. <u>Sampling of Soils</u>

Soils used in this project were sampled in accordance with Test Method Tex-100-E by District 1 representatives and shipped to Austin.

B. <u>Preparation of Soils</u>

All soils were prepared by Materials and Tests Division personnel in accordance with Test Method Tex-101-E, Parts I and II.

C. <u>Determination of Soil Constants</u>

Soil constants (Atterberg Limits) were determined in accordance with Test Methods Tex-104-E, Tex-105-E and Tex-106-E for the Liquid Limit and Plasticity Index respectively.

D. Determination of Hydrometer and Mechanical Analysis of Soils

These were determined in accordance with Test Method Tex-110-E.

E. Determination of Moisture-Density Relations of Soils and Base Materials

These were determined in accordance with Test Method Tex-113-E.

F. Soil-Lime Compressive Strength Test Methods

Triaxial classifications and unconfined compressive strengths of soil-lime mixtures were determined in accordance with Test Method Tex-121-E, with some modification of curing times and processes for this project. These modifications of the Test Method include both the long-time (up to 3 years) curing processes in capillarity and burial of specimens in the plot at District 14.

V. TEST DATA

A. Visual Examination

Roadway condition and soil-lime subgrade quality were examined at the five sample stations on FM 71.* The evaluation covered 3.54 miles from the junction with FM 2653 to the junction with FM 1531.

Sample No. 1 (71-359-R) Station 434+50, .4 miles west of FM 2653 and FM 71 junction.

Note: All test methods mentioned are contained in the Appendix attached to this report.

* Sample No. 2 (71-360-R) was located .15 miles west of Kensing Store on FM 895. No examination was made since it was not on FM 71.

In general the roadway looked good, with no patches and only a few depressions. The surface treatment wearing course is a crushed limestone material and appears to be in good condition. The roadway section had 6" of Tehuacana limestone flexible base and 6" of lime treated subgrade amounting to 7% lime by weight on this end of the job. The surface was 3/4" to 1" thick consisting of the original and one resurfacing since placed in 1962. Coring indicated that the base contained the full depth of 6" with the bottom interface damp and showing a thin layer (about 1/2") of lime treated subgrade that was moderately plastic. The remainder of the soil-lime subgrade was very hard and had to be removed with a hammer and chisel.

Sample No. 3 (71-411-R) Station 360+50, 1.8 miles northwest of FM 2653 and FM 71 junction.

Plans called for 6% lime by weight. Depths were as in previous holes and met plan dimensions. Condition of the roadway was good even though the entire roadway is covered with water several times a year from river overflow. At the time of this sampling, the water had been over the roadway less than six hours previously but due to good surface and well-compacted base the materials appeared no wetter, if as wet, as the other areas. The soil-lime subgrade was firm and friable when removed but did not appear to be nearly as hard as the previous two holes sampled. General appearance of the roadway was very good under the weather conditions and little or no rutting was noted.

Fig. 1
Condition of Roadway at Sample No. 1

Fig. 2
Sample No. 1 Hole Showing Surface and Base Removed.

Fig. 3
Roadway Condition at Sample No. 3

Sample No. 4 (72-120-R) Station 378+50, 600 ft. east of South Sulphur River bridge.

This point contained 6% hydrated lime according to the plans. The condition of the roadway was good and the depths were according to plans. The soil-lime subgrade was similar to that described in Station 434+50 except that the raw soil was probably more plastic as shown in the soil tests. Treated soil was quite hard and this point probably was overflowed by floods numerous times. Base and soil-lime were tight and dense except for about 1/2" of friable-to-plastic material at the interface of base and lime-treated subgrade.

Fig. 4
Roadway Condition at Sample No. 4.

Sample No. 5 (72-267-R) Station 349+50, 100 ft. into Delta County.

The sampling point was in one of the two patches noted on the entire job where the water flow through the old river bed had overflowed and damaged the pavement. The patch was made of pre-mix, covering the entire roadway and was very smooth. Sampling through the old surface plus patch (total 3-3/4") left about 6-1/4" of Tehuacana flexible base over the 6% lime treated subgrade which was about 6" thick. The lime treated soil was lightly cemented and friable when broken up but was not as well cemented as in previous sample holes. Some sticks and/or other organic matter appeared in the hole. This spot had overflowed many times according to District personnel. Base material appeared well compacted but slightly different color (grayer) than the remainder of the flexible base.

Fig. 5
Roadway Condition at Sample No. 5.

Sample No. 6 (73-7-R) Station 285+00, .4 miles east of FM 1531.

The outer wheel path of the east-bound lane showed some noticeable depression or rutting estimated to be about 1" deep. This rutting was gradual, probably holding some water during rains. Base depth was slightly over 4" and was either placed deficient in depth or was a combination of too little base depth plus consolidation by traffic.

The extent of the rutting was not determined, but the general appearance with ruts was good since the surface was quite uniform looking. The base, although thin, was very firm with the top 1/2" of the lime treated soil being friable, but not cemented greatly. Below about 1/2" in the 5% lime treated soil the lime was very hard and well cemented. Pieces of the treated material were estimated to have an unconfined compressive strength of at least 300 to 400 psi and perhaps more. This lime treated soil was the best encountered in the five holes and ranked above Station 434+50 which was well cemented below the 1/2" top which contained some plastic material.

General Remarks:

This 3.54 mile section of FM 71 was built in 1962 and at age 12 years has had little maintenance or damage. Riding qualities are good since Potential Vertical Rise (PVR) has been general and fairly uniform with few bumps or transverse waves which cause noticeable discomfort to drivers. There were only two patches of any size on the entire job and these had been placed recently.

Fig. 6
Roadway Condition at Sample No. 6.

It is estimated that under present traffic patterns this road should last many years with a minimum of maintenance. The soil-lime stabilization appears good and effective although the middle of the job has poorer soils and not as good cementation as the ends. Both District personnel and investigating personnel agree that the section across the river bottom would have long since had to be rebuilt without the lime treated subgrade. It is postulated that 1/2" (generally) of softer or less cemented material is caused by wetting and drying, blading and recompacting or otherwise working and shaping the top of the lime treated subgrade soil. In heavy clays, such as in a good deal of this section, it appears that additional lime slurry should be used in the final sprinkling water to "sweeten up" the lime content of the top of the subgrade where the soil may have been disturbed several times and exposed to a few wet and dry cycles which are detrimental.

For a 12-year old FM road with as little maintenance as reported, this FM 71 section of 3.54 miles is in extremely good condition.

B. Compressive Strength and Moisture Content

Figures for unconfined compressive strengths and moisture contents are given in Tables I through VI and correspond to soil Samples 1-6. The figures are an average of two specimens unless noted otherwise. A moisture-density curve is shown in Fig. 20 (Appendix) for each soil sample and a set of specimen molding data (Fig. 21) is given in the Appendix for one sample. Inclusion in this report of molding data for all specimens would serve no useful purpose. Figures are on file at the Materials and Tests Division.

Table I
Compressive Strengths and Moisture Contents

Sample No. 1 + 3% Lime

71-359-R	Age (Days)	Capillarity Psi	Capillarity % Moisture	Buried Psi	Buried % Moisture
	10	68.6	17.9	87.7	14.3
	30	88.9	18.1	87.2	13.7
	60	107.1	18.4	91.5	14.6
	90	111.3	18.2	92.7	15.7
	180	141.9	18.1	91.1	14.3
	360	177.1	18.6	94.2	11.0
	720	198.0	19.9	81.9	10.4
	1080	207.2	21.1	70.5	7.6
	+ 1-1/2% Lime				
	10	52.9	18.3	60.6	13.9
	30	56.2	17.9	51.6	18.3
	60	61.4	18.0	58.9	15.5
	90	63.2	18.5	57.8	15.5
	180	62.2	20.7	33.0	16.2
	360	64.4	19.8	61.0	7.8
	720	57.0	21.7	14.7	15.4
	1080	50.4	22.7	68.9	7.1

Table II
Compressive Strengths and Moisture Contents

Sample No. 2 + 2% Lime

71-360-R	Age (Days)	Capillarity		Buried	
		Psi	% Moisture	Psi	% Moisture
	10	78.0	10.7	114.9	7.4
	30	80.8	10.8	94.8	8.4
	60	79.5	10.8	86.3	8.8
	90	77.3	11.0	85.6	9.4
	180	73.3	10.9	61.7	11.2
	360	68.5	11.2	89.8	6.7
	720	58.7	12.1	24.4	12.5
	1080	60.1	11.9	76.5	5.9
	+ 1% Lime				
	10	59.8	11.6	71.5	9.9
	30	58.3	12.2	73.4	10.4
	60	57.6	12.7	74.4	10.4
	90	53.4	12.7	54.9	11.7
	180	50.9	12.9	39.5	12.0
	360	46.4	12.6	51.3	8.4
	720	33.0	13.5	20.6	12.8
	1080	31.3	13.4	25.5	9.7

Table III
Compressive Strengths and Moisture Contents

Sample No. 3 + 6% Lime

71-411-R	Age (Days)	Capillarity		Buried	
		Psi	% Moisture	Psi	% Moisture
	10	64.8	25.6	62.6	21.2
	30	80.5	25.4	56.9	23.7
	60	92.0	25.4	63.8	25.1
	90	95.8	25.3	68.8	24.9
	180	148.3	26.5	27.4	29.5
	360	173.0	26.2	13.6*	27.5*
	720	209.2	27.2	8.9	34.2
	1080	182.1	26.9	6.2	34.6
	+ 3% Lime				
	10	40.2	28.4	41.2	21.1
	30	42.3	28.8	35.7*	21.4*
	60	46.3	28.8	28.9	22.0
	90	45.7	28.8	27.7	21.6
	180	44.6	29.8	7.2	38.3
	360	38.7	30.3	7.1	33.3
	720	23.8	36.3	6.4	35.7
	1080	24.6	35.2	5.0	35.8

* One specimen only.

Table IV
Compressive Strengths and Moisture Contents

Sample No. 4 + 6% Lime

72-120-R	Age (Days)	Capillarity		Buried	
		Psi	% Moisture	Psi	% Moisture
	10	139.1	23.7	158.1	20.5
	30	162.4	24.2	240.4	22.2
	60	186.8	24.2	310.3	22.3
	90	222.9	24.5	338.6	21.6
	180	297.9	24.2	82.4	24.7
	360	458.1	24.0	42.3	28.4
	720	565.3	25.8	9.6	34.5
	1080	618.7	25.4	7.7	35.2
	+ 3% Lime				
	10	136.3	24.1	227.3	15.2
	30	179.4	25.3	95.5	25.2
	60	207.5	25.2	115.9	23.3
	90	234.4	25.2	110.6*	20.7*
	180	253.3	26.1	10.4	30.2
	360	234.7	25.6	11.6	32.1
	720	153.1	27.3	8.4	34.1
	1080	127.1	28.3	6.2	33.8

* One specimen only.

Table V
Compressive Strengths and Moisture Contents

Sample No. 5 + 4% Lime

72-267-R	Age (Days)	Capillarity Psi	Capillarity % Moisture	Buried Psi	Buried % Moisture
	10	120.5	19.1	221.4	14.3
	30	169.0	19.4	196.4	15.0
	60	207.5	19.2	191.0	15.6
	90	224.4	19.5	123.5	17.1
	180	321.4	19.7	93.0	20.3
	360	353.9	20.0	9.9	25.8
	720	444.8	20.4	10.1	20.7
	1080				

+ 2% Lime

72-267-R	Age (Days)	Capillarity Psi	Capillarity % Moisture	Buried Psi	Buried % Moisture
	10	86.9	20.4	140.8	13.8
	30	105.5	20.7	96.1	16.7
	60	106.0	21.8	68.2	18.3
	90	106.3	21.6	45.1	19.1
	180	116.0	21.7	80.8	21.0
	360	113.0	22.1	6.5	24.6
	720	111.9	23.1	7.6	24.3
	1080				

Table VI
Compressive Strengths and Moisture Contents

Sample No. 6 + 3% Lime

73-7-R	Age (Days)	Capillarity Psi	Capillarity % Moisture	Buried Psi	Buried % Moisture
	10	83.4	14.9	99.8	13.5
	30	92.7	15.5	101.9	13.4
	60	96.7	15.5	104.1	13.7
	90	108.3	15.3	122.8	13.5
	180	118.2	15.2	324.1	10.1
	360	173.9	15.6	118.2	13.6
	720	279.6	16.2	52.0	17.0
	1080				
	+ 1-1/2% Lime				
	10	74.1	14.8	99.2	12.3
	30	80.2	15.3	91.2	12.9
	60	81.2	15.8	85.7	13.8
	90	84.8	15.4	84.2	13.3
	180	79.6	15.4	153.2	6.5
	360	89.5	15.5	42.7	13.8
	720	92.4	16.8	26.6	14.9
	1080				

C. Soil Constants

Table VII
Soil Constants of Raw Soils

Lab No.	Liquid Limit	Plasticity Index	Shrinkage Limit	Linear Shrinkage	Shrinkage Ratio	%-No. 40
71-359-R	38	14	23.4	6.5	1.58	100
71-360-R	26	9	17.4	4.5	1.77	100
71-411-R	76	42	14.8	23.0	1.93	100
72-120-R	67	47	12.0	21.6	1.97	100
72-267-R	47	31	15.1	14.5	1.88	100
73-7-R	30	13	17.2	6.6	1.81	100

Table VIII
Soil Constants of Lime-Treated Soils

Lab No.	Liquid Limit	Plasticity Index	Shrinkage Limit	Linear Shrinkage	Shrinkage Ratio	Corresponds to Raw Soils
74-309-R	50	8	38	4.8	1.28	71-359-R
74-311-R	55	32	21	14.2	1.68	71-411-R
74-310-R	47	13	28	7.7	1.48	72-120-R
74-312-R	51	31	20	13.4	1.74	72-267-R
74-313-R	34	7	27	3.7	1.54	73-7-R
None						71-360-R

D. Plasticity Indices of Treated Soils

Table IX
Sample No. 1, 71-359-R

Age (Days)	+ 3% Lime		+ 1-1/2% Lime	
	Capillarity	Buried	Capillarity	Buried
10	8	9	6	7
30	9	8	6	11
60	8	7	9	11
90	8	9	8	7
180	6	8	9	15
360	6	10	10	16
720	8	11	11	15
1080	9	13	10	16

Table X
Sample No. 2, 71-360-R

Age (Days)	+ 2% Lime		+ 1% Lime	
	Capillarity	Buried	Capillarity	Buried
10	7	8	7	7
30	7	7	7	6
60	8	8	8	7
90	7	8	8	7
180	5	6	7	6
360	8	5	8	7
720	7	8	7	9
1080		9		

Table XI
Sample No. 3, 71-411-R

Age (Days)	+ 6% Lime		+ 3% Lime	
	Capillarity	Buried	Capillarity	Buried
10	9	9	17	18
30	9	8	17	21
60	11	12	19	21
90	11	12	20	30/26
180	10	13	17	43
360	12	26	19	36
720	11	35	27	47
1080				

Table XII
Sample No. 4, 72-120-R

Age (Days)	+ 6% Lime		+ 3% Lime	
	Capillarity	Buried	Capillarity	Buried
10	6	5	14	14
30	6	7	18	15
60	7	8	14	18
90	7	12	15	20
180	12	10	17	17
360	12	12	17	18
720	11	14	20	25
1080				

Table XIII
Sample No. 5, 72-267-R

Age (Days)	+ 4% Lime		+ 2% Lime	
	Capillarity	Buried	Capillarity	Buried
10	10	11	14	15
30	8	13	14	15
60	9	12	16	15
90	10	9	16	17
180	9	10	15	18
360	7	13	14	
720				
1080				

Table XIV
Sample No. 6, 73-7-R

Age (Days)	+ 3% Lime		+ 1-1/2% Lime	
	Capillarity	Buried	Capillarity	Buried
10	8	7	8	9
30	8	9	8	10
60	7	8	10	9
90	7	7	9	10
180	7	7	9	11
360	7	7	8	10
720	8	9	7	11
1080				

VI. DISCUSSION

A. General

The method of weathering by sprinkler was considered and judged to be too harsh, since long experience had shown the need for a surface or other course to cover the samples to approximate subbase conditions. It was decided to subject half the lime-treated specimens to weathering while buried, the other half to capillarity in the moist room.

This investigation involved determining the triaxial classification of the six subgrade soils containing the specified percent and one-half of the specified percent lime as recommended by the AASHTO T-220 chart. In addition to these classifications, the unconfined compressive strengths of specimens containing the two lime percentages are presented for an age of 10, 30, 60, 90, 180, 360, 720 and 1080 days. The moisture contents of both buried specimens and those in capillarity are presented for the corresponding ages, as well as the inches of rainfall for those specimens buried in the plot at District 14 in Austin. P. I. (plasticity index) determinations after aging are also shown for these samples. Results of chemical and petrographic analyses of the six subgrade soils are also shown in this report. Although some specimens remain to be tested at this writing, enough specimens have been tested to establish a trend for all six of the soils included in this project.

. Plasticity Indices

Since the buried samples gave such erratic readings, only the moist room samples are discussed below. The data in Tables I-VI are graphically represented in Figures 8-19. The effect of precipitation on moisture content of the sample at the time of testing is also shown in this series of graphs. The chart in Figure 7 below gives a summary view of soil strengths over the test period.

Sample No.	% Lime	Strength
1	3	Very good continual gain
1	1-1/2	Fair, nearly static
2	2	Fair, gradual decrease
2	1	*Borderline, gradual decrease
3	6	Very good continual gain
3	3	*Below 50 psi, decreased from 60-day max.
4	6	Extremely good continual gain
4	3	Decreased rapidly from 180-day max.
5	4	Very good continual gain
5	2	Nearly static
6	3	Very good gain
6	1-1/2	Slight gain

*Indicates doubtful quality

Fig. 7

From the data in Figure 7 it can be seen that the moist room capillarity test as modified for long term exposure gave results showing that two of the twelve specimens were of doubtful or low quality for subgrade use with the particular lime additions. Both of these contained only half the lime designated by the AASHTO Table.

B. Chemical and Petrographic Analysis

1. Chemical analysis for water solubles and ion exchange capacity revealed nothing in the soils which would lead to degradation of strengths obtained by stabilizing with lime. See Appendix for detailed chemical analysis.

2. Petrographic analysis of the six soil samples showed three to be composed mostly of quartz sand with minor amounts of clay and the other three to be mostly silty clay with small amounts of sand. Organic material was present in several of the soils (see Appendix Figs. 22-36).

C. Evaluation of Burial Samples

The only plot available for burial of the samples was a sloping area of thin soil in District 14. It soon became evident that rainfall was the dominant factor in controlling sample moisture, not capillarity. Hence the strength characteristics varied as erratically as the wet and dry weather cycles. Rainfall data shown in Figures 9, 11, 13, 15, 17 and 19 show the great fluctuations in monthly and yearly precipitation over the test period.

It is postulated that the comparatively loose soil around the specimens as compared with "in-situ" conditions, provided too severe wetting and drying effects for useful test data. Also the bottom of the burial plot was limestone rather than soil and as some water drained into the pit from the hillside the wet-dry conditions worsened. A better plot for these demonstrations was not available at that time.

D. Evaluation of Test Specimens Using Test Method Tex-121-E Amounts of Lime

Figure 7 shows that in the case of all six soil samples that laboratory tests by Test Method Tex-121-E, and using the full amounts of lime recommended, would predict good service since all are above 50 psi minimum recommended in lime treated subgrade. The roadway examined where five of these soils are treated with similar amounts of lime are performing extremely well.

Soil sampled near Kensing Store was not lime treated and no roadway comparison was possible. This soil was Sample No. 2 (71-360-R).

APPENDIX

Chemical Analysis

Determination	Sample No. 71-359-R (72-690-J)	 71-360-R (72-691-J)	 71-411-R (72-692-J)	 72-120-R (72-1011-J)	 72-267-R (72-2500-J)	 73-0007-R (73-412-J)
Total water soluble solids	0.00% or 29 ppm	0.01% or 100 ppm	0.02% or 239 ppm	0.04% or 380 ppm	0.17% or 1714 ppm	0.01% or 126 ppm
Water soluble sulfate as SO_4	None	None	None	None	None	None
Water soluble chloride as Cl	None	None	None	None	None	None
Water soluble calcium as Ca	None	None	None	None	0.11% or 1145 ppm	None
Water soluble magnesium as Mg	None	None	None	None		None
pH of the water soluble portion	7.7	6.3	7.5	8.8	7.7	7.0
Ion exchange capacity	None	None	None	None	None	None
Total sulfate as SO_4	0.10% or 1049 ppm	0.10% or 1028 ppm	0.12% or 1255 ppm	0.06% or 637 ppm	0.44% or 4,352 ppm	0.52% or 5,183 ppm

Compositional characteristics of these soils which might cause degradation of strengths obtained by lime stabilization include high salt contents, specifically sulfates and zeolite type clays which have an ion exchange capacity.

The water soluble sulfate, chloride, calcium and magnesium contents were all too low to detect by normal analytical means. The total sulfate, including both soluble and insoluble material was determined and it was quite low on all four soils. None of the soils evidenced any ion exchange capacity.

Based on these tests, there does not appear to be anything in the chemical make-up of these soils which would lead to degradation of strengths obtained by stabilizing with lime.

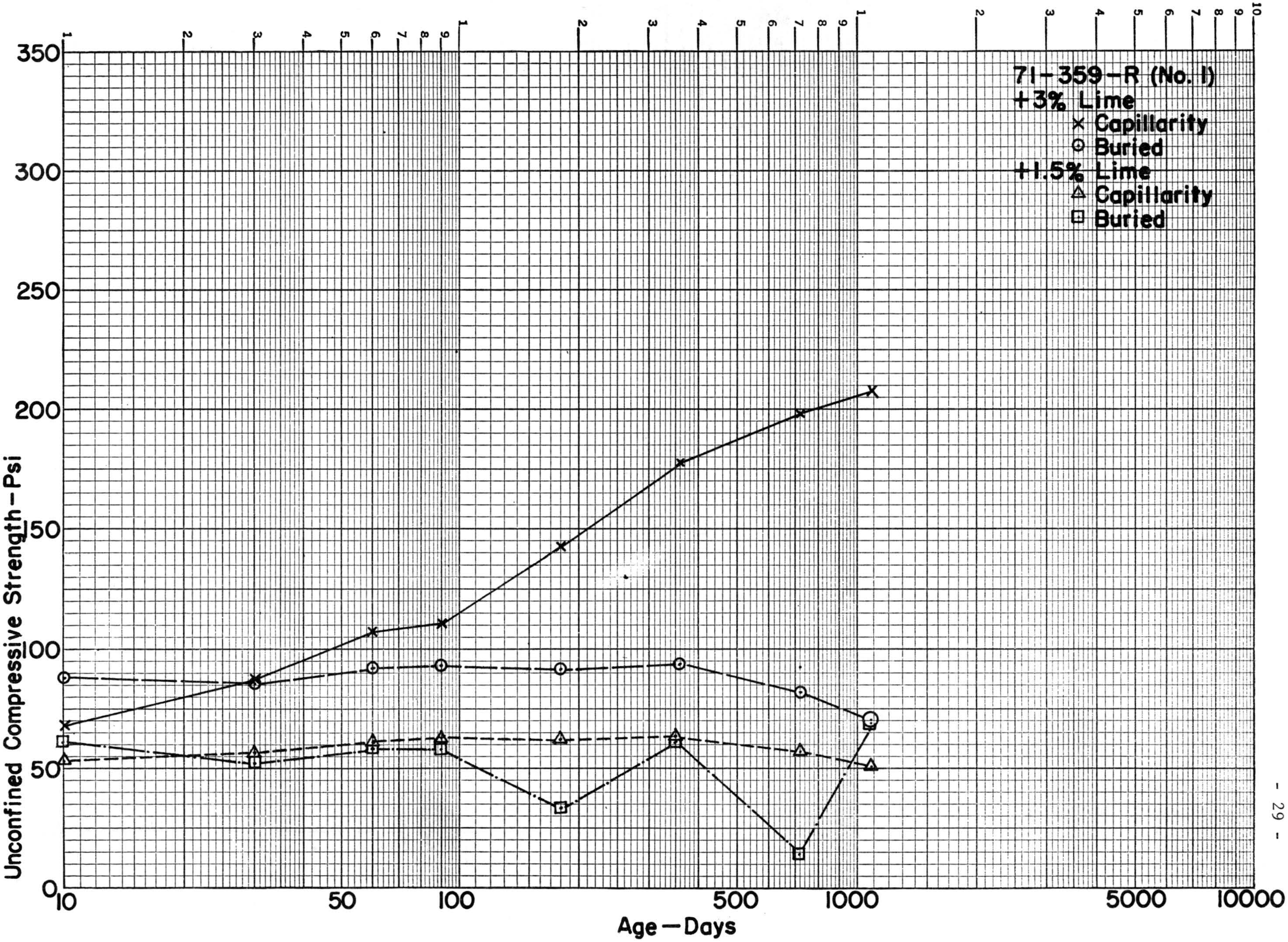

71-359-R (No. I)
+3% Lime
× Capillarity
⊙ Buried
+1.5% Lime
△ Capillarity
⊡ Buried
Unconfined Compressive Strength-Psi
0
50
100
150
200
250
300
350
Age—Days
10
50
100
500
1000
5000
10000

Fig. 8

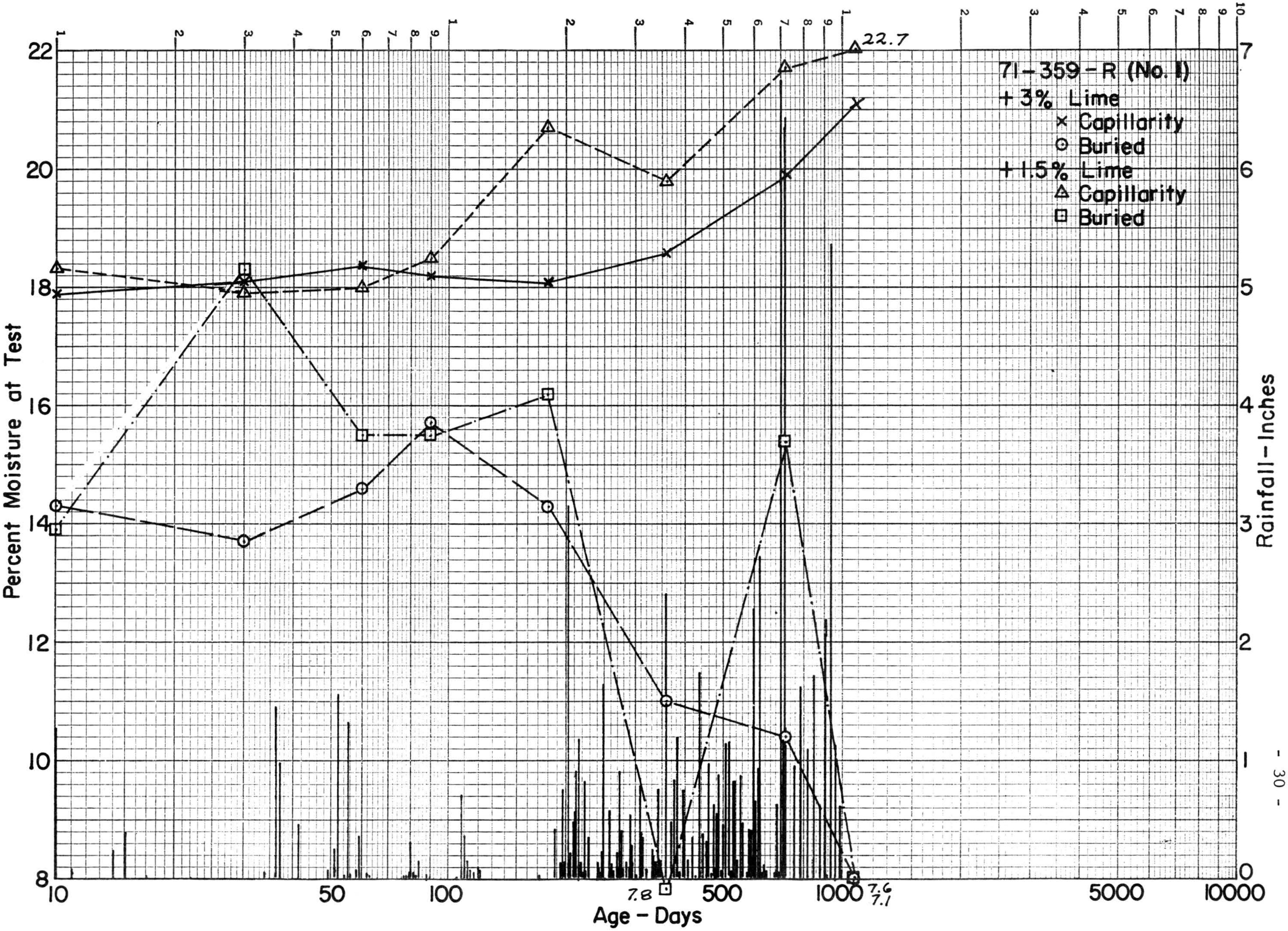

71-359-R (No. 1)
+3% Lime
× Capillarity
○ Buried
+1.5% Lime
△ Capillarity
□ Buried
22.7
7.8
7.6
7.1
Percent Moisture at Test
Rainfall-Inches
Age - Days
8
10
12
14
16
18
20
22
0
1
2
3
4
5
6
7
10
50
100
500
1000
5000
10000

Fig. 9

Fig. 10

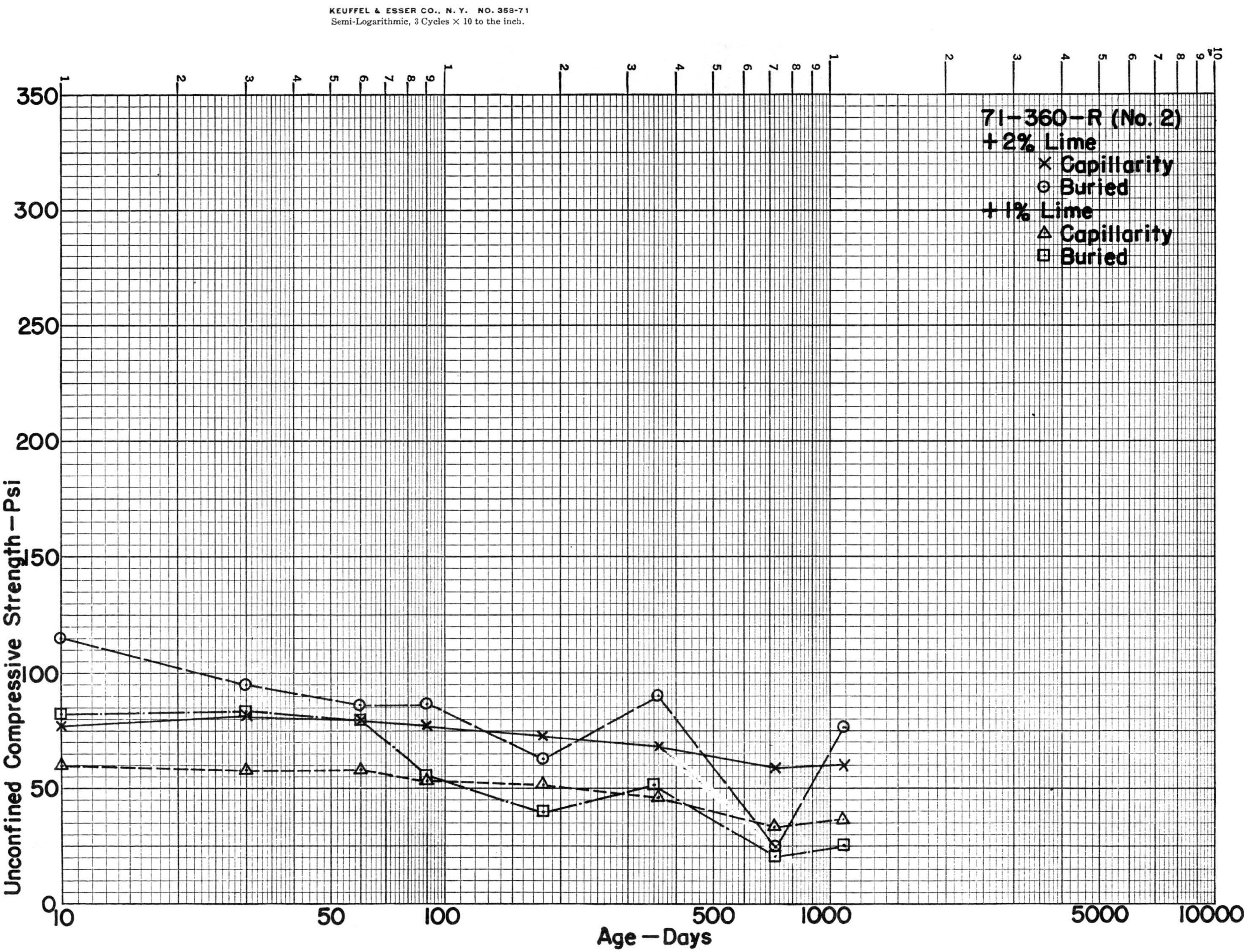
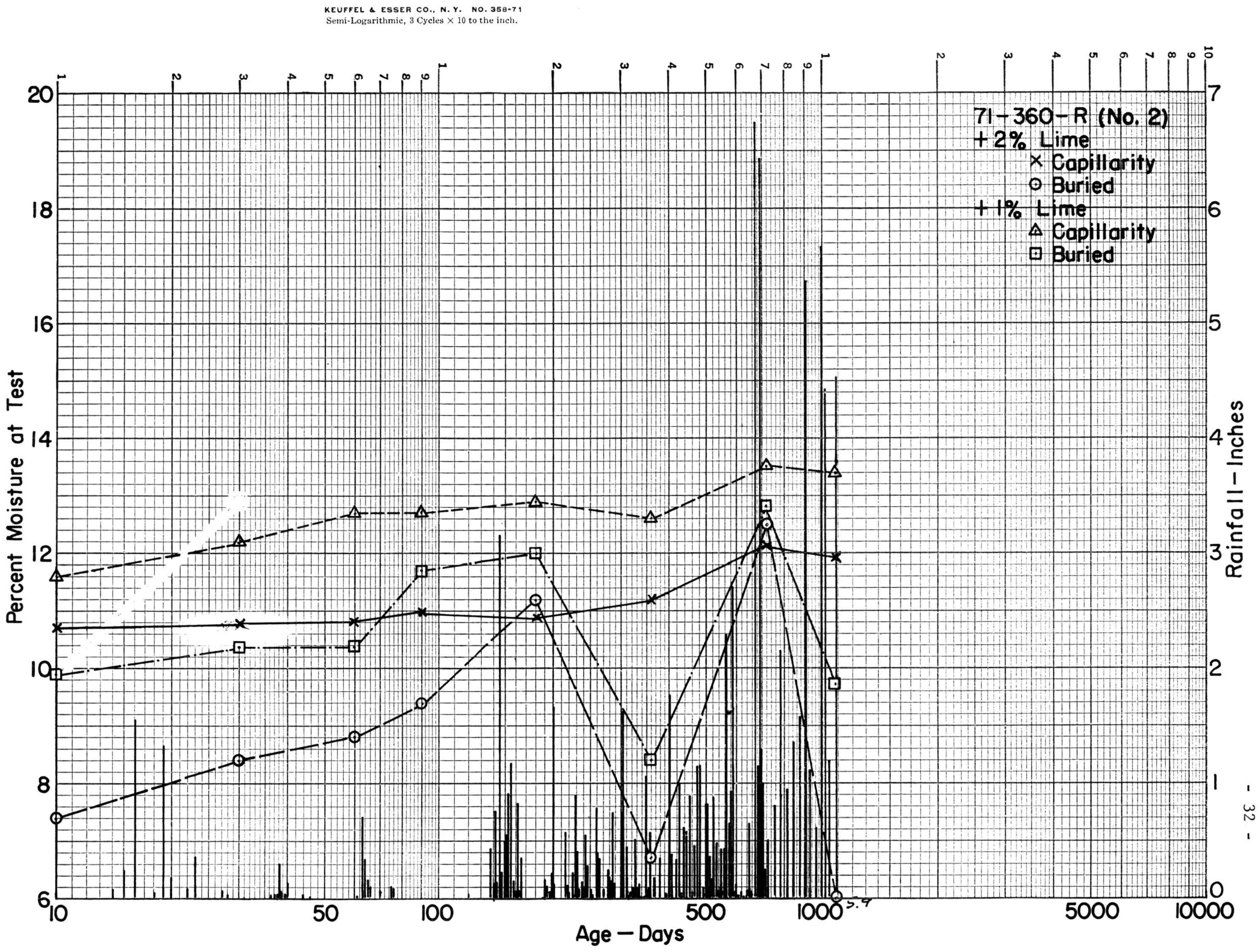

KEUFFEL & ESSER CO., N.Y. NO. 358-71
Semi-Logarithmic, 3 Cycles × 10 to the inch.
71-360-R (No. 2)
+2% Lime
× Capillarity
○ Buried
+1% Lime
△ Capillarity
□ Buried
Unconfined Compressive Strength—Psi
0
50
100
150
200
250
300
350
Age—Days
10
50
100
500
1000
5000
10000

Fig. 11


KEUFFEL & ESSER CO., N. Y. NO. 358-71
Semi-Logarithmic, 3 Cycles × 10 to the inch.
71-360-R (No. 2)
+2% Lime
× Capillarity
○ Buried
+1% Lime
△ Capillarity
⊡ Buried
Percent Moisture at Test
20
18
16
14
12
10
8
6
Rainfall-Inches
7
6
5
4
3
2
1
0
10
50
100
500
1000
5000
10000
Age — Days
5.4

Semi-Logarithmic, 3 Cycles × 10 to the inch.

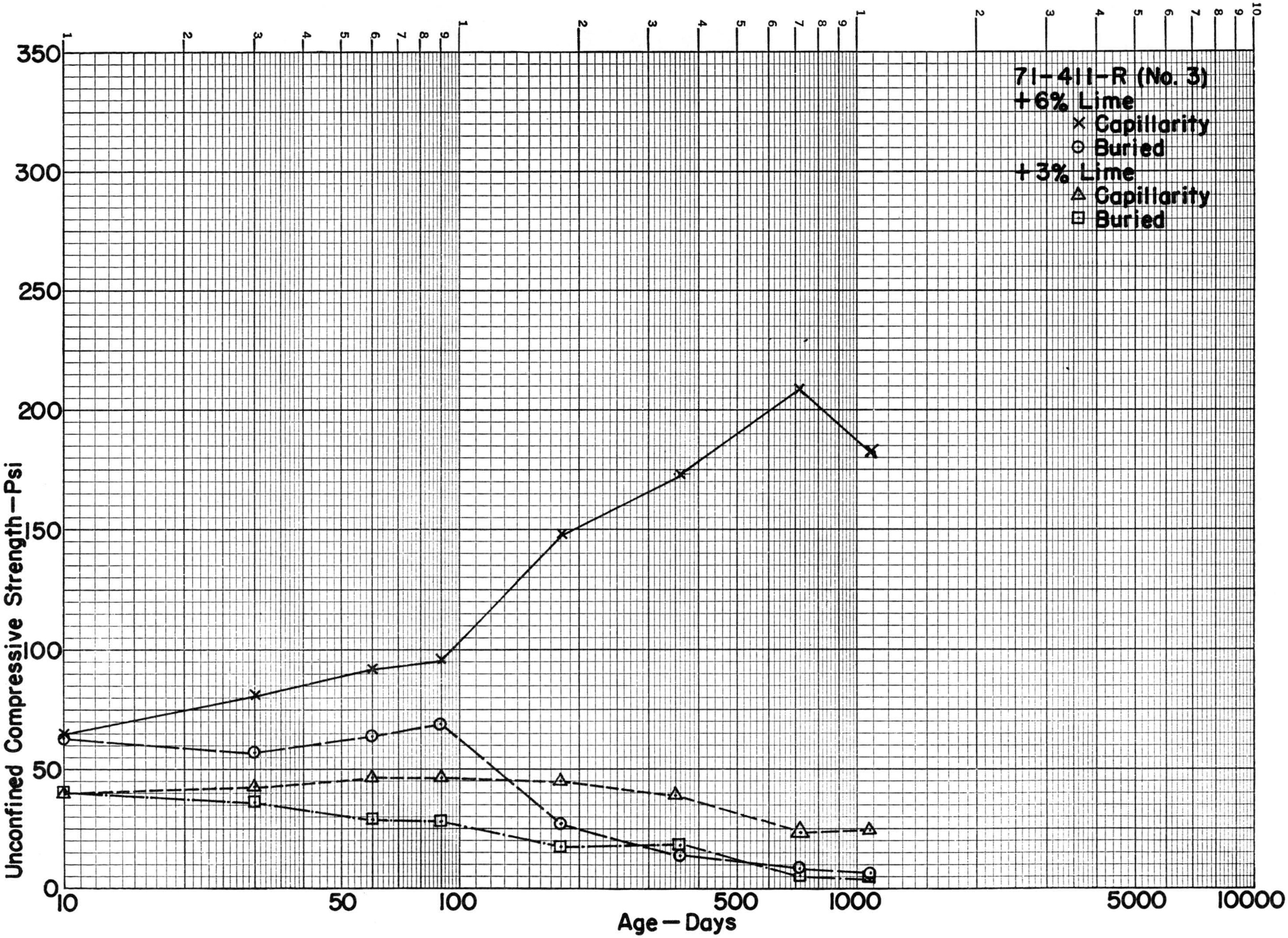


Fig. 12

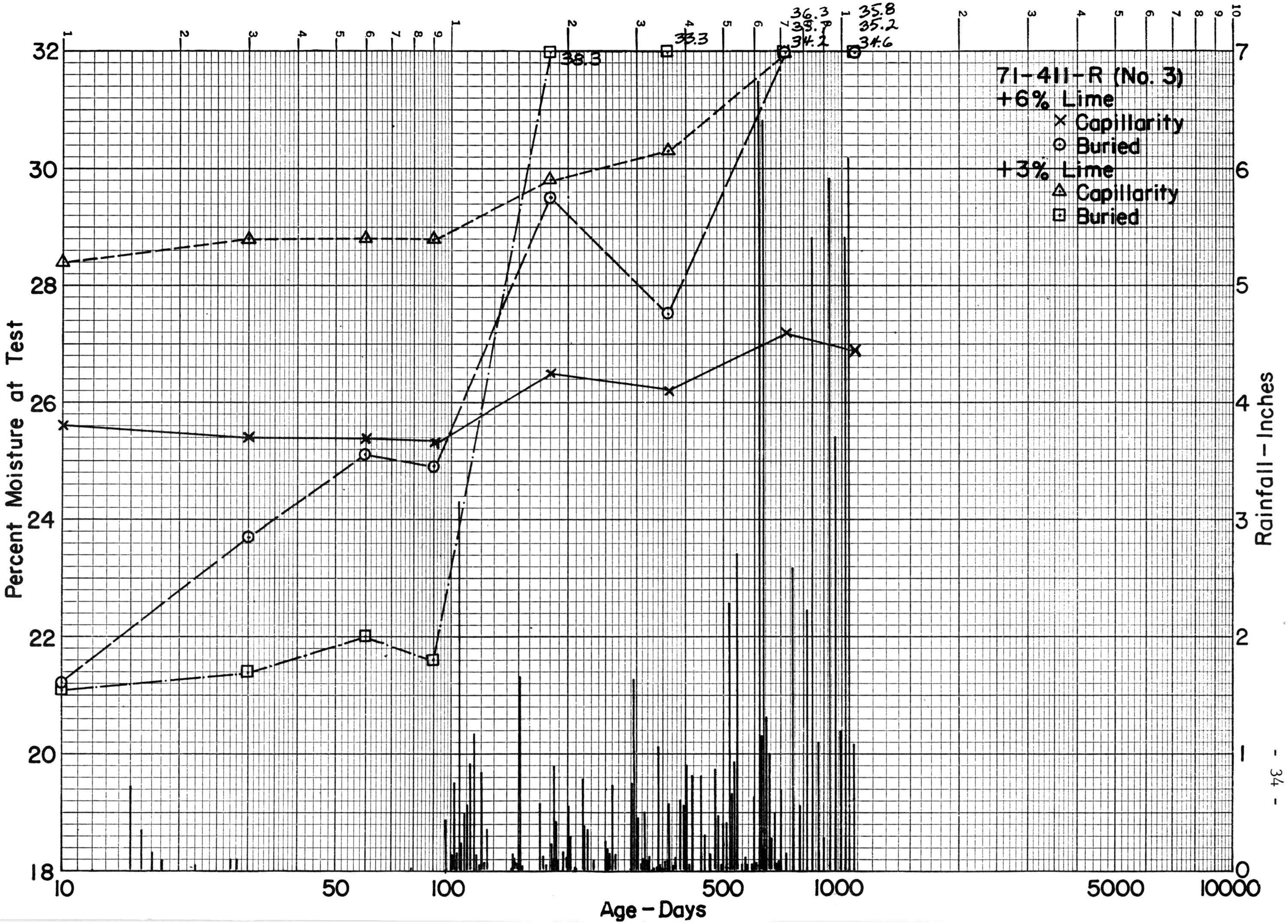

71-411-R (No. 3)
+6% Lime
× Capillarity
⊙ Buried
+3% Lime
△ Capillarity
⊡ Buried
Percent Moisture at Test
Rainfall - Inches
Age - Days
18
20
22
24
26
28
30
32
0
1
2
3
4
5
6
7
10
50
100
500
1000
5000
10000
38.3
33.3
36.3
33.8
34.2
35.8
35.2
34.6

Fig. 13

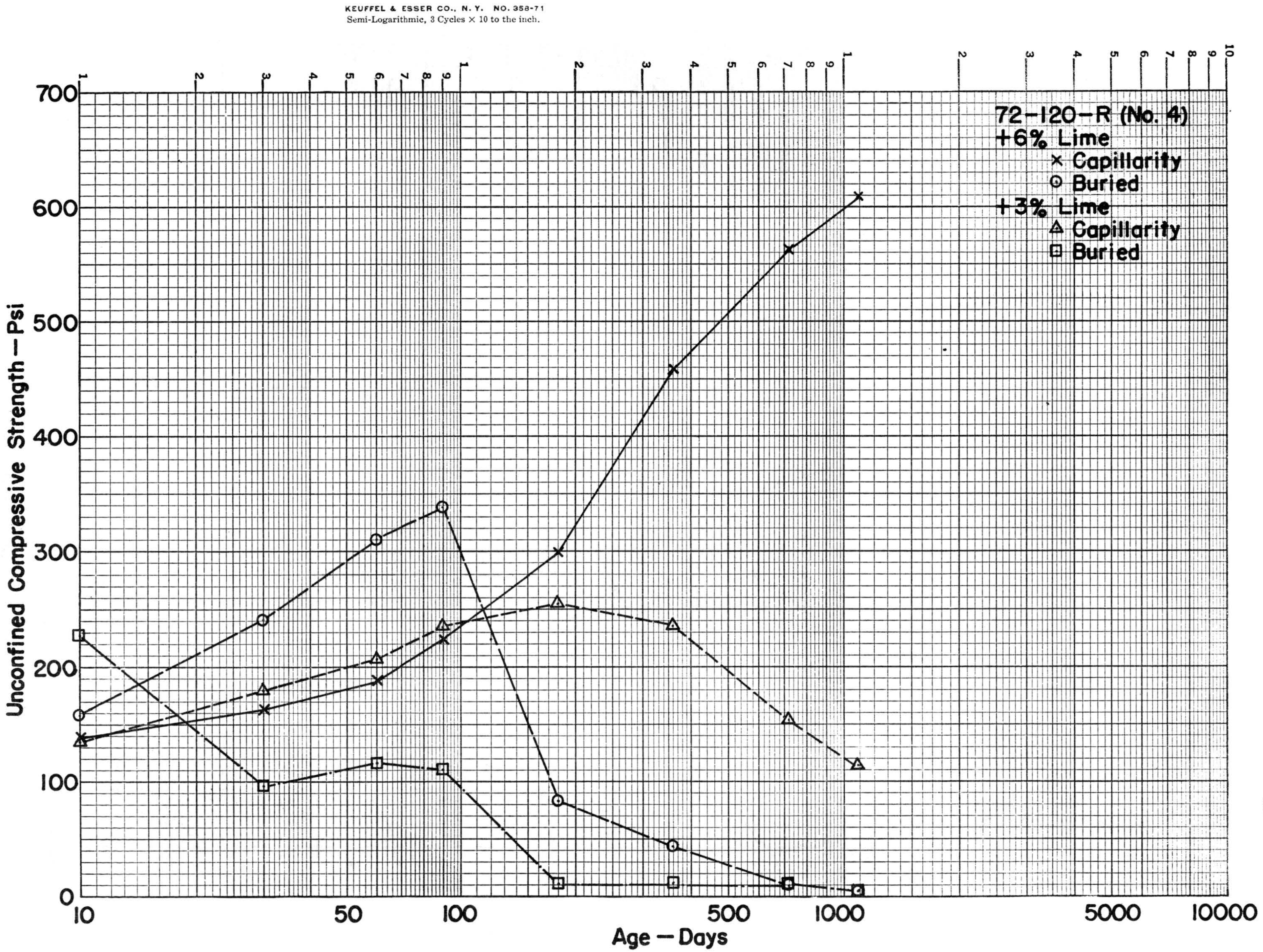

KEUFFEL & ESSER CO., N. Y. NO. 358-71
Semi-Logarithmic, 3 Cycles × 10 to the inch.
72-120-R (No. 4)
+6% Lime
× Capillarity
○ Buried
+3% Lime
△ Capillarity
□ Buried
Unconfined Compressive Strength — Psi
0
100
200
300
400
500
600
700
10
50
100
500
1000
5000
10000
Age — Days

Fig. 14

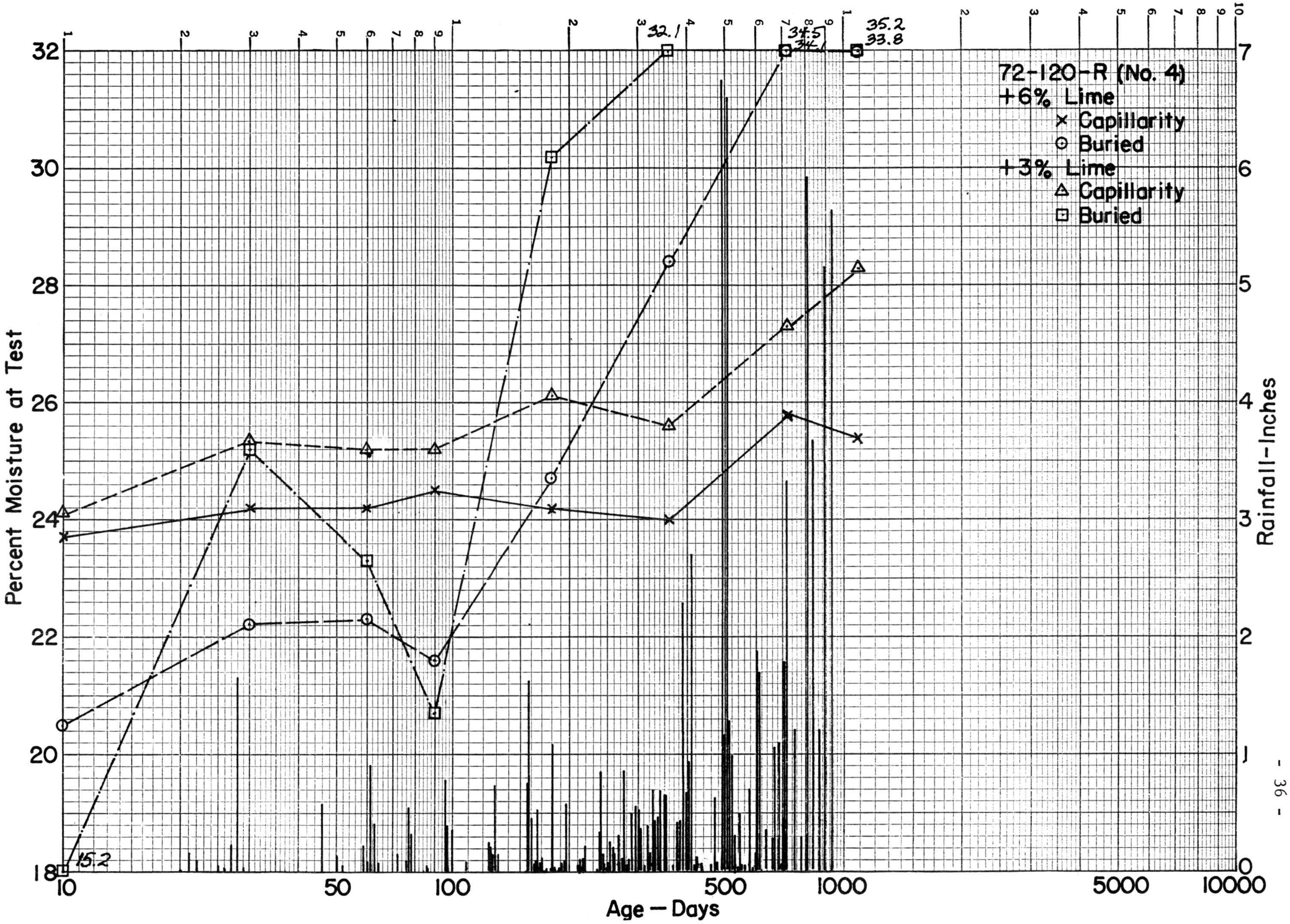
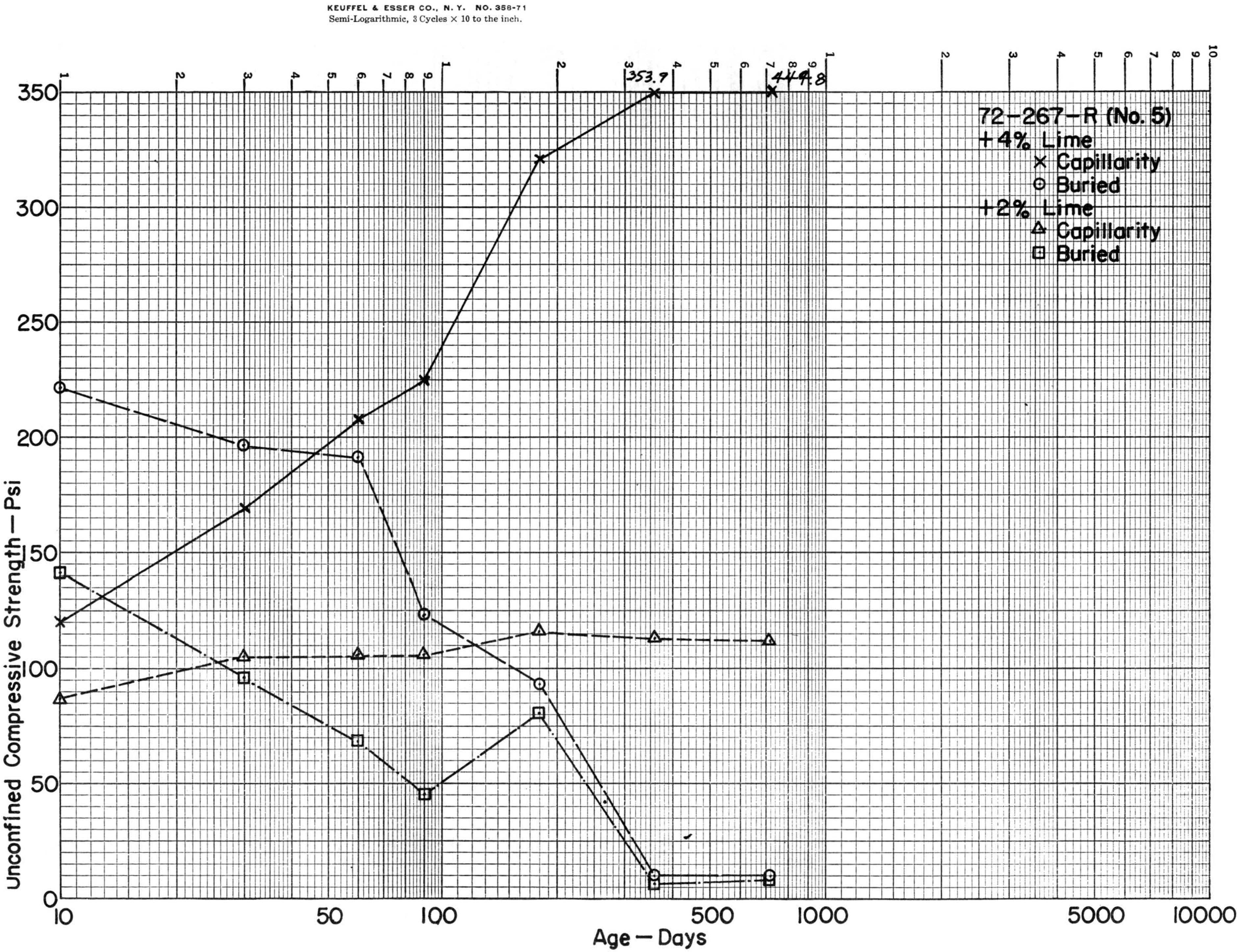

72-120-R (No. 4)
+6% Lime
× Capillarity
⊙ Buried
+3% Lime
△ Capillarity
⊡ Buried
Percent Moisture at Test
Rainfall-Inches
Age — Days
10
50
100
500
1000
5000
10000
18
20
22
24
26
28
30
32
0
1
2
3
4
5
6
7
32.1
34.5
34.1
35.2
33.8
15.2

Fig. 15



KEUFFEL & ESSER CO., N. Y. NO. 358-71
Semi-Logarithmic, 3 Cycles × 10 to the inch.
72-267-R (No. 5)
+4% Lime
× Capillarity
○ Buried
+2% Lime
△ Capillarity
□ Buried
353.9
449.8
Unconfined Compressive Strength — Psi
0
50
100
150
200
250
300
350
Age — Days
10
50
100
500
1000
5000
10000

Fig. 16

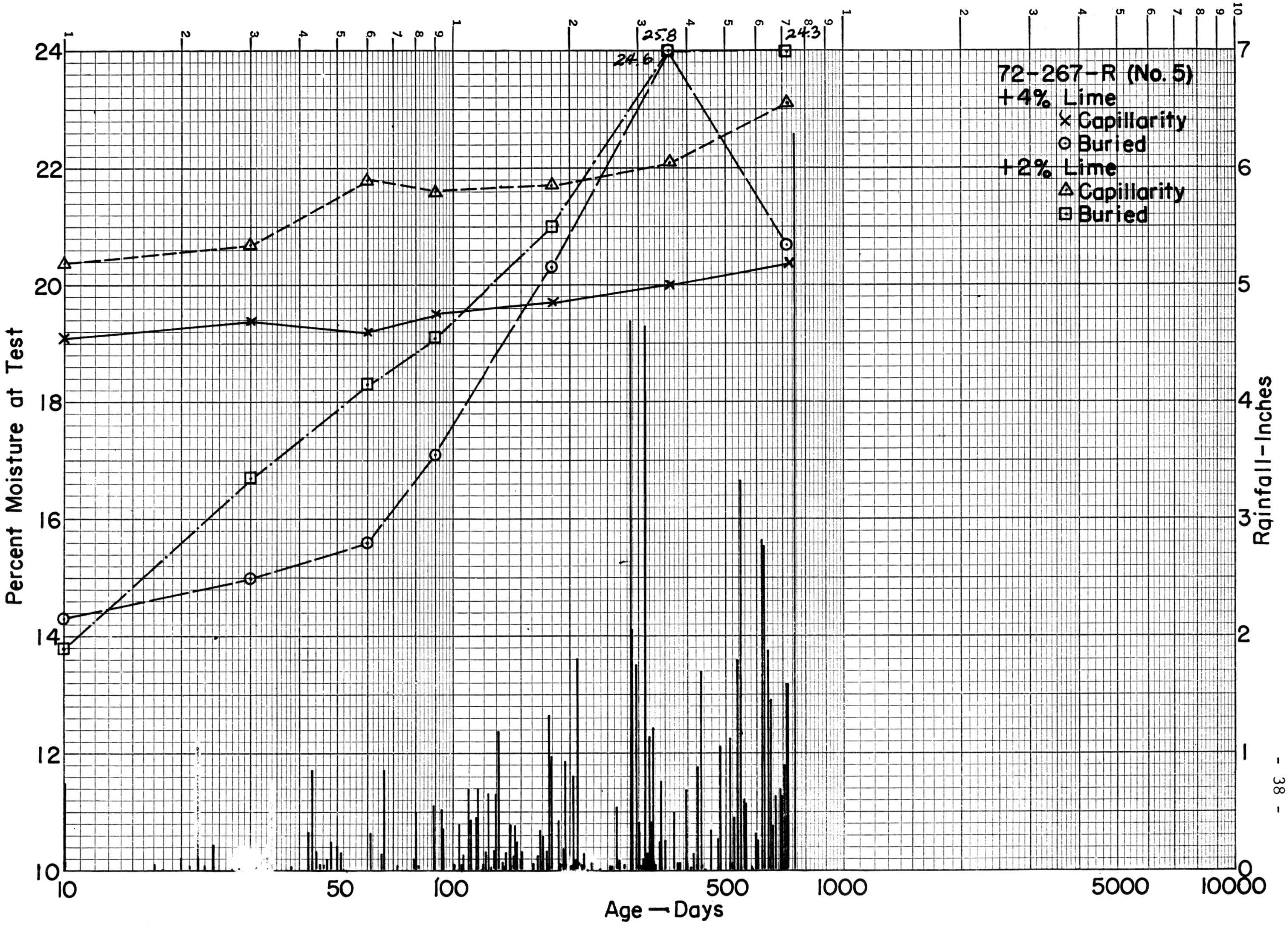

72-267-R (No. 5)
+4% Lime
× Capillarity
○ Buried
+2% Lime
△ Capillarity
⊡ Buried
25.8
24.6
24.3
Percent Moisture at Test
Rainfall-Inches
Age — Days
10
12
14
16
18
20
22
24
0
1
2
3
4
5
6
7
10
50
100
500
1000
5000
10000

Fig. 17

Semi-Logarithmic, 3 Cycles × 10 to the inch.

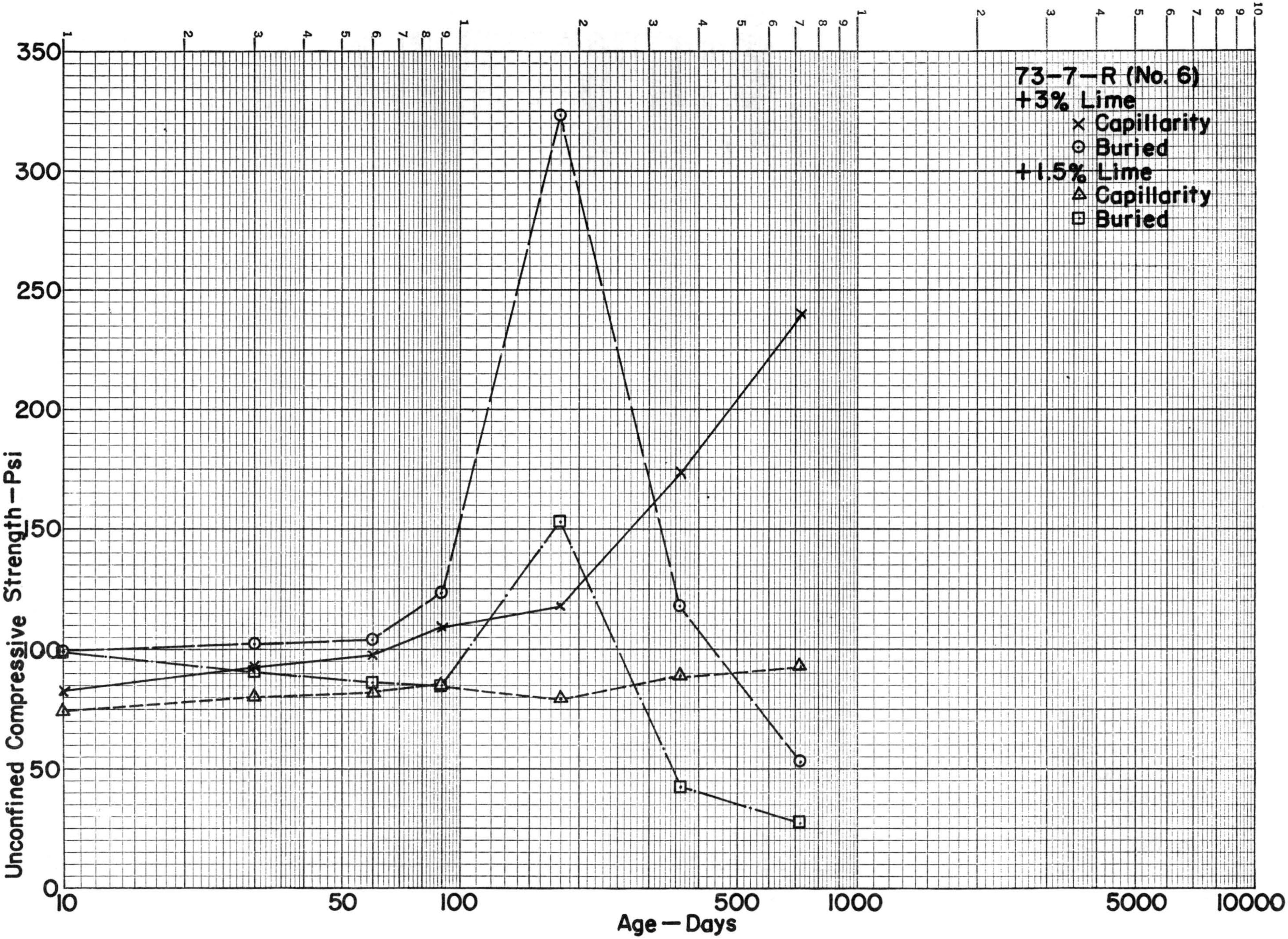


Fig. 18

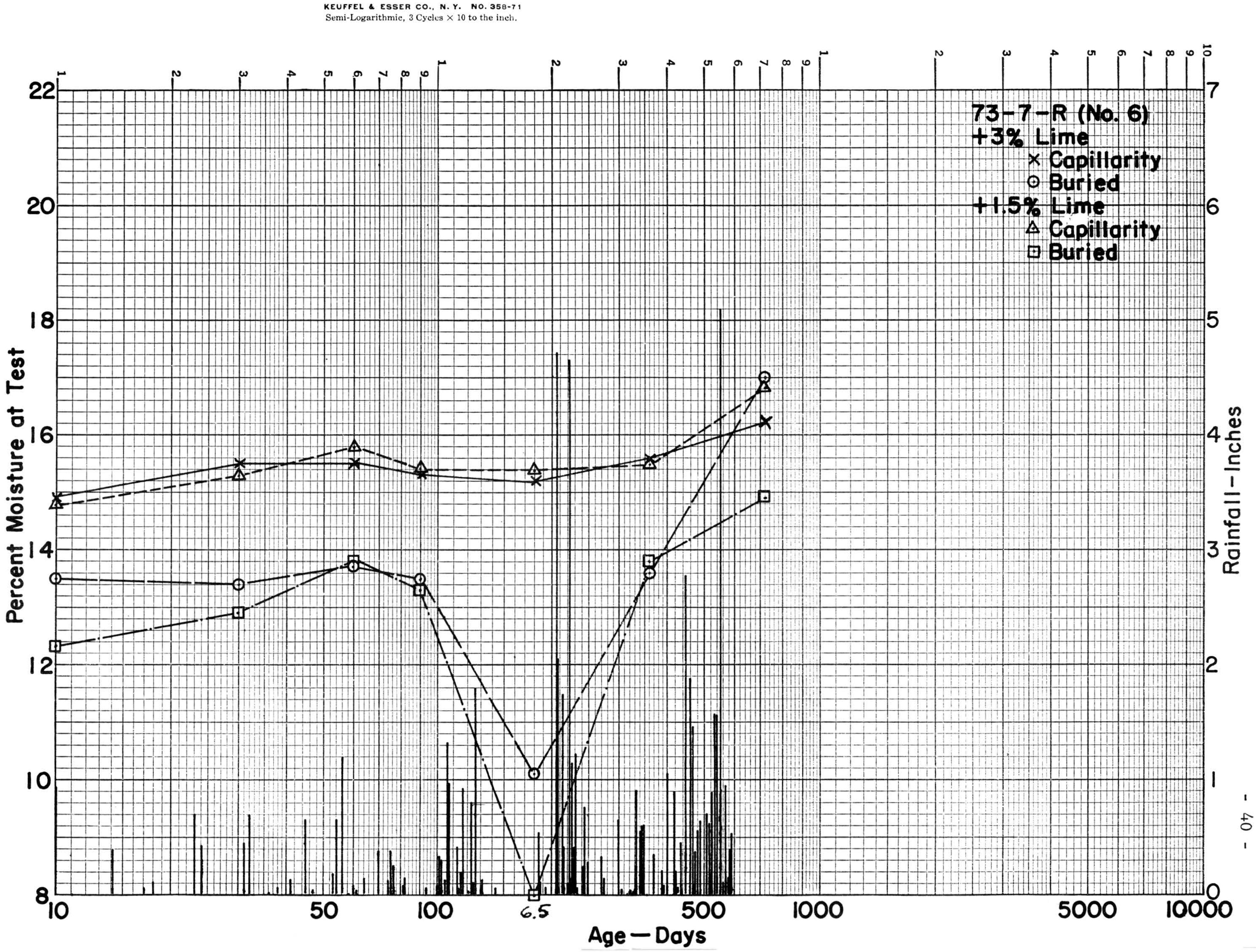

KEUFFEL & ESSER CO., N.Y. NO. 358-71
Semi-Logarithmic, 3 Cycles × 10 to the inch.
73-7-R (No. 6)
+3% Lime
× Capillarity
⊙ Buried
+1.5% Lime
△ Capillarity
⊡ Buried
Percent Moisture at Test
Rainfall-Inches
Age — Days
22
20
18
16
14
12
10
8
7
6
5
4
3
2
1
0
10
50
100
6.5
500
1000
5000
10000

Fig. 19

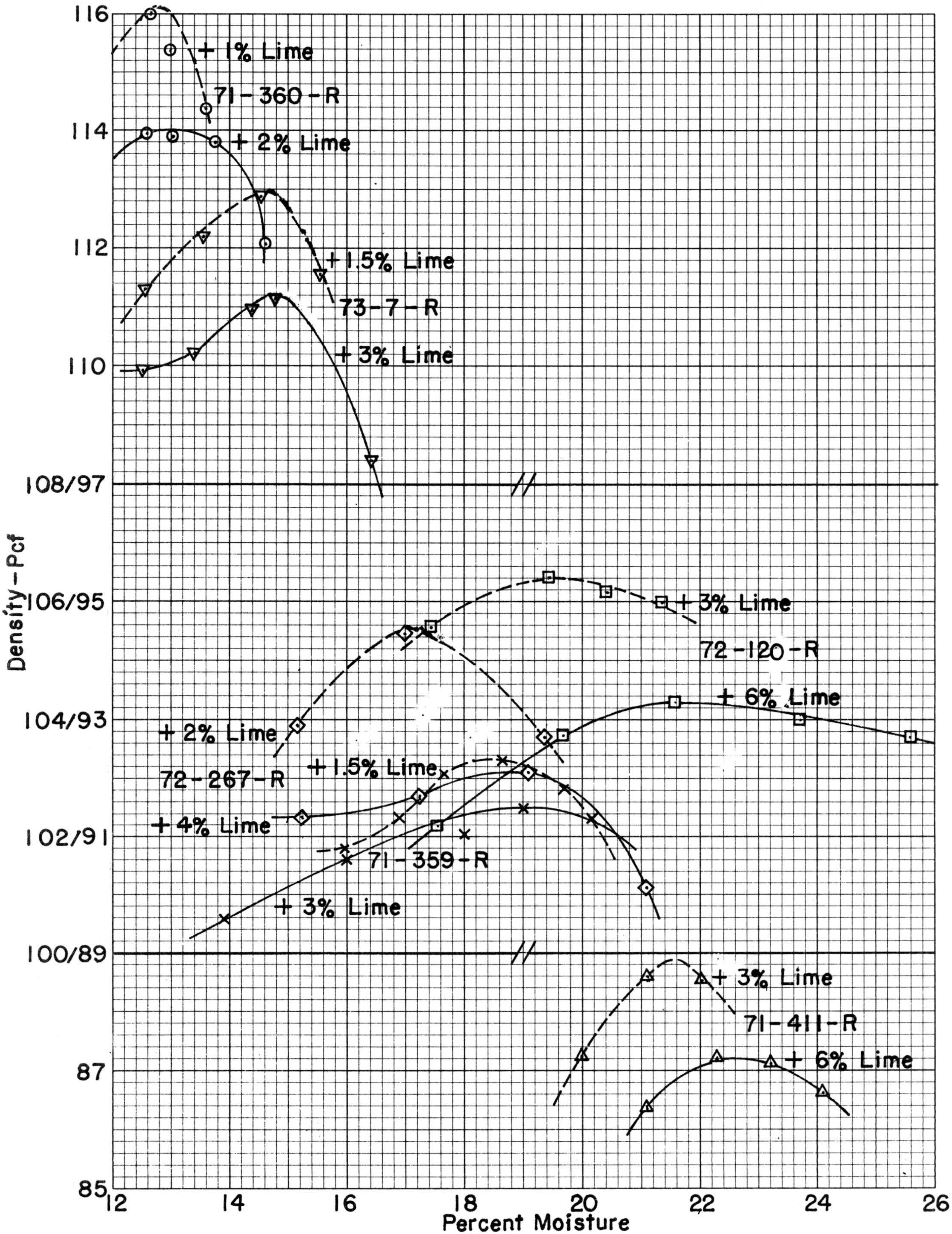

Density - Pcf
116
114
112
110
108/97
106/95
104/93
102/91
100/89
87
85
12
14
16
18
20
22
24
26
Percent Moisture
+ 1% Lime
71-360-R
+ 2% Lime
+ 1.5% Lime
73-7-R
+ 3% Lime
+ 3% Lime
72-120-R
+ 6% Lime
+ 2% Lime
72-267-R
+ 1.5% Lime
+ 4% Lime
71-359-R
+ 3% Lime
+ 3% Lime
71-411-R
+ 6% Lime

Fig. 20

M/D & TRIAXIAL WORK SHEET

LAB NO. 71-359-R

2.9 % HYGRO ALLOWED

Date Molded	30 Sep 71			→	1 Oct 71					→	4 Oct 71	→
Sample No.	1	2	3	4	5	6	7	8	9	10	11	12
Compactive Effort	2P 3% L											→
Total % Water	12.0	14.0	16.0	18.0	20.0	22.0	19.0	19.5	19.0			
Pounds Material	15.000 .437 lime	13.000 .379 lime	13.250 .386 lime	13.250 .386 lime	13.250 .386 lime	13.250 .386 lime	13.250 .386 lime	13.250 .386 lime	13.500 .394 lime			
Pounds Water Desired	1.802	1.822	2.122	2.387	2.653	2.918	2.520	2.586	2.568			
Pounds Hygroscopic Water	.423	.366	.373	.373	.373	.373	.373	.373	.380			
Pounds Water Added	1.379	1.456	1.749	2.014	2.280	2.545	2.147	2.213	2.188			
Tare Weight of Jar	1.370	1.370	1.370	1.370	1.370	1.370	1.370	1.370	1.370			
Weight Jar and Water	2.749	2.826	3.119	3.384	3.650	3.915	3.517	3.583	3.558			
Mold No.	2											→
Wet Wt. Specimen & Mold												
Tare Weight Mold												
Wet Weight Specimen	12.622	14.840	15.379	15.642	15.907	16.158	15.786	15.828	16.072	16.073	16.071	16.083
Height of Mold												
Dial Reference		7.0										→
Dial Reading		.865	.920	.884	.848	1.137	.854	.854	1.001	1.010	1.012	1.008
Height Specimen	6.966	7.865	7.920	7.884	7.848	8.137	7.854	7.854	8.001	8.010	8.012	8.008
Vol. per Linear Inch	.016478											
Vol. of Specimen	.114786	.129599	.130506	.129913	.129319	.134081	.129418	.129418	.131840	.131989	.132022	.131956
Wet Density Specimen	109.96	114.51	117.84	120.40	123.01	120.51	121.98	122.30	121.91	121.76	121.73	121.88
Dry Weight Pan & Specimen	15.451	17.002	17.199	17.448	17.740	17.413	16.922	17.199			17.471	17.360
Tare Weight Pan	4.171	3.971	3.939	4.192	4.503	4.171	3.658	3.922	S.C.	S.C.	3.951	3.824
Dry Weight Material	11.280	13.031	13.260	13.256	13.237	13.242	13.264	13.277	13.522	13.522	13.520	13.536
Weight Water	1.342	1.809	2.119	2.386	2.670	2.916	2.522	2.551	2.550	2.551	2.551	2.547
Percent Water on Total	11.90	13.88	15.98	18.00	20.17	22.02	19.01	19.21	18.86	18.87	18.87	18.82
Dry Density	98.27	100.55	101.60	102.03	102.36	98.76	102.50	102.59	102.57	102.43	102.41	102.58
Guestimated Dry Density	98.18	100.45	101.59	102.03	102.51	98.78	102.50	102.34	102.45	102.32	102.29	102.42

Fig. 21

PETROGRAPHIC ANALYSIS

Soil Sample 71-359-R
(Sample No. 1)

Geologic Setting

Surface sediments in the area consist of silty sands which make up the upper terrace deposits (Quaternary Age) along the South Sulphur River. The underlying bedrock material consists of silty and sandy clays of the Navarro Group (Upper Cretaceous Age).

Mineralogy

The following list of mineral components is based on a modified grain count method and the percentages are approximations.

90% Quartz (including chert and chalcedony)
10% Accessory minerals: clays, limonite, hematite, feldspar and opaque metallics (magnetite and ilmenite)

Although very minor in overall volume of the sample, clay minerals were observed both as grain coatings and as isolated lumps (Fig. 22) which readily slake, expand slightly, and fall apart in the presence of water. Figures 23 and 24 are reflected and transmitted light views to show particle gradation and shape. The sand-size fraction, Fig. 24, is sub-rounded to sub-angular. The bulk of the sample is very fine sand to silt size and the gradation appears to be poor. No carbonates were detected during acid treatment.

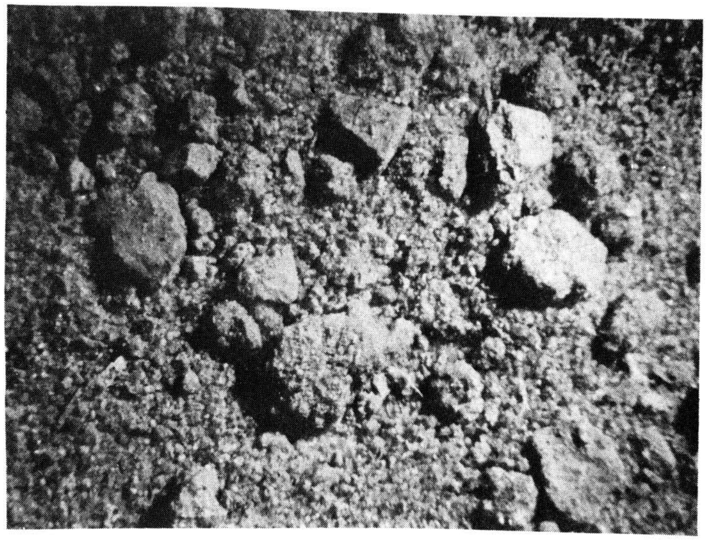


Fig. 22 View of sample #359-R showing clay lumps and silt conglomerates. (Mag. 7.5X)

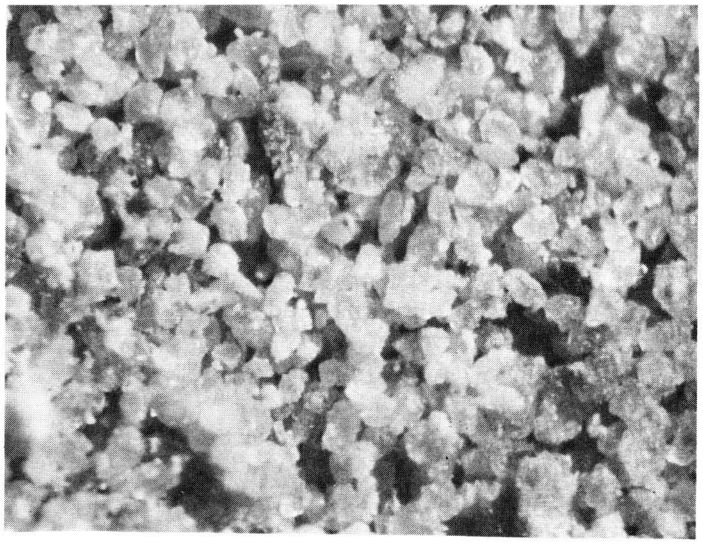


Fig. 23 Sample viewed with reflected light. (Mag. 45X)

Fig. 24 Sample viewed with transmitted light. (Mag. 52X)

Soil Sample 71-411-R
(Sample No. 3)

Geologic Setting

The site is on the flood plain deposits (Quaternary Age) of the South Sulphur River near the man-made "Rectified Channel." In general, the sediments in the area consist of alluvial silt and clay deposits.

Mineralogy

Clay minerals comprise the bulk of the sample as revealed through the microscope, however, appreciable quantities of silt-sized quartz, opaque minerals, metallic oxides and organic debris (plant tissue and charcoal) were also noted. Most of the clay lumps in the sample slaked upon contact with water and had negligible volume change. The shape of the silt-sized quartz grains was angular to subangular. The dark gray color of the sample is caused mainly by organic content and metallic oxides. Calcium carbonate, as indicated by acid treatment was essentially negligible.

The accompanying photomicrographs show the clay lumps as received (Fig. 25), the mud-cracked appearance of a dried sample after being slaked with water (Fig. 26), and a sample mounted in water viewed with transmitted polarized light (Fig. 27).

Fig. 25 Soil sample #71-411-R showing clay lumps and fine silt. (Mag. 7.5X)

Fig. 26 Slaked and dried sample showing shrinkage cracks. (Mag. 7.5X)

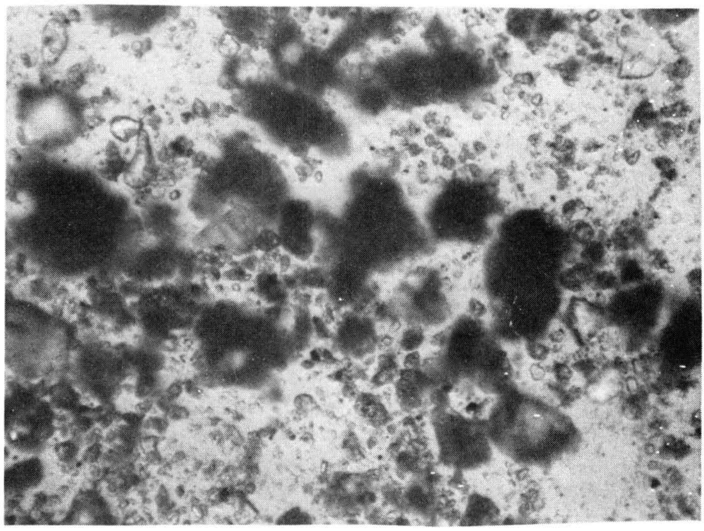


Fig. 27 Transmitted polarized light photomicrograph showing conglomerates of clay (amber and brown bodies) and silt-sized quartz grains (blue and yellow grains. (Mag. 200X)

Soil Sample 71-360-R
(Sample No. 2)

Geologic Setting

The site is geologically situated near the contact of Quaternary Age river terrace deposits and underlying Marlbrook marl and Navarro clays. The latter two are Upper Cretaceous in age.

Mineralogy

Scanning the sample under low magnification revealed appreciable amounts of organic matter such as lignite, charcoal, plant tissue, seeds and pollen. The silt conglomerates, as shown in Figure 28, surprisingly contained little clay when broken down with water. Although some clay was present, it essentially was found as grain coatings only. No carbonates were detected during acid treatments. The following minerals comprised the fine-sand size fraction:

Quartz (clear, milky and chert)
Iron oxides (hematite and limonite)
Opaque metallics (magnetite and ilmenite)

Figures 29 and 30 show that the bulk of the sample is glassy-like quartz with some minor accessory minerals (listed above). The organic fractions were removed by flotation methods and were not included in these two photos. However, particle shape (subangular to subrounded) and gradation can be noted. No attempt was made to identify the finer silt-size and clay fractions.

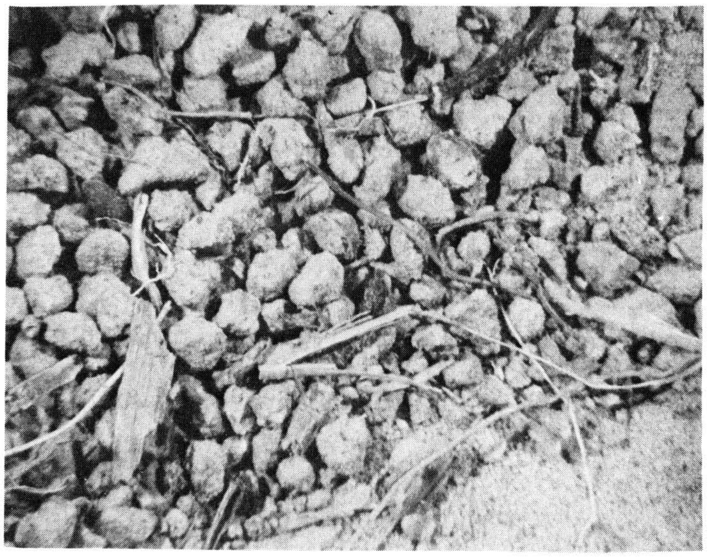


Fig. 28 View of Sample #360-R showing plant tissues, roots and seeds. The silt lumps contain very little clay and are easily broken up. (Mag. 3.2X)

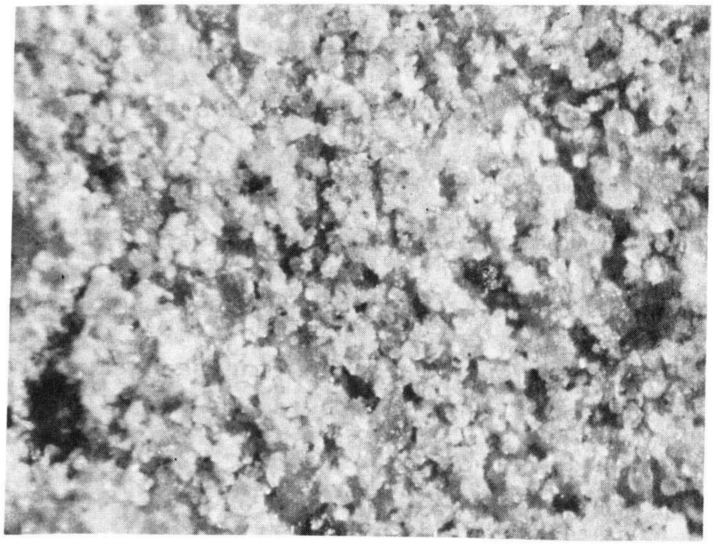


Fig. 29 Sample viewed with reflected light. (Mag. 52.5X)

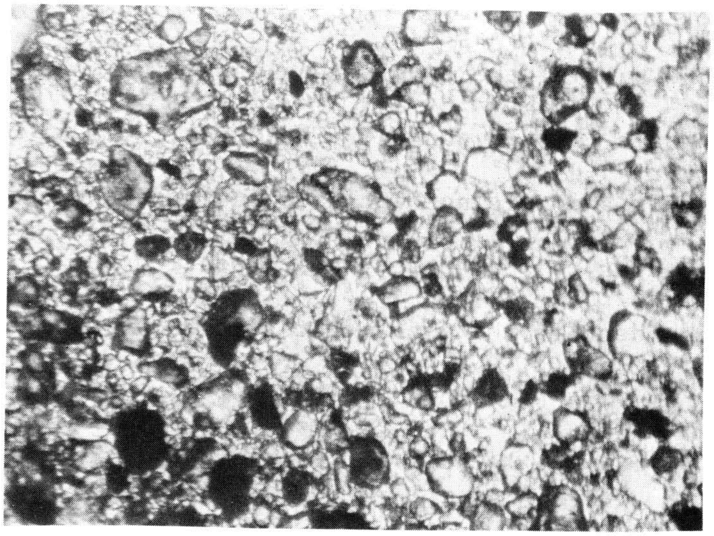


Fig. 30 Sample viewed with transmitted light. (Mag. 52.5X)

Soil Sample 72-120-R
(Sample No. 4)

Geologic Setting

The soils at this locality are products of flood-plain deposits of Recent Age.

Mineralogy

The buff colored sample was determined microscopically to be primarily composed of clay, fine clay lumps, silty clay (85-90) with minor amounts of quartz, feldspar and calcium carbonate (10-15%). Traces of opaque minerals (metallic oxides) and plant debris were also observed.

The attached photomicrographs show the character of the silty clay soil after wetting and drying. Only slight swelling was noticed when moistened and some slight shrinkage occurred upon drying (Fig. 31). Figure 32 illustrates the silty condition of the clay sample. The larger, irregular, light colored areas are "clay lumps." Silt-sized quartz and calcium carbonate grains are also present.

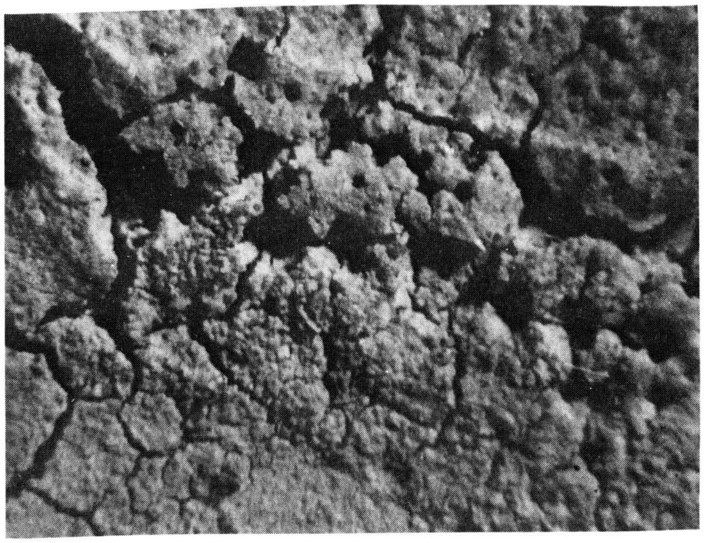


Fig. 31 View of silty-clay sample 72-120-R showing shrinkage cracks upon drying. (Mag. 10X)

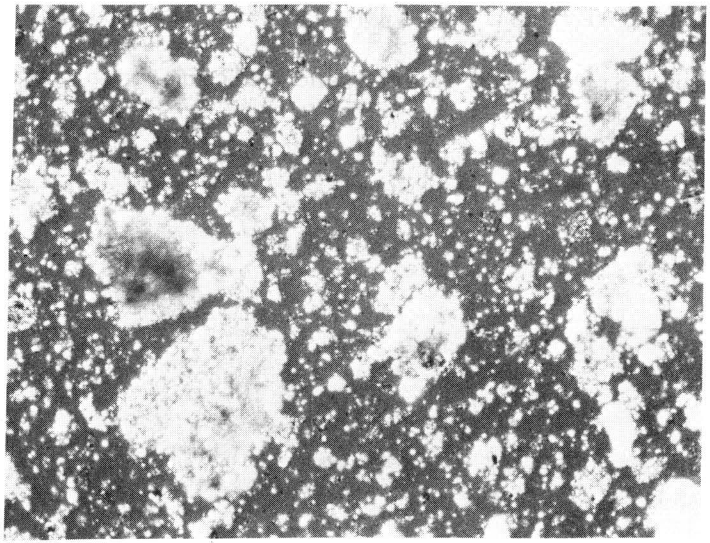


Fig. 32 View of above soil sample showing clay lumps and silt particles. Transmitted polarized light. (Mag. 125X)

Soil Sample 73-7-R
(Sample No. 6)

Geologic Setting

The locality is geologically situated along the outcrop of the Navarro formation, Upper Cretaceous Age.

Mineralogy

This soil sample consists of clayey and silty sand. Enough clay materials are present to make the soil lumpy. The subrounded sand grains are composed primarily of quartz. No carbonates were detected with acid treatment. Some plant tissue was observed. No swelling of the clayey sand lumps was found.

The attached photomicrographs show the characteristics of the soil sample.

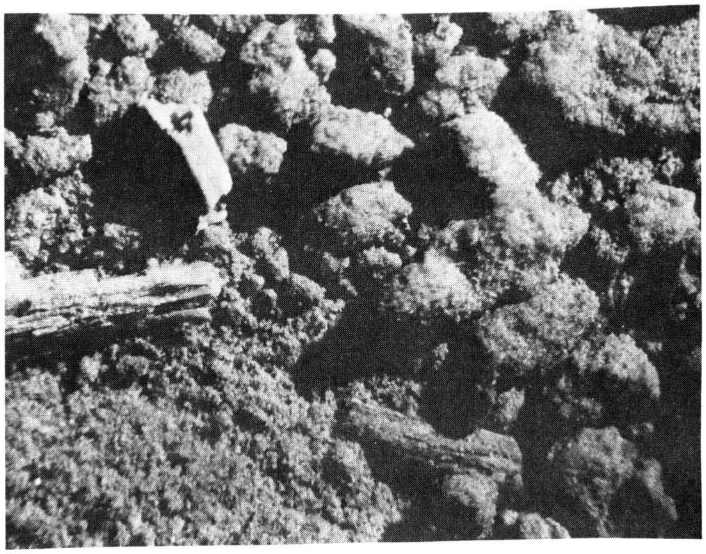


Fig. 33 View of Soil Sample 73-7-R showing clayey sand lumps and plant fragments. (Mag. 10X)

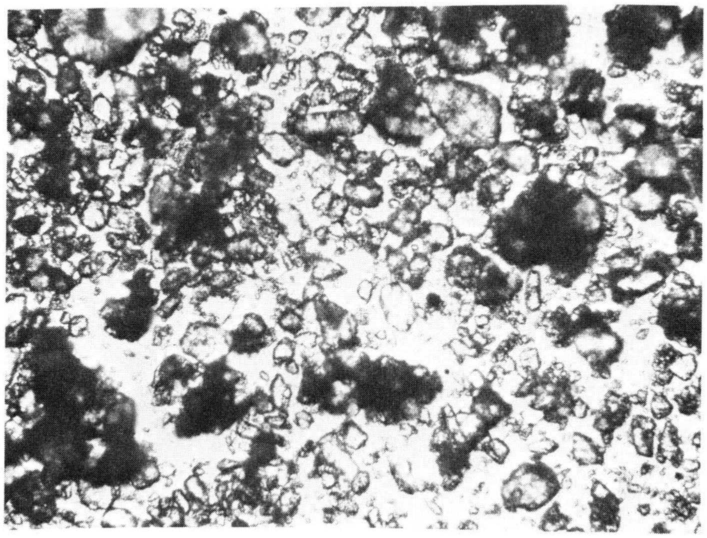


Fig. 34 Photomicrograph of above sample showing sand grains with some clay material. Transmitted light. (Mag. 125X)

Soil Sample 72-267-R
(Sample No. 5)

Geologic Setting

Soils at this locality are products of flood-plain deposits of Recent Age.

Mineralogy

This soil sample consists of silty clay (75-80%), some of which is brown and some dark gray. The silt and sand particles are composed primarily of well-rounded quartz grains (20-25%). Much of the brownish color results from limonite (iron oxide) stain. Microscopic examination and acid treatment indicates that no carbonates are present. Some plant debris is present. When slaked with water no swelling was observed; however, the soil became sticky when rubbed between the fingers.

The attached photomicrographs show the characteristics of the sample as observed microscopically.

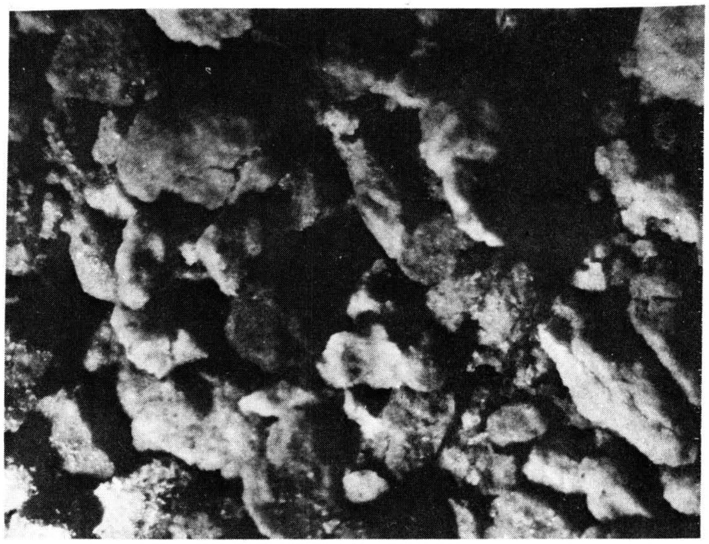


Fig. 35 View of sandy clay sample 72-267-R. (Mag. 10X)

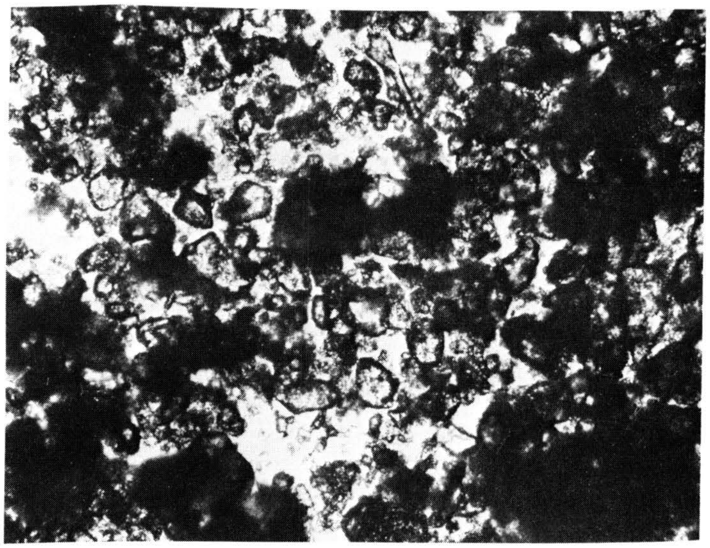


Fig. 36 View of sample 72-267-R showing sandy nature of clay soil. Transmitted plane light. (Mag. 125X)

APPENDIX

Test Method Tex-100-E

June 1962

Texas Highway Department

Materials and Tests Division

SURVEYING AND SAMPLING SOILS FOR HIGHWAYS

Scope

The soil survey is an important part of the engineering survey for the design, location and construction of a highway. The investigation should furnish the following information:

1. The extent and location of each type of soil or rock in the subgrade
2. The condition of subsoils (moisture and density) upon which embankments will be constructed
3. The design of ditches and backslopes in cut sections to prevent slides
4. The location and selection of suitable material for fills, subgrade treatment and backfill adjacent to structures
5. The location of local material for base and aggregate
6. The need for stabilization of subgrade, subbase and base materials
7. The investigation of soils for their supporting values as foundation materials.

Securing Representative Samples

A representative sample of disturbed soil consists of a combination of the various particles in exactly the same proportion as they exist in the natural ground, roadway or pit. The proper method to use in sampling will depend on the place, the quantity of material, and the proposed treatment and the tests to be performed in the laboratory. Unless it is known that different types of materials are to be uniformly mixed in certain proportions, samples should contain only materials of like color and texture, and should not be a composite of materials apparently different in character.

It is impossible to obtain from the earth a sample which is entirely undisturbed, because the removal of the surrounding soil releases the pressure from the specimen and this causes a certain amount of disturbance. The intent of this sampling, however, is to obtain a core of soil from the earth with as little disturbance as possible to the natural density, moisture content, and the structural arrangement of the particles. Such a soil core is satisfactory for all practical purposes and can be classified as an undisturbed sample of soil.

Record Form

The soil samples should be properly identified on Form 202, Sample Identification Slip or Form No. 513.

Apparatus

Many factors will affect the type and amount of equipment to be used in sampling such as the nature of the terrain, the kind of material, the depth of material below the surface, the equipment available and the use that will be made of the survey information. Small hand tools are satisfactory for use where the materials are at a shallow depth and can be easily dug. However, if the materials are very hard, power equipment and dynamite may be more economical to use in sampling. The only feasible method of sampling strata located at a considerable depth below the surface is by means of a power drill machine with core or auger attachment. The following list of equipment should suffice for ordinary conditions:

1. Post-hole digger
2. Soil auger
3. Pick
4. Shovel
5. Prospector's pick
6. Jack hammer and air-compressor
7. Power drill rig with core and auger attachment
8. Sample-splitter or quartering cloth
9. A supply of sample bags and moisture cans
10. Engineer's level and level rod
11. Metallic tape (100 ft.) and 6 ft. rule
12. Supply of stakes
13. Supply of paraffin and cheese cloth
14. Gasoline burner and pan
15. Box for packing undisturbed cores

Size of Sample

It should be clearly understood that the larger the field sample, the greater probability of its being representative. The size of sample needed to fulfill the requirements will depend upon the maximum size aggregate in the material, the number and kind of tests to be made in the laboratory. The largest diameter of undisturbed core that is feasible to obtain will give the most reliable test data. This is especially true of undisturbed cores of fractured clays.

The minimum size soil sample for various tests is listed below:

1. Soil constants - 3 to 30 pounds depending upon the amount of soil binder
2. Sieve analysis - 30 pounds
3. Disintegration of aggregate by ball mill - 30 pounds. Los Angeles abrasion test - 30 pounds.

4. Triaxial test - 200 pounds
5. Soil-cement stabilization - unconfined compression test - 200 pounds
6. Soil-lime stabilization - 200 pounds
7. Soil-asphalt stabilization, triaxial test - 300 to 400 pounds for one type asphalt.
8. Moisture density determination, Tex-114-E - 150 pounds

Sampling Subgrade Soils

The greatest benefits from the least number of tests can be obtained by establishing soil area concepts based upon a study of available USDA county soil maps, geology maps, contour maps, aerial photographs and a reconnaissance of exposed soil formations and materials encountered in test holes. The field work consists of making an examination of soils by means of test holes placed at close enough intervals and sufficient depth to determine the extent of each significant soil type. The soil types may be recognized by observing the color, textural structure and physical characteristics. After the soil types and boundaries of each material are established, representative samples are selected for laboratory testing.

Sampling Pit and Borrow Source

Tests should be made on all pit and borrow source materials to determine the quality and quantity of materials and to furnish the Engineer a means of checking these materials during construction.

To sample an exposed surface of material in an old pit, geological out-crop or in a large test hole, a groove of uniform cross-sectional area should be cut down the face for the full depth of each type of material encountered. In many locations a drilling rig equipped with auger or core bit can be used effectively when the source is large or the overburden thick. Each type of material is identified as the holes are being dug and the depth and location of each stratum accurately measured and recorded.

A sufficient number of test holes should be made to outline the boundary of the source and to discover, if possible, any variations in materials. Several samples of each type of material are selected and tested separately for soil constants and grading. It is usually not necessary to test all of the materials in every test hole dug. In sampling a source consisting of several different types of materials, the various types encountered in any one test hole may be combined in their proper proportions, if mixing these materials during construction is contemplated.

Sampling Flexible Base Material from Stockpile or Cars

Flexible base materials very often segregate badly when placed in stockpiles or loaded in freight cars. In such cases it may be necessary to take samples from several different locations in the car or pile. Materials should be sampled in sufficient depth to get average products from the pile. Areas of segregation such as exist in the junction of two piles should be avoided. The test results for these samples are then compared for variations. It is usually easier to obtain representative samples during the crushing and loading operations.

Sampling from Roadway

If a truck load of material is to be delivered to the road, deposited within a given small area and uniformly mixed, a representative sample will consist of a combination of several portions taken at various points over the area. It is usually preferable to secure representative samples after the windrow of truck piles have been blended.

Composite Samples

If several different types of material are to be thoroughly and uniformly mixed for its contemplated use, such as material from a borrow or material source, a representative sample of the final product may be secured by selecting a representative sample of each of the various types of material encountered and combining these into a composite sample made up of exactly the same proportion of each type material as is expected in the final mixture.

Quartering a Sample

After the sample has been systematically collected, so that the entire quantity of material being sampled has been represented proportionally in the gross sample, it shall be crushed by hand or mechanical means down to the maximum size permitted in its contemplated use. The crushing operation shall be done under such conditions as to prevent loss of material or accidental admixture of foreign material. The gross sample is then ready to be reduced to "laboratory size" by passing it through a quartering device (see Fig. 1) or by the "quartering method," as described below (see Fig. 2).

The gross sample shall be placed on a quartering cloth and thoroughly mixed by first raising one corner of the cloth and then the other so as to roll the material back and forth. After the mixing operations the material shall be formed into a conical pile by raising all four corners of the cloth at once. The four corners are then carefully and gradually lowered simultaneously to avoid segregation of the larger aggregate which is usually near the top of the cone while the four corners of the cloth are raised. The tendency of the larger aggregate to segregate while lowering the four corners of the cloth can usually be corrected by flattening the apex of the cone with a scoop or block of wood as the four corners of the cloth are being lowered. If after the corners of the cloth have been released and spread out to their original position on the floor and the cone flattened, there is still an obvious segregation of the larger aggregate, this larger material may be redistributed as uniformly as possible by hand and eye. The flattened pile of material, which shall be of uniform thickness and diameter, shall then be divided into four quarters as follows: Insert rod, broom handle, or other similar instrument under the quartering cloth and material in such manner as to divide the sample into two exactly equal parts. Carefully separate the two portions of material by raising both ends of the rod simultaneously, sufficiently far from the floor that the ridge or crease in the quartering cloth will definitely separate the two portions of the sample. The rod is then withdrawn and again inserted underneath the cloth and sample at a right angle to its first position so as to accurately bisect each of the two portions now on the cloth. Similar to the first procedure the rod is raised vertically in a horizontal position so as to leave the crease in the quartering cloth distinctly and equally dividing each of the first two portions of the sample. The sample is now divided into four equal portions. Two diagonally opposite quarters of the sample shall then be shoveled away and discarded, and the space that they occupied brushed clean of fine material. The material remaining in the other two diagonal quarters shall then be combined, mixed, coned and quartered successively until the sample is reduced to the desired quantity for a laboratory sample.

Sampling Undisturbed Materials

It is not considered within the scope of this procedure to cover the details of the equipment nor is it possible to set forth a definite plan to be followed in making a foundation investigation due to the many geological formations and widely divergent job conditions encountered in the various parts of the state. The size of the structure or approach embankment will be a principal factor in selecting the method, extent of the exploration and sampling. The rotary core drill rigs are ordinarily furnished to the districts by the Highway Department and operate out of Austin under the supervision of skilled personnel. These core rigs are equipped to use the following methods of sampling:

1. Wet barrel or double wall barrel sampling
2. Dry barrel or single barrel core sampling
3. Push barrel sampling
4. Cohesionless sand sampling
5. Wash boring

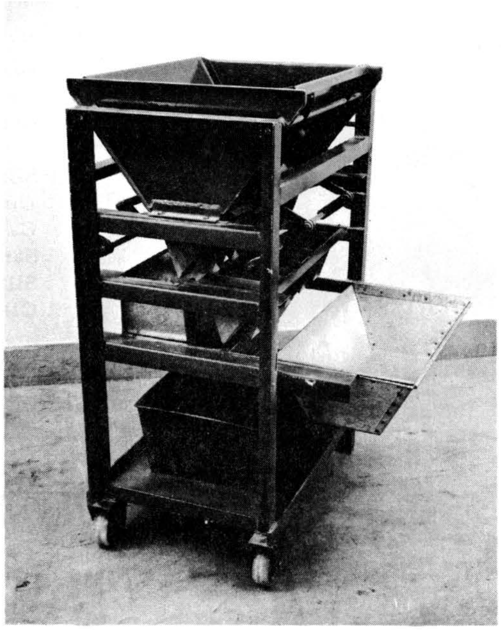


Figure 1
Quartering Device

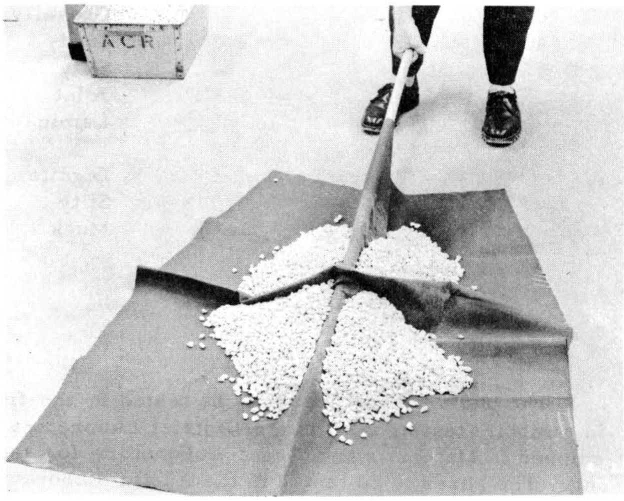


Figure 2
Reducing sample on quartering cloth

A complete record of materials should be made showing the formation, kind of material, color, texture, condition, location, depth from surface and thickness of layer. A suggested classification is shown on the following page.

Formation	Kind of Material	Structure and Condition
Rock	Granite Limestone Sandstone Conglomerate	Hard Soft Loosely cemented Laminated Nodular Fossilized
Gravel	Silica Limestone Caliche Sandy Silty Clayey	Coarse Fine Dense Compact Loose Water Bearing
Shale	Sandy Silty Clay Seams	Hard Soft Fissured
Sand	Gravelly Silty Clayey Laminated	Coarse Fine Dense Water Bearing
Silt	Gravelly Sandy Clayey Organic	Dense Loose Water Bearing
Clay	Shaley Gravelly Sandy Silty Joint Laminated	Hard Stiff Plastic Soft Very Soft Fissured
Organic	Lignite Silty Muck	Very Soft Odorous

The undisturbed cores may be tested in the field in a mobile testing unit, in the District Laboratory or shipped to Materials and Tests Laboratory for testing. The cores to be tested in the Austin Laboratory should be removed from the sample barrel, carefully sealed with paraffin to prevent loss of moisture and properly packed in a box for shipment.

Texas Highway Department

Materials and Tests Division

PREPARATION OF SOIL AND FLEXIBLE BASE MATERIALS FOR TESTING

Scope

This test method describes in Part I a procedure for the preparation of disturbed soil samples for mechanical analysis and the determination of the soil characteristics. This portion of the method is in close agreement with wet preparation A.A.S.H.O. Designation T 146-49, but differs from the dry preparation methods A.A.S.H.O. T 87-49 and A.S.T.M. D 421-58 for materials which contain particles larger than the No. 40 mesh sieve. Part II describes dry preparation of soils for tests (compaction, triaxial, and stabilization) which require laboratory molded specimens.

Definitions

Soil Binder: That portion of the material passing the Standard U.S. No. 40-mesh sieve shall be known as soil binder.

Percent Soil Binder: The ratio of the soil binder to the total sample times 100 calculated on the basis of the air-dry weight.

Apparatus

1. Sieves: Standard U. S. woven wire sieves with square openings (A.S.T.M. E 11 specifications) 3-inch, 2-1/2-inch, 2-inch, 1-3/4-inch, 1-1/4-inch, 7/8-inch, 5/8-inch, 1/2-inch, 3/8-inch, No. 4, No. 10, No. 20 and No. 40.
2. Heavy Duty Scale: A scale of adequate capacity and sensitive to 0.5 pound or less.
3. Scale: A scale with 10 to 70 pound capacity and sensitive to 0.01 pound or less. (Class IV-C)
4. Electric air dryer with temperature range 130° - 140°F.
5. Crusher: A 5 inch by 6 inch jaw crusher which can be adjusted to produce material passing the 1/4-inch sieve.
6. A small crusher: A flat face jaw crusher which can be adjusted to produce material passing 10-mesh.
7. Mechanical pulverizer
8. Wedgewood Mortar and Pestle, 165 m.m.
9. Rubber-covered pestle
10. Scoop
11. Small siphon tube
12. Sample containers, metal pans, cardboard cartons
13. Filter paper 20" x 20" cut to convenient size.
14. Absorbent molds (Plaster of Paris or other absorbent material).

Note: The Plaster of Paris molds must be air dried at a temperature not to exceed 140°F after forming and after each use.

Materials

Clear potable water.

Test Record Form

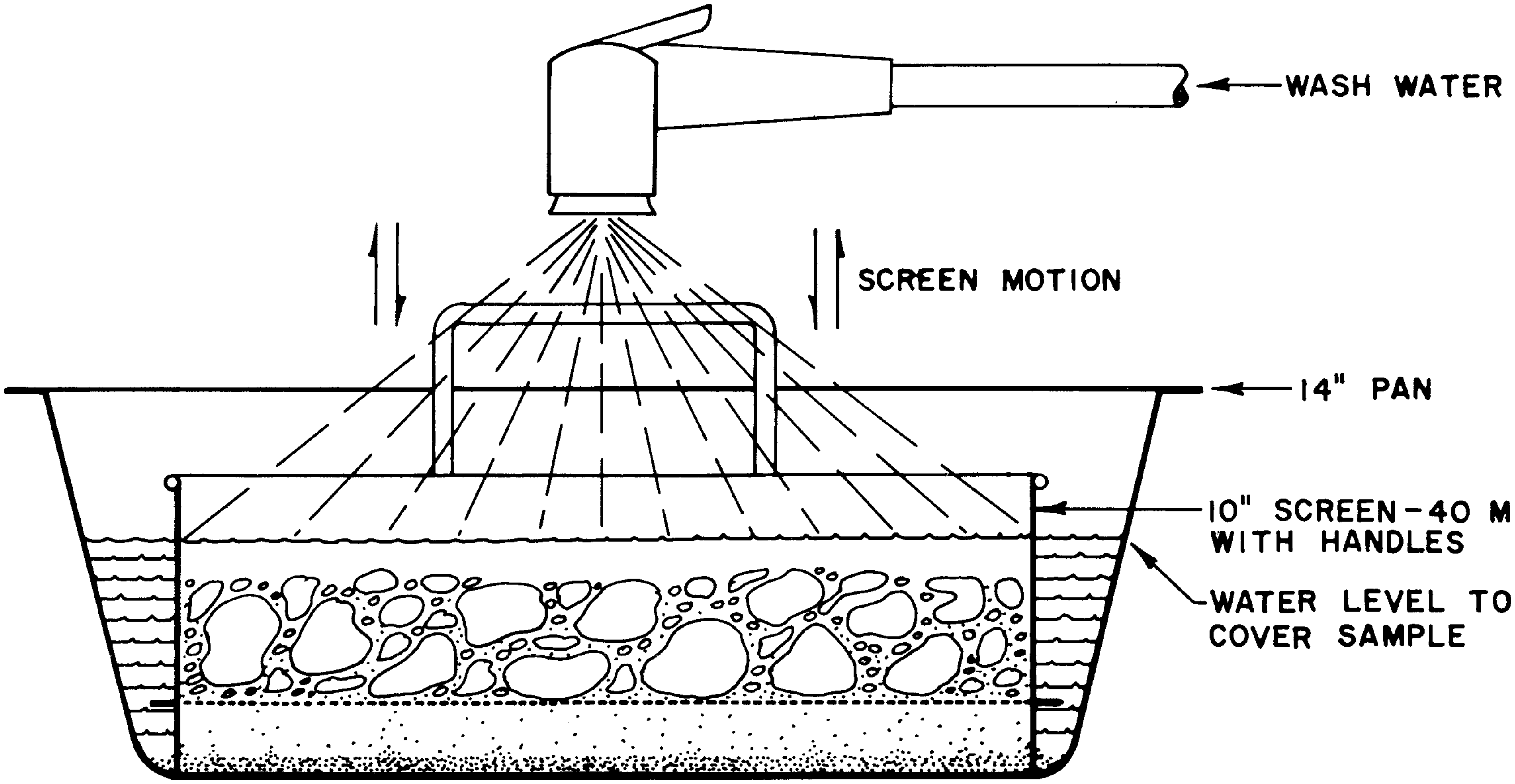
Each soil sample should be given an identification number. This number placed on a suitable card remains with each portion of the sample throughout the processing and testing of the material. Record test data on Form 359, Soil Work Card and Form 409, Soil and Base Materials Work Sheet.

PART I

WET PREPARATION OF DISTURBED SOIL FOR SOIL CONSTANTS AND HYDROMETER ANALYSIS TESTS

Procedure

1. Select a representative sample according to the procedure outlined in Test Method Tex-100-E.
2. Stone or flexible base materials, containing large aggregate, that will be processed in crushing plant or broken down by other means during construction, should be crushed to the maximum size permitted by specifications.
3. Dry the sample in air dryer at a temperature not to exceed 140°F.
4. Examine the sample by visual inspection or slake a small portion in water to determine if the material has any particles larger than the 40 mesh size. If the material contains no particles larger than 40 mesh in size, or if the amount of aggregate is small and can be easily distinguished, remove these particles by hand and proceed to steps 11 and 12 for preparation of sample.
5. For materials containing a considerable amount of aggregate, the fine loose portion may be separated from the coarse particles by means of a 40-mesh sieve. Set the soil binder passing the 40-mesh aside and later recombine with additional binder obtained from steps 6 through 11. If desirable, the total material may be slaked.



WET SEPARATION OF BINDER FROM SOIL SAMPLE

Figure 1

WET PREPARATION OF DISTURBED SOIL FOR SOIL CONSTANTS & HYDROMETER ANALYSIS TESTS

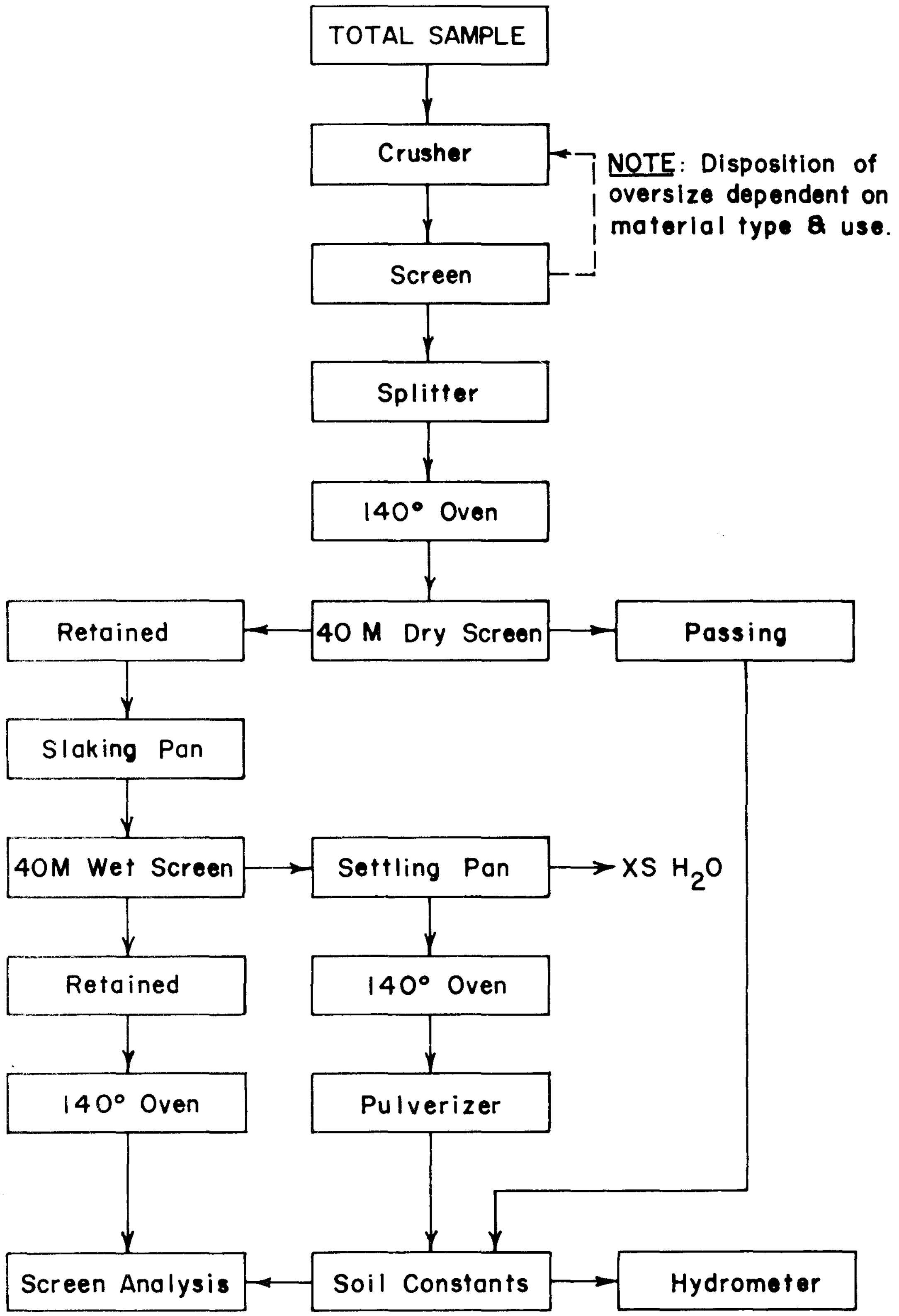


Figure 2

6. Place either the total material or material retained on 40-mesh sieve in a pan, cover with clear water and allow to soak for a period of 2 to 24 hours. The slaking time for base materials can be determined by procedure of test method Tex-102-E or Tex-109-E.

7. After slaking, wash the material over a No. 40-mesh sieve in the following manner: Place the empty sieve into a clean pan and pour the liquid from the wet sample through it. Enough additional water is poured into the pan to bring the water level about 1/2-inch above the mesh of the sieve. A small amount of the soaked material is then placed in the water on the sieve and stirred by hand at the same time the sieve is agitated up and down. If the material retained on the sieve contains lumps that have not disintegrated, but which can be crumbled between the thumb and fingers so as to pass the sieve, such lumps shall be broken and washed through the sieve. After all of the soil binder appears to have passed through the sieve, the sieve is held above the pan and the retained aggregate washed clean by pouring a small amount of water over it and letting the water drain into the pan. Transfer the aggregate from the sieve to a clean pan (Figure 1.)

8. Repeat the procedure of step 7 until all of the sample has been washed.

9. Dry the retained portion of the sample and rescreen over the 40-mesh sieve. Add the portion passing to the binder obtained in step 5. Weigh and save the aggregate retained on the 40-mesh sieve for use in the mechanical analysis of aggregate test method Tex-110-E.

10. Place the pan containing the soil binder and wash water aside where it will not be disturbed until all of the soil has settled to the bottom of the pan and the water above the soil is clear. The clear water is then decanted or siphoned off. The soil remaining in the pan is dried in an air dryer at a temperature not to exceed 140°F. If the water is not clear at the top in a reasonable length of time, two to three hours, the water may have to be evaporated or the settling time reduced by placing the pan of material in the 140° F air dryer overnight. In cases where the materials fail to settle in a reasonable time the following procedure may be used:

a. Decant the water and pour into porous molds lined with filter paper.

b. When the water has disappeared, air dry the filter paper with adhering soil. This may be done by placing on a wire rack to be placed on top of pan of wet soil remaining after step a.

c. When the material from steps a and b are air dried sweep the soil from the filter paper with a stiff brush into the pan of fines.

11. The dried soil binder is broken down in a mortar with a pestle. A suitable mechanical pulverizer, with opening set from 0.025 to 0.035 inches by means of a thin blade spatula or other convenient gage, may also be used to pulverize the aggregations of soil particles into separate grains which will just pass the No. 40 sieve. When the mechanical pulverizer is used it is intended that some of the material will have to be reduced using the mortar and pestle in order to preclude the possibility of the mechanical pulverizer breaking up the separate grains of the soil smaller than the No. 40.

12. Combine all of the soil binder obtained from steps 5, 9 and 11 and weigh to nearest gram or .01 pound. Mix thoroughly to produce a uniform sample of all the particles (Figure 2).

13. Add the weight obtained from steps 9 and 12 for the total weight of sample.

Calculations

Calculate the percent soil binder, equals

$$\frac{\text{Dry weight passing No. 40-sieve}}{\text{Total dry weight of sample}} \times 100$$

Note: Alternate Method

The sample may be slaked for wet preparation by use of the method and equipment of Test Method Tex-109-E, PART II.

PART II

DRY PREPARATION OF DISTURBED SOIL SAMPLED FOR COMPACTION, TRIAXIAL AND STABILIZATION TESTS

Scope

This preparation procedure applies to all material except wetted stabilized materials sampled from the roadway during construction. These materials should be quartered to approximate specimen size batches and be compacted without air drying. When M-D curves are desired this material may be dried by exposure to air or fan draft while it is being stirred.

Procedure

1. Select a 200-pound representative sample according to method Tex-100-E. Check specifications for maximum size aggregate.

2. Spread sample on clean floor to air dry or use forced drafts of warm air.

3. Clay and other soils which form into hard lumps when dried but contain no appreciable amount of aggregate should be crushed to pass the No. 10 sieve. The sample is then separated into two portions by means of a No. 20 sieve. In preparing medium heavy and heavy clays for the Moisture Density test for Compaction Ratio (Tex-114-E) at least two thirds of the material passing the No. 10 sieve should pass the No. 20 sieve.

4. Clay and other soils containing aggregate should be broken up to pass a No. 4 sieve without breaking the aggregate. This may be done by means of a plastic mallet, rubber-covered tamp or similar hand tool. The material is then separated as described in step 5.

5. Aggregate materials, caliche, crushed rock, and gravel should be separated into sizes by dry screening to convenient cuts. The following size sieves: 1-3/4", 1-1/4", 7/8", 5/8", 3/8", No. 4 and No. 10 are adequate for average materials. In cases of unusual grading other sieves may be used to give better cuts. (Figure 3 shows 1/2 cu. ft. batch sieve shaker.)

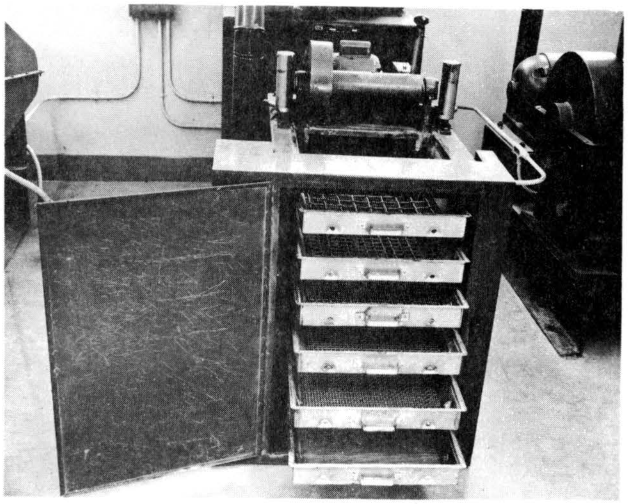


Figure 3
Gilson Shaker

6. Mix each size to make moisture as uniform as possible.

7. Weigh each size of material and compute the percentages, cumulative, retained on each sieve. These values are not to be used as a true sieve analysis, but are to be used in recombining the sample for individual specimens.

8. On the basis of the cumulated sieve size percents obtained in step 7 above, calculate and weigh out a 10-pound representative sample for soil constants and sieve analysis.

Calculations

1. Determine the percentage retained on each sieve, i.e.,

$$\text{Percent retained} = \frac{\text{Weight retained}}{\text{Total Weight of sample}} \times 100$$

2. Weight retained (any sieve) =

$$\frac{10.0 \text{ lbs. x percent retained}}{100}$$

General Notes

1. Sample preparation shall be subject to controls specified by the individual tests.

2. Do not scoop or pour materials to reduce to laboratory test size. Always use sample splitter or quartering cloth.

3. Check sieves for broken mesh or distorted openings.

4. Check mechanical pulverizer for proper adjustment of grinding plates.

5. Prevent the loss of any fine material during the process of crushing or washing of sample.

6. Do not overheat soils. Temperatures higher than 140°F. may change the physical and chemical characteristics of the soil.

7. Do not use chemicals to speed up the slaking and settling of soils in a water suspension. Most chemicals tried for this purpose reduce the plasticity of the soil.

Reporting Test Results

Report the percent of soil binder on Form No. 476-A, Soils and Base Material Report. Note that materials which contain aggregate prepared by Part I of this method usually have a higher percentage of soil binder than those prepared by Dry Method A.S.T.M. D-421-58 and A.A.S.H.O. T 87-49.

Test Method Tex-104-E
Rev: January 1, 1973

Texas Highway Department

Materials and Tests Division

DETERMINATION OF LIQUID LIMIT OF SOILS

Scope

This test method, which is a modification of A. S. T. M. Designation: D 423-61T, describes the procedure for determining the liquid limit of soils. The test is performed by preparing soil binder, mixing with water and manipulating until a definite consistency of moisture has been attained.

Definition

Liquid Limit: The liquid limit of a soil is that water content, expressed as a percentage of the weight of oven-dried soil, at which the soil changes from a plastic to a liquid state as determined by the following procedure.

Apparatus

1. Evaporating dish: A porcelain dish 4 to 5 inches in diameter.
2. Spatula: A flexible spatula having a blade 4 inches long and about 3/4-inch in width
3. Balance: Analytical balance of 200 gram capacity sensitive to 0.001 gram
4. Balance: A balance with 300 or more grams capacity, sensitive to 0.01 gram.
5. Oven: A vented drying oven capable of maintaining a temperature of 230°F (110°C) ± 9°F.
6. Weighing dish: An aluminum dish with lid which will prevent the loss of moisture during weighing
7. Burette: A burette of 50 cubic centimeters capacity graduated by 0.1 cc. intervals
8. Desiccator
9. Grooving tool with dimensions shown in Figures 1 and 1-B.

Materials

Water: The water used in this test shall be distilled or a good quality of demineralized water.

Test Record Form

Record test data on Soil Work Cards, Forms 359 or 491.

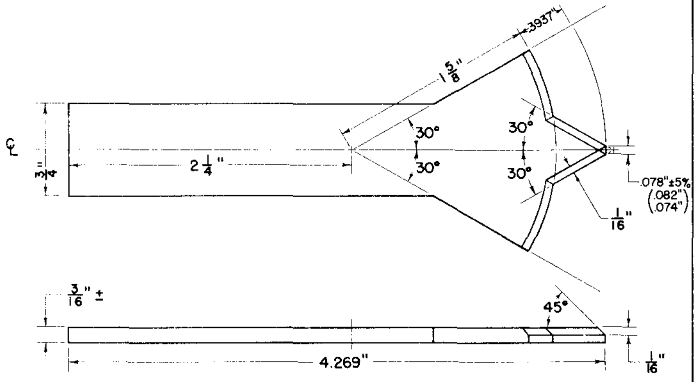
Preparation of Sample

The liquid limit test is performed on the soil binder prepared in Part I of Test Method Tex-101-E. The sample prepared in this manner has particle sizes sufficiently small enough so that all of the soil can be thoroughly mixed and uniformly wetted in performing this test.

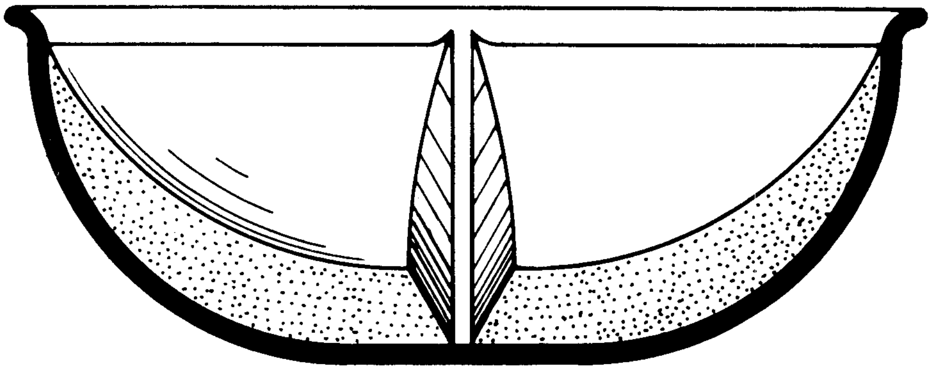
HAND METHOD

Procedure

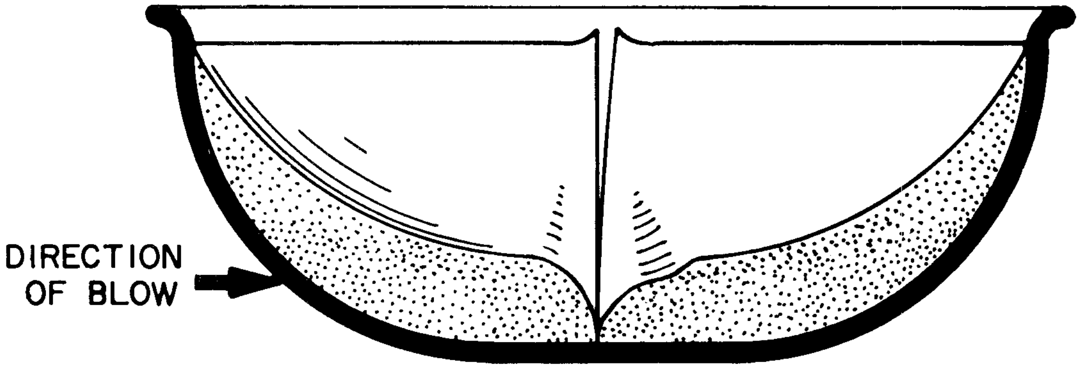
1. Use the burette for measuring the water and the small table balance to obtain the total weight of dry soil binder and use these quantities as a burette check on the liquid limit determination. A convenient



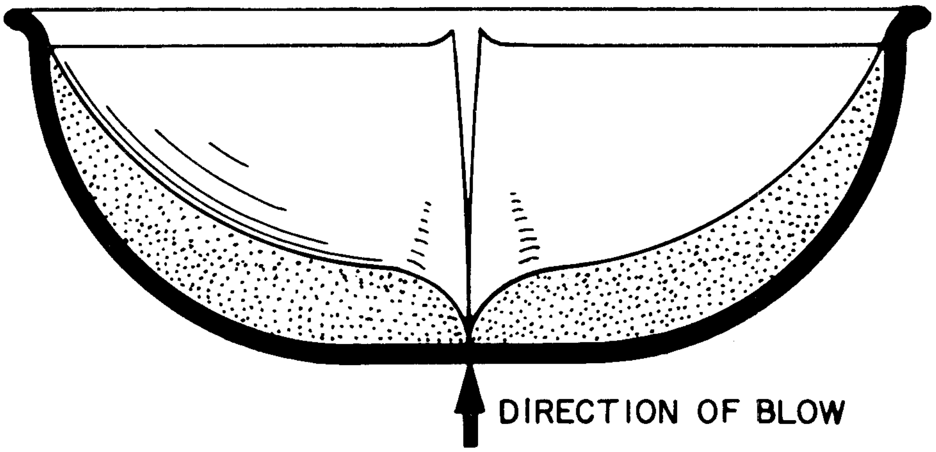
GROOVING TOOL
Fig. 1



a. SOIL CAKE GROOVED FOR TEST

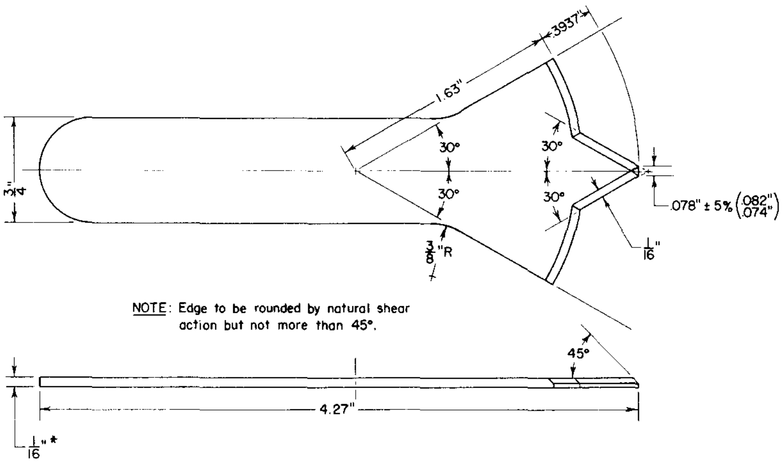


b. SOIL CAKE AFTER NORMAL TEST



c. SOIL CAKE AFTER SPECIAL SAND TEST

Fig. 2. DIAGRAM ILLUSTRATING LIQUID LIMIT TEST



NOTE: Edge to be rounded by natural shear action but not more than 45°.

*MATERIAL: 14 to 16 Gauge Stainless Steel, Type 304, 2B Finish

GROOVING TOOL

Fig. 1-B

way to obtain the weight of soil binder used in the test is to place a small dish on the balance, set the scale on some even number of grams and add prepared soil binder to balance. Use soil from this dish in performing the liquid limit test and reweigh dish and dry soil to obtain weight of material used.

2. The wetting of the soil is done by adding dry soil to water. Place 15 to 20 cubic centimeters of water in a clean evaporating dish. Pour some of the soil binder, previously weighed, slowly into the evaporating dish until all of the free water has been absorbed by the soil. Using the broad side of the spatula mix the soil and water thoroughly for several minutes. Continue adding small increments of dry soil and mixing until the soil reaches the consistency of a fairly thick paste.

3. The soil mass shall then be shaped into a layer with smooth surface approximately 1/2-inch in thickness against the side of the evaporating dish and divided into two portions by means of the grooving tool shown. Hold the metal grooving tool so that the beveled edge will face the direction of the cut and, with the shank of the tool perpendicular to the point of contact, draw the point of the tool through the soil specimen to the edge or to the center of the dish, leaving a V-shaped groove in which the dish at the bottom of the groove is clean, as illustrated in Figure 2-a.

4. The dish shall be held firmly in one hand, with the groove in the soil parallel to the line of sight, and tapped lightly with a horizontal motion against the heel of the other hand ten times. The movement of the dish shall be perpendicular to the length of the V-shaped groove in the soil and parallel to a tangent to the dish at the midpoint of the groove. Before tapping the dish, place the dish on the heel of the hand to locate the point where the dish will strike the hand. Keep the distance between this point and the groove, shown as the distance D in Figure 3, constant each time the dish is tapped.

5. When the lower edges of the two portions of the soil specimen barely flow together at the tenth blow for a length of approximately 1/2-inch of the groove, as illustrated in Figure 2-b, the moisture content equals the liquid limit. To determine definitely whether the soil has joined at the bottom of the groove, use the spatula to push one side away from the other side of the groove. If the two portions of soil can be separated completely along the original line of division in the groove by one push of the spatula, the moisture content is below the liquid limit.

When the moisture content of the soil is above the liquid limit, the bottom of the V-shaped groove closes with less than ten blows. Add water or dry soil as the case may be, repeat the mixing and testing procedure until the proper consistency of the soil is obtained. The importance of thoroughly and uniformly mixing after each addition of dry soil or water cannot be overstressed. When testing plastic clay, the mixing can be greatly aided by covering the dish with a damp cloth to prevent evaporation from the soil and setting aside for several minutes to allow the water to permeate all of the soil particles.

6. Some cohesionless soils will slide in the dish when tested by tapping as described in steps 4 and 5. Use the following procedure for grooving and tapping this type of material (Figure 2c).

(a) After the soil has been shaped into a smooth layer approximately 1/2 inch thick against the side of the dish, divide the specimen by using several strokes of the grooving tool, cutting out only a small portion of the soil with each stroke.

(b) Hold the dish by the edge opposite the groove and use a vertical motion, tap the dish ten times against the heel of the other hand held beneath the dish. The groove should be horizontal and directly above the point of contact with the hand. The intensity of the blow should be the same as that used in step 4.

(c) Examine the groove for 1/2 inch closure. Use the spatula and push against one side of the groove and if the groove does not completely open the soil is at the liquid limit. If the groove closes under the ten blows but one push of the spatula completely opens the groove, the moisture content is below the liquid limit. In this case add and mix a small amount of water, smooth into a layer, groove and tap ten blows, even though the groove may close at a lesser number of blows. Use the spatula again to push against one side of the groove and if the groove does not completely open with one push, the soil is at the liquid limit. In case the groove does open completely with one push of the spatula, the process of adding water, mixing, smoothing, grooving and tapping must be continued until a condition is reached where the groove cannot be opened with one push of the spatula.

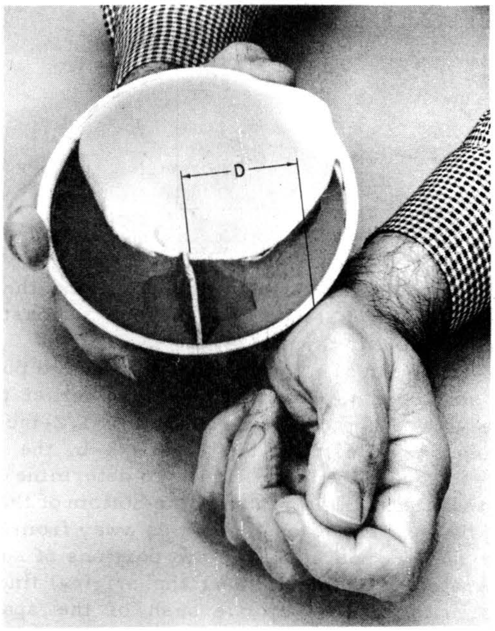


Figure 3

Position of Dish and Hands for Tapping

7. Reshape the soil into a smooth layer. Take moisture sample across the layer normal to the groove location. Determine the moisture content according to the procedure given in Test Method Tex-103-E.

Calculations

$$\text{Liquid Limit} = \frac{\text{weight of water}}{\text{weight of oven-dry soil}} \times 100$$

Burette Check LL =

$$\frac{\text{cubic centimeters of water}}{\text{grams of air-dry soil used}} \times 100$$

Precautions

1. Use only soil binder (minus 40-mesh) for the liquid limit test.
2. In order to obtain test results that can be reproduced, thoroughly mix the soil and water and use the same intensity of blow for testing all types of soils.
3. Do not vibrate or jar test specimen after grooving and prior to tapping.
4. Place the tested soil into the container and cover with lid immediately after completion of test to prevent further loss of moisture.

Notes

The moist soil portion remaining from the Liquid Limit test may be used in performing the Plastic Limit test described in Test Method Tex-105-E or for the soil pat in determining the shrinkage factors of soils, Test Method Tex-107-E.

The burette value for Liquid Limit should always be recorded as a check for errors in weighing or calculations. The burette value will usually be slightly less than the liquid limit obtained by drying the sample because the air-dried soil may contain some hygroscopic moisture.

MECHANICAL METHOD - ONE POINT LIQUID LIMIT

Apparatus

1. All of the apparatus listed under Items 1 through 8 for the Hand Method for determining liquid limit.
2. Liquid Limit Device and Grooving Tool: A mechanical device consisting of a brass dish and carriage constructed according to plan and dimensions shown in Figure 4. Although a combination grooving tool and gauge is shown in Figure 4, the grooving tool shown in Figure 1 should be used.

Calibration of Equipment

1. Inspect the liquid limit device to assure that the device is in good working condition; that the pin connecting the cup is not worn to permit side play; that the screws connecting the cup to the hanger arm are tight; and that a groove has not been worn in the cup through long usage. Check the grooving tool to determine that the critical dimensions are as shown in Figure 4A.
2. Use the gauge on the handle of the grooving tool and the adjustment plate H, shown in Figure 4, to adjust the height of the cup (c) which is lifted so that the point on the cup which comes in contact with

the base is exactly one centimeter (.3937 in.) above the base. Secure the adjustment plate by tightening the screws, I. With the gauge in place, check the adjustment by revolving the crank rapidly several times. If the height of drop for the cup is correct, a slight ringing sound will be heard when the cam strikes the cam follower. However, if no sound is heard or the cup is raised off the gauge, further adjustment is required.

Procedure

1. The preparation of the soil binder and the mixing of the soil and water (step 2) are the same as outlined for the Hand Method.

2. After the soil and water have been thoroughly mixed, transfer a quantity of wet soil from the evaporating dish to the cup of the mechanical liquid limit device shown in Figure 4. Use the broad side of the spatula to shape and smooth a layer of the wet soil to a depth of about 3/8-inch located above the spot where the cup rests on the base of the device.

3. The soil layer shall be divided by firm strokes of the grooving tool along the diameter through the centerline of the cam follower, so that a sharp groove of the proper dimensions will be formed. Sandy or cohesionless soils may require several strokes of the grooving tool to avoid tearing the sides of the groove.

4. The cup containing the grooved specimen shall be lifted and dropped by turning the crank at the rate of two revolutions per second until the two sides of the sample come in contact at the bottom of the groove along a distance of about 1/2 inch. Count the number of blows required to close the groove.

5. Adjust the moisture content of the test specimen by adding dry soil or water to obtain the following conditions:

(a) For clay or plastic soils have the consistency of the material such that the closure of the groove occurs between 20 to 30 blows of the cup.

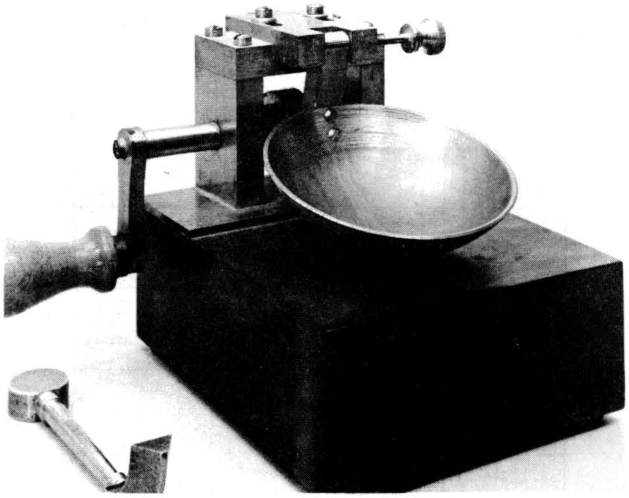


Figure 4

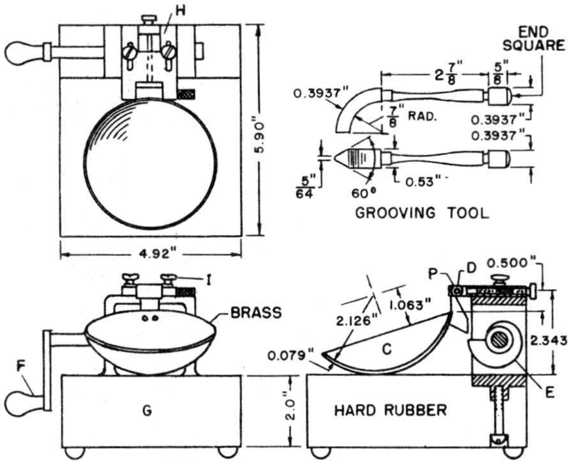
(b) For sands or other cohesionless soils which slide in the cup, use the minimum amount of water to obtain 1/2-inch closure of the groove with only one blow of the cup.

6. Determine the moisture content as outlined in step 7 of the Hand Method for Liquid Limit.

Charts

(a) Plot the moisture content versus number of blows for plastic soils on the chart in Figure 5. Draw a line through this point parallel to the nearest curve on the chart. The moisture content corresponding to the intersection of this line with the 25 blow line is the liquid limit.

(b) Use the moisture content and graph given in Figure 6 to find liquid limit of cohesionless and/or soils which slide in the cup.



MECHANICAL LIQUID LIMIT DEVICE

Figure 4A

Figure 5

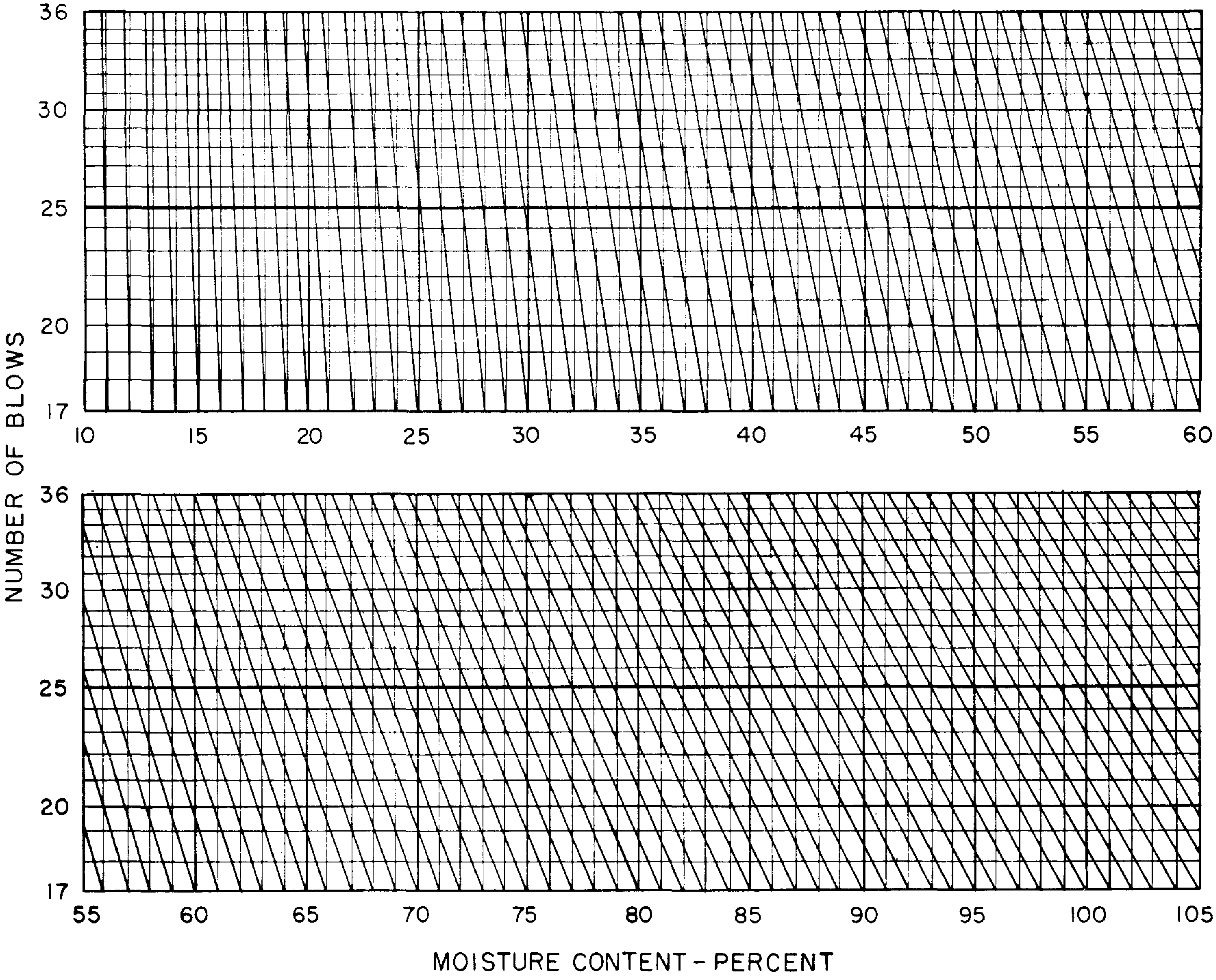


CHART for the CALCULATION of the LIQUID LIMIT

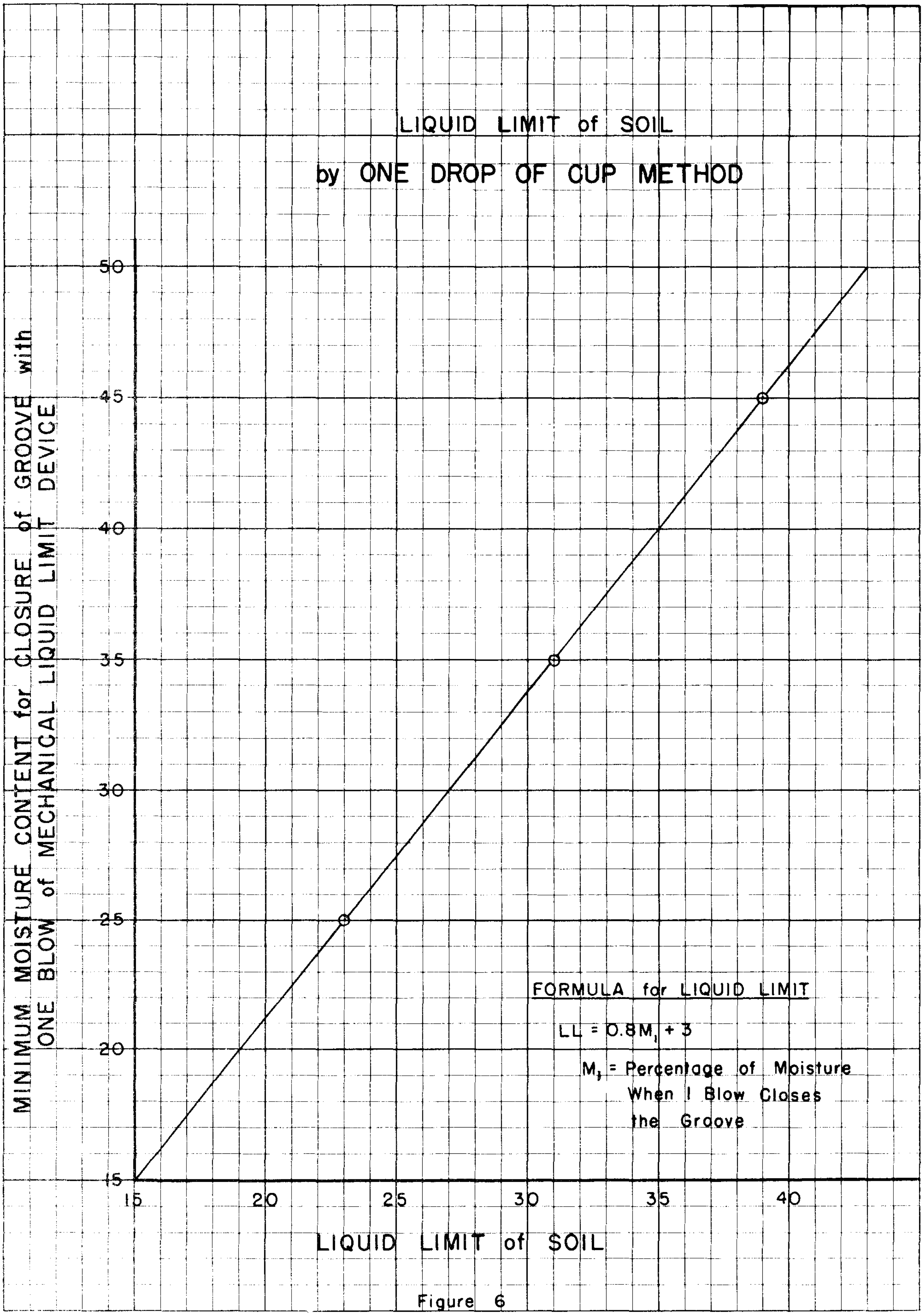

LIQUID LIMIT of SOIL
by ONE DROP OF CUP METHOD
MINIMUM MOISTURE CONTENT for CLOSURE of GROOVE with ONE BLOW of MECHANICAL LIQUID LIMIT DEVICE
50
45
40
35
30
25
20
15
15
20
25
30
35
40
LIQUID LIMIT of SOIL
FORMULA for LIQUID LIMIT
LL = 0.8M₁ + 3
M₁ = Percentage of Moisture When 1 Blow Closes the Groove

Figure 6

Test Method Tex-105-E
Rev: September 1966

Texas Highway Department

Materials and Tests Division

DETERMINATION OF PLASTIC LIMIT OF SOILS

Scope

This test method, which is a modification of A. S. T. M. Designation: D 424-54T covers the procedure for determining the plastic limit of soils. The test is performed on the prepared soil binder by mixing with water, adding dry soil and manipulating until the soil changes from a plastic to a semi-solid state.

Definition

Plastic Limit: This constant is defined as the lowest moisture content, expressed as a percentage of the weight of the oven-dried soil, at which the soil can be rolled into threads one-eighth inch in diameter without the threads breaking in pieces.

Apparatus

1. Evaporating dish: A porcelain dish 4 to 5 inches in diameter.
2. Spatula: A flexible spatula having a blade 4 inches long and about 3/4-inch in width
3. Surface for rolling: A piece of medium density plastic faced plywood or linoleum about 12 x 12 inches.
4. Balance: Analytical balance of 200 gram capacity sensitive to 0.001 gram
5. Balance: A balance with 300 or more grams capacity, sensitive to 0.01 gram.
gram
6. Oven: An oven capable of maintaining a temperature of 230°F (110°C) ± 9°F.
7. Aluminum dish: An aluminum dish with lid which will prevent loss of moisture during weighing
8. Desiccator

Materials

Water: The water used in this test shall be distilled or a good quality of demineralized water.

Test Record Form

Record test data on Soil Work Cards, Form 359 or 491.

Preparation of Sample

The plastic limit test is made on the soil binder (passing a No. 40 sieve) portion of the material which has been prepared in accordance with Test Method Tex-101-E, Part I. Place approximately 30 grams of material in an evaporating dish and thoroughly mix with water to a consistency at which the mass becomes plastic. Wet soil binder remaining from the liquid limit determination may be used.

Procedure

1. A portion of the plastic soil shall be taken from the mixing dish, a small amount of dry soil binder added to it and thoroughly mixed by squeezing and kneading with the fingers and palm of hands. The amount of manipulation necessary to mix materials thoroughly will depend upon the type of soil; considerable pressure must be exerted on very plastic clay. After the soil has been thoroughly mixed, form a specimen roughly ellipsoidal in shape by rolling the mass of soil between the palms of the hands.

2. Place the specimen on the rolling surface and roll the soil into a thread 1/8-inch in diameter under the palm of hand, Figure 1. The rolling shall be accomplished in such a manner as to cause the soil specimen to slowly elongate and decrease in size to produce a thread of uniform diameter throughout its length as illustrated in Figure 2A. When such a thread is formed and if when an attempt is made to roll it to any diameter smaller than 1/8-inch the thread breaks into pieces, the moisture content of the soil is at the plastic limit. If the soil thread breaks before it is rolled down to the 1/8-inch diameter, the moisture content of the soil is less than the plastic limit, as illustrated in Figure 2-B. The moisture content is above the plastic limit when the soil thread can be rolled to a diameter less than 1/8-inch without breaking into pieces. Add damp soil or dry soil binder to moist soil depending upon whether the moisture content is below or above the plastic limit and continue the mixing and rolling operation until the proper end point has been reached.

3. Use the following procedure for cohesionless soils:

(a) Mix the sandy soil with water to a consistency considerably wetter than the plastic limit.

(b) Place a portion of the wet soil on the rolling surface and use the fingers to shape it into a mass approximately 3/8-inch in diameter and 2 inches in length.

(c) Roll the mass of soil into a thread by applying just enough pressure with the fingers or a spatula to cause a gradual but continual decrease in the diameter of the thread being formed.

(d) Use a towel to remove the moisture film left on the rolling surface and continue rolling until the soil crumbles. This is considered to be a satisfactory end point for the plastic limit. When the specimen crumbles, the diameter of the thread may or may not be 1/8-inch; usually, it will be larger than this dimension.

4. Collect the broken or crumbled soil threads and place in a suitable container provided with a lid. Weigh the soil and container and use the procedure in Test Method Tex-103-E to determine the moisture content.

Calculations

$$\text{Plastic Limit} = \frac{\text{Weight of water}}{\text{Weight of oven-dry soil}} \times 100$$

Precautions

1. Use only soil binder (passing No. 40 sieve) for this test.

2. In order to obtain test results that can be reproduced, thoroughly mix the soil and use the proper pressure during rolling.

3. It may be necessary to roll several lumps of soil in order to secure enough sample to dry. Place the tested portion into the container and cover with lid immediately after end point has been reached to prevent further loss of moisture.

4. Be careful in weighing sample because no burette check is made on the amount of water used.

Notes

The plastic limit of a soil is usually not reported, but it is an important soil constant used with the liquid limit to determine the plasticity index of the soil.

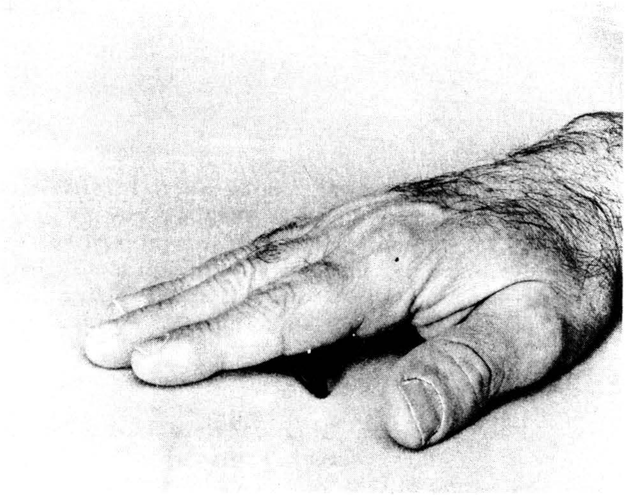


Figure 1
Rolling the Threads for the Plastic Limit

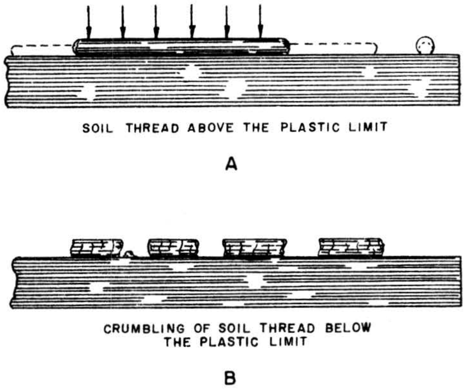


Figure 2

Test **Method Tex-106-E**

June 1962

Texas Highway Department

Materials and Tests Division

METHOD OF CALCULATING THE PLASTICITY INDEX OF SOILS

Definition

The plasticity index of a soil is the numerical difference between the liquid limit and the plastic limit. The liquid limit and the plastic limit are both expressed as a percent moisture content. The plasticity index of a soil is the range of moisture in which a soil remains in a plastic state while passing from the semi-solid up to the liquid state of the soil.

Calculations

The plasticity index shall be calculated by the formula:

Plasticity Index = Liquid Limit - Plastic Limit

Reporting of Results

Record test data on Form 359 and report the test results to the nearest whole number on Form 476-A.

Notes

The liquid limit shall be determined in accordance with Test Method Tex-104-E and plastic limit in accordance with Test Method Tex-105-E.

Texas Highway Department

Materials and Tests Division

DETERMINATION OF HYDROMETER AND MECHANICAL ANALYSIS OF SOILS

Scope

This method, which is a modification of A. A. S. H. O. Designation T 88-57 and A. S. T. M. Designation D 422-61T, describes a procedure for the quantitative determination of the distribution of particle sizes in soils. The difference in this method and the methods cited above consists of running the tests on the material prepared to pass the No. 40 sieve instead of the No. 10 sieve. The mechanical analysis of the washed clean + No. 40 material is taken from the sieve analysis.

Apparatus

1. Balances: A balance of 15,000 gram capacity sensitive to 1 gram for weighing the material retained on No. 40 mesh sieve, and a balance of 300 gram capacity sensitive to 0.01 gram for weighing the material passing the No. 40 sieve and retained on the No. 200 sieve.

2. Stirring Apparatus: Either apparatus A or B may be used. Apparatus A, shown in Figure 1, consists of a mechanically operated device in which a suitably mounted electric motor turns a vertical shaft equipped with a replaceable stirring paddle made of metal, plastic or hard rubber. A specially designed dispersion cup conforming to either of the cups shown in Figure 3 is used to hold the sample. Apparatus B consists of a specially designed air-tube which fits into a standard hydrometer cylinder and equipped with air hose and pressure gauge as shown in Figure 5.

3. Hydrometer: A Bouyoucos hydrometer graduated in grams of soil per liter of suspension, Figure 4.

4. Sedimentation Cylinder: A glass hydrometer cylinder 18 inches in height and 2-1/2 inches in diameter graduated for a volume of 1000 cubic centimeters.

5. Thermometer: A mercury thermometer, range of 0 to 220°F., accurate to 1°F.

6. Set of Standard Sieves: The sieves required are sieve size designation 3", 2-1/2", 2", 1-3/4", 1-1/4", 7/8", 5/8", 3/8", Nos. 4, 10, 20, 40, 60, 100 and 200, conforming to A. S. T. M. E-11-58-T for woven wire cloth sieves.

7. Glass beakers of 500 cubic centimeter capacity.

8. A Water Bath: An insulated water tank satisfactory for maintaining the soil suspension at a constant temperature.

9. Timing Device: A watch or clock with a second hand.

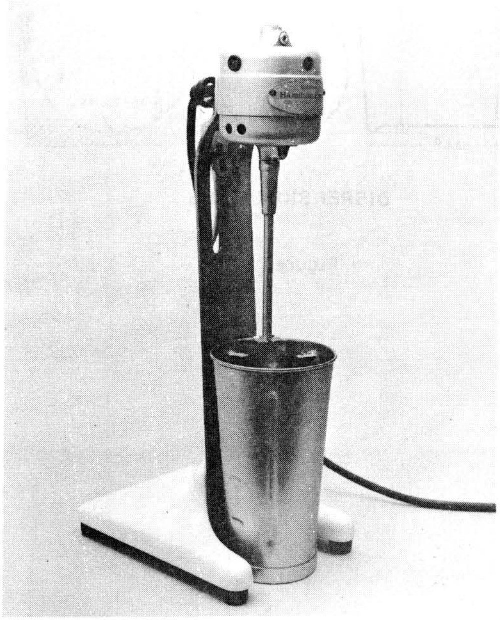
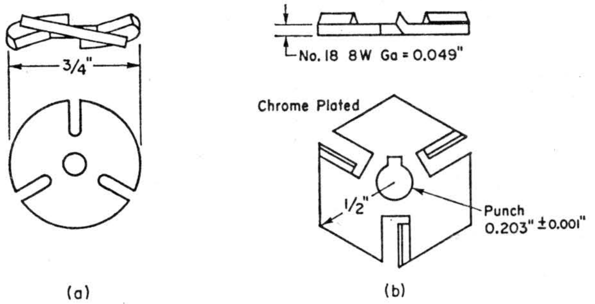


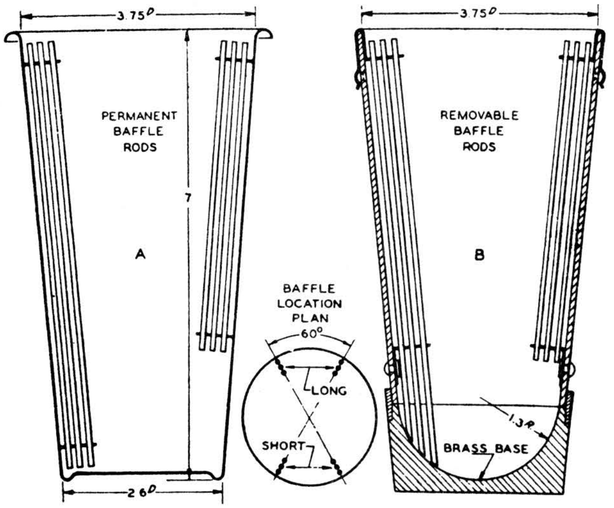
Figure 1
Mechanical Stirring Device



(a) (b)

Detail of Stirring Paddles.

Figure 2



DISPERSION CUPS

Figure 3

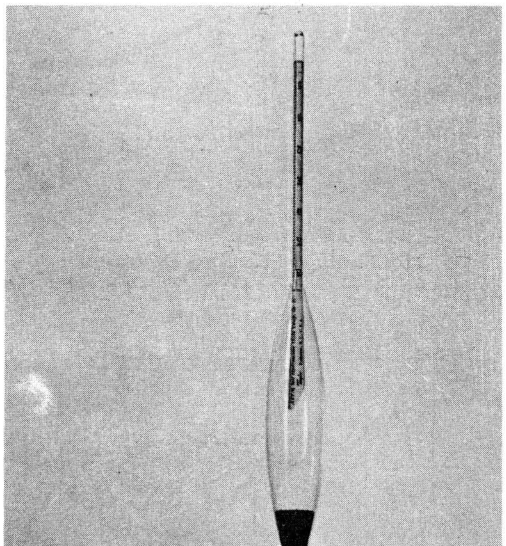


Figure 4
Hydrometer

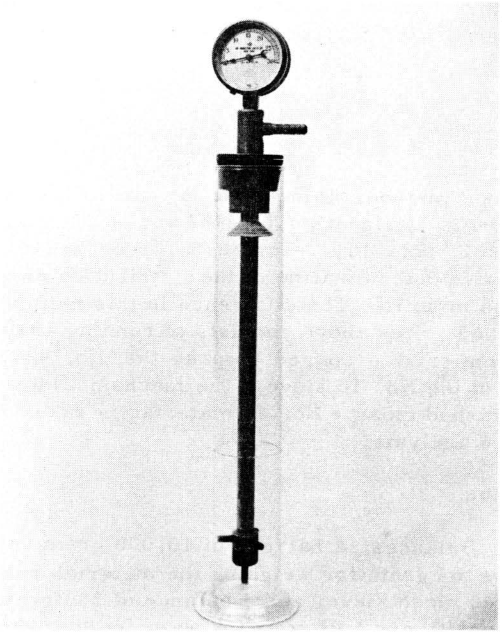


Figure 5
Air Dispersion Device

Materials

1. Dispersing agent

   a. Sodium Metasilicate, a solution prepared by dissolving 38.25 grams of $Na_2SiO_3 \cdot 9H_2O$ crystals in a liter of distilled water.

   b. Sodium Hexametaphosphate, $Na_2O(1:1)$ P_2O_5, a solution prepared by dissolving 40.0 grams of sodium hexametaphosphate in distilled or demineralized water diluting to a liter of solution and then adjusting the pH range of the resulting solution by making slow additions of sodium carbonate in the necessary amounts to bring the final pH of the solution between pH 8.0 and 9.0. In adjusting the pH range to the proper value either a pH meter or a visual indicator may be employed. Twenty drops (0.5ml.) of prepared phenolphthalein indicator solution per liter of sodium hexametaphosphate solution will at a pH of approximately 8.3 change from a clear to a light pink colored solution. This light pink coloration if it persists for at least two minutes may be used as an assurance that sufficient sodium carbonate has been added to the initial sodium hexametaphosphate solution to properly adjust the pH range to within the range of pH of 8.0 to 9.0 as required. The "prepared phenolphthalein indicator solution" may be prepared by dissolving 0.5 gram of powdered phenolphthalein, A.C.S. grade, in 60 ml. of Isopropal (rubbing) alcohol and adding 40 ml. of water.

2. Water: The water used in the hydrometer test shall be distilled or a good grade of demineralized water.

3. A source of compressed air. For apparatus B.

Test Record Form

Record test data on Hydrometer and Mechanical Analysis Work Card, Form 360. (Figure 7)

Preparation of Sample

1. Use soil binder prepared according to the procedure of Part I in Test Method Tex-101-E.

2. Determine the hygroscopic moisture of the soil binder, material passing the No. 40 sieve, in accordance with Test Method Tex-103-E.

3. Determine the specific gravity of the soil binder, portion passing the No. 40 sieve, in accordance with Test Method Tex-108-E.

Calibration of Apparatus

Formulas for percentage of soil in suspension, as shown under Calculations, are based on the use of distilled water. A dispersing agent is used in the water, however, and the specific gravity of the resulting liquid is changed. The hydrometers are calibrated by the manufacturer at 67°F. and graduated to be read at the bottom of the meniscus formed by the liquid on the stem. Variations in temperature from this standard temperature produce inaccuracies in hydrometer readings. Since it is impossible to secure hydrometer readings of soil suspensions at the bottom of the meniscus, readings must be taken at the top and a correction applied. The net correction for the three items may be determined experimentally.

Prepare a 1000 cubic centimeter solution in the hydrometer cylinder composed of distilled water and dispersing agent in the same proportions as used in the hydrometer test (20 cc. of sodium metasilicate to 875 cc. of water or 125 cc. of sodium hexametaphosphate to 960 cc. of water).

Place the cylinder in the water bath and obtain hydrometer readings at constant temperatures over the range of expected test temperature, including 67°F. as one of the readings. Allow the liquid in the cylinder and the hydrometer to come to constant temperature after each change in temperature of water bath. Read the hydrometer at the top of the meniscus formed on the stem to the nearest 0.5 gram per liter. The correction is the difference between the hydrometer reading and zero. For example, if the reading were + 9.0 at 65°F., a correction of 9.0 must be subtracted from the readings of the hydrometer. (Figure 6).

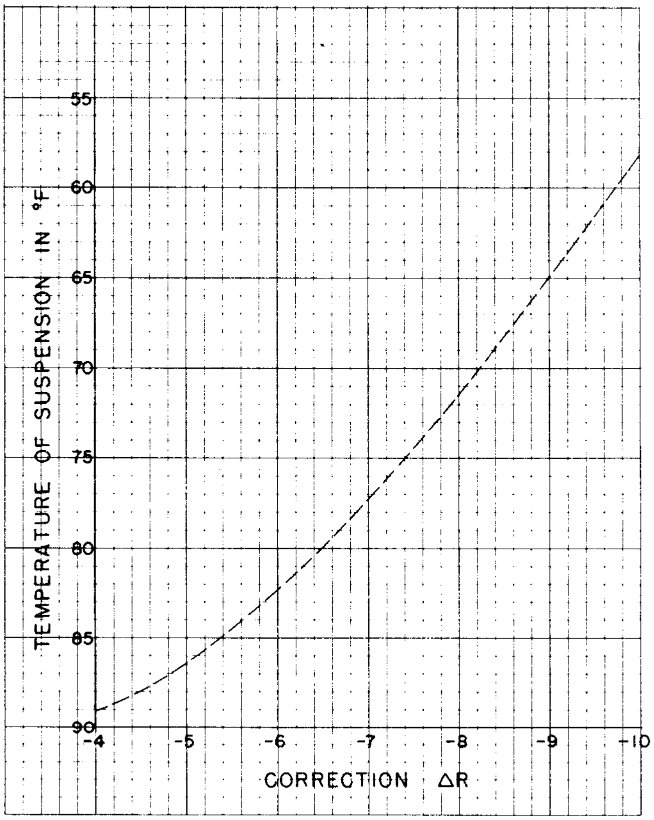


Figure 6

Total Correction of Hydrometer Readings Determined for Each Dispersing Agent

HYDROMETER AND SIEVE ANALYSIS OF SOIL BINDER PASSING NO. 40 SIEVE

Procedure

1. Accurately weigh 50 grams of soil binder and place in 500 cc. beaker or in hydrometer cylinder if the dispersion tube is available. Add either 20 cc. of sodium metasilicate solution or 125 cc. of the sodium hexametaphosphate solution and cover with distilled water. Stir the soil thoroughly and then allow to soak for at least 18 hours.

2. After soaking, the soil shall be dispersed by means of either the stirring device or the soil dispersion tube as follows:

a. Stirring Device: The soil is washed into the dispersion cup and distilled water added until the cup is within 2 inches of being filled. The contents are then dispersed for a period of 1 minute in the mechanical stirring device. After dispersion, transfer the soil slurry to the hydrometer cylinder and add sufficient distilled water having the same temperature as the water bath, to bring the level of the water to the 1,000 cc. mark on the cylinder. The cylinder containing the soil suspension shall then be placed in the constant temperature water bath.

b. Soil Dispersion Tube: Add about 300 cc. of distilled water to the soaked sample and carefully place the dispersion tube into the hydrometer cylinder. Adjust the air pressure by means of the valve and disperse the soil. Use an air pressure of 25 p.s.i. for five minutes to disperse silty and clay soils and 10 p.s.i. pressure for five minutes on sandy soils. Wash the soil from dispersion tube into cylinder and add sufficient amount of distilled water to bring the level of the water to the 1,000 cc. mark before placing into the constant temperature bath.

3. When the soil suspension attains a temperature of the bath (67°F), the graduate is removed and its contents thoroughly shaken for one minute, the palm of the hand being used as a stopper over the open end of the cylinder. Mix the contents of the cylinder by alternately turning the cylinder upside down and right side up and loosening any material remaining on the bottom by vigorously shaking the cylinder while in the inverted position.

4. At the conclusion of this shaking, place the hyrdometer cylinder on the table, immediately lower the hydrometer into the suspension and record the time. Read the hydrometer at the top of the meniscus formed on the stem to the nearest 0.5 gram per liter at the end of 1/2, 1 and 2 minutes from the time the graduate was set on the table. Remove the hydrometer and carefully place the cylinder with contents into the constant temperature bath. Obtain hydrometer readings at time intervals of 5, 15, 30, 60, 250 and 1440 minutes after the beginning of sedimentation. About 15 seconds before the time for each reading, slowly and carefully lower the hydrometer into the soil suspension and read the hydrometer after it has come to rest. After each reading subsequent to the two minute readings, remove the hydrometer from the cylinder in such a manner as to cause as little disturbance of the soil suspension as possible. Determine and record the temperature of the suspension each time a hydrometer reading is taken. Record data on work card, Form 360, Figure 7

Sieve Analysis

At the conclusion of the final hydrometer reading, pour the soil suspension onto a No. 200 sieve and rinse the retained particles with tap water until the wash water is clear. Transfer the retained material to an evaporating dish, dry to constant weight at a temperature of 110°C. and perform a sieve analysis using the following sieves: Nos. 60, 100, 140 and 200. The percentage of the dispersed soil sample retained on each sieve is obtained as follows:

$$\text{Percent retained} = \frac{\text{Cumulative weight retained}}{\text{Dry weight of dispersed soil}} \times 100$$

The percentage of the total original material that is retained on any given sieve may be obtained as follows:

$$\begin{matrix}\text{Percent retained} \\ \text{Total Sample}\end{matrix} = \frac{\text{\% dispersed}}{\text{soil retained}} \times \frac{\text{\% soil binder}}{100} + \begin{matrix}\text{\% retained on} \\ \text{No. 40 sieve}\end{matrix}$$

Calculations

1. Calculate the dry weight of the test sample by the expression:

$$\text{Dry weight of soil } W_o = \frac{\text{Weight of air dried soil}}{100 + \text{\% hydroscopic moisture}} \times 100$$

2. Percentage of soil in suspension

The percentage of the dispersed soil in suspension represented by different corrected hydrometer readings depends upon both the amount and the specific gravity of the soil dispersed. The percentage of soil binder remaining in suspension at the time a hydrometer reading is taken is calculated as follows:

$$P = \frac{R\,a}{W_o} \times 100$$

Where P = percentage of soil binder in suspension

R = corrected hydrometer reading (see Fig. 6 for total correction)

W_o = weight of dry soil

a = constant depending on the density of the suspension and varies with the specific gravity of the soil (G).

Sample No. 62-1-R **Date** 1-24-62 **SOIL LABORATORY WORK CARD**
Starting Time 9:00 A.M. **HYDROMETER & MECHANICAL ANALYSIS**
Hydrometer No. 285148 **OF SOIL BINDER**
Standard Time 9:20 A.M. Defl. Ag. $Na_2O(1:1)P_2O_5$ Weight Air Dry Sample= 50
Percent Soil Binder 24.2 % Ret. on No. 40 75.8 Corr. Wt. of Soil= 49.46

A Hydrometer Reading	T Corr. DR	Corr. Hyd. Read.	% Soil in Suspension	Time Min.	Temp °F	Grain Diam. MM (Theo.)	CORR. COEFS. Elev. of Hyd. (K_L)	Sp. Gr. (K_G)	Vis. (K_N)	Corr. Grain Diam. MM
42.9	-7.9	35.0	17.1	0.5	72	.111	.473	.995	.97	.050
40.9	-7.9	33.0	16.1	1.0	72	.078	.477	"	"	.036
38.4	-7.9	30.5	14.9	2.0	72	.055	.4825	"	"	.026
34.9	-7.9	27.0	13.2	5.0	72	.035	.4895	"	"	.017
30.7	-7.7	23.0	11.2	15.0	73	.020	.498	"	.96	.0095
26.7	-7.2	19.5	9.5	30.0	76	.014	.5065	"	.94	.0066
21.4	-5.9	15.5	7.6	60.0	83	.010	.518	"	.90	.0046
13.0	-4.0	9.0	4.4	250.0	89	.005	.5335	"	.86	.0026
15.5	-8.5	7.0	3.4	1440.0	68	.002	.529	"	1.0	.0010

D. No. 1 % Hyg M= 1.1
W.W. 27.17 D.W. 26.99
D.W. 26.99 T.W. 11.34
.18 15.65

Sp. Gr. Flask No. A_1
Tare = 636.03
Corr. Wt. Soil = 49.46
T+S = 685.49
L = 667.02
T+S—L = 18.47
Sp. Gr. = $\frac{49.46}{18.47}$ = 2.67a = .996

Ret. On	Grams	% S B.	% T.
No. 60.	4.8	9.7	78.1
No. 100	9.1	18.4	80.3
No. 140	11.5	23.2	81.4
No. 200	13.8	27.9	82.0

Texas Highway Department
Form 360 3-50-10m

SOIL LABORATORY
MECHANICAL ANALYSIS OF SOIL
AND BASE COURSE AGGREGATE

SAMPLE NO. 62-1-R

Size or No. of Sieve	Weight of Mtl. Grams	Sieve No. or Grain Dia.	Percentage of Material Retained	Remarks
Ret. 3"				
" 2 1/2"			0.0	
" 2"	102		2.2	
" 1 3/4"	168		3.7	
" 1 1/4"	256		5.6	
" 7/8"	587		13.0	
" 5/8"	1154		25.5	
" 3/8"	1706		37.7	
" No. 4	2481		54.8	
" " 10	3050		67.4	
" " 20	3270		72.3	
" " 40	3431		75.8	
Pass No. 40 by Slaking and Washing		No. 60	78.1	
	1092	" 100	80.3	
Total Sample	4523	" 140	81.4	
		" 200	82.0	
		0.05MM	82.9	
		0.005MM	92.0	
		0.001MM	96.6	

B1765-350-10m

Figure 7

Work Card for Hydrometer and Mechanical Analysis of Soils

The value of "a" for a specific gravity G and a water density at 67°F. of 0.9984 may be obtained from the following formula:

$$a = \frac{2.6500 - 0.9984}{2.6500} \times \frac{G}{G - 0.9984}$$

The values of a, for different values of specific gravity of soil G, are shown in Table I,

TABLE I

VALUES OF a, FOR DIFFERENT SPECIFIC GRAVITIES.

Specific Gravity, G	Constant, a
2.95	0.94
2.85	0.96
2.75	0.98
2.65	1.00
2.55	1.02
2.45	1.05
2.35	1.08

Where part of the original material is retained on the No. 40 sieve, the percentage remaining in suspension may be converted to the percentage of the total sample including the fraction retained on No. 40 sieve by the expression:

$$\text{Percent soil in suspension } P = \frac{R\,a}{W_o} \times \text{ \% Soil Binder}$$

3. Diameter of Particles in Suspension: The maximum diameter of the particles in suspension, corresponding to the percentages indicated by a given hydrometer reading, can be calculated by the use of Stokes Law.

According to Stokes Law:

$$d = \sqrt{\frac{30\ nL}{980\ (G - G_1)\ T}}$$

Where d = the maximum grain diameter in millimeters

n = the coefficient of viscosity of the suspending medium in poises. Varies with changes in temperature.

L = the distance in centimeters through which soil particles settle in a given period of time.

G = the specific gravity of soil.

G_1 = the specific gravity of suspending medium 0.9984 (at 67°F)

T = the time in minutes, period of sedimentation.

The maximum grain diameters in suspension for assumed conditions and corresponding to the periods of sedimentation specified in this procedure are given in Table II. These grain diameters shall be corrected for the conditions of test by applying the proper correction factors as described and given below:

TABLE II

MAXIMUM GRAIN DIAMETERS IN SUSPENSION UNDER ASSUMED CONDITIONS

Time in Minutes	Max. Grain Diameter, mm.
1/2	0.111
1	0.078
2	0.055
5	0.035
15	0.020
30	0.014
60	0.010
250	0.005
1440	0.002

The grain diameters give in Table II are calculated according to the following assumptions:

L, the distance through which the particles fall is constant and equals 32.5 centimeters.

n, the coefficient of viscosity equals .0102 that of water at 67°F.

G, the specific gravity of the soil particles is constant and equal to 2.65.

The grain diameters corrected for other than the assumed conditions are obtained by the formula:

$$d = d' \times K_L \times K_G \times K_n$$

Where:

d = corrected grain diameter in millimeters.

d' = grain diameter obtained from Table II.

K_L = correction factor determined for each hydrometer as shown in Figures 8 and 8a.

K_G = correction factor for specific gravity obtained from Fig. 9.

K_n = correction factor for variation in viscosity obtained from Figure 10.

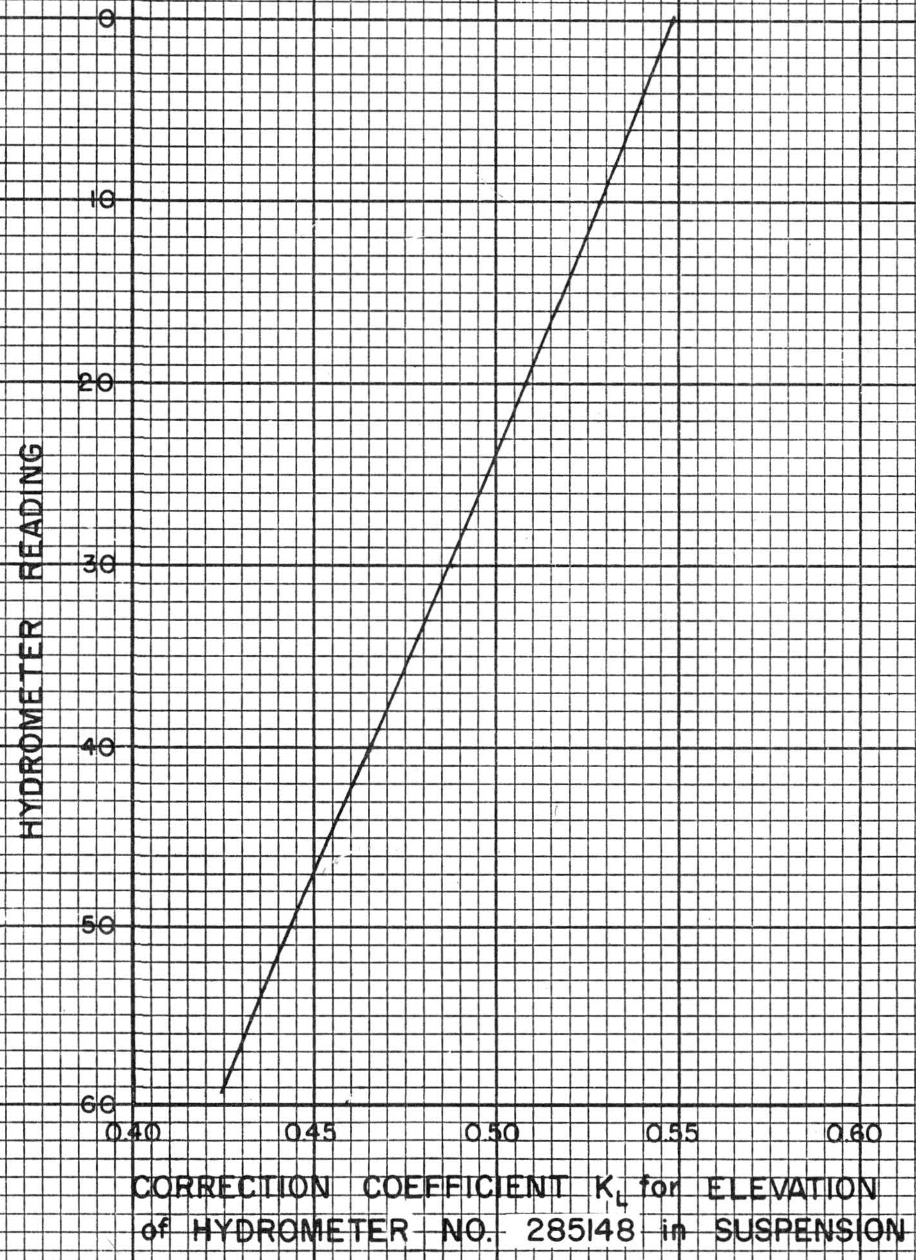
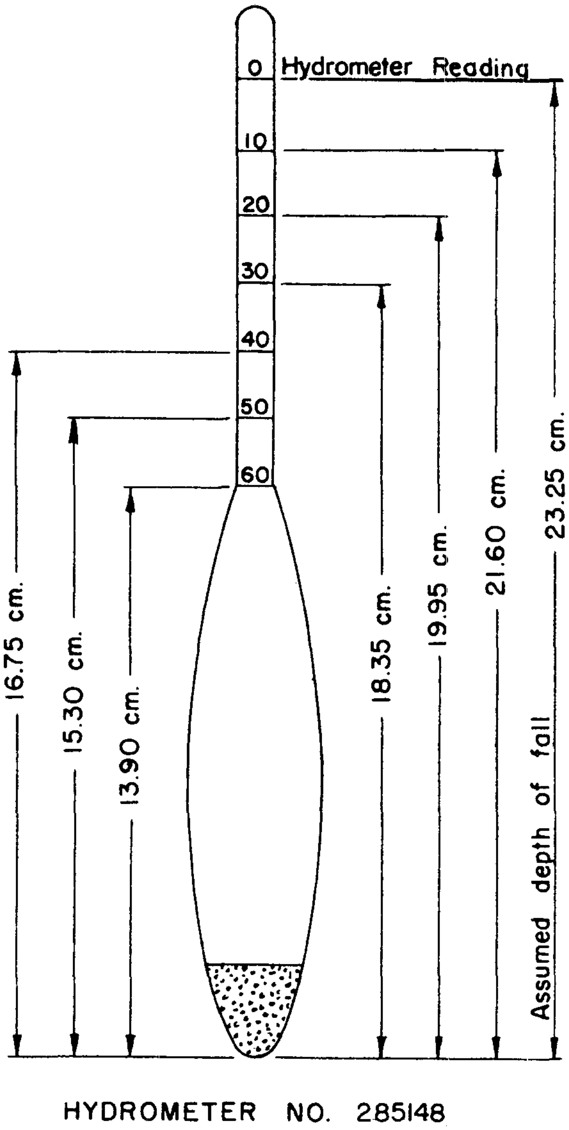

HYDROMETER READING
0
10
20
30
40
50
60
0.40
0.45
0.50
0.55
0.60
CORRECTION COEFFICIENT K_L for ELEVATION of HYDROMETER NO. 285148 in SUSPENSION

Figure 8



ASTM Method of Calibrating Hydrometer for K_L

Figure 8a

Correction Coefficients

1. The correction factor K_L corrects for the distance through which the particles fall and varies with the position of the hydrometer in the suspension. Since the density throughout a suspension is not uniform and varies with the grading of the material in suspension and the time of sedimentation, a fixed distance cannot be used. It has been found by experiment that for the methods of dispersion described in this procedure, an assumed distance which bears a constant ratio to the depth of the hydrometer in the suspension, but which is less than the distance indicated by the center of volume of the hydrometer, gives closer agreement to mechanical analysis performed by the pipette methods. The assumed distance of fall is taken as 0.42 of the distance from the surface of the suspension to the elevation of the bottom of the hydrometer. (See Figure 8a)

The correction coefficient for elevation of hydrometer K_L varies with the hydrometer readings and may be obtained by measuring the hydrometer and substituting values in the following formula:

$$K_L = \sqrt{\frac{\text{Assumed depth of fall in centimeters} \times 0.42}{32.5}}$$

2. The correction factor K_G corrects for variations in specific gravity from that used (2.65) in the preparation of Table II. The correction coefficient K_G may be calculated by the formula:

$$K_G = \sqrt{\frac{1.65}{\text{Specific Gravity of Soil} - 1}}$$

3. The correction factor K_n corrects for variations in viscosity of the suspending medium and varies with changes of temperature. The viscosity correction may be obtained from the following formula:

$$K_n = \sqrt{\frac{\text{Viscosity coefficient at temperature T}}{0.0102}}$$

The coefficients K_G and K_n are independent of the apparatus used and are shown in Figures 9 and 10.

MECHANICAL ANALYSIS OF AGGREGATE

Procedure

1. Perform a sieve analysis on the aggregate portion prepared according to Test Method Tex-101-E, Part 1, of the sample retained on the No. 40 mesh sieve by separating the sample into a series of sizes using such sieves as are necessary to determine compliance with specification for the material. The hand sieving operation is done by means of a lateral and vertical motion of the sieve, accompanied by a jarring action so as to keep the material moving continously over the surface of the sieve. Do not turn or manipulate particles through the sieve by hand. Limit the amount of material on each sieve to a single layer and continue hand sieving until not more than one percent by weight of the residue passes any sieve in one minute of continuous shaking. When mechanical sieving is used, test the thoroughness of sieving by the above described hand screening method.

2. Determine the weights of aggregate retained on each sieve using the balance with a capacity large enough to obtain the weight of the total sample. Weigh the portion retained on the largest size sieve first, record this weight; then place the contents of the next largest size sieve on balance and obtain the cumulative weight of the two sizes. Continue this operation of obtaining cumulative weights until the contents of the smallest sieve used has been emptied on the balance and weighed.

3. Use the cumulative weights to calculate the percentages retained on the various sieves on the basis of the dry weight of the total material which includes the weight of the soil binder (passing the No. 40).

Plotting Test Results

The percentages of grains of different diameters are plotted on semi-logarithmic paper to obtain a grain size accumulation curve such as that shown in Figure 11. The data obtained from the hydrometer analysis are plotted as percent of material in suspension (% passing) against corrected grain diameter in millimeters. The data from the mechanical analysis are plotted as percent retained against sieve size.

Reporting Test Results

Report the **total** percentages retained on each sieve, or grain diameter to the nearest whole number as follows: Sieves, opening in inches: 3", 2-1/2", 2", 1-3/4", 1-1/4", 7/8", 5/8", 3/8", sieve numbers: 4, 10, 20, 40, 60, 100, 200, grain diameter, millimeters: .05, .005, .001, as shown in Figure 7 on Form 476-A. In cases where a complete gradation is neither desired nor required it should be noted under Procedure that compliance in a particular test has been met when a series of sieve sizes has been used as are necessary to determine compliance with the specification for the material. The sieve sizes listed above are suggested sizes only and may be specified only in part.

When no constant temperature bath is available, the hydrometer analysis may be run taking temperature at time of each reading. The temperature corrections are used in the calculations.

This procedure is not preferred as there is no correction for temperature variations between readings.

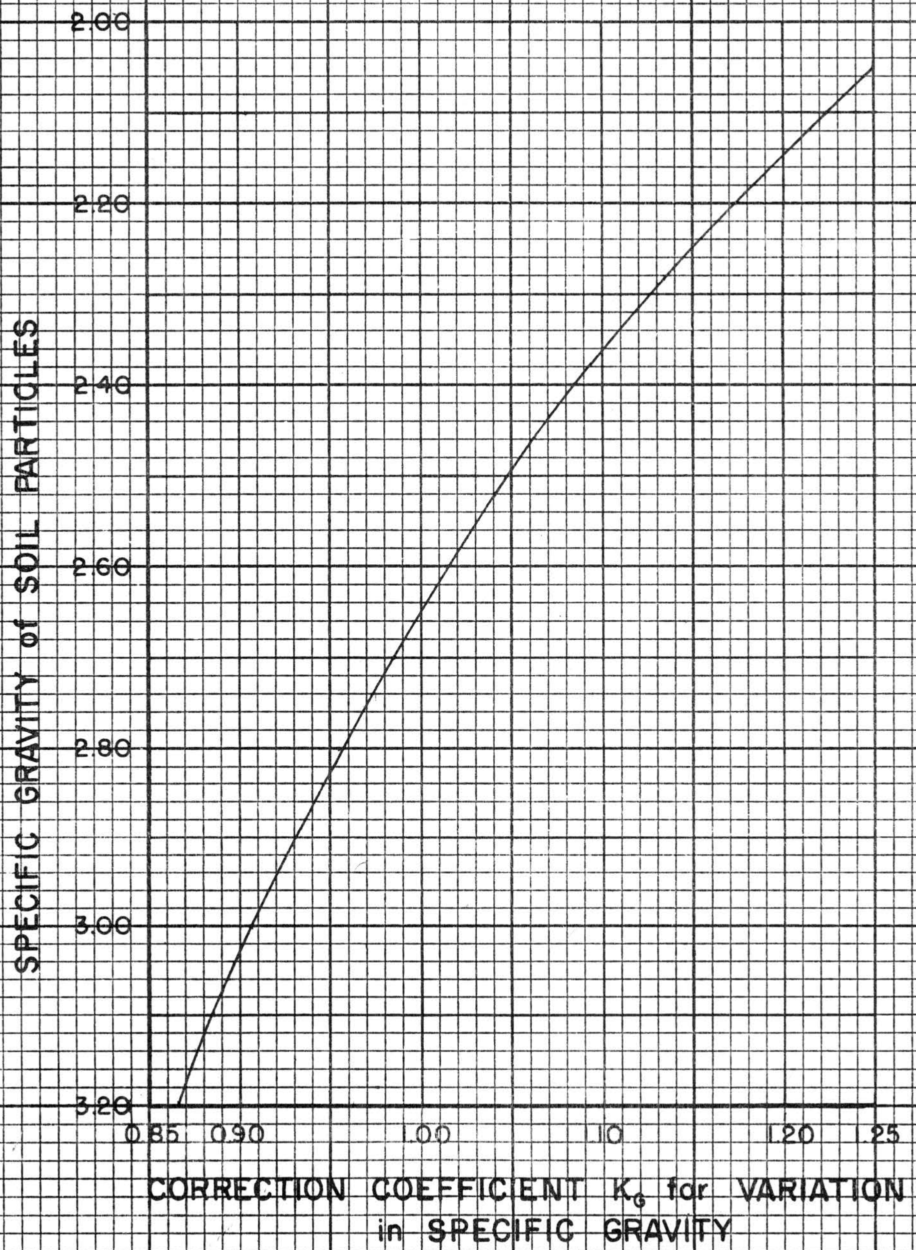

2.00
2.20
2.40
2.60
2.80
3.00
3.20
SPECIFIC GRAVITY of SOIL PARTICLES
0.85
0.90
1.00
1.10
1.20
1.25
CORRECTION COEFFICIENT K_G for VARIATION in SPECIFIC GRAVITY

Figure 9

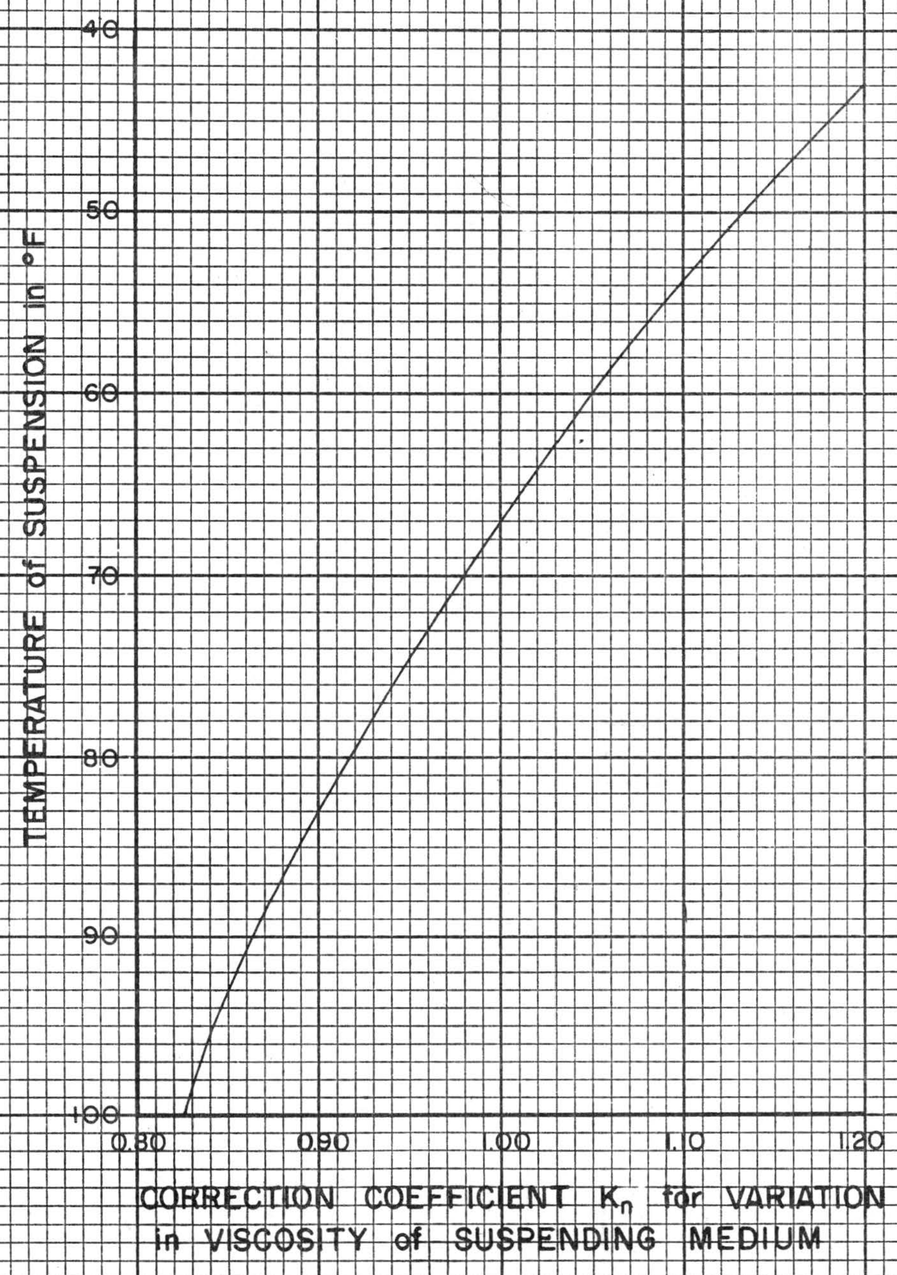
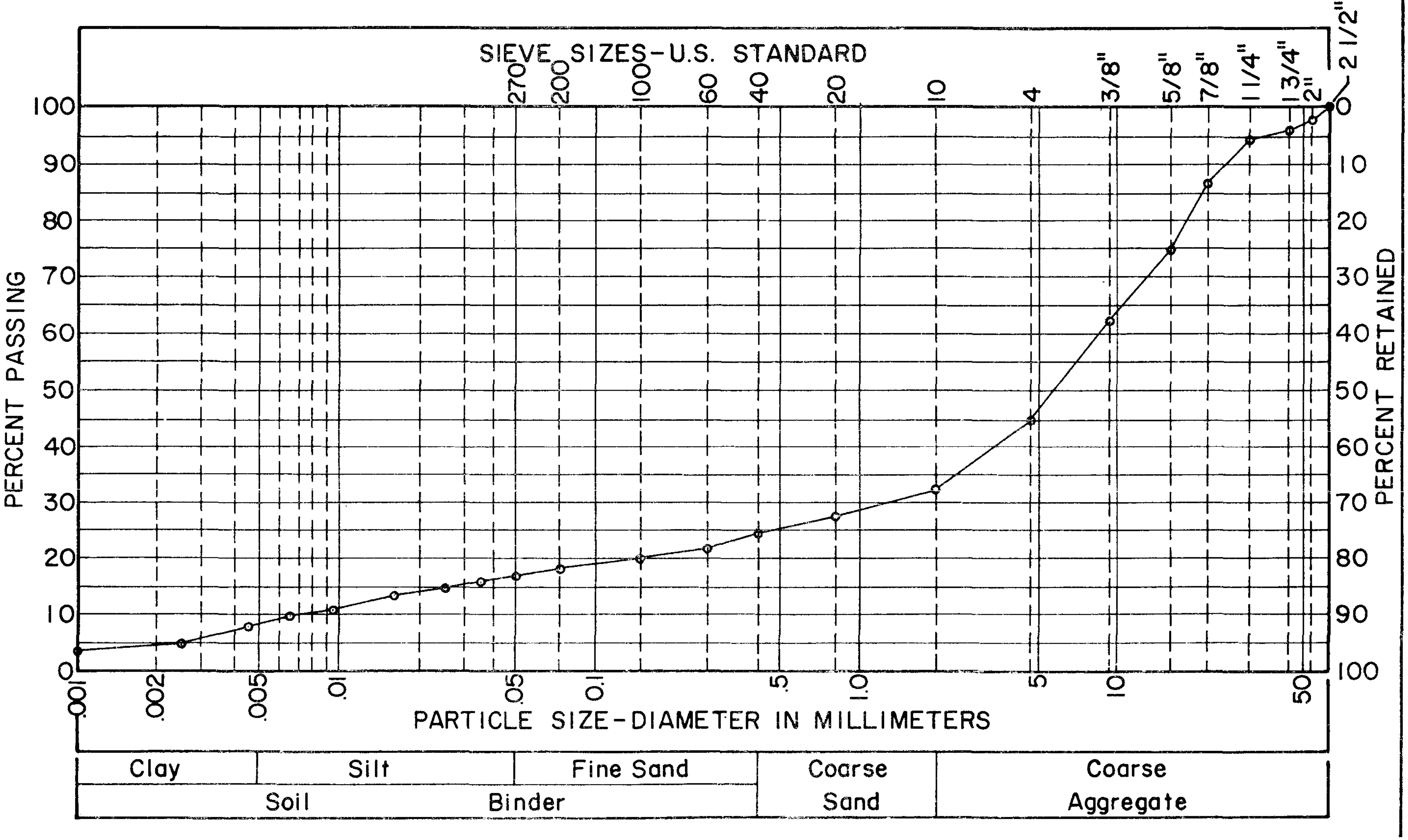

TEMPERATURE of SUSPENSION in °F
40
50
60
70
80
90
100
0.80
0.90
1.00
1.10
1.20
CORRECTION COEFFICIENT K_n for VARIATION in VISCOSITY of SUSPENDING MEDIUM

Figure 10

Test Method **Tex-110-E**
June 1962

CUMULATIVE MECHANICAL ANALYSIS

Sample No. 62-1-R County Bowie Project F-1118-(3)-6 Highway State 26



Test Method Tex-113-E
Rev: January 1, 1974

Texas Highway Department
Materials and Tests Division

DETERMINATION OF MOISTURE-DENSITY RELATIONS OF SOILS AND BASE MATERIALS

Scope

This test method is intended for determining the relation between the moisture content and density of soils or flexible base materials when compacted in the laboratory as specified herein. The test is performed on prepared materials passing the 1-3/4 inch sieve by mixing with water and determining the wet weight and volume of compacted specimens. The procedure differs from A.S.T.M. D-1557-64T and A.A.S.H.O. T-180-57 methods in relation to the size of aggregate particles, size of specimen, new material for each specimen, laboratory apparatus and compactive efforts of the automatic tamper.

Definitions

1. Maximum Density: The highest value for density, calculated on basis of dry weight of material per cubic foot, shown on moisture-density curve denotes the maximum density obtainable with the compactive effort used.

2. Optimum Moisture: The moisture content corresponding to the maximum density is designated as the optimum moisture content.

3. Compactive Effort: This term is defined as the total energy, expressed as foot-pounds per cubic inch of specimen, used in compacting the material. This compactive effort is attained by dropping a ten-pound ram eighteen inches on a layer of material two inches thick and six inches in diameter.

Apparatus

1. Automatic Tamper: A compaction device (Figure 1) with base plate to hold 6-inch I.D. forming molds, equipped with 10 pound ram and adjustable height of fall. Striking face of 10 pound ram, 40 degree segment of 3 inch radius circle.

2. Compaction mold, 6 inch I.D. $^{+.0625}_{-.0156}$ and 8-1/2 inch height ± 1/16 inch, with removable collar.

3. Measuring device, micrometer dial assembly (Figure 2) for determining height of specimens, with set of standard spacer blocks.

4. Scale, rated 30 pound capacity, sensitive to 0.01 pound

5. Extra base plate to hold forming mold (Figure 3)

6. Press, to eject specimens from mold

7. Drying oven, controlled to 230°F (110°C) ± 9°F.

8. Metal pans, wide and shallow for mixing and drying materials

9. Circular porous stones slightly less than 6 inches in diameter and 2 inches high

10. A supply of small tools, hammer, plastic mallet, level and others.

Test Record Form

Record test data on work sheet, M-D and Triaxial Work Sheet

Calibration of Equipment

Specimens approximately 6 inches in diameter and 8 inches in height are molded in performing this test. The compacted material is not trimmed with a straight edge and does not completely fill the mold. Therefore, it is necessary to determine the volume per linear inch of height for the mold.

1. Measure the diameter of the mold, by means of the micrometer caliper and micrometer dial, at the ends and several intermediate points to obtain an average value for the diameter.

2. Use the average diameter to calculate a mean cross sectional area of the mold.

3. Calculate the volume in cubic feet for one inch of height of the mold as follows:

$$\text{Volume of mold Cu. Ft. per inch} = \frac{\text{Area in sq. in.} \times 1 \text{ inch}}{1728}$$

Preparation of Sample

Prepare the material according to the procedure outlined in Part II of Test Method Tex-101-E.

Note: Wetted stabilized materials taken from the roadway are prepared using the method described in Tex-101-E, Part II under Scope.

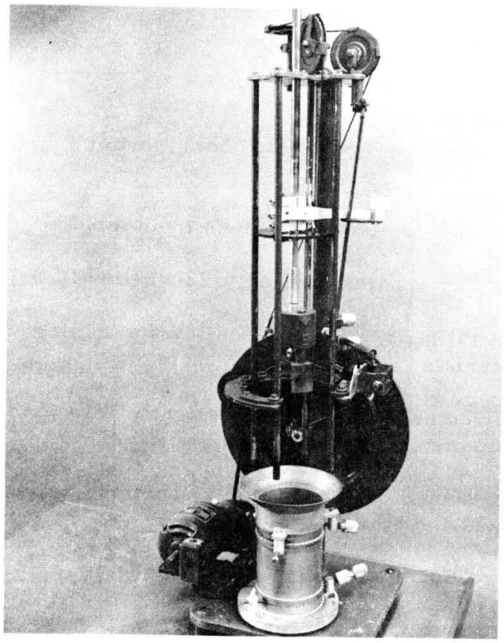


Figure 1
Automatic Tamper

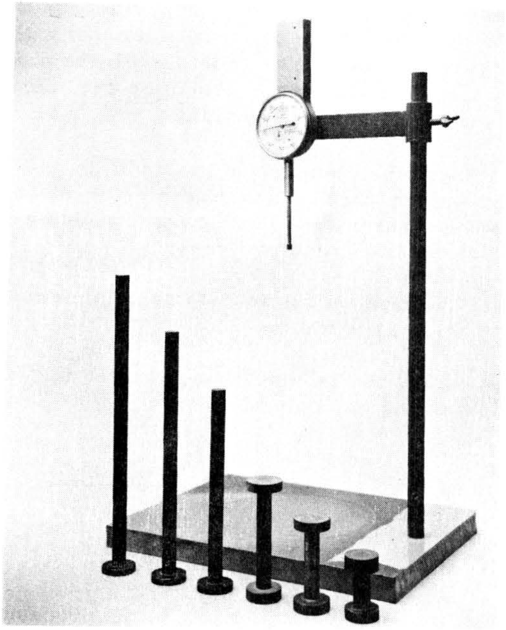


Figure 2
Height Measuring Device

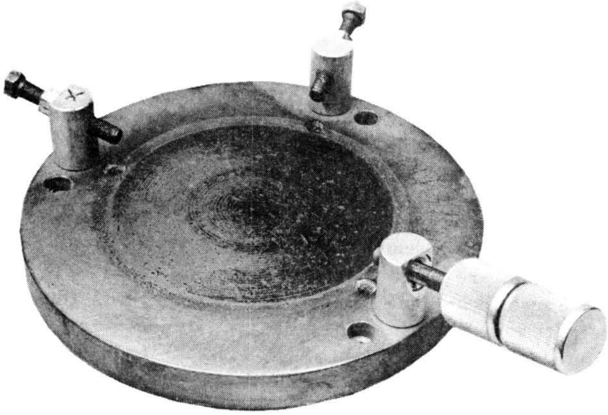


Figure 3
Mold Base for Finishing

Compactive Effort

In performing the moisture-density test, it is important to consider the type of material in selecting a compactive effort that will produce the degree of compaction required by the conditions of the proposed use of the material. See calculations for determining the number of ram blows to produce certain compactive efforts. The usual compactive efforts to obtain best results are as follows:

1. For flexible base materials and select granular soils with little or no tendency to swell or shrink, use 50 ram blows per layer (13.26 ft. lbs. per cu. in.).

2. For moderately active soils with plasticity indices from 20 to 35 and containing a high percentage of soil binder (passing No. 40 sieve), use 25 blows per layer (6.63 ft. lbs. per cu. in.).

3. Very plastic clays, subject to large volume change and plasticity indices from 35 to 45, should be molded using 15 to 20 ram blows per layer (4 to 5 ft. lbs. per cu. in.). Subgrade soils whose plasticity indices are greater than 45 should be compacted using 15 ram blows per layer (4 ft. lbs. per cu. in.).

4. Cohesionless sands are exceptions and require special treatment. Equip the compaction device with 10 pound ram with a twin striking face, still being 10 pounds weight, and a 1/2 inch thick firm rubber or neoprene pad. This pad should just slide into the mold on top of the sand layer and will divert some of the impact to vibrations. Use 100 blows per layer on eight, 1 inch layers.

Note:

For the purpose of this test a cohesionless sand is defined as a sandy soil when wetted to slightly below optimum moisture content, mixed thoroughly and molded using 50 ram blows of 18" drop 2 inch layer, that at the last blow the ram is shearing or tearing the layer in excess of 1 inch or half the thickness of the layer. In making this determination it is suggested that enough soil for only one layer of approximately 2 inch thickness be wet and molded.

5. For selection of compactive effort used in compacting specimens to be used in preliminary laboratory strength tests containing cement, lime or asphalt, see Test Methods Tex-119-E, Tex-120-E and Tex-121-E.

6. For density control of compaction by field equipment, see Test Method Tex-114-E.

Procedure

1. Re-mix material in all sizes of a sample prepared by Part II Tex-101-E if sample has been stored in laboratory several days after preparation. Determine the percent hygroscopic moisture in the material, using a representative sample of all the sizes of the material. Estimate weight of air-dry material that will, when wetted and compacted, fill the 6" diam. 8 1/2" high mold to approximately 8". Use this estimated weight and the percentages of the various sizes of particles obtained in the preparation of the large sample, compute the cumulative weights of each size to combine to make a specimen.

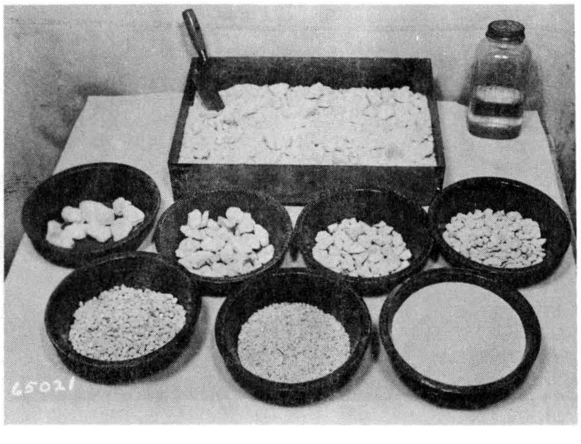


Figure 4
Material separated into Sizes for Specimen Batching

2. Weigh up the sample as calculated in step 1, keeping the aggregate portion and minus #10 sieve for flexible base material or the clay lumps and minus #20 sieve fines for soils separate.

3. Estimate the percent moisture at optimum, start the M-D Curve with a moisture content one or two percent below this estimate, calculate the water to add based on weight of dry soil or air dry soil. Weigh this amount of water into a tared sprinkling jar.

4. For base or subbase material or materials with considerable amounts of aggregate, place the aggregate portion, retained on No. 10 sieve, in the mixing pan and wet with all or part of the mixing water. Mix thoroughly breaking up the soil lumps. Do not break any of the aggregate particles. Turn the wet material over with the mixing trowel to allow the aggregate particles to absorb water.

5. Place the plus No. 20 sieve material (clay lumps) of clay soils in the mixing pan. Add part or all of the mixing water, let set until water has soaked to the bottom of the pan or until all free water has disappeared.

6. Pour the fine material passing the #10 or #20 sieve over the wet portion of sample, use trowel to cut grooves in material to cause dry fines to fall into small amount of water on bottom of pan and then mix until uniform. Take care not to lose any of the material and cover the mixture to prevent loss of moisture by evaporation.

7. In order to get uniform distribution of moisture, pass the clay soil materials through a 1/4 inch hardware cloth screen.

8. Calculate the weight of material for one layer as 1/4 of the weight of material and water in mixing pan. Separate the larger aggregate into the quadrants of the pan in a way that equal and representative portions will be weighed in each layer. Weigh out the first layer and place some loose fines, approximately 1/2" in the bottom of the mold. Continue with the larger aggregates, intermediate sizes and fines. In loading the layer it will be necessary to carefully watch the placing, using the hands or convenient hand tools, to load for maximum density. Use a spatula or similar hand tool to spade around the inside of the mold allowing some fines to fill the outside cavities before compacting the layer. Repeat this procedure on all layers using 1/4 inch of fines in lieu of 1/2 inch at bottom of subsequent layers. Layers of fine grained soils, containing little or no aggregate should be placed in the mold and leveled as described immediately above. Soils which are "fluffy" and make thick loose layers in the mold should be leveled with the hand tools then subjected to the weight of a flat plate weighing not more than 1/2 psi for a few seconds. The finishing tool may be used for this purpose. Do not push this layer

down by hand or other means than that described above. Compact the layer using a predetermined number of accurately adjusted 18 inch drops of the 10 pound ram. Stop the compactor as frequently as necessary in order to clean the ram face of sticking material.

9. After the last layer has been compacted, fasten the mold containing the material upon the top of the extra base plate and finish the specimen by means of the various hand tools, such as putty knife, rawhide hammer or plastic mallet and circular plate with smooth surface. Use the small level to check the surface of the specimen so that it will be plane and level with the top of the forming mold. Do not trim the specimen. When surface is level the following schedule of blows on the flat face finishing tool may be used.

No. of 10 lb. 18" ram blows per layer	Type of hand hammer	No. of hand hammer blows and description
15-20	1 to 2 lb. hammer	2 to 4 light "pecking blows"
25	1 to 2 lb. & 4 to 5 lb. rawhide	5 to 10 light and 2 med. firm
50 or above	1 to 2 lb. plastic and 4 to 5 lb. rawhide	5 to 10 light and 5 firm

10. Remove mold from base plate, weigh the specimen in the mold to the nearest estimated 0.001 of a pound and measure the height by means of the measuring device to the nearest 0.001 of an inch (Figure 5). Record data on M-D and Triaxial Work Sheet. (Figure 7).

11. Carefully center the specimen over a porous stone, place in press to extrude molded specimen. Push the material on the bottom stone upward out of the mold. (See Figure 6a)

12. Place specimen in tared drying pan, break up material and dry at controlled temperature 212° to 230°F. When a set of test specimens is to be made for triaxial tests enclose the M-D specimens in a triaxial cell with top and bottom porous stones in place until the test specimens are complete. Break up and dry out only the specimens on the dry and wet side of optimum moisture. Obtain the dry weight to the nearest 0.001 lb.

13. If necessary, adjust the weight of material to obtain an 8 inch specimen within 1/8" ± (usually to the nearest 1/4 lb. of dry material). Vary the percentage of mixing water and repeat the operations detailed above to obtain several points on the moisture density curve. When the optimum appears to fall between two points one or more specimens should be made to completely define the curve with respect to both percent moisture and pounds per cubic foot of density. Calculate moisture and density and plot on M-D Curve Figure 8.

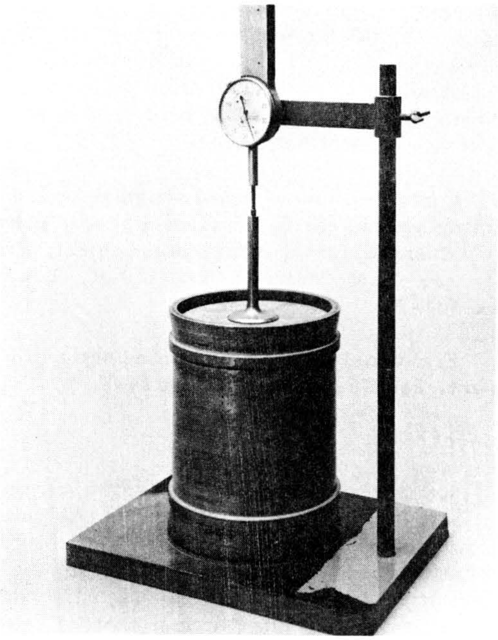


Figure 5
Measuring Height of Specimen

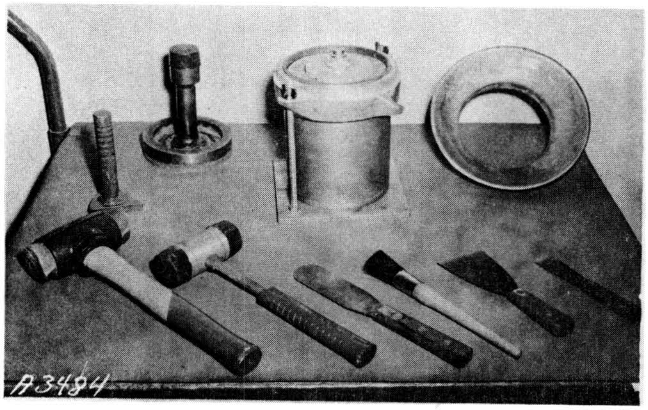


Figure 6
Tools Used in Finishing Top of Specimen

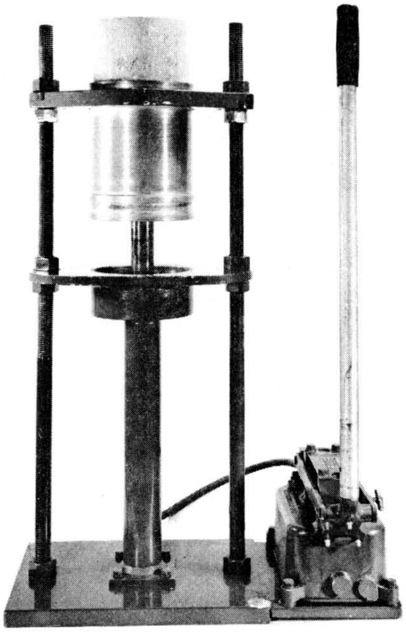


Figure 6a
Press Extruding Specimen

Calculations

1. Calculate compactive effort as follows:

Compactive effort =

$$\frac{\text{No. of blows x weight of ram x fall of ram}}{\text{Volume of layer of material}}$$

As proposed in this procedure, the modified ram weighs 10 pounds and falls 1.5 feet to compact layers of material 2 inches thick and 6 inches in diameter; 25 blows will equal a compactive effort of 6.63 ft. lbs./cu. in.

$$\text{Compactive Effort} = \frac{25 \text{ x } 10 \text{ lbs. x } 1.5 \text{ ft.}}{3 \text{ in. x } 3 \text{ in. x } 3.1416 \text{ x } 2 \text{ in.}} =$$

6.63 ft. lbs./cu. in.

2. Volume of Specimen = volume per in. of mold x height of specimen.

3. Adjust the molded height of specimen as follows:

$$\text{Dry weight of material} = \frac{\text{Dry weight of specimen}}{\text{Height of specimen}}$$

x 8 inches

4. Calculate dry density of specimens as follows:

$$\text{Dry density} = \frac{\text{Dry weight of specimen in pounds}}{\text{Volume of specimen in cu. ft.}}$$

5. Moisture content by Test Method Tex-103-E, percent =

$$\frac{\text{Weight of sample wet - weight of sample dry}}{\text{Weight of sample dry}} \text{ x } 100$$

6. Calculate zero air voids density by use of the following expression:

$$\text{Zero air voids density} = \frac{\text{Specific gravity x } 62.5}{1 + (\text{sp. gr. x} \frac{\%\text{ moisture}}{100})}$$

Where the specific gravity is not known, a value of 2.65 may be used as an average specific gravity.

Graphs

Plot the dry density and zero air voids density against the percent of molding moisture as shown in Figure 8.

Notes: (Precautions)

It should be noted under paragraph 8 of Procedures, above, that in placing material in the mold, larger aggregates should be placed well down near the bottom of the layer. Usually, aggregates of 3/4" size or larger do not move down into the layer during the action of the ram. The finer sizes on top will beat down into the larger aggregates, but care and judgment must be exercised in order to get away from building internal voids into the specimen. The finished top should be as free as possible from aggregates with corners that will bear on the top porous stone.

General Notes

When determining the M-D Curve for defining molding conditions for accelerated test of Tex-117-E, Part II, Group d and e, be sure to define the shape of the top of the M-D Curve to see if a flat top exists.

When determining the M-D curve for lime stabilized subgrades and base materials, refer to Figure 3 in Test Method Tex-121-E for the recommended amounts of lime to be used.

M/D & TRIAXIAL WORK SHEET

LAB NO.____________

____% HYGRO ALLOWED

Date Molded												
Sample No.												
Compactive Effort												
Total % Water												
Pounds Material												
Pounds Water Desired												
Pounds Hygroscopic Water												
Pounds Water Added												
Tare Weight of Jar												
Weight Jar and Water												
Mold No.												
Wet Wt. Specimen & Mold												
Tare Weight Mold												
Wet Weight Specimen												
Height of Mold												
Dial Reference												
Dial Reading												
Height Specimen												
Vol. per Linear Inch												
Vol. of Specimen												
Wet Density Specimen												
Dry Weight Pan & Specimen												
Tare Weight Pan												
Dry Weight Material												
Weight Water												
Percent Water on Total												
Dry Density												
Guestimated Dry Density												

Figure 7

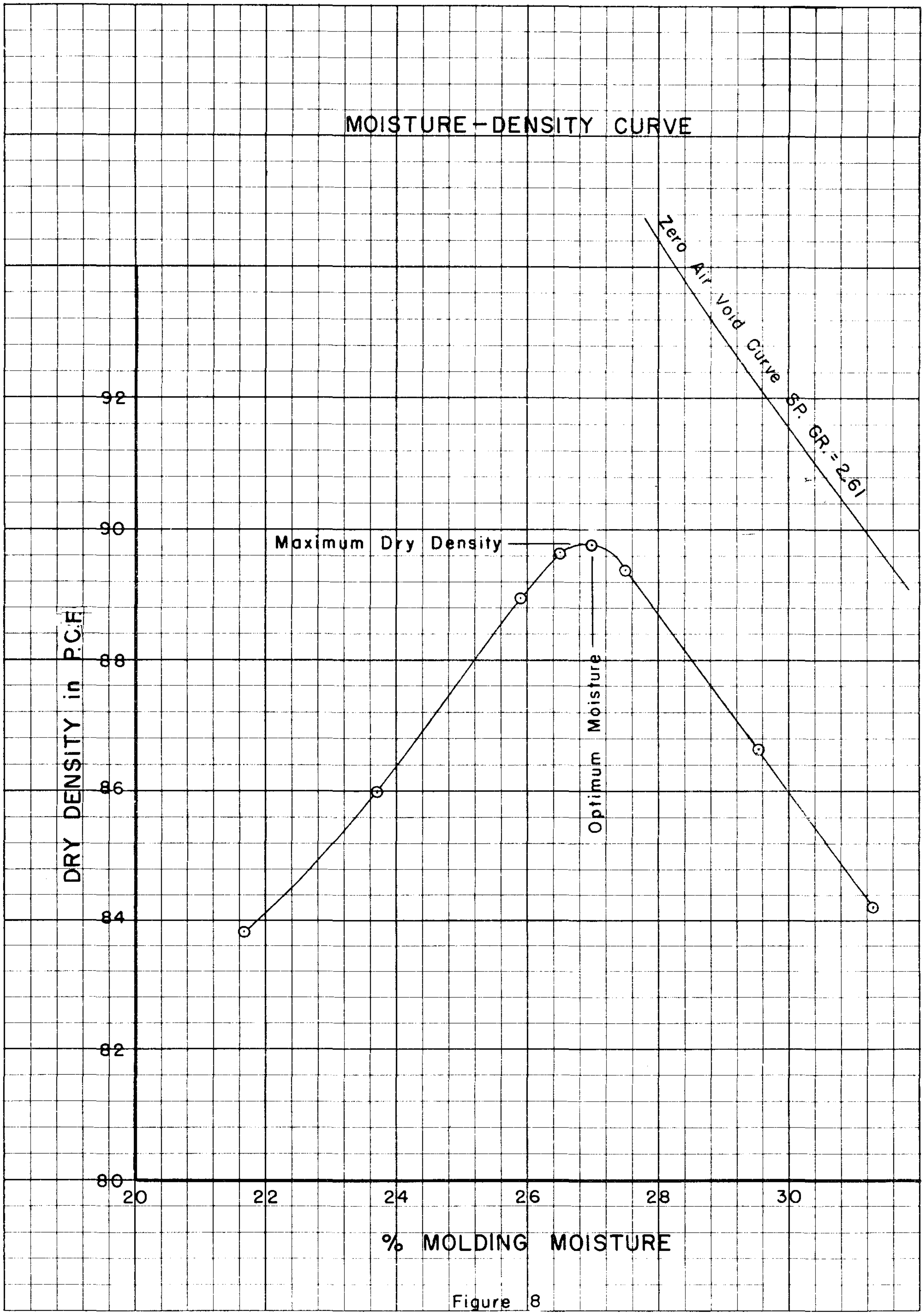

MOISTURE-DENSITY CURVE
Zero Air Void Curve SP. GR. = 2.61
Maximum Dry Density
Optimum Moisture
DRY DENSITY in P.C.F.
92
90
88
86
84
82
80
20
22
24
26
28
30
% MOLDING MOISTURE

Figure 8

Texas Highway Department

Materials and Tests Division

SOIL-LIME COMPRESSIVE STRENGTH TEST METHODS

Scope

This method describes a procedure for determining the triaxial classification and unconfined compressive strength as an index of the effectiveness of hydrated lime treatment in imparting desirable properties to flexible base and subgrade materials.

Apparatus

The apparatus outlined in Test Methods Tex-101-E, Tex-113-E, Tex-117-E and a Compression Testing Machine meeting the requirements of A.S.T.M. Designation D 1633-59T. Capacity 60,000 lbs. The Tri-Axial Screw Jack Press Tex-117-E may be used when anticipated strengths are not in excess of 300 to 400 psi.

Materials

1. A fresh supply of hydrated lime.
2. Water - a good quality tap water.

Test Record Form

Record test data on "Compressive Strength Worksheets Nos. 1 and 2", Figures 1a and 1b.

Preparation of Sample.

Select a representative sample approximately 200 pounds in size and prepare the material according to the procedure of Part II in Test Method Tex-101-E. See General Notes

Procedure

1. Determining optimum moisture and density: Use the method described under Test Method Tex-113-E and determine the optimum moisture and maximum density for the soil-lime mixture. The amount of lime to use is a percentage based on the dry weight of the soil. In performing this part of the test, mix the lime with the portion of material passing the No. 10 sieve. Wet the plus No. 10 portion with some or all of the weighed quantity of water (depending on how little or how much plus No. 10 the sample contains) and stir and wet the aggregates thoroughly. Then add in the mixture of minus No. 10 material with lime, mix thoroughly and compact each layer with a compactive effort of 13.26 ft.-lbs. per cubic inch. (50 blows per 2 inch layer using the 10 pound ram with 18 inch drop).

Note: In clay soils separate the material on the No. 20 sieve. Mix approximate proportionate amounts of the lime to be used with both fractions. Sprinkle the mixing water on the + No. 20 fraction using most or all of the water as required. Add in the - No. 20 fraction and the remainder of water if any. Mix thoroughly and mold as above.

2. Compaction of the Test Specimen: Compact six specimens 6" in diameter and 8" in height at the optimum moisture and density found by using 13.26 ft. lbs. /cu. in. compactive effort for each percentage of lime selected. These lime-treated subgrade soil or flexible base specimens molded for the triaxial test should be compacted as nearly identical as possible. If the material to be improved by lime treatment is a flexible base material and the unconfined compression test is used to evaluate the strength, only three identical specimens need to be molded for each percentage of hydrated lime.

3. Curing Test Specimens

(a) The test specimens with top and bottom porous stone in place are covered with a triaxial cell immediately after extruding from the forming mold. The specimens are now stored at room temperature for a period of 7 days.

(b) After this moist curing period, remove the cells and place the specimens in an air dryer and dry at a temperature not to exceed 140°F. for about 6 hours or until one-third to one-half of the molding moisture has been removed. All lime-treated soils are dried as given above even though a considerable amount of cracking may occur. Allow the specimens to cool to room temperature before continuing the test.

(c) Weigh, measure, and enclose the specimens in triaxial cells and subject them to capillarity for ten days. Use a constant lateral pressure of 1 p.s.i. and a surcharge weight of 1/2 p.s.i. to 1 p.s.i. depending upon the use of the material being tested.

4. Testing the Specimens: The specimens are prepared and tested as outlined in Test Method Tex-117-E. A compression testing machine of adequate range and sensitivity may be used.

Calculations and Graphs

The calculations, plotting of test data and interpretation of test results are the same as for the Triaxial Compression Test, Part I, of Test Method Tex-117-E, except that lime stabilized clay soils are not currently recommended for top course of base, regardless of the triaxial class.

Reporting of Test Results

Report the test results on Compression Test Results, Figure 2. Include triaxial strength classification or unconfined compressive strength values, density, moisture and recommended lime contents.

General Notes

Wetted stabilized materials taken from the roadway during construction should be quartered to approximate specimen size batches and molded. This material should not be prepared in accordance with Test Method Tex-101-E. Where M-D curves are desired, material drier than the roadway mix can be produced by stirring the material or by drying back under a fan while stirring the mix.

Store hydrated lime in air tight container or use a fresh supply.

Notes

This test has been devised as a means of determining the quality of soils treated with hydrated lime to be used for subbase or base protected with a wearing surface. Flexible base materials and granular soils can usually be stabilized with about 3% hydrated lime. A larger amount may be required to improve the strength of a very plastic clay subgrade if it is intended to improve and use the treated clay as part of the subbase. Unconfined compressive strength of 100 p. s. i. is satisfactory for final course of base construction and it is desirable that materials for such courses contain a minimum of 50 percent plus No. 40 before treatment. The amounts of lime from Figure 3 (from AASHO T 220-66) are recommended amounts for stabilization of subgrade soils and base materials. These percentages of lime should be substantiated by these methods to insure adequate strengths. Unconfined compressive strengths of at least 50 psi are suggested as adequate for subbase soils treated with lime. It is possible for short term tests of soil-lime mixes, using smaller percentages of lime than suggested in Figure 3, to give misleading results due to field variations in materials, mixing, lower densities and so forth.

It is intended that field density control shall be based on testing roadmix samples in accordance with Test Method Tex-114-E. It is suggested that a minimum of 98% of compaction ratio density be obtained for base course treatments and 95% of compaction ratio density be obtained for subgrade treatments.

COMPRESSIVE STRENGTH TEST WORKSHEET #1
MOLDING DATA FOR SOIL-LIME MIXES

SAMPLE NO. 73-7-R	1	2	3	*4	*5	*6
DATE MOLDED	2-6-73	→	→	→	→	→
DATE TESTED	2-26-73	→	→	→	→	→
PERCENT LIME	3	3	3	3	3	3
PERCENT WATER ADDED	14.92	12.92	10.92	13.42	→	→
PERCENT HYGRO. MOIST	2.14	2.14	2.14	2.14	→	→
TOTAL % MOIST. IN SPEC.	17.06	15.06	13.06	15.56	→	→
POUNDS SOIL (DRY)	13.217	13.902	13.902	14.098	→	→
POUNDS LIME	.397	.417	.417	.423	→	→
LBS. SOIL (DRY) + LIME	13.614	14.319	14.319	14.521	→	→
LBS. SOIL + (HYGRO. MOIST.)	13.500	14.200	14.200	14.400	→	→
POUNDS LIME	.397	.417	.417	.423	→	→
LBS.SOIL+HYGRO.MOIST.+LIME	13.897	14.617	14.617	14.823	→	→
WT. WATER ADDED (LBS.)	2.031	1.850	1.564	1.949	→	→
TARE WT. JAR	1.337	1.337	1.337	1.337	→	→
WT. WATER + JAR	3.368	3.187	2.901	3.286	→	→
WT. PER LAYER	3.98	4.12	4.05	4.19	→	→
MOLD NO.	2	2	2	2	2	2
WET WT. SPEC. + MOLD						
TARE WT. MOLD						
WET. WT. SPECIMEN	15.846	16.394	16.117	16.692	16.691	16.693
CALCULATED DRY WT. SPEC.	13.537	14.248	14.255	14.444	14.444	14.445
HEIGHT SPECIMEN	7.615	7.836	7.905	7.936	7.934	7.944
VOL. PER LIN. INCH	.016486	→	→	→	→	→
VOLUME OF SPEC.	.125541	.129184	.130322	.130833	.130800	.130965
CALCULATED DRY DENSITY SPEC.	107.83	110.29	109.38	110.40	110.43	110.30
				*(Test Specimens)		

Figure 1a

COMPRESSIVE STRENGTH TEST WORKSHEET #2
CURING, WETTING, TESTING, AND DRYING DATA FOR SOIL-LIME MIXES

SAMPLE NO. 73-7-R	1	2	3	4	5	6
CELL NO.				102	164	79
LBS. OF ADDED SURCHARGE				10	10	10
DATE MOLDED				2-6-73 →	→	→
DATE IN AIR DRYER				2-13-73 →	→	→
DATE IN MOIST. ROOM				2-16-73 →	→	→
DATE OUT MOIST. ROOM				2-26-73 →	→	→
HT. SPEC. IN CAPILLARITY				11.944	11.931	11.955
HT. SPEC. OUT CAPILLARITY				11.956	11.948	11.967
WT. SPEC. AFTER AIR DRY				24.627	24.642	24.651
DRY WT. STONES				8.922	8.938	8.976
DRY WT. SPECIMEN				14.543	14.542	14.555
WT. MOIST. IN SPEC.				1.162	1.162	1.120
% MOIST. TO CAPILLARITY				7.99	7.99	7.69
WT. SPEC. AFTER CAPILLARITY				26.338	26.352	26.423
WET WT. STONES				9.619	9.642	9.650
WET WT. SPECIMEN				16.719	16.710	16.773
DRY WT. SPECIMEN				14.543	14.542	14.555
WT. MOIST. IN SPECIMEN				2.176	2.168	2.218
% MOIST. AFTER CAPILLARITY				14.96	14.91	15.24
LOADING RATE (IN. PER MIN.)				0.15	0.15	0.15
TOTAL COMPRESSIVE LOAD				2,406	2,354	2,340
COMP. STRENGTH (P.S.I.)				84.31	82.48	81.99
DRY WT. PAN & SPECIMEN	17.801	18.622	18.558	18.512	18.510	18.458
TARE WEIGHT PAN	4.192	4.292	4.232	3.969	3.968	3.903
DRY WEIGHT SPECIMEN	13.609	14.330	14.326	14.543	14.542	14.555

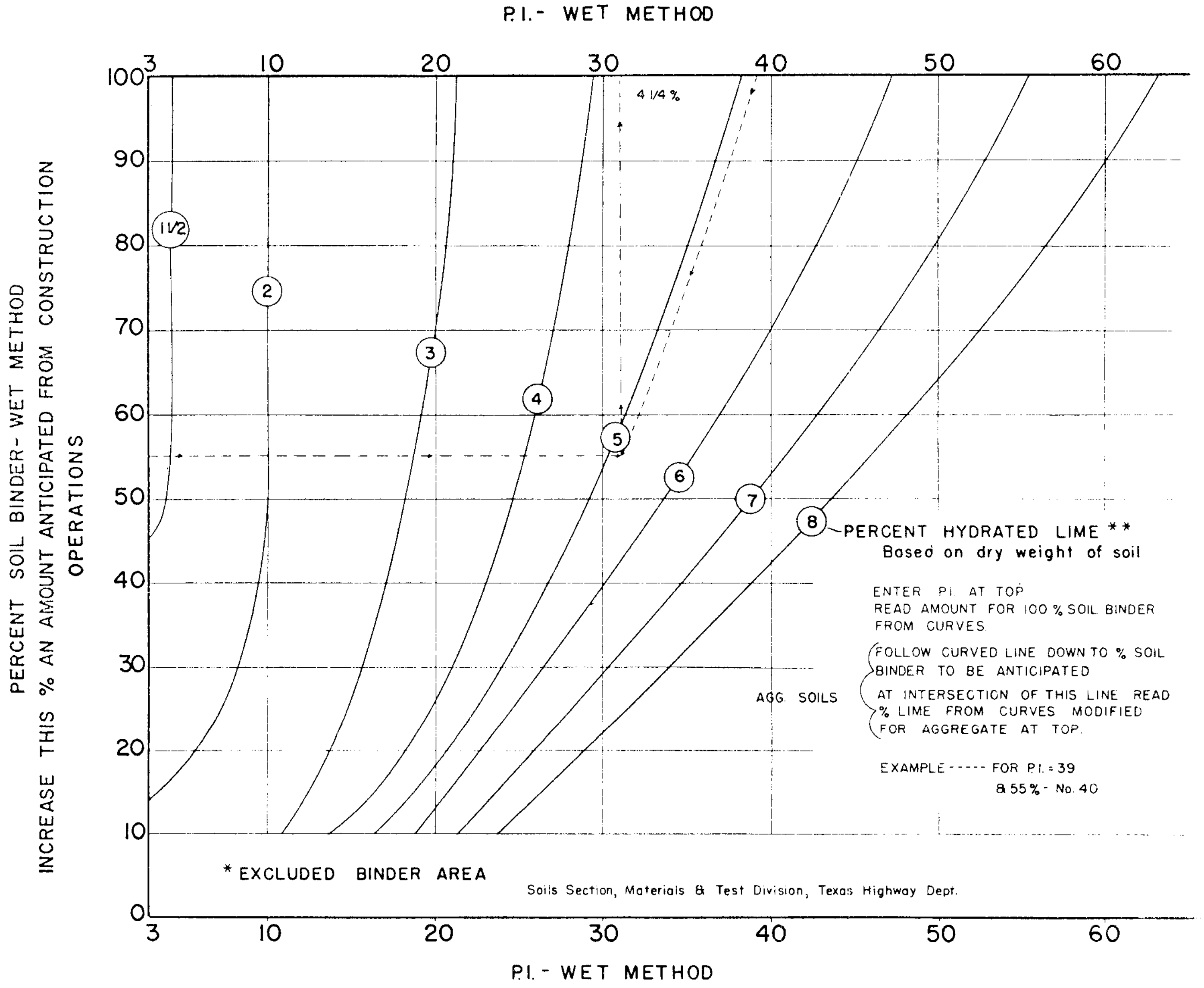
Figure 1b

COMPRESSION TEST RESULTS

LAB. NO.	PERCENT LIME ON BASIS OF DRY WEIGHT OF SOIL	DRY DENSITY IN #/CU. FT. OF SOIL AND LIME	COMPRESSIVE STRENGTH P.S.I.	PERCENT MOISTURE ABSORBED	OPTIMUM MOISTURE OF SOIL PLUS LIME

Figure 2

RECOMMENDED AMOUNTS OF LIME FOR STABILIZATION OF SUBGRADES AND BASES. (THESE PERCENTAGES SHOULD BE SUBSTANTIATED BY APPROVED TESTING METHODS ON ANY PARTICULAR SOIL MATERIAL)



PERCENT HYDRATED LIME **
Based on dry weight of soil

ENTER P.I. AT TOP
READ AMOUNT FOR 100 % SOIL BINDER FROM CURVES
FOLLOW CURVED LINE DOWN TO % SOIL BINDER TO BE ANTICIPATED
AT INTERSECTION OF THIS LINE READ % LIME FROM CURVES MODIFIED FOR AGGREGATE AT TOP.

EXAMPLE ----- FOR P.I. = 39
& 55 % - No. 40

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* Exclude use of chart for materials with less than 10 % - No. 40 and cohesionless materials (P.I. less than 3)

** Percent of relatively pure lime usually 90 % or more of Ca and/or Mg hydroxides and 85 % or more of which pass the No. 200 sieve. Percentages shown are for stabilizing subgrades and base courses where lasting effects are desired. Satisfactory temporary results are sometimes obtained by the use of as little as 1/2 of above percentages. Reference to cementing strength is implied when such terms as "Lasting Effects" and "Temporary Results" are used.

Figure 3