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In addition, various means to determine optimum lime and moisture content for a given soil were tried. One method employing statistics and a sand bath test appears to show promise as a satisfactory test method.

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STATE OF CALIFORNIA
HIGHWAY TRANSPORTATION AGENCY
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

INTERIM REPORT
on
EFFECTS of HYDRATED LIME
in
TREATING SOILS

65-08

December 1965

State of California
Department of Public Works
Division of Highways
Materials and Research Department

December 8, 1965

Expenditure Authorization
Number 431068

Mr. J. C. Womack
State Highway Engineer
Division of Highways
Sacramento, California

Dear Sir:

Submitted for your consideration is:

AN INTERIM REPORT ON

LIME TREATMENT OF SOILS

Study made by..................................Pavement Section
Under general direction of.....................Ernest Zube
Work supervised by.............................Clyde Gates
Report prepared by.............................Mas Hatano

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

Attach

INTRODUCTION

This report covers work performed in the laboratory as well as in the field on lime treatment of soils. Various items such as effects of compacted curing time, a test for durability, effects of recompacton and overnight soak moisture were explored.

In addition, various means to determine optimum lime and moisture content for a given soil were tried. One method employing statistics and a sand bath test appears to show promise as a satisfactory test method.

SUMMARY AND CONCLUSIONS

1. Our present Test Method No. Calif. 301-F requires a one day compacted curing period for testing lime treated soils. Prior to this time, the test method required a 7 day compacted curing time. There has been some question raised concerning the validity of this change in curing time.

Some data has been accumulated comparing R-values of lime treated soils having a 1 and 7 days compacted curing time. The samples cured for 7 days showed an average of 6 R-value units greater than the 1 day cured samples.

Although the 7 days cured tests show higher R-values in the laboratory, lime treatment of soils during construction normally can never be performed as well in the field. This indicates that the one day cured tests would be more representative of what is attained in the field.

2. Breaking up and recompacting of some lime treated materials may lower the R-value as much as 50 R-value units. Therefore, re-working of compacted mixes in the field should be avoided.

3. A sand bath test was utilized to give an indication of the durability of the lime treated material. The method consists of surrounding the treated specimen with sand and giving the specimen access to free water by capillary action of water through the sand.

4. Preliminary tests were made with a chemical Base Exchange Test. This test could be used to indicate the "response" characteristics of various clay soils. More work needs to be done with this test before any definite conclusions can be reached.

5. Laboratory tests indicate that lime treated clay soils need a short mellowing or loose curing period after the final addition of water and lime. An example is cited where a treated specimen was unable to sustain a compaction foot pressure of 6 psi air pressure. However, this same specimen had an R-value of 58 after 1 day of compacted cure time.

6. The R-value of a lime treated soil is affected by the amount of overnight soak moisture. The greater the amount of soak, the lower the R-value. However, there are indications that specimens with the higher R-values obtained with the lower overnight soak moisture are not as durable. Our present R-value soak criteria, which states that 1/2 to 2/3 of the moisture at 300 exudation is to be used for overnight soak moisture, is satisfactory for lime.

7. A two factor analysis of variance method (Statistical Method) was developed for determining optimum moisture and lime content for any soil. When used in conjunction with the routine R-value and the sand bath test, the data indicates that a moisture content around 500 exudation pressure is a more realistic value than our present 300 exudation pressure. This method may give more economical designs. It is anticipated that another year's work will be necessary before the method is finalized.

DISCUSSION

EFFECTS OF 1 AND 7 DAYS COMPACTED CURE TIME ON LIME TREATED SOILS

Our present Test Method No. Calif. 301-F requires a 1 day compacted cure time before determining the R-value of a lime treated soil. Previous test methods required a 7 days compacted curing time. Some comparative test data was collected and is presented, which indicates why this change was made.

Table 1 shows a tabulation of 23 lime treated tests from 8 counties performed with a 1 and 7 days compacted curing time. The data is also displayed on a scatter diagram (Figure 1). Since this data is somewhat limited, a statistical method as outlined in "ASTM Manual on Quality Control of Materials" was used to evaluate the test data. Initially a normal distribution curve was developed from the data and is shown on Figure 2. Then, the area under the distribution curve for the various differences between 1 and 7 day values were determined by calculations. Statistically speaking, based on the available data, we can make an estimate of the trend as follows:

About 20% of the 7 day cured R-values will be less than the 1 day R-value.

About 51% of the 7 day cured R-values will be from 0 to 10 units more than the 1 day R-values.

About 26% of the 7 day cured R-values will be from 11 to 19 units more than the 1 day R-values.

About 3% of the 7 day cured R-values will be 20 units or more than the 1 day R-values.

On an average, the 7 day cured samples are 6 R-value units greater than the 1 day cured tests.

Lime distribution in soils during construction normally can never be performed as well as in the laboratory. This indicates that although the 1 day cured R-values are generally lower, the 1 day tests would be more representative of what is attained in the field.

In any event, it would be desirable to obtain more data on the strength of lime treated materials in the roadway. Laboratory testing methods can then be modified as necessary to more truly reflect field conditions.

EFFECT OF RECOMPACTING LIME TREATED MATERIAL

Figures 3 and 4 show lime treated samples which were broken up, recompacted and retested for R-value. The laboratory data indicate that, after fabrication, lime treated materials should be left undisturbed in order to maintain their maximum strength. This would indicate that in the field the material should not be re-worked after it is once compacted.

SAND BATH TEST

A non-standard test used in the past by the laboratory for bituminous testing was applied to lime treated soils. The method is called a "Sand Bath Test" which consists of a test specimen being surrounded by sand and having free access to water (Figure 5). This gives us an accelerated test in the laboratory which simulates a roadway which becomes saturated sometime after construction. This gives some measure of the durability of the lime treated specimen.

BASE EXCHANGE CAPACITY TEST

Some soils do not respond to lime or remain as durable after treatment as other soils. One test which gives some indication of the "response" property of soils to lime is the following Base Exchange Test:

When a sample of soil is placed in a solution of a salt such as sodium chloride, a portion of the sodium is absorbed or taken up by the soil and an equivalent amount of other cations is displaced into solution. This reaction is termed base exchange, or more precisely, cation exchange, and the cations displaced from the soil are referred to as replaceable or exchangeable cations. The total amount of exchangeable cations that a soil can hold, is expressed in milliequivalents per 100 grams of soil, and is called the cation exchange capacity of the soil. It is often convenient to express the relative amount of a given cation on the exchange complex in terms of the percent saturation with that cation. For example, the exchangeable-sodium-percentage is equal to 100 times the milli-equivalents of exchangeable sodium per 100 grams of soil divided by the cation exchange capacity of the soil.

Grim[1] indicated the various clay minerals possessed general base exchange capacities as follows:

Montmorillonite	80-150
Illite	10- 40
Kaolinite	3- 15

The following Table II shows base exchange test data on a few samples:

TABLE II

Test No.	Grading #4	#200	5u	PI	Untr. R-value	% Lime	Lime Tr. R-V.	Base Exchange Capacity.
65-1182	100	77	Floc	15	7	3.0	46	10.9
65-1685	100	50	21	8	16	3.0	82	13.9
65-1183	100	74	Floc	20	9	3.0	53	14.4
65-1682	100	90	26	11	23	3.0	75	16.0
65-1686	100	90	40	-	11	3.0	75	20.5
62-1115	100	79	28	12	12	3.0	69	22.2
64-3133	100	95	59	25	9	3.0	87	46.9

The data is plotted on Figure 6.

There is some correlation between the Base Exchange Test and the "response" property of soils to lime. However, further tests are necessary before any definite relationship can be established for detecting non-responsive soil.

LABORATORY COMPACTION

Figure 7 shows test data for a lime treated material. It is interesting to note that in many instances the R-value of a test specimen is high (65) while the exudation pressure is low (120) and the compactor foot pressure used to fabricate the briquette is also low (12 psi). This is not normally true for untreated material. The paradox in this case is due to compacting the specimen before any cementing takes place in the lime. The R-value is high because of the cementing action which takes place during the 16 to 24 hours compacted cure.

1 "Applied Clay Minerology" by R. E. Grim, 1962

This indicates that although compaction equipment may push or cause quaking in the lime treated clay soil during construction, the lime treated material may stabilize during curing. This is apparently what happened on a construction project to be mentioned later in this report.

EFFECT OF OVERNIGHT SOAK MOISTURE IN THE R-VALUE TEST

Figures 8, 9, and 10 show R-value tests on a lime treated material with varying amounts of overnight soak moisture (loose curing period). There appears to be general lowering of R-value as the soak moistures increase. The present Test Method No. Calif. 301 indicates that 1/2 to 2/3 of the moisture at 300 exudation pressure should be added as the overnight soak moisture. This criteria appears satisfactory and does not appear to significantly affect the final R-value of the lime treated soils.

CONSTRUCTION PROJECT A

(San Joaquin County on Copperopolis Road between Duncan and Hewitt Road)

This particular project involved treating the native soil with 4 percent lime (by dry weight of the aggregate). The soil was mixed with the lime and allowed to loose cure from 2 to 3 days. When the compaction operations were begun, severe quaking occured in many areas. The road was open to traffic and some heavily loaded trucks and earthmovers were using the road.

Construction operations were stopped for the next two days during which time about 1-1/2 inches of rainfall were recorded. When the weather cleared, a motor grader was operated over the areas where quaking had occurred during the rolling operations. At this time, there was only minor quaking in isolated areas. Apparently, most of the road had "firmed up" in 2 days.

Samples were obtained of the untreated soil and the treated soil from the good and bad areas. The following Table III shows the test data.

TABLE III

UNTREATED MATERIAL							3% Lime	
Grading							Routine Lab	
#4	#200	5u	SE	PI	R-value	Moist at 300 Exud.	R-value	Moist at 300 Exud.
100	59	20	11	7	22	10.5%	82	13.0%

LIME TREATED FIELD SAMPLES (4% Lime planned)

Sampled from Stable Area			Sampled from Unstable Area		
R-value	Field Moist.	Exud. Pr.	R-value	Field Moist	Exud. Pr.
50	10.9%	230	21	13.1%	50

Analysis of the data indicates that difficulty in obtaining compaction of the lime treated material obtained from the field was primarily due to an excess of moisture with poor distribution of the lime, a contributing factor.

At this point, it may be well to mention that a 2 or 3 days loose curing period may not be desirable. Mitchell and Hooper[2] indicate in their studies that for a given compactive effort, a delay in mixing and compaction is detrimental in terms of density, swell, and strength. Their studies indicate a delay over 24 hours is not desirable.

Mateos and Davidson[3] indicated that loose curing periods over 4 hours are not desirable.

[2] The Influence of Time Between Mixing and Compaction on Properties of a Lime Stabilized Expansive Clay by J. K. Mitchell & D. R. Hooper 1961 HRB Bulletin 1961

[3] Compaction Characteristics of Soil Lime Fly Ash Mixtures by Manuel Mateos and Donald T. Davidson, January, 1963 HRB Bulletin 1963

DEVELOPMENT OF A DESIGN PROCEDURE

Additional studies were made to develop an improved test method for determining optimum moisture and lime content for lime treatment of soils. It has been known for some time that lime treated materials become water resistant and develop some slab strength when properly cured.

Some ideas have been discussed and at the present time, it seems that the following factors would have to be considered for a design procedure.

1. In order for lime treated soils to gain maximum strength, there must be adequate moisture available. In practically all cases, it is greater than the optimum moisture indicated by Test Method 216.

2. The amount of lime used in laboratory tests should be increased by about 0.5% in the field over that shown by laboratory tests, to insure satisfactory strength. Mixing and curing of treated materials are not normally as good in the field as in the laboratory.

3. Some materials do not respond well to lime treatment. This could be due to some compound such as iron oxide or sulfates in the soil. This type of material usually does not remain durable when given access to additional water after compaction. Many times, the R-values are below 60 with 5 & 6% lime. Some test such as the sand bath test could be used for determining the adaptability of this type of soil for lime treatment.

4. Use of about a 500 exudation pressure to determine design R-values. This would represent a moisture content wetter than field test optimum and dryer than the present 300 exudation moisture used for untreated soils. Tests on lime treated soils give some indication that around 500 exudation pressure is a reasonable figure.

In the testing of untreated soils, the moisture at saturation is incorporated during fabrication. This concept appears reasonable since the moisture level of roadways will attain this saturated condition some time during its design life.

With respect to treated soils, the primary purpose of additives is to keep the moisture out of the compacted roadway. It therefore appears that the laboratory test specimens should be compacted at a moisture level used in construction. The specimens should then be given access to additional moisture by some means such as the sand bath test to see if moisture is actually kept out of the treated material. At the present time, it appears that our testing procedure, which requires fabrication of saturated specimens could give us lower R-values and greater cover requirements than would be necessary in some instances.

Figure 11 shows a plot of moisture versus R-value for specimens compacted at varying lime contents. The specimens were cured for 7 days and placed in a sand bath for 7 days. The test data indicates the optimum moisture is around 400 or 500 exudation pressure. The maximum strength can be achieved with about 4% lime.

The optimum lime and moisture content can be obtained in a simpler manner by using a two factor analysis of variance method (a statistical method). The principle of this method is illustrated in Figure 12. The percent lime is plotted against percent moisture and the R-values are shown as contour lines. In this case, the optimum would be around 15.5% moisture with 5.0% lime.

Applying the above method, a tentative new test procedure has been outlined. The test procedure would necessitate batching 8 to 10 specimens. Normally, 3 to 4 specimens would be required for the lime treated R-value test with 3% lime. While performing the R-value test, the operator must be sure that at least one specimen will have an exudation pressure greater than 500 psi. The moisture at 500 exudation will give a starting moisture for fabricating the lime treated specimens as follows:

1. One specimen with 3% lime and a moisture content 1-1/2% below 500 exudation pressure.

2. One specimen with 3% lime and a moisture content 1-1/2% above 500 exudation pressure.

3. One specimen with 5% lime and a moisture content 1-1/2% below 500 exudation pressure.

4. One specimen with 5% lime and a moisture content 1-1/2% above 500 exudation pressure.

The 500 exudation pressure was used only as a guide for moisture selection. When fabricating these specimens, an exudation pressure not to exceed 350 psi will be applied as a leveling load. The specimens are then placed in a sand bath for 7 days. The stabilometer test would be performed on the specimen without the expansion pressure test.

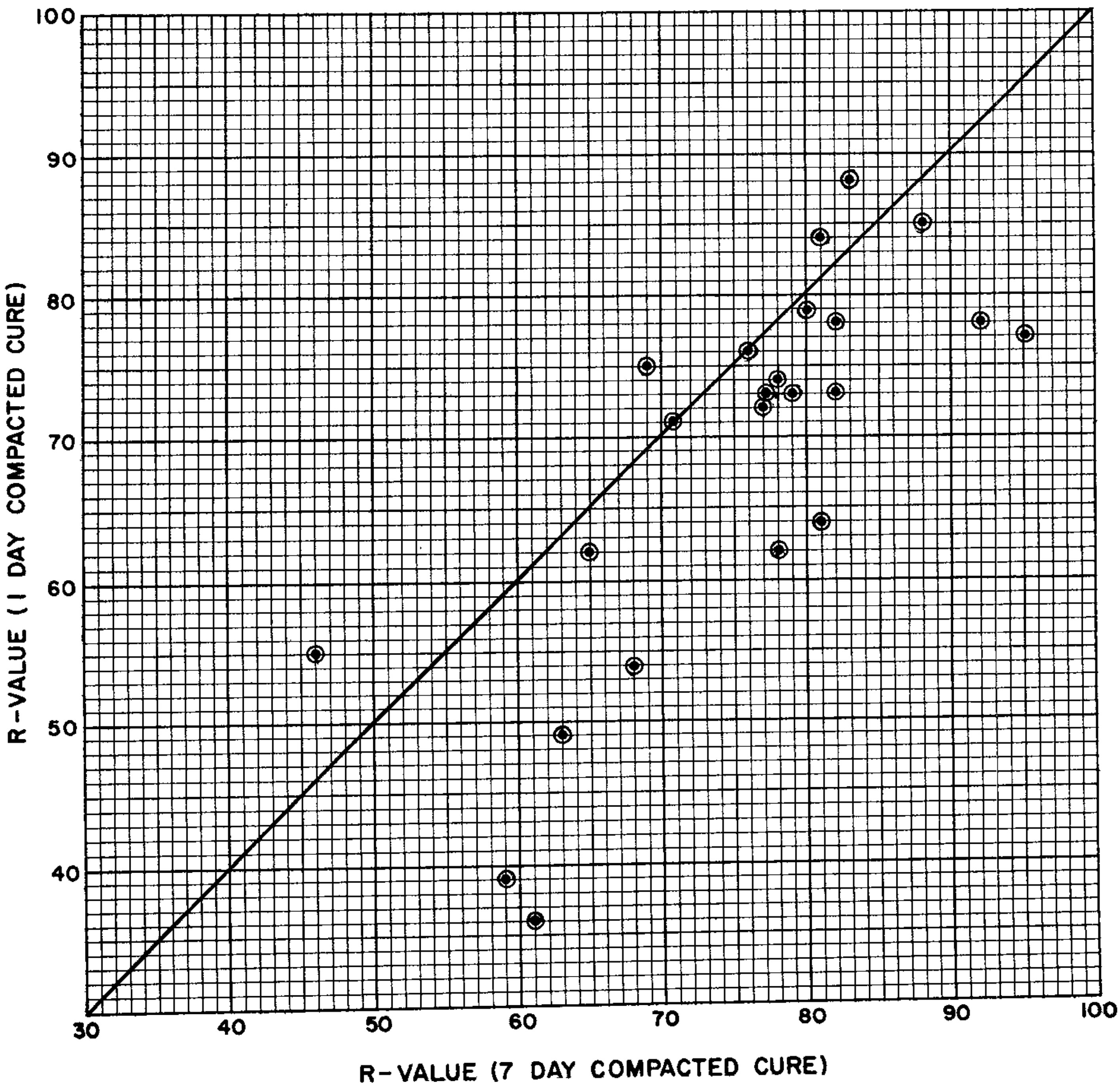
The R-value test data from the four specimens would be plotted as shown on Figure 12 and R-value contour lines interpreted. Additional specimens may be required if the optimum lime and moisture contents cannot be determined.

The selection of the design lime and moisture contents can be determined from Figure 12. In the example, a maximum R-value (greater than 73) can be obtained with 5% lime and 15.5% moisture. Normally, 0.5% additional lime should be used to compensate for variations in lime distribution during construction.

TABLE I

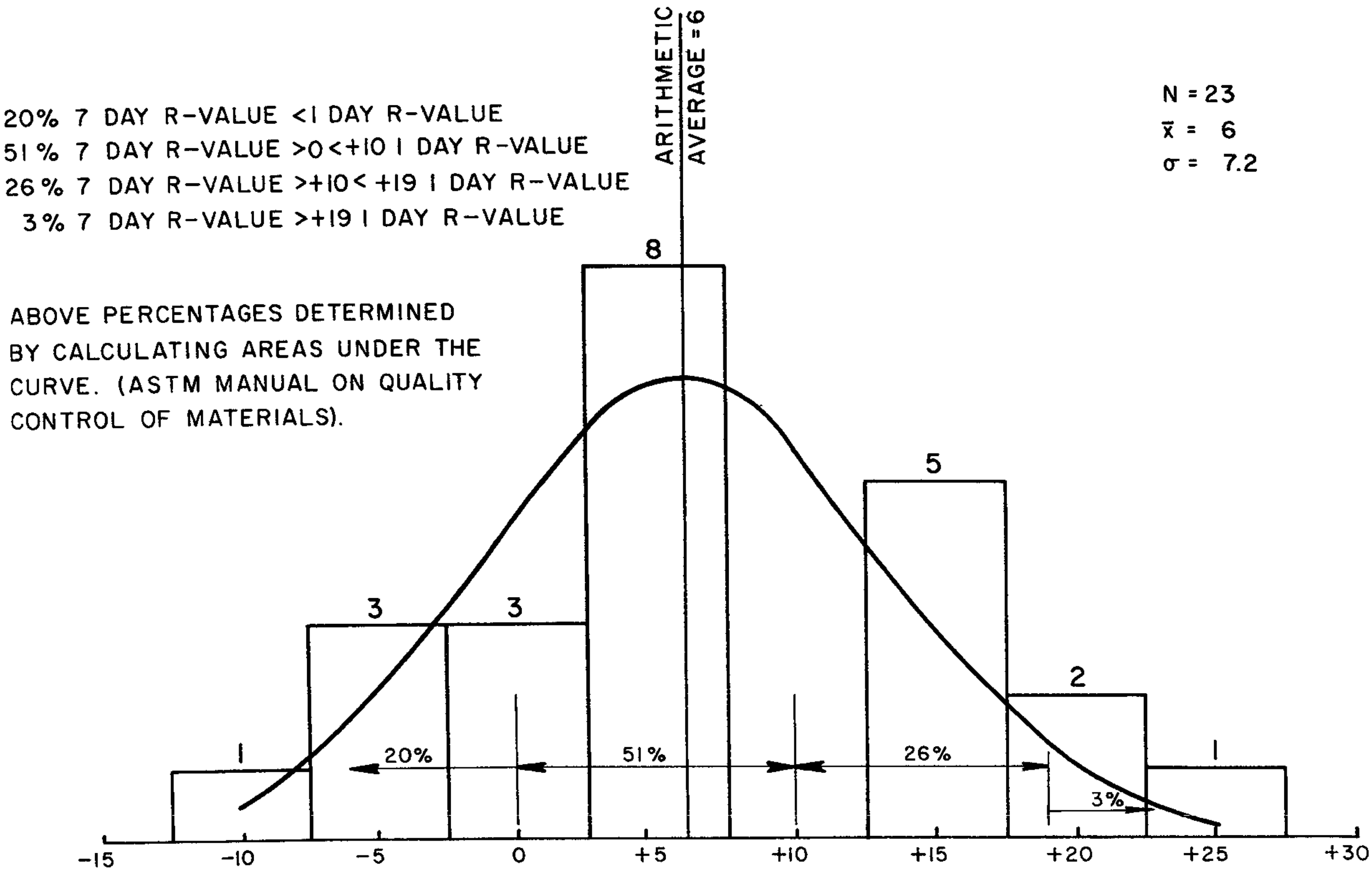
Test No.	Material From Co.	Untr. "R"	% Lime	R-VALUE WITH VARIOUS COMPACTED CURE PERIODS (Days)					
				1	3	7	14	28	62
61-1329	Col	5	2.0	55	42	46		69	
62-2567	Fre	5	3.0	77	86	95		95	
64-1669	Ker	7	4.0	36		61			
64-1225	Ker	9	4.0	79		80			
64-1215	Ker	12	3.0	84		81			
61- 721	Ker	12	0.4	62	65	65	66	67	
64-1213	Ker	16	3.0	88		83			
59-1075	SB	20	3.0	78	93	92		96	
62-2812	Sac	49	3.0	73		82			
64-2841	Yub	63	3.0	73	80	79	76	61	65
64-2841	Yub	63	6.0	85	87	88	85	84	82
56- 610	Kin	68	2.0	76	77	76			
62-2810	Sac	72	3.0	71	70	71			
62-2811	Sac	74	3.0	74	75	78			
64-0336	Yol	12	2.0	54		68			
" "	"	12	4.0	72		77			
" "	"	12	6.0	75		69			
64-0338	Yol	7	2.0	49		63			
" "	"	7	4.0	64		81			
" "	"	7	6.0	78		82			
63-3230	Yol	5	2.0	39		59			
" "	"	5	4.0	62		78			
" "	"	5	6.0	73		77			

COMPARISON OF LIME TREATED R-VALUE OF SAMPLES TESTED WITH 1 AND 7 DAYS COMPACTED CURE TIME



NORMAL DISTRIBUTION CURVE

FOR 1 AND 7 DAY CURED LIME TREATED R-VALUE TESTS

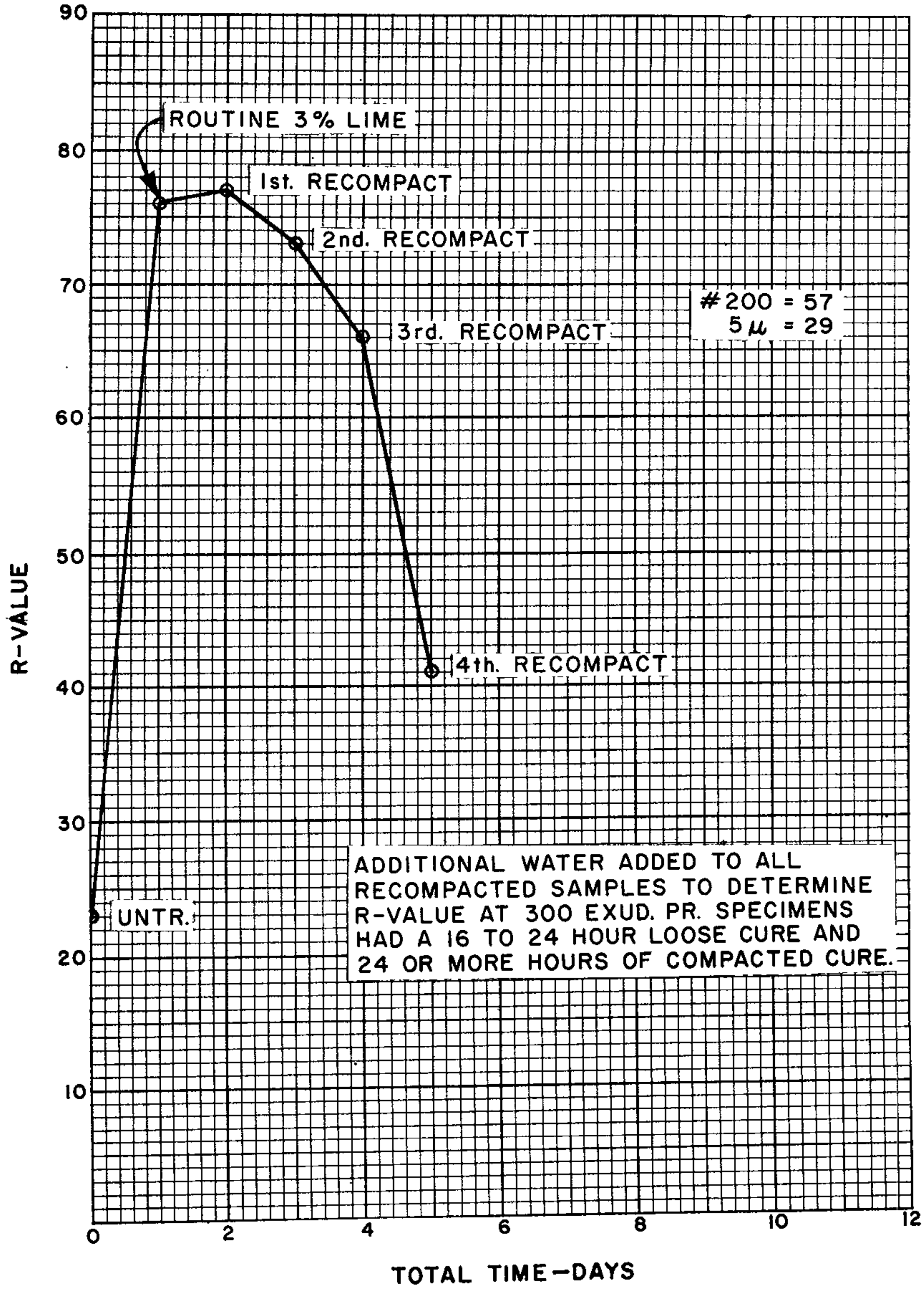


DIFFERENCE IN R-VALUE BETWEEN 1 AND 7 DAY CURED SAMPLES

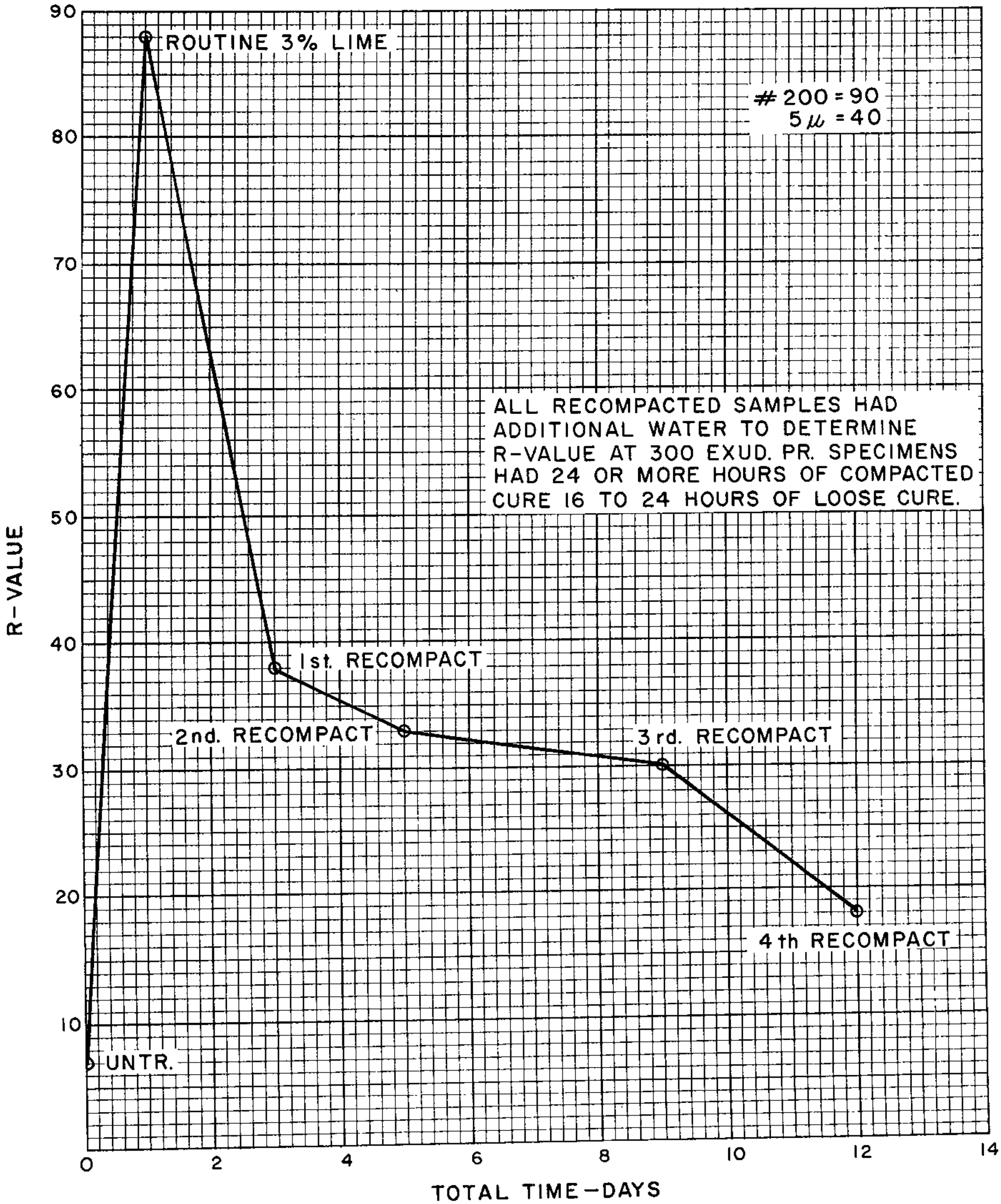
FIGURE 2

FIGURE 3

EFFECT OF BREAKING UP AND RECOMPACTING LIME TREATED MATERIAL



EFFECT OF BREAKING UP AND RECOMPACTING LIME TREATED MATERIAL



SCHEMATIC OF SAND BATH TEST

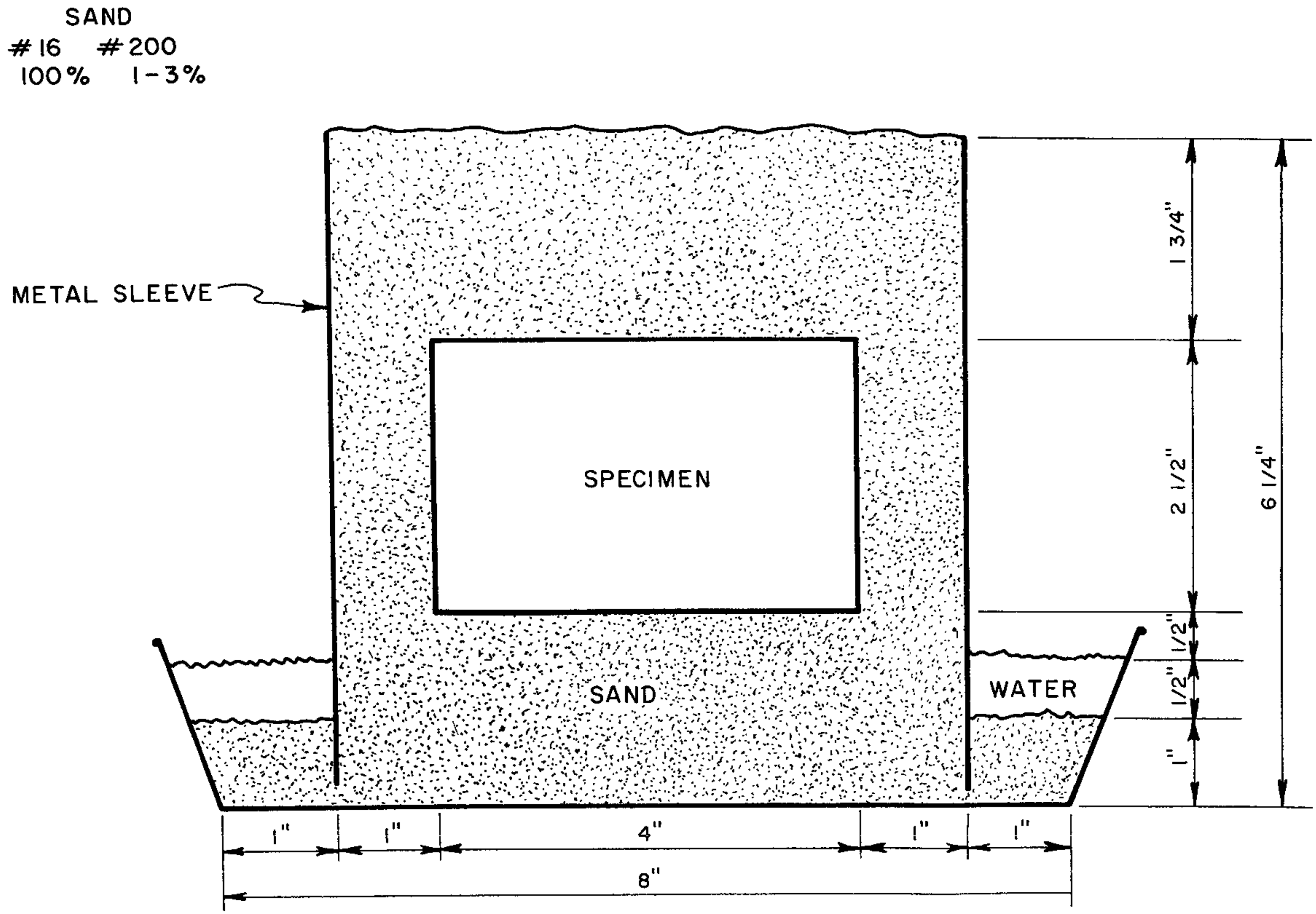
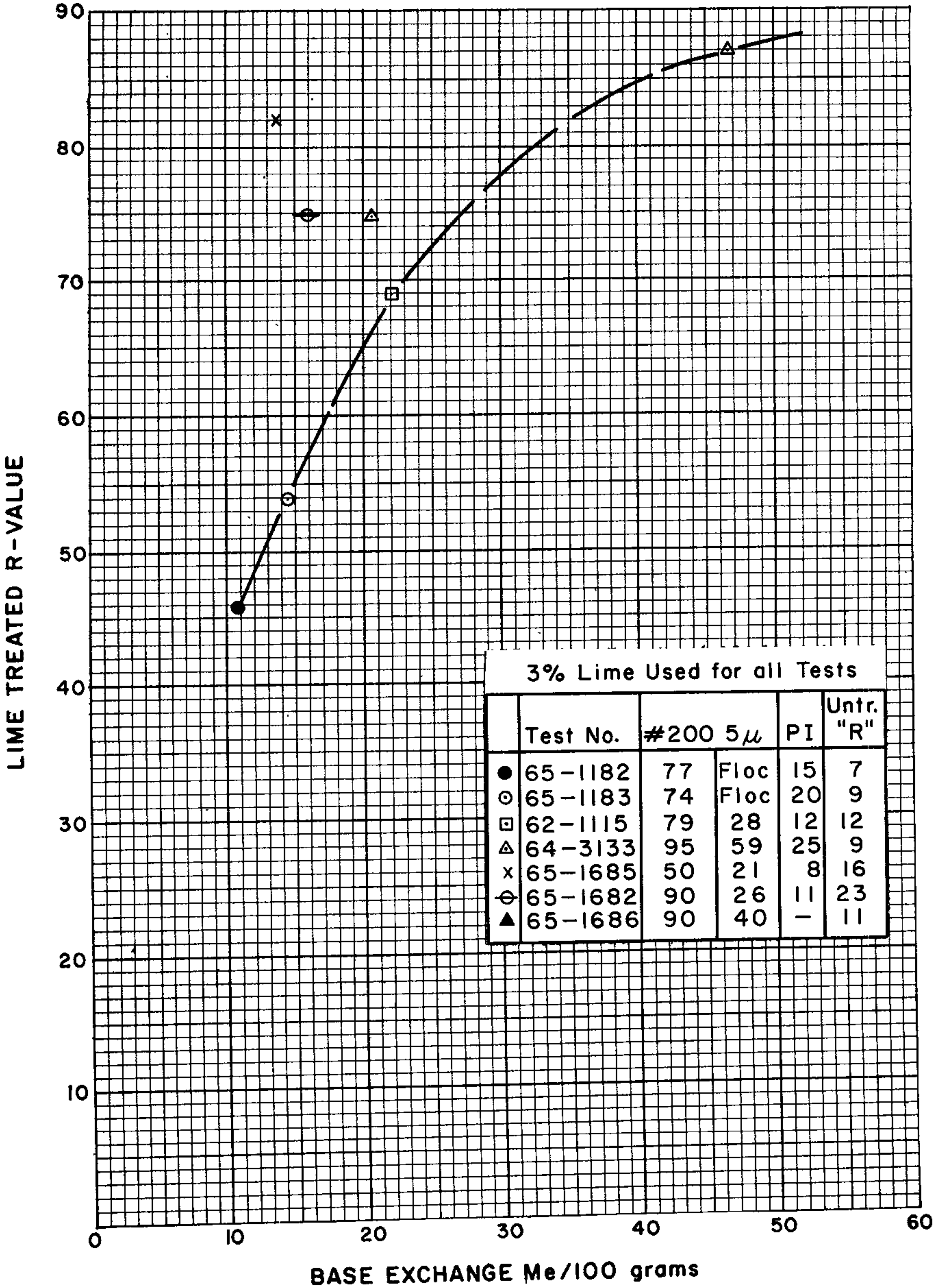


FIGURE 5

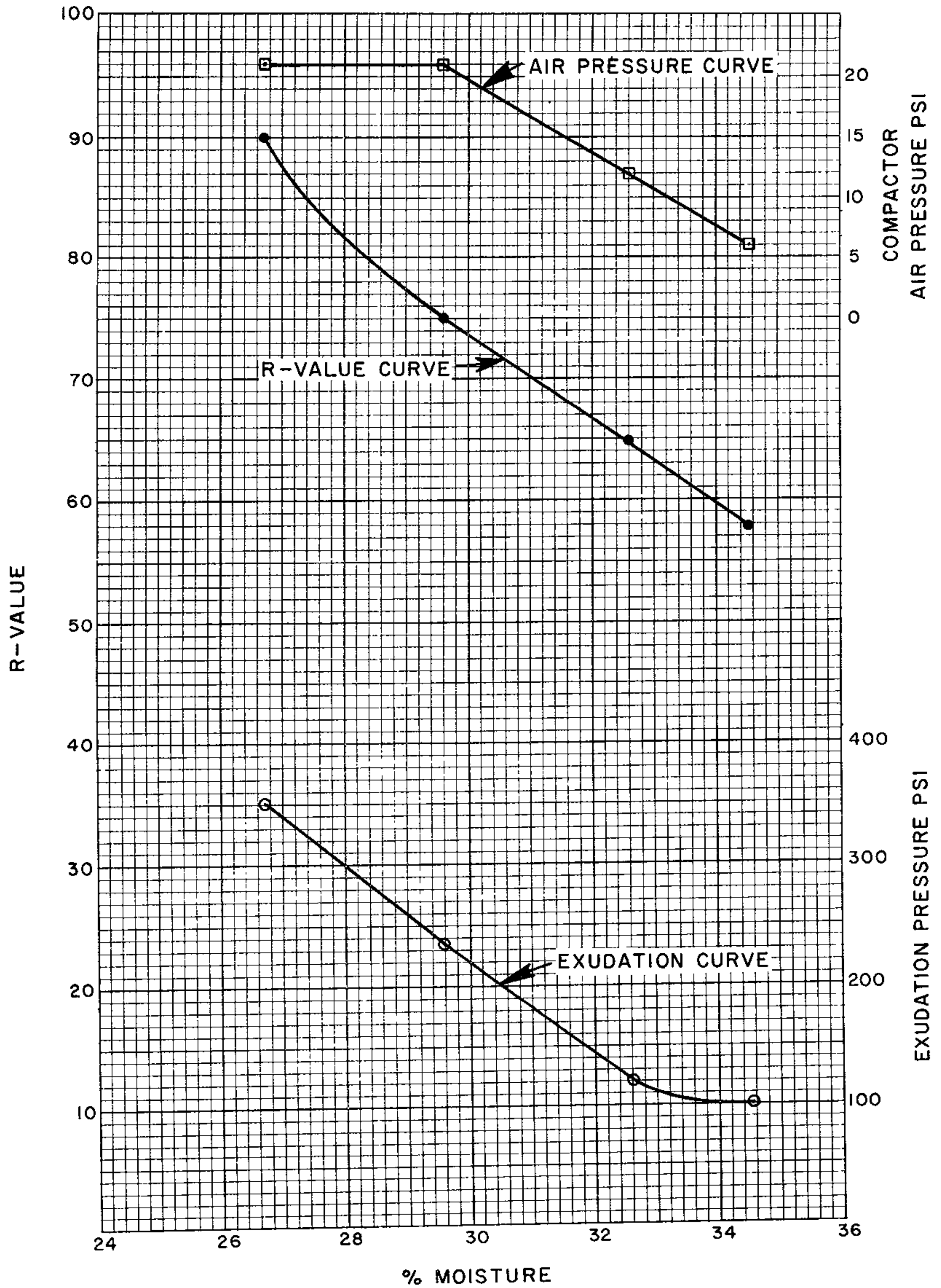
BASE EXCHANGE VERSUS R-VALUE



3% Lime Used for all Tests

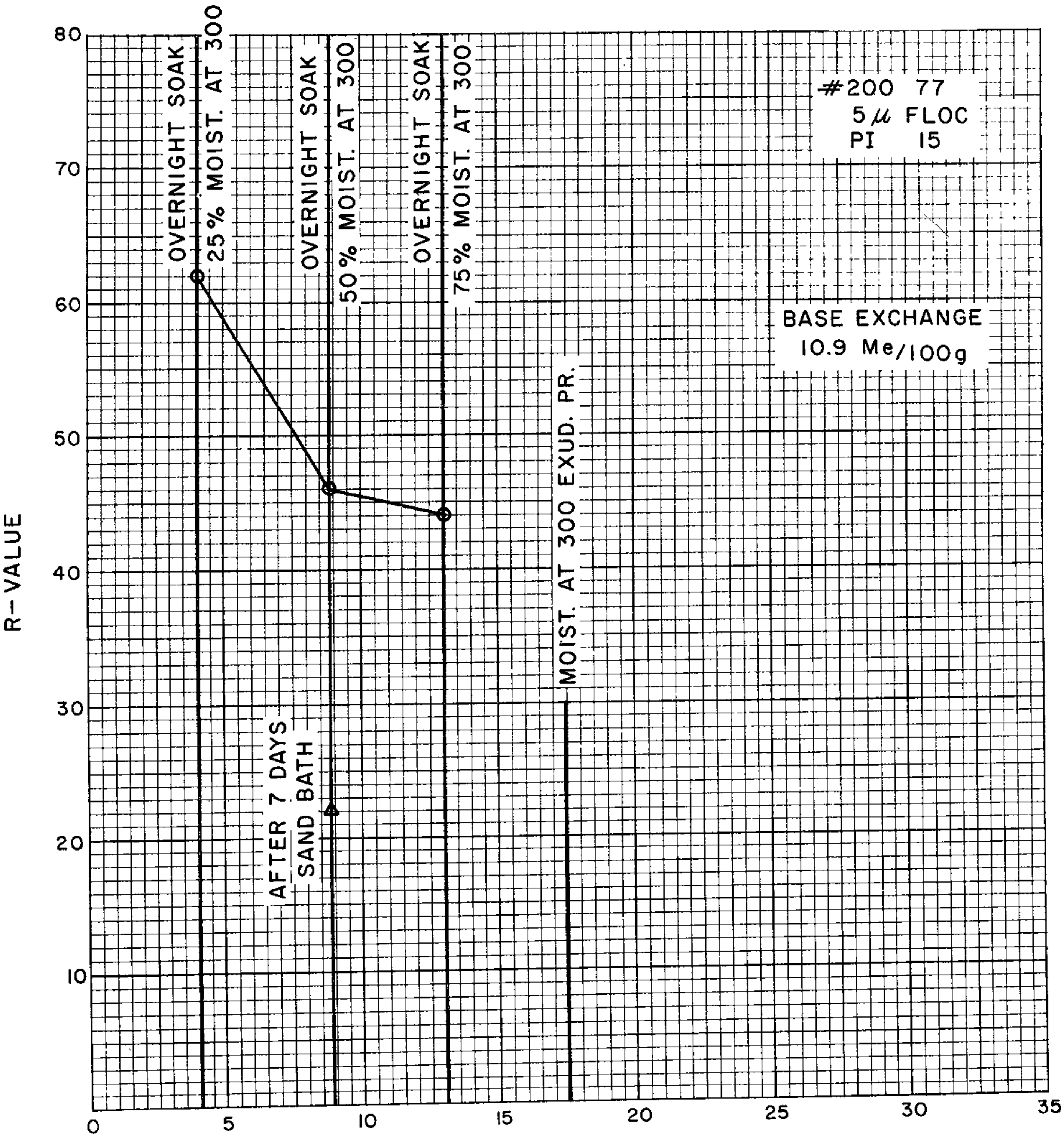
	Test No.	#200	5μ	PI	Untr. "R"
●	65-1182	77	Floc	15	7
⊙	65-1183	74	Floc	20	9
⊡	62-1115	79	28	12	12
△	64-3133	95	59	25	9
x	65-1685	50	21	8	16
⊖	65-1682	90	26	11	23
▲	65-1686	90	40	–	11

RELATION BETWEEN R-VALUE FOOT PRESSURE AND EXUDATION PRESSURE



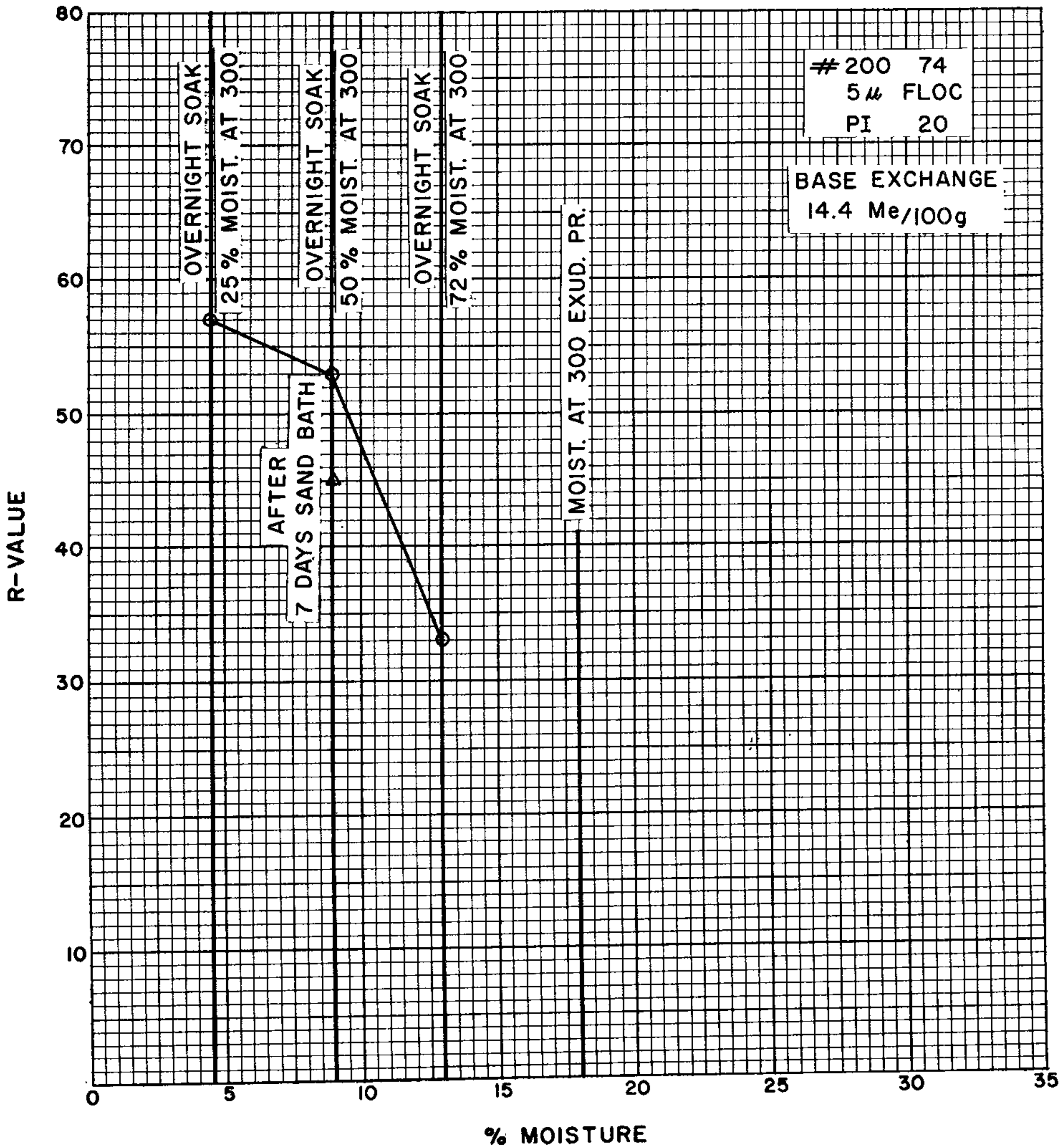
EFFECT OF VARYING OVERNIGHT SOAK MOISTURE ON A LIME TREATED MATERIAL

3% LIME



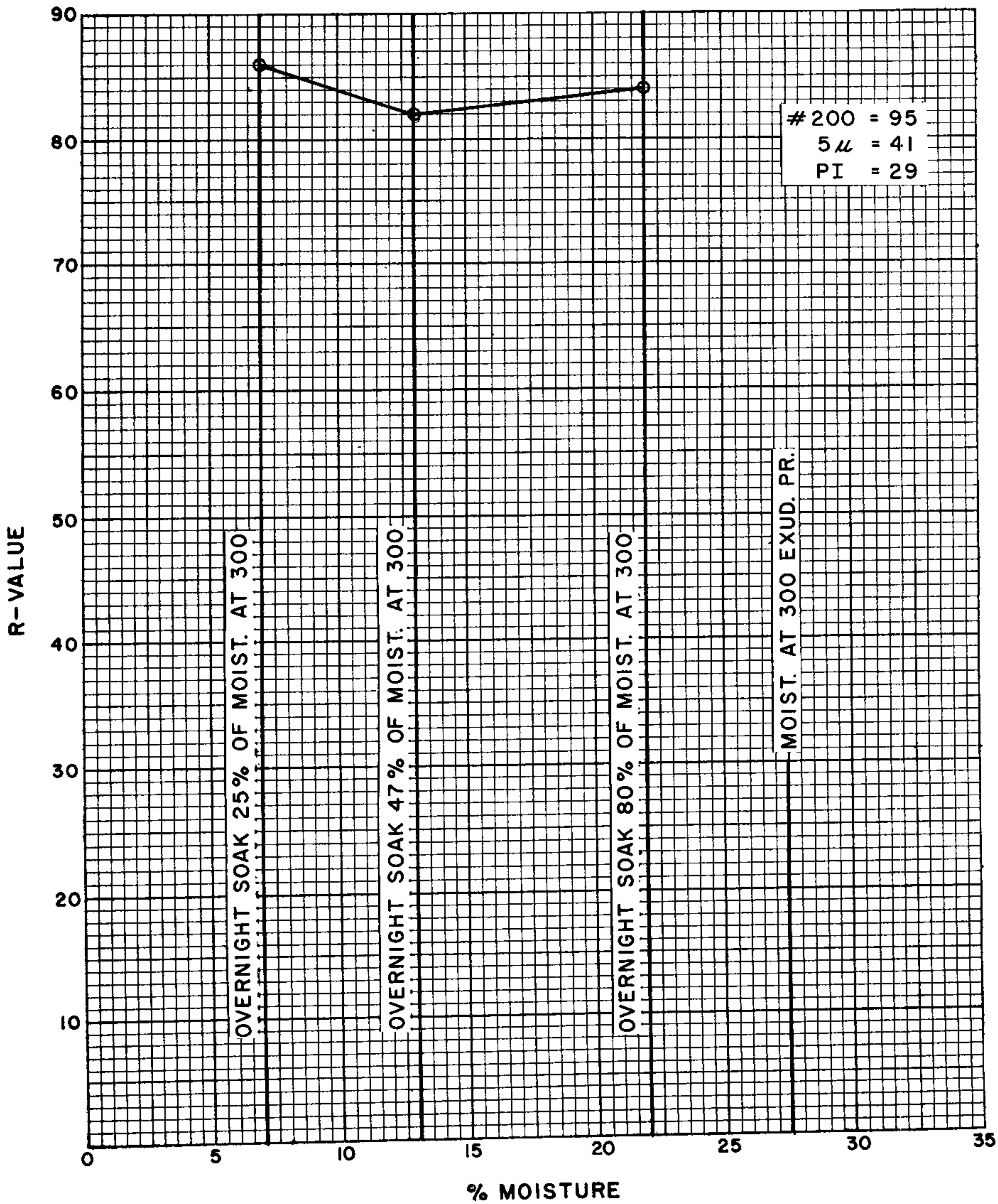
EFFECT OF VARYING OVERNIGHT SOAK MOISTURE ON A LIME TREATED MATERIAL

3% LIME



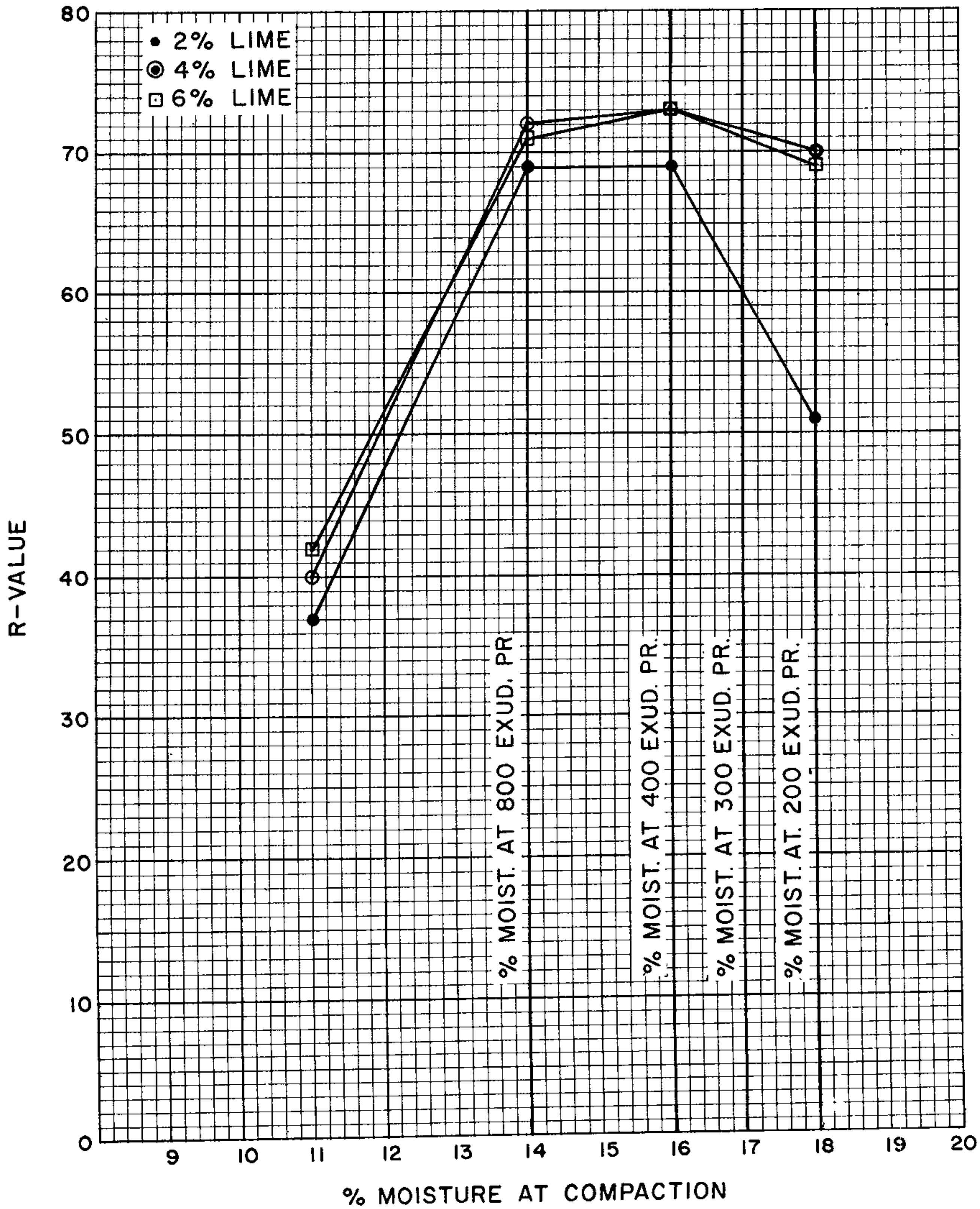
EFFECT OF VARYING OVERNIGHT SOAK MOISTURE ON A LIME TREATED MATERIAL

3% LIME



MOISTURE VERSUS R – VALUE AT VARIOUS LIME CONTENTS

SPECIMENS HAD 7 DAY COMPACTED CURE
AND
7 DAYS IN A SAND BATH



TWO FACTOR ANALYSIS OF VARIANCE METHOD FOR DETERMINING OPTIMUM MOISTURE AND LIME CONTENT

SAMPLE HAD 7 DAY COMPACTED CURE
AND
7 DAYS IN SAND BATH