

**CBR AND UNCONFINED COMPRESSIVE STRENGTH TESTS  
ON A LIME STABILIZED CLAY SOIL**

by

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**Thesis submitted to the Graduate Faculty of the  
Virginia Polytechnic Institute  
in candidacy for the degree of  
MASTER OF SCIENCE  
in  
Civil Engineering**

**November, 1962**

**Blacksburg, Virginia**

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## INTRODUCTION

In designing highway pavements it is essential to know the strength of the materials used in the base course, subbase or subgrade. One of the methods used is the California bearing ratio or CBR test. This method was originated by the California Division of Highways. In essence the CBR of a soil is a ratio of the force required to penetrate a three square inch piston into the material in question by 0.1 inches, to the force required under similar conditions for a standard material, usually 3000 pounds. However, the use of CBR test in pavement design work is on an empirical correlation basis. It is believed that this type of test may not be suitable for the testing of soil lime mixture, study of which has aroused considerable interest in Virginia. Since lime produces a natural hardening effect in the soil, it might be expected that the penetration test such as CBR might be unduly affected by such hardening and not truly reflect the settlement type of characteristics so important in pavement design.

The unconfined compression test is another method of determining the strength of soil. It is the easiest and the quickest of the laboratory methods. This test could be considered as a special form of the triaxial test. It measures the compressive strength of soil to which no lateral support is offered, although a shear failure may be produced. It is not a punching test like CBR; therefore, strain reflects the settlement characteristics of the soil.

The primary purposes of this study are threefold:

1. To show the reliability of the CBR test in

testing soil lime mixtures.

2. To show any existing correlation between the OBR and unconfined compressive test.
3. To show the variation in unconfined compressive strength, due to various methods of curing.

## REVIEW OF LITERATURE

## History

Highways play a very dominant role in the social and economical life of a country. In the United States, highways have now completely overshadowed railroads, and many branches of railroads are in the process of being abandoned. With modern techniques of construction and invaluable researches by numerous investigators, there has been a tremendous development of highways in the past decade. According to 1950 statistics (5) there are 41,000,000 vehicle registrations, and there is an average of one vehicle for every 3.4 persons. At present the country is engaged in building a 41,000 mile national system of interstate highways to connect its centers of population. To a very great extent it will consist of four or more lanes of divided highways without stoplights and crossings at grades.

Concerning the earliest development of roads, "paths and trails that finally became roads have been used by men since the dawn of history. Nomadic tribes used them for travel between seasonal hunting and fishing. As barter developed between tribes, routes for travel and exchange of goods became necessary." (13)

There is ample evidence of ancient roads in Egypt, China, India, Persia, Spain and Denmark. It is believed that the art of road making was fairly well known to them. The Greek geographer Strabo (63 B.C. - 22 - 24 A.D.) described the ancient road from Babylon to Nineveh as having been paved with brick laid in asphalt. The earliest roads about which anything is known as regards construction are those of

ancient Rome, one of the oldest and most celebrated being the Appian Way, which was commenced in 312 B.C. Ever since, the art of road making has been progressing. Although much has been gained, perfection is the object. Research and investigation are in progress to improve some of the deficiencies of the design procedures.

The basic material used in these ancient years was soil. However, there is considerable evidence that lime was used as a stabilizer (9). Not much information is available on the design procedure, and it is presumed that empirical designs were carried out and that experience was the guiding factor. McDowell (7) is of the opinion that the usage of lime preceded history. It is believed that lime was used in the construction of the pyramids of Shensi in the Tibetan Mongolian Plateau. Chinese and Indian engineers have also used lime in the construction of dams.

#### Compaction

The most important factor in soil stabilization is the proper compaction of the soil. Not much was known until Proctor (25) in 1933 developed the well-known compaction test. The basic purpose of this test is to determine a moisture content at which soil must be compacted in the field to give maximum density. Soil compaction is a process in which soil particles are packed more closely by reduction in air voids. Proctor, after extensive studies, gave the following conclusions:

1. Dry density of the soil depends upon the moisture content and amount of compaction applied.



2. For a given compactive effort and for a given soil there exists a moisture content at which dry density is maximum. This moisture content is called the optimum moisture content, and the density is known as Proctor density.
3. Increase in compactive effort results in increase in dry density and decrease in optimum moisture content.

#### Use of Lime as Admixture

As stated earlier, use of lime was known to our ancestors. The modern practice is an outgrowth of ancient procedures which have been modified by laboratory and field tests to fulfill a variety of stabilization requirements. In places where the climate is moderate and soil is very plastic, lime stabilization gives excellent results by both reducing the plasticity of the soil and increasing its strength. In the state of Texas, consumption of lime is about 9 to 10 thousand tons per month. Virginia also uses lime, but here the usage is mainly to improve the workability by reducing the plasticity. Gain in strength is the secondary effect. Where available lime is inexpensive, economical stabilized roads can be constructed.

Types of lime used. Lime mostly used for stabilization is calcium hydroxide or hydrated lime,  $\text{Ca}(\text{OH})_2$ . Quick lime,  $\text{CaO}$ , has also been used but in many cases has caused injuries to the workers. The lime used should be pure and is generally purchased under A.S.T.M. designations C-6-49 or 207-49. (30)

Chemical reactions. There are many reactions that take place in soil lime mixtures, but the following are the most important:

1. The first is of base exchange in nature; it reduces plasticity index and gives the soil a loose, friable appearance.
2. The second is a reaction of calcium with available silica and alumina to form a compound of non-slaking mono-calcium silicates and aluminates. This reaction is popularly known as pozzolanic reaction.
3. The third is the slowest reaction and involves the absorption of  $\text{CO}_2$  from the atmosphere which combines with calcium hydroxide  $\text{Ca}(\text{OH})_2$  to form limestone or calcium carbonates. These chemical reactions result in:
  - a. Decrease in liquid limit.
  - b. Increase in plastic limit.
  - c. Decrease in plasticity index.
  - d. Decrease in dry density with increasing amount of lime.
  - e. Increase in moisture content with increasing amount of lime.

Quantity of lime to be added. There are diversified views as to the critical percentage of lime to be used for lime stabilization. In a nut shell, the following were the results of tests conducted by investigators:

- a. Harrison, Hilt, and Davidson (17) stated that with increasing amount of lime, plasticity remains constant, but strength increases.
- b. Nichols (23) found that the percentage of lime used greatly varies with the project condition, i.e. the greater the plasticity of the soil the greater is the amount of lime required.
- c. Fuller and Dabney (15) found that the addition of more than five percent of lime did little or no good. However, other investigators have found this not to be true.
- d. In 1955 Chu, Davidson, and Moh (11), after performing a series of experiments concluded that 25 percent of lime and flyash have greater compressive strength than those containing 15 percent of lime.

With all these conflicting conclusions it is very difficult to state correctly the critical percentage of lime to be mixed with various soils. Much will depend upon the type of soil used. However, some of the investigators recommend an admixture of four percent lime. Though this may not be the critical level, it is on the economical side.

Lime fixation. Research in the past has shown that the addition of very small amounts of lime improved the workability of the highly plastic soils but added very little to the strength. Additional lime improved the strength and bearing capacities of those soils, and addition of flyash caused an even more significant increase in the

strength of the soil. It was believed that lime added to the soil must first satisfy an affinity of soil for lime.

Harrison, Hilt and Davidson (17), after a series of experiments, concluded that lime fixation in clayey soil does take place. Lime fixation capacity may be defined as the percentage by oven dry weight of calcium hydroxide which can be fixed by a given soil. This amount of lime improves the workability of soil but not the strength. As such there would be no pozzolanic reaction of lime with soil until this capacity is reached. They also concluded that the amount of lime added above the lime fixation capacity causes the formation of cementing materials within clayey materials.

One important point to note is that the quantity of lime added is one of the many factors that control the strength of the soil. Some of the other important factors are compactive effort, moisture content, rate and type of curing.

#### Measurement of Soil Strength

The behavior of soil under stress is generally more complex than any other material. Different soil types differ in their resistance to deformation under stress. This deformation in turn depends upon the density, moisture content, internal structure of the soil, and very greatly on the way the stress is applied. Another difficulty is that subgrade soils are seldom homogeneous, and large variations may occur both in the horizontal and vertical plane.

Types of Tests. Generally the types of tests performed to determine strength properties of soil could be classified in three broad categories, namely:

1. Shear tests
2. Bearing tests
3. Penetration tests.

Triaxial Compression Test. The triaxial compression test is the most commonly used shear test. In this test, the apparent cohesion and angle of internal friction of the soil, under test loading conditions similar to those expected to occur in the soil mass, is determined. These tests are performed on relatively small samples in the laboratory, and as such they determine effectively the strength properties at a point in a soil mass. To get a better picture of the soil condition a number of tests on soils from different points should be performed. The unconfined compression test is a special type of triaxial test in which no lateral pressure is applied. This is a very simple and quick test. It shall be dealt with in detail later.

Bearing and Penetration Tests. Essentially bearing and penetration tests are the same; the difference lies in the scale. The bearing test is carried out in the field with large apparatus and with a loaded area of several square feet. Deflection caused by the application of the load is partly elastic and partly due to the plastic deformation. The most common type of bearing test is the plate loading test.

The penetration test is carried out in a much smaller scale in the laboratory with a loaded area of a few square inches. The penetration obtained is of the same magnitude as in the bearing test, but since it occurs over a very small area it is mainly due to the plastic flow. Thus the bearing test measures the elastic properties and compressibility of soil, while the penetration test measures mainly the plastic deformation of soil due to punching shear. The most important penetration test is the California bearing ratio test. This test will be dealt with in detail in later paragraphs.

#### California Bearing Ratio Test

To quote McFadden, Gayle and Fringle (12), "It is recognized that the OBR method may not supply the ultimate answer in the flexible pavement design. Pavement failures have occurred in cases where design was adequate according to the OBR method; however, these instances are very few." This method was developed during World War II where speed and simplification of the design were the two main considerations.

During the years 1928 and 1929, the California Division of Highways started investigations as to the causes of the pavement failures throughout the state. Investigations were carried out under general supervision of Stanton and under the immediate direction of O. J. Porter who is considered to be the pioneer of the OBR method.

Three main causes of pavement failures are:

1. Lateral displacement of subgrade material.

2. Differential settlement of the material underlying the pavement.
3. Excessive deflection of the material underneath the pavement due to the repetitions of load.

Failures due to the first two causes were attributed to poor compaction and poor drainage condition, while the failure of type three was insufficient thickness of the pavement.

A simple and quick method that could rate the strength of the base, subbase and subgrade material and one that would be satisfactory for establishing the density that should be used in the construction of subgrade was sought. As a result, a field load test was devised, but a great difficulty in performing this test was that it was impossible to moisten the soil in the field to the depth affected by the load test. To eliminate some of the objections of the load test, the laboratory CBR test was devised. CBR is an empirical relation between the unit load to a standard load. The values of standard load were obtained by testing a high quality crushed stone. In this test, the increments of penetration are large with respect to the loaded area, and the results are influenced only to a minor degree by elastic deformation.

Since it is practically impossible to test a large specimen over a considerably larger area, the results are influenced to a considerable extent by cohesion and interlocking of particles as stated earlier. In the case of clean, round sand in which particle interlocking and cohesion are low, it is desired that a surcharge be placed on the area adjacent to the penetration piston in order to develop friction in the

sand. However, surcharge weights are also very important in the case of plastic soils, especially when conducting soaked CBR tests.

After many investigations, past experience and field observation, it was believed that subgrade and base course soils under impervious pavements usually increased in water content by capillarity and condensation of moisture. In some cases it was noted that the soil became completely saturated. It is true this condition will not exist in all pavements; however, to be on the conservative side the specified design is based on soaked CBR values. It is believed that four days soaking period will approach conditions existing in the field. In the case of ideal subgrade conditions, the Corps of Engineers permit a reduction in pavement thickness up to 20 percent.

Variables which generally affect CBR results are molding water content, density of the soil and the method of compaction. Among these, molding water content appears to be the major factor governing the strength of the soil.

Jervis and Eustis (15) have conducted many experiments, and the conclusions they derived are as follows:

1. Small changes in density greatly affect CBR, especially at high densities. The effect of density is more pronounced for cohesionless soils and soils of low plasticity.
2. Small changes in molding water content greatly affect the CBR of unsoaked laboratory samples except clean sand and gravel. At constant



density, values of soaked CBR decrease with increasing water content.

3. For impervious high swelling soils, soaked CBR increases with an increasing water content. This increase is up to a certain limit after which values of CBR start decreasing.
4. CBR for specimens of soils of low plasticity with little or no swell when compacted and soaked showed an appreciable decrease with a slight increase in molding water content for a constant density, particularly when molding wet of optimum.
5. In general the effect of varying the soaking surcharge on the CBR increases with the increase in the plasticity of the soil. The soaking surcharge greatly affects the CBR of soils with from medium to high plasticity. It moderately affects those of low plasticity, and it has practically no effect on CBR of cohesionless soils.

Charles R. Foster (13), after his experiments, has confirmed long expressed opinion that after a certain density is reached there will be reduction in CBR with the increase in moisture content. Foster has presented laboratory and field data to show that for given moisture contents increase in density results in increase in strength as

measured by CBR up to a certain density, after which increase in density results in decrease in CBR. The decrease in strength is believed to be the result of development of pressure in the void phase of the soil structure. As long as the combination of moisture and density is such that no pore pressures develop, increases in density should not produce decreases in strength.

#### Contributions by Virginia Council of Highway Research and Investigation

The use of lime has aroused considerable interest, and its use is now quite recognized in Virginia. The Virginia Council of Highway Research and Investigation, a cooperative organization sponsored jointly by the Virginia Department of Highways and the University of Virginia, has done considerable research on lime stabilization. A summary of some of their work is given below.

1. In 1957, the Virginia Council of Highway Research and Investigation carried out many CBR and unconfined compression tests (UCS) on lime soil mixtures. For the CBR test, a tight lid with a rubber gasket was devised so that laboratory samples of various mixtures could be compacted in these molds, sealed and cured at 140°F to speed up reactions. After seven days curing the lids were removed and the sample subjected to a four day soaking period. Results of the studies indicated

that an addition of 3 percent lime raised CBR of soils ranging from 2.5 percent to 9.5 percent to values of 32 to 79 percent.

2. Soaking time has considerable effect on values of CBR. The Corps of Engineers believe that four days soaking for all soils is sufficient. However, the Virginia Council of Highway Research and Investigation are of the view that this time may prove insufficient to predict loss of strength of certain soils. The Council is conducting an extensive study on the effect of increased soaking time on CBR values. From the results they hope to prepare curves from which it will be possible to predict value of CBR under many extended periods.
3. According to an unpublished report, in 1962 the Council is working on a plan to determine a suitable method to determine strength properties of soil lime mixtures. Such a method will be a:
  - a. Measure of gain of strength
  - b. Means of determining optimum amount of lime to be used with a given soil
  - c. Measure of field performance and durability.

Previous studies made by the Council in this connection have shown that:

- a. Realistic curing period had to be established that would give properties attained by soil lime mixture under simulated field condition.
- b. Lime stabilization was restricted by climatic conditions. High temperatures were desired for field curing.
- c. Laboratory methods should indicate the strength required for adequate field performance and the amount of lime required.

#### Unconfined Compression Test

The unconfined compression test is a special type of triaxial test in which no lateral pressure is applied. The unconfined compression test is a simple and quick test. However, this test can be used only for cohesive soils, since a cohesionless soil will not form an unsupported cylinder. The unconfined compression test has three advantages over the direct shear test:

1. Stress and strain imposed are of more uniform nature.
2. Shear failure in unconfined test will develop in the weakest portion of clay, while in the case of direct shear test failure occurs along a predetermined plane which may or may not be the weakest one.
3. It gives measure of compressive strength before any failure occurs. In the actual test vertical strain of the sample is measured along with the applied load increments. Failure generally occurs along a single

diagonal plane by bulging. If it occurs along a single diagonal plane, the maximum load obtained is the failure load. If, however, the failure is due to bulging, the load which causes a strain equal to 20 percent of the initial height of the sample is commonly considered to be the failure load.

As stated earlier, the unconfined compressive strength test is a very simple and quick test. With respect to the OBR test it requires a very small amount of soil. The Virginia Highway Department is extensively using the OBR test. If some relation could be found between OBR and the unconfined test there could be great saving in time, labor and money.

#### Curing Time for Lime Stabilized Soil

It has now been generally accepted that for any strength test soil lime specimens should receive a certain amount of curing. In 1960 the Virginia Council of Highway Research and Investigation began a study to investigate effects on strength of soils by different means of curing. They mainly studied gain in strength of lime stabilized soils under the following two conditions of curing:

1. Simulated field curing
2. Accelerated laboratory oven curing.

The following results were observed:

1. There could be a correlation between field cured and oven cured unconfined compressive strength.

2. The 120°F oven curing proved to be a more realistic procedure than did 140°F curing.
3. The results of CBR tests were scattered and no conclusions could be derived.

On this basis another set of experiments was carried out in 1961 by the Council. For the compaction of unconfined compressive strength specimens, instead of using a spring loaded compaction device, a miniature drop hammer was developed and used. Specimens so prepared were wrapped with aluminum foil and coated with wax to preserve molded moisture content. Conclusions derived by Anday (2) on the basis of results of these two experiments are as follows:

1. "Soil-lime specimens subjected to field curing in a simulated road will show an increase in unconfined compressive strength. However, the amount and rate of gain of strength will depend upon the type of soil and climatic effects.
2. "At Charlottesville, Virginia, during the summer of 1961, about 40-45 days were required to develop a maturity of 3000 degree days if 0°F is taken as datum temperature.
3. "The unconfined compressive strength of soil-lime specimens having this maturity could be predicted by an accelerated curing of two days at 120°F.
4. "If it is assumed that there exists only one maturity curve for each soil, then not much

reaction of soil should be expected at temperatures below 50°F."

#### Correlation of CBR and UCS for Sand Cement Mixtures

The author did not find any literature on actual results or attempts made to establish relation between CBR and unconfined compressive strength for lime stabilized clay. However, a correlation between unconfined compression test and CBR for sand-cement mixtures was established by Davidson (31). He and the co-authors suggested the relationship  $\log \text{CBR} = 1.115 / 0.66 \log \text{UCS}$ . Davidson also concluded that the above equation could only be used as a working relationship between two tests under varying experimental conditions.

The following results were obtained by the said authors after statistical analysis of the data:

1. "A true relationship, valid over a wide range of experimental conditions does not exist between unconfined compressive test (UCS) and CBR.
2. "The equation  $\log \text{CBR} = 1.115 / 0.666 \log \text{UCS}$  provides a working relationship between the California bearing ratio and the unconfined strength under varying conditions.
3. "A true functional relationship likely does not exist between the CBR and the UCS for a given experimental condition where only one factor is varied, e.g. if the soil cement content and method

of curing were kept constant and only length of curing varied. Thus the above equation, although it cannot be considered an estimate of a single true relationship, can be the average of many single factor relationships.

4. "It may be true that an actual relationship exists between the CBR and the UCS of stabilized soils where the only variable is the soil type. It should be kept in mind, however, that soil type is not as well defined a factor as cement content, curing time or method of curing."



## SCOPE OF PROJECT

## Soil Used

The soil used in the project was obtained from the excavation for the foundation of the new Engineering Building at Virginia Polytechnic Institute. This soil is reddish yellow in color and is a predominantly plastic clay. Results of mechanical grain-size analysis and atterberg limits of this soil are presented below.

## Grain Size Analysis

Sieve No. U.S. Standard	Diameter mm	Percent Finer
# 10	2.00	100
# 40	0.42	99.2
#100	0.147	98.02
#200	0.074	96.94
	0.018	96.5
	0.0125	95.4
	0.0092	93.0
	0.0064	90.05
	0.0045	88.00
	0.0033	87.20
	0.0024	85.50
	0.0016	83.7

## Atterberg Limits

<u>Percent Lime</u>	<u>Liquid Limit</u>	<u>Plastic Limit</u>	<u>Plasticity Index</u>
0	67	37	30
5	64	41	23
10	68	45	23

## X-Ray Diffraction Analysis

Barney, a graduate student at V.P.I., carried out X-ray diffraction analysis of the clay fraction of the same soil. His results are interpreted as follows:

1. 30 percent of the soil belongs to the kaolinite group.
2. 10 percent of the soil belongs to the montmorillonite group.
3. 10 percent of the soil is chlorite.
4. 10 percent of the soil is illite.
5. 40 percent of the soil is amorphous ferrous and aluminum oxides and hydroxides.

## Project Description

The project was accomplished in two basic parts.

## PART I

Using a Harvard miniature compaction apparatus, compaction curves were determined for the basic test conditions, which were:

1. Standard AASHO compactive effort.
2. Addition of 5 and 10 percent lime by weight.

From these compaction curves, the moisture contents to be used for strength tests were found. These moisture contents were dry of optimum (optimum - 6%), optimum, wet of optimum (optimum + 6%).

## PART II

a. CBR specimens were fabricated at three moisture contents using 0, 5 and 10 percent lime for each of the three moisture contents. In all, nine samples were tested.

b. This was repeated using the miniature equipment for making unconfined compression test specimens. Six samples were prepared for each test condition. Two of these were tested as molded, two after damp curing, and two after oven curing. In all, 54 specimens were made.

## LABORATORY INVESTIGATIONS

## Density Tests

Density tests were performed on air dry samples by both the standard AASHO method (A.S.T.M. 698-58T, method A) and the Harvard miniature apparatus. In the case of the Harvard apparatus two spring loaded compaction devices were tried (20 and 40 pound springs) and the one which gave results similar to those obtained by the standard AASHO test was finally adopted. (This was the 40 pound spring.) Some difficulty was found in compacting uniformly soil wet of optimum with the loaded spring device. It is recommended that instead of the spring a drop hammer should be used. This type of hammer has already been used by the Virginia Council of Research and Investigation.

## CBR Tests

CBR tests were carried out essentially in accordance with A.S.T.M. designation D1883-61T. A compactive effort was used in compacting the CBR specimens that was approximately equal to the standard AASHO compactive effort. CBR compaction procedures were in accordance with method B of A.S.T.M. 698. CBR values were determined on the sample prior to soaking, and after four days soaking time. The soaking and testing were done with the specimen having 20 pounds surcharge weight.

## Unconfined Compression Test

For the unconfined compression test, the Harvard miniature apparatus was used. The following procedure was adopted for preparing

the samples:

1. Proper amount of soil and water were weighed and thoroughly mixed.
2. Soil was compacted in three layers by means of the spring loaded compaction device. 25 blows were applied to each layer.
3. The soil and the mold were weighed to determine the dry density of the soil.
4. Specimens were ejected from the mold by means of a jack.

These samples so prepared were tested as molded and after curing.

Two types of curing methods were carried out:

1. Accelerated oven curing.
2. Damp curing.

Accelerated Oven Curing. As stated earlier, this method was proposed by Anday (2) and has already been discussed. Samples prepared were wrapped in aluminum foil and then coated with paraffin. Samples were then allowed to cure in an oven for two days at a constant temperature of 120°F. They were weighed before and after the curing period. A slight loss in weight was observed. This might be accounted for by the melting of wax in the oven.

Damp Curing. In the case of damp curing the specimens were cured in a moist room for four days at a temperature of 67°F. Samples were kept in a container in such a way as to fulfill two objectives, namely:

1. Moisture should not enter the container.
2. The container should not be completely air tight, in order to permit the specimen to be in the humid atmosphere.

The specimens cured by these two procedures were tested for unconfined compression. The rate of loading applied was 0.5 inches per minute.

The main difficulty in performing these tests occurred in the case of dry samples in that it was difficult to eject these samples from the mold without having some breakage from the specimen.

## DISCUSSION OF RESULTS

Figure 1 shows a comparison between the compactive methods used; namely, the standard AASHO and the Harvard miniature methods. The curve labelled new soil was determined from soil sampled three months later than the old soil.

Figure 2 gives moisture density relationships for various percentages of lime, using the miniature apparatus. These and all other tests in the study were carried out with the new soil. From the figure it is evident that lime decreases the dry density and increases the optimum moisture content.

Figures 3, 4 and 5 give the corrected OBR load penetration curves for the various percentages of lime used. A OBR value was determined at 0.1 and 0.2 inch penetration, and the larger values were used. The results of the OBR test are summarized in Table I.

## As Molded OBR Relationships

The dry density and as molded OBR relationship has been shown in Figure 6. As molded OBR increases with the increase in dry density for 0 and 10 percent lime condition. In the case of 5 percent lime there is a decrease in dry density as as molded OBR increases. From these curves it appears that with the addition of lime the optimum moisture content increases, resulting in dry density, but proportionately there is not much increase in the molded strength.

Figure 7 shows a relationship between as molded OBR and percent swell. As expected, 0 percent lime gave the maximum swell and 10

FIGURE 1  
DENSITY, MOISTURE, COMPACTIVE EFFORT RELATIONSHIP

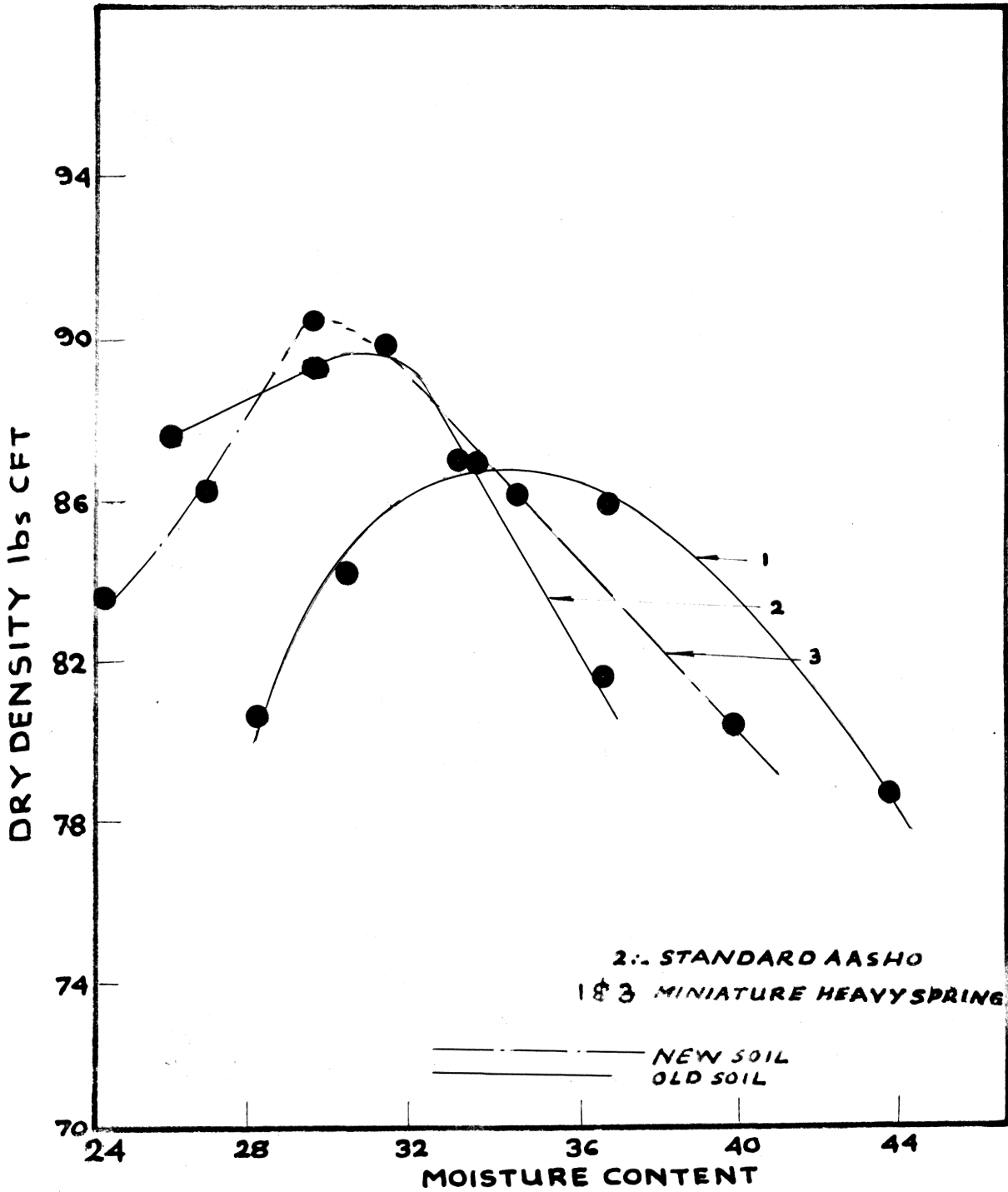




FIGURE 2  
DENSITY-MOISTURE RELATIONSHIP

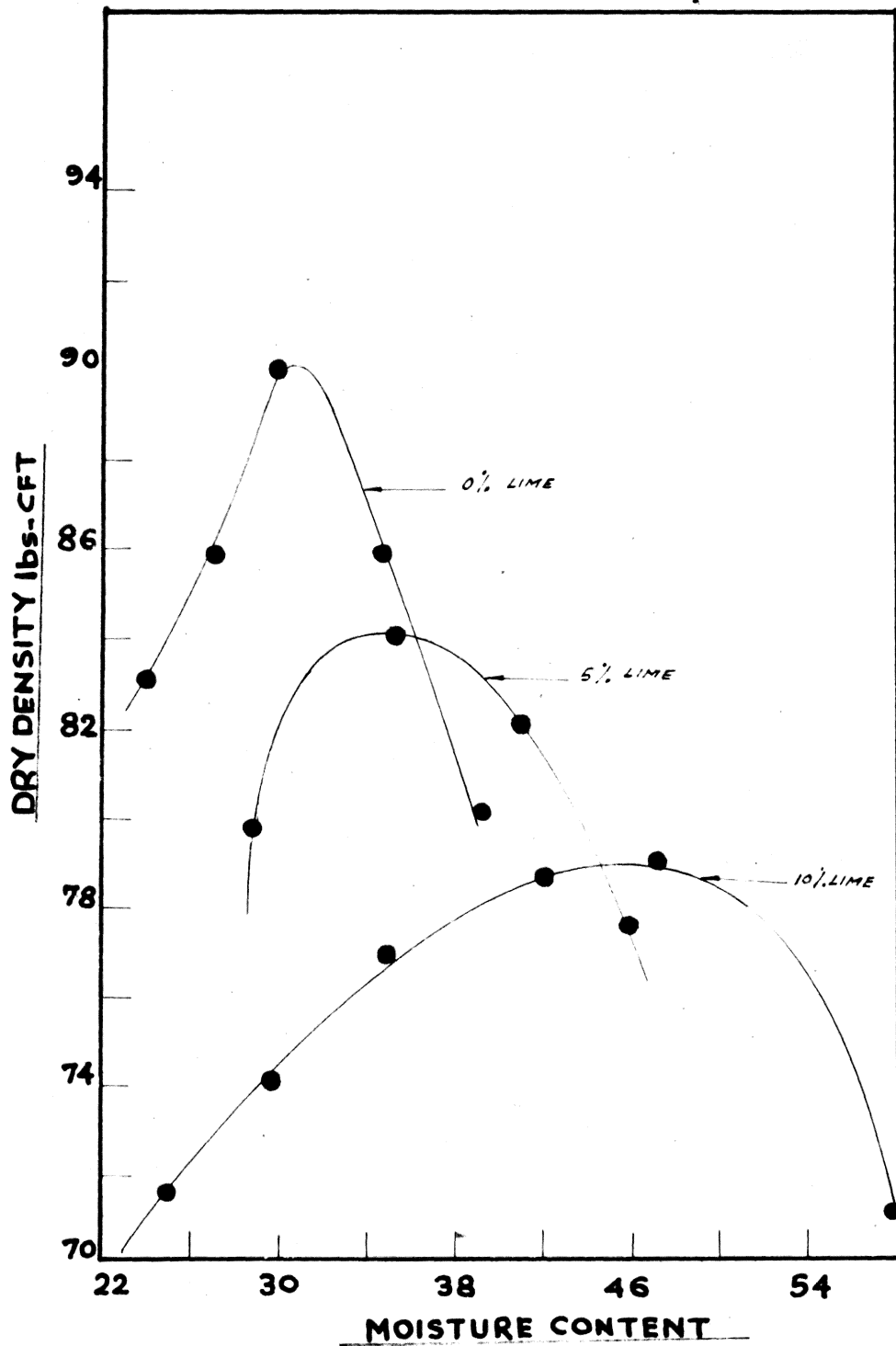


FIGURE 3  
 C.B.R. LOAD PENETRATION CURVE  
 0-PERCENT LIME

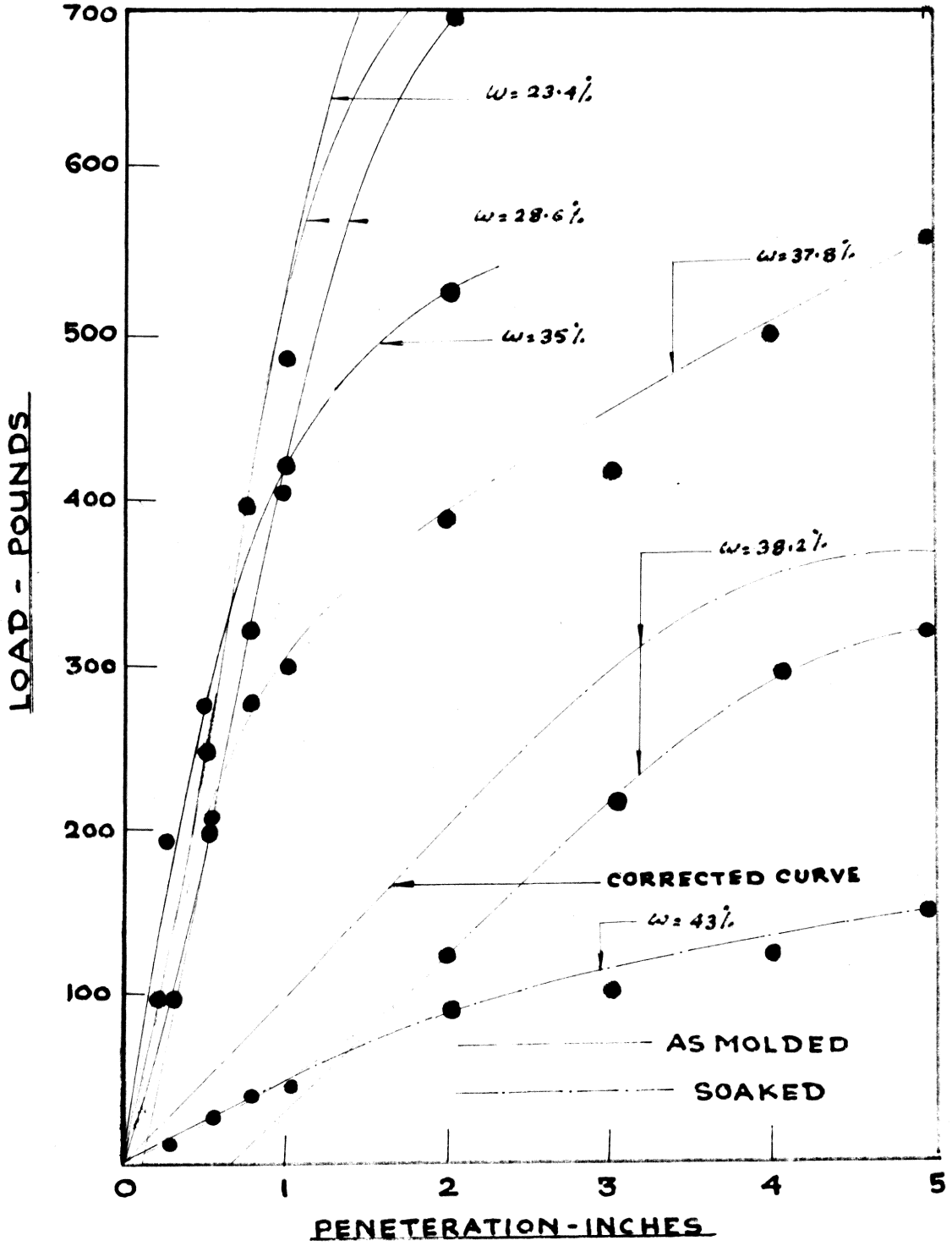


FIGURE 4  
 C.B.R. LOAD PENETRATION CURVE  
 5 PERCENT LIME

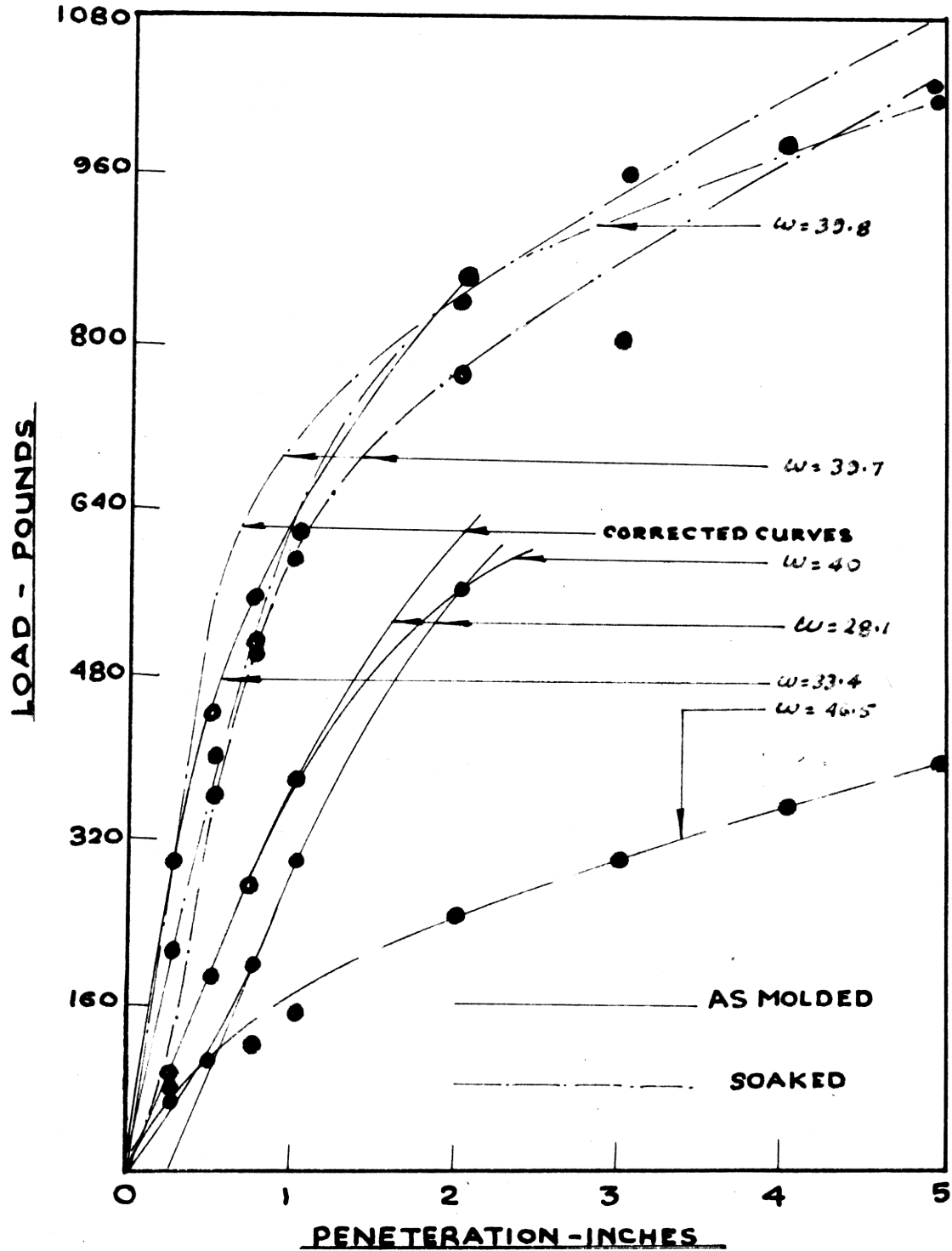


FIGURE 5  
 C.B.R. LOAD PENETRATION CURVE  
 10 PERCENT LIME

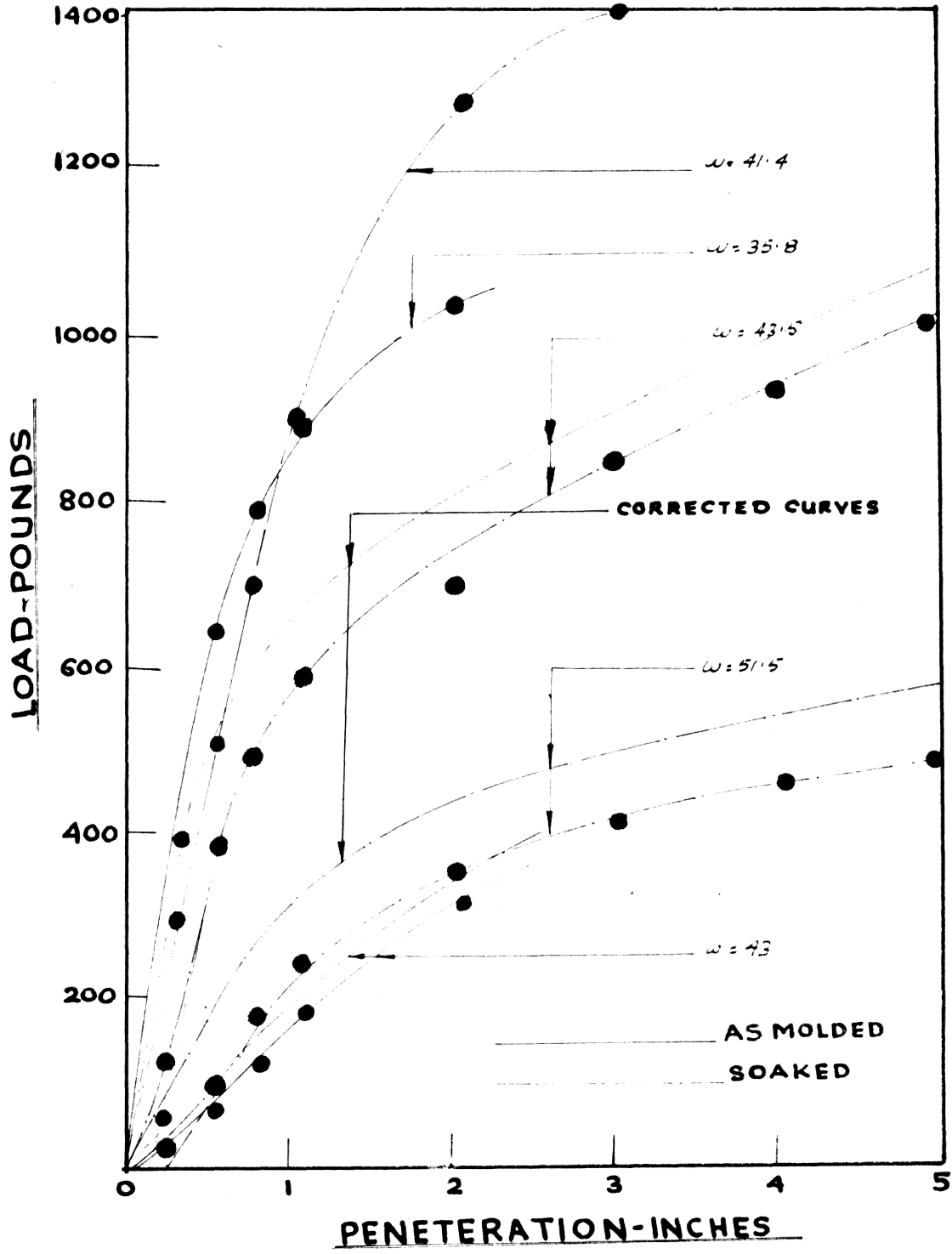


TABLE I

Moisture Content, Dry Density, Degree of Saturation,  
As Molded and Soaked OBR of OBR Specimens

Percent Lime	Moisture Content	Dry Density lb/cft	Degree Saturation	% Swell 4 Days Soaking	As Molded OBR	4 Days Soaked OBR
	23.4	87.0	100	4.53	17.8	2.11
0	28.6	82.5	94.6	1.60	15.5	4.8
	35.0	80.0	91.0	0.625	13.66	10.0
	28.1	75.0	97.0	1.93	23.33	5.45
5	33.4	79.4	94.0	0.50	21.2	20.00
	40.0	81.4	100	0.175	12.8	23.40
	35.8	79.7	99.5	0.30	29.8	30.00
10	43.0	75.7	95.7	0.20	14.4	23.00
	46.5	74.5	99.5	0.025	2.16	11.00

FIGURE 6

## DRY DENSITY — AS MOLDED C.B.R.

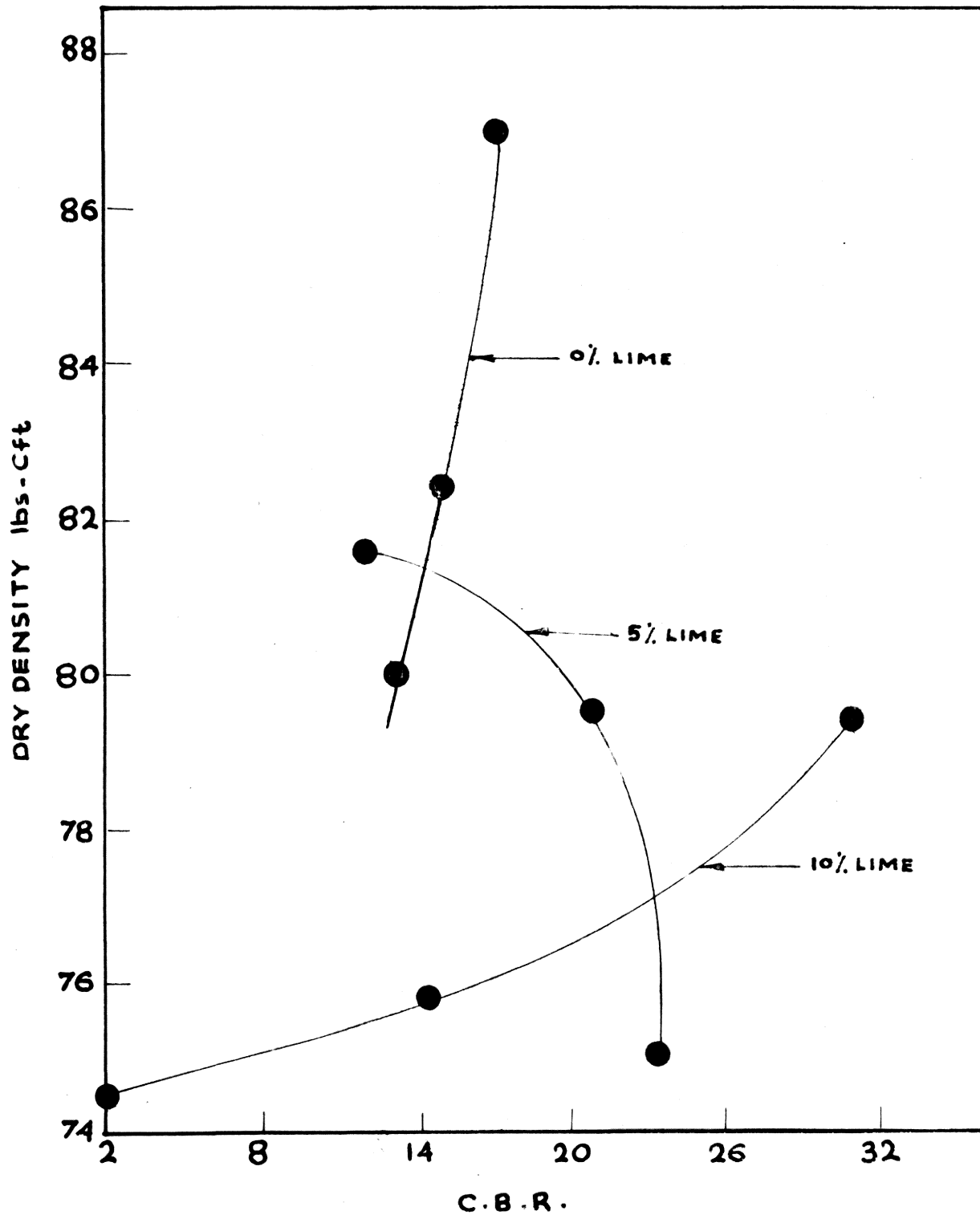
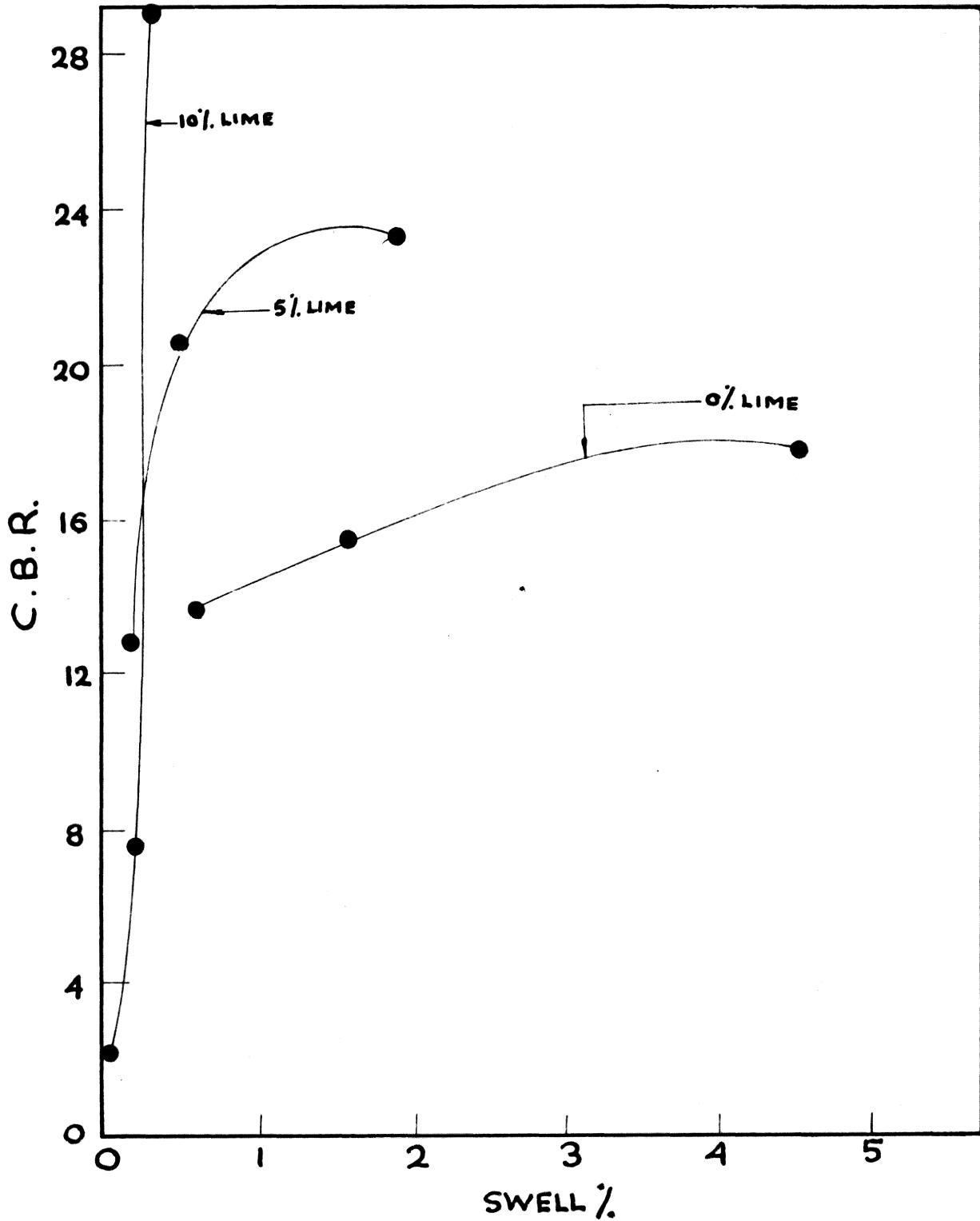


FIGURE 7  
PERCENT SWELL-AS MOLDED C.B.R.



percent lime the minimum. Also there is an increase in the percent swell with an increasing value of CBR. Hence it may be concluded that the swell decreases with the increasing percentage of the lime and increases with the increasing value of CBR.

Higher as molded strengths are generally a reflection of a flocculated soil structure and a low moisture content. Both of these conditions are conducive to high swell values.

Figure 8 represents a relationship between as molded CBR and percent lime. From the figure it appears that on the dry side there is an increase in the values of CBR with increasing percentages of lime. However, the same is not true for the optimum and wet conditions. On the wet side there is a decrease in strength with increasing amount of lime. For the optimum condition the maximum strength was obtained with five percent lime.

Figure 9 shows a relationship between as molded CBR and moisture content. Although there is an increase in strength with the addition of lime content, this is not very appreciable. As can be seen, an increase in moisture content has a very important effect on as molded CBR.

#### Soaked CBR Relationship

Figures 10 and 11 show relationship between soaked CBR, percent lime and moisture content. There is an increase in strength with an increasing amount of lime both for dry and optimum conditions. In the case of wet side of optimum there is an appreciable decrease in strength when the lime concentration was increased from 5 to 10 percent.



FIGURE 8  
AS MOLDED C.B.R. — PERCENT LIME

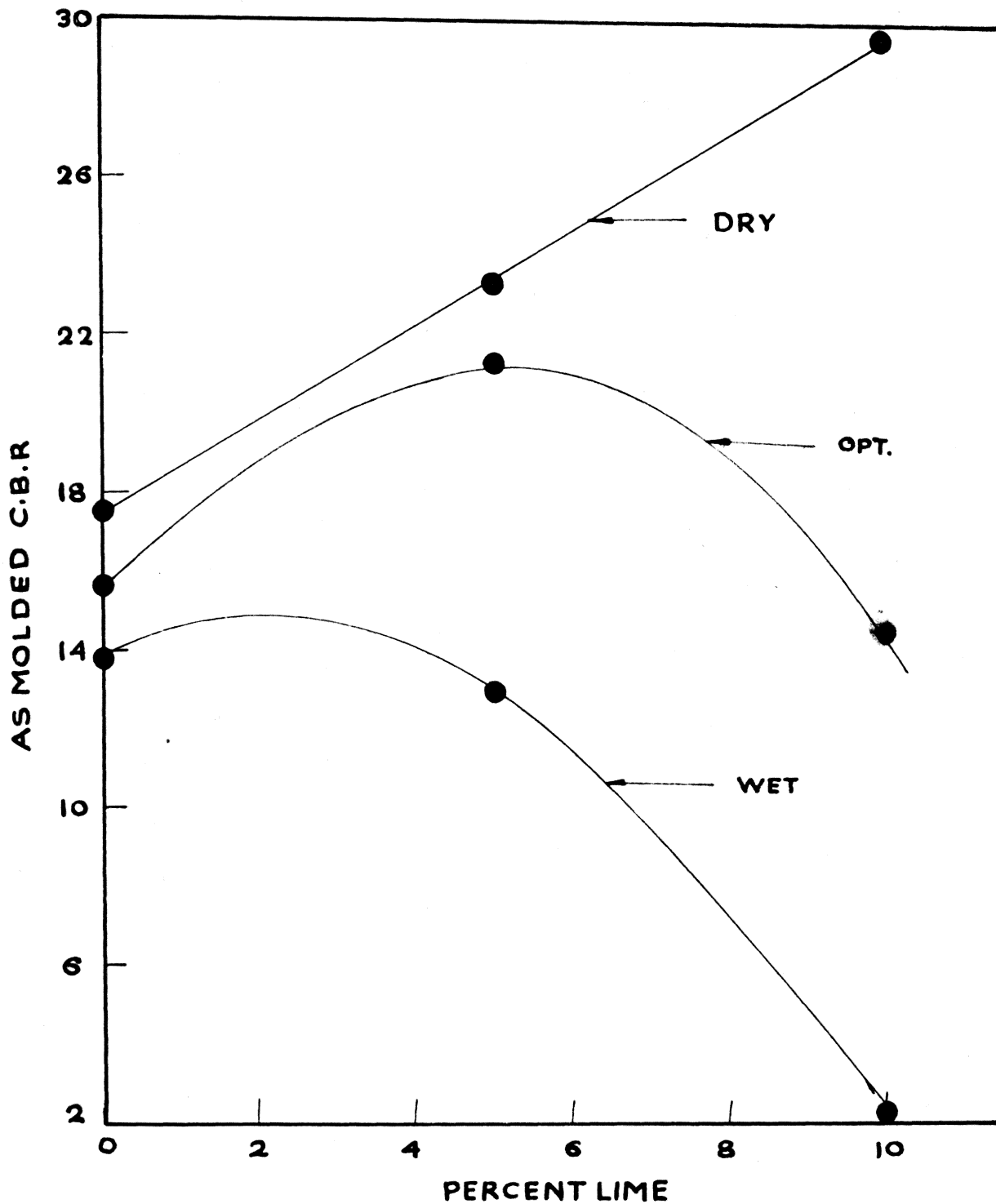


FIGURE 9

## AS MOLDED C.B.R.— MOISTURE CONTENT

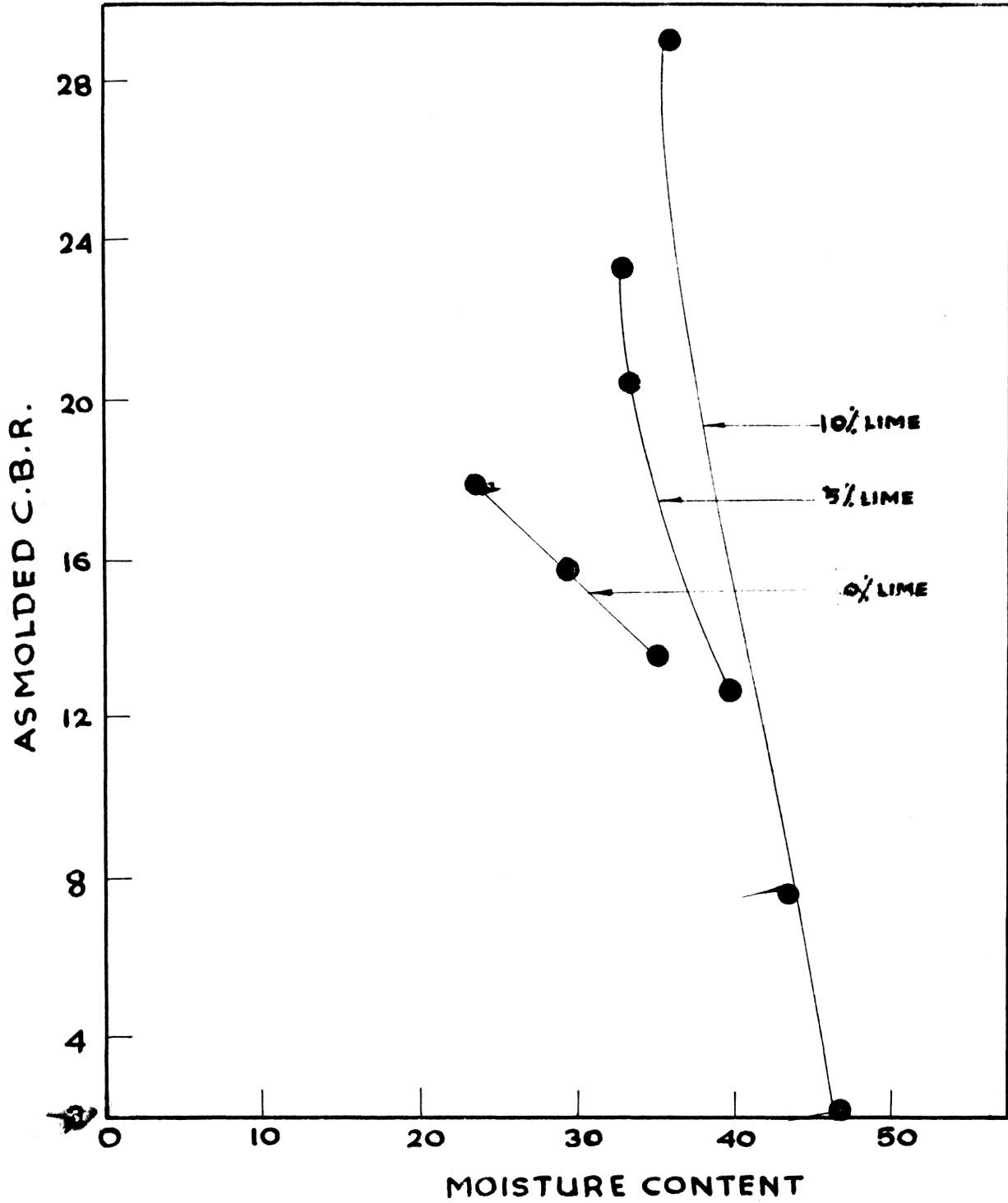


FIGURE 10  
SOAKED C.B.R. - PERCENT LIME

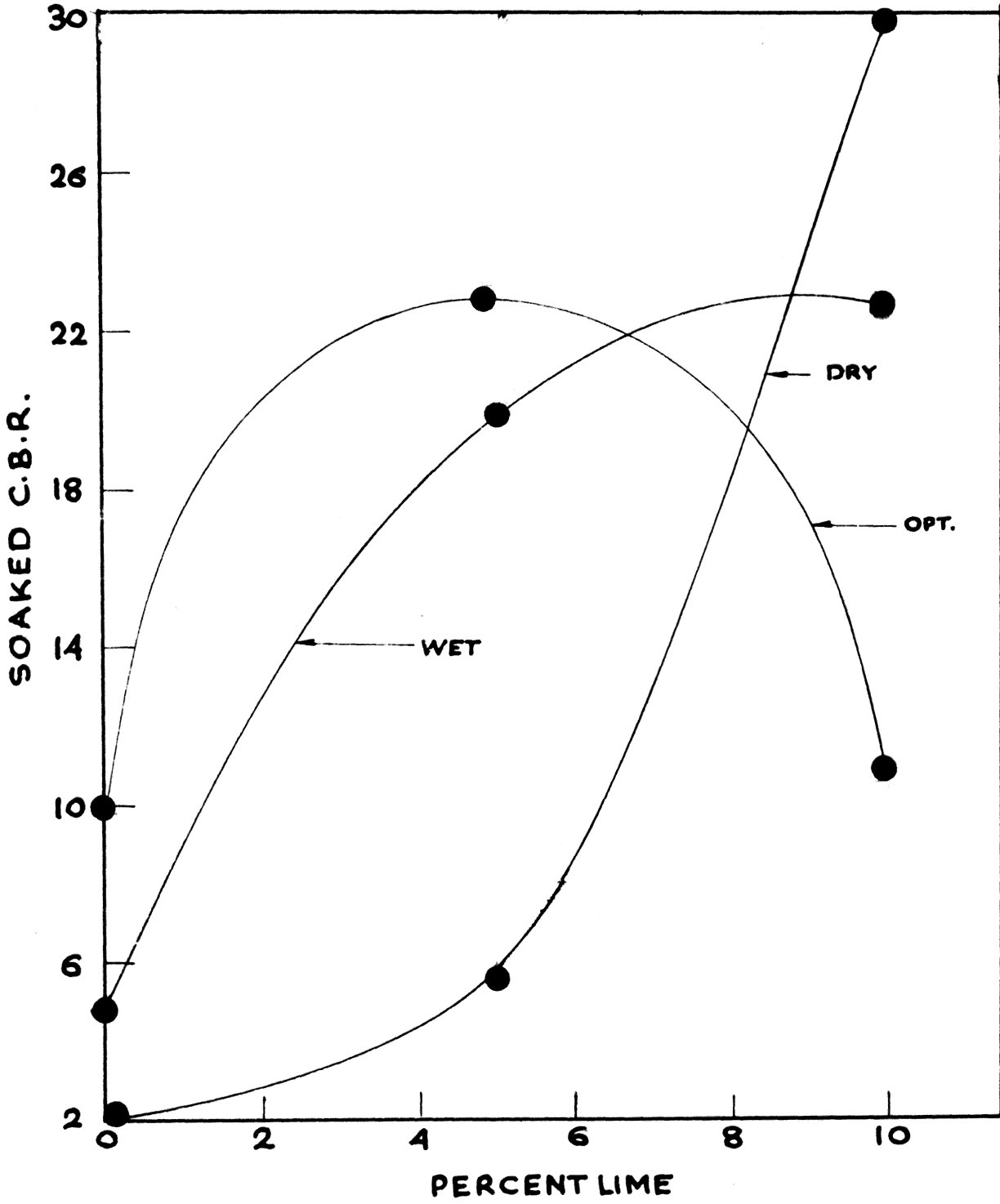
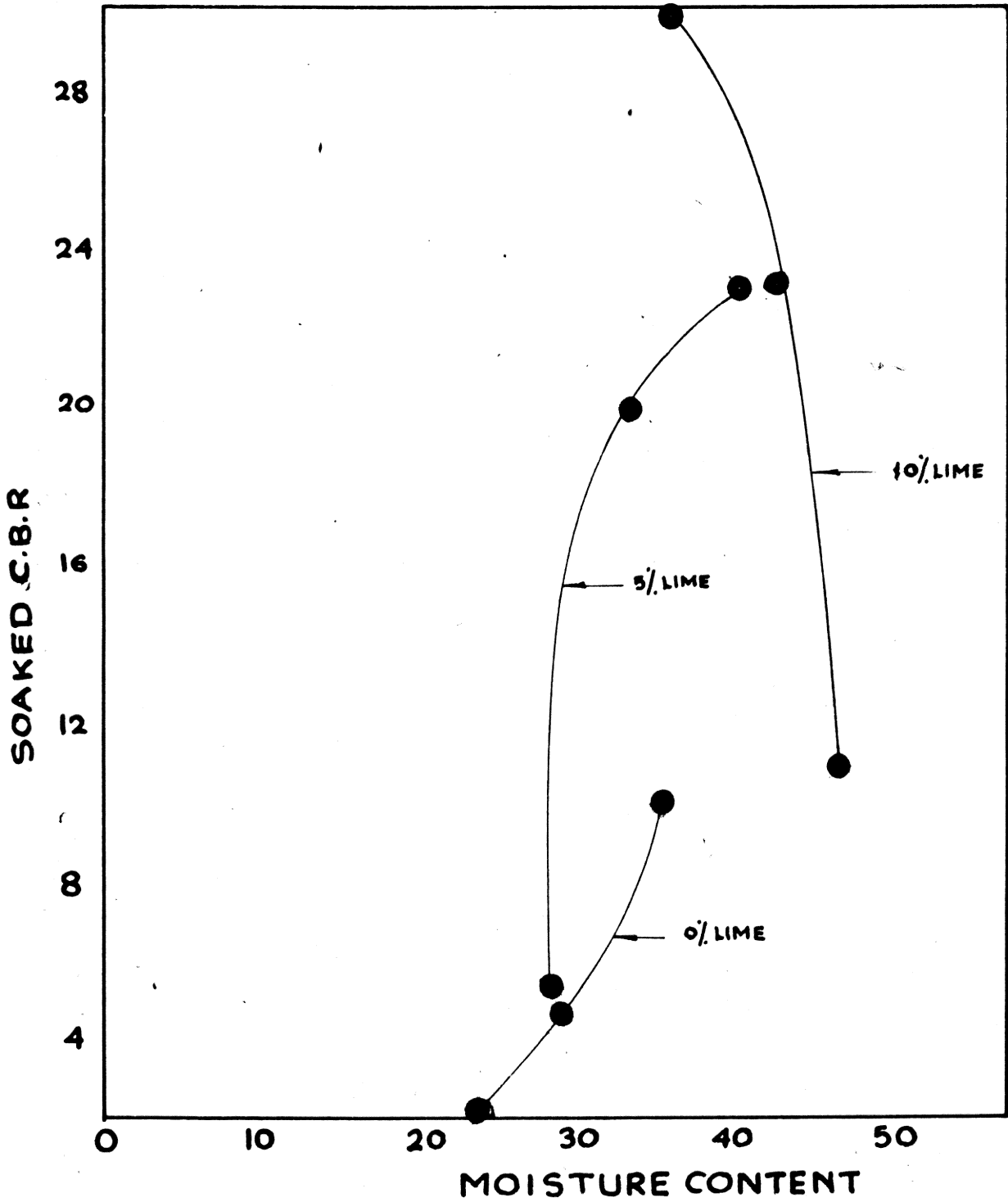


FIGURE II  
SOAKED C.B.R. - MOISTURE CONTENT



#### As Molded UCS Relationship

Figure 12 gives a relationship between as molded unconfined compressive strength (UCS) and percent lime. It is very interesting to note that the results obtained are very similar to those obtained in the CBR test as shown in Figure 8. For the dry side there is an increase in strength with an increasing moisture content. For optimum moisture there is an increase in strength with 5 percent lime, but addition of 10 percent lime decreases the strength. In the case of wet condition there is a decrease in strength with increasing percentages of lime.

Figure 13 shows a relationship between as molded UCS and moisture content. Unlike results as obtained on CBR tests (Figure 9) there is no initial decrease in strength with addition of water for 0 and 5 percent lime. In the case of 10 percent lime there is a decrease in strength with addition of moisture.

#### Damp Cured UCS Relationship

Figures 14 and 15 give a relation between damp cured UCS, percent lime and moisture content. From Figure 14 it appears that for the dry condition there is a definite increase in strength with addition of lime. However, this is not so for the wet condition. Figure 15 is a plot of moisture content and damp cured UCS. These results are similar to those obtained on soaked CBR test (Figures 10 and 11). For zero and five percent lime maximum strength is obtained at optimum moisture content, while for 10 percent lime increasing moisture content decreases UCS. Again on the dry side there is an increase in strength with addition of lime but the same is not true for optimum and wet conditions.

FIGURE 12  
AS MOLDED U.C.S.—PERCENT LIME

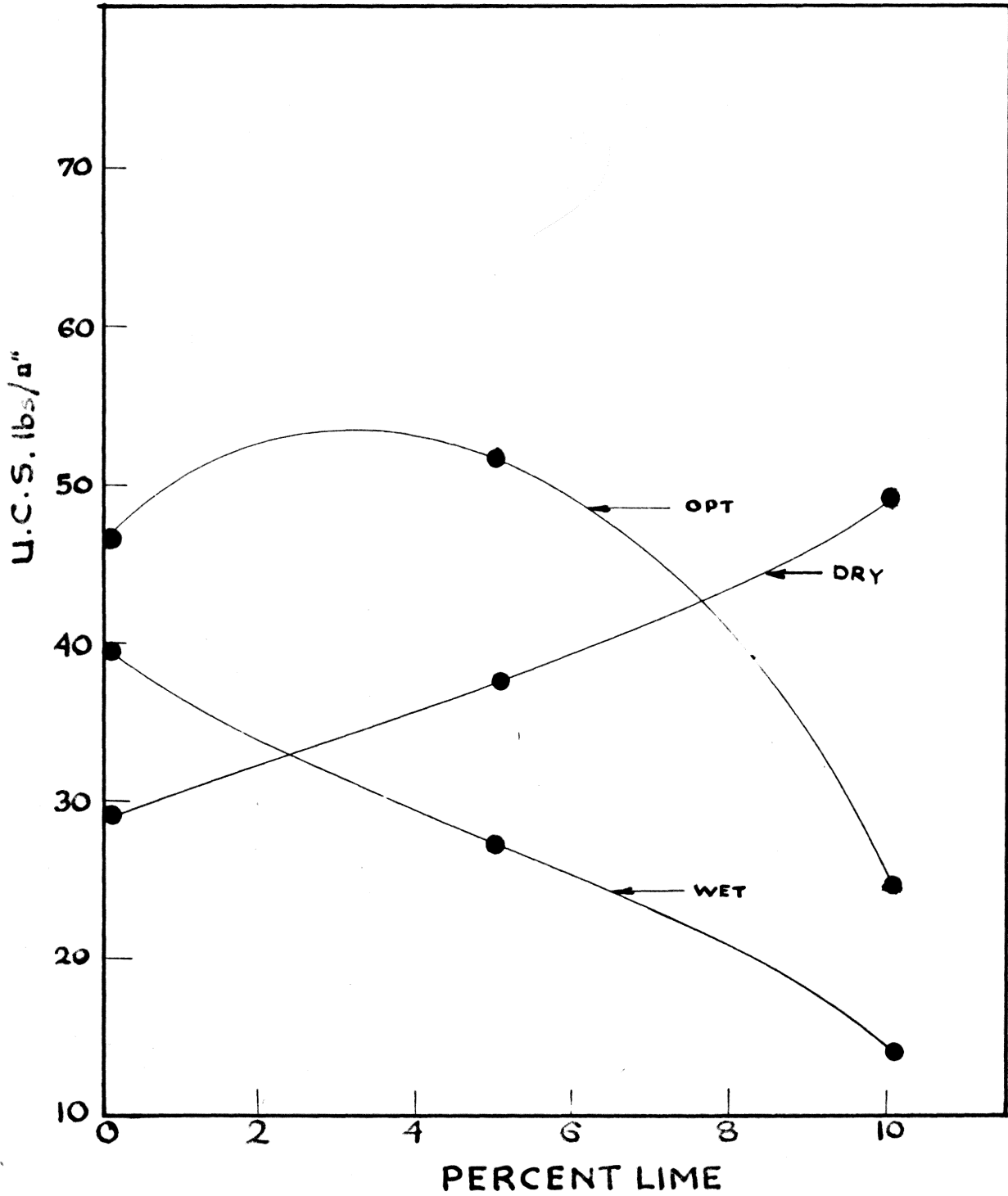


FIGURE 13  
AS MOLDED U.C.S - MOISTURE CONTENT

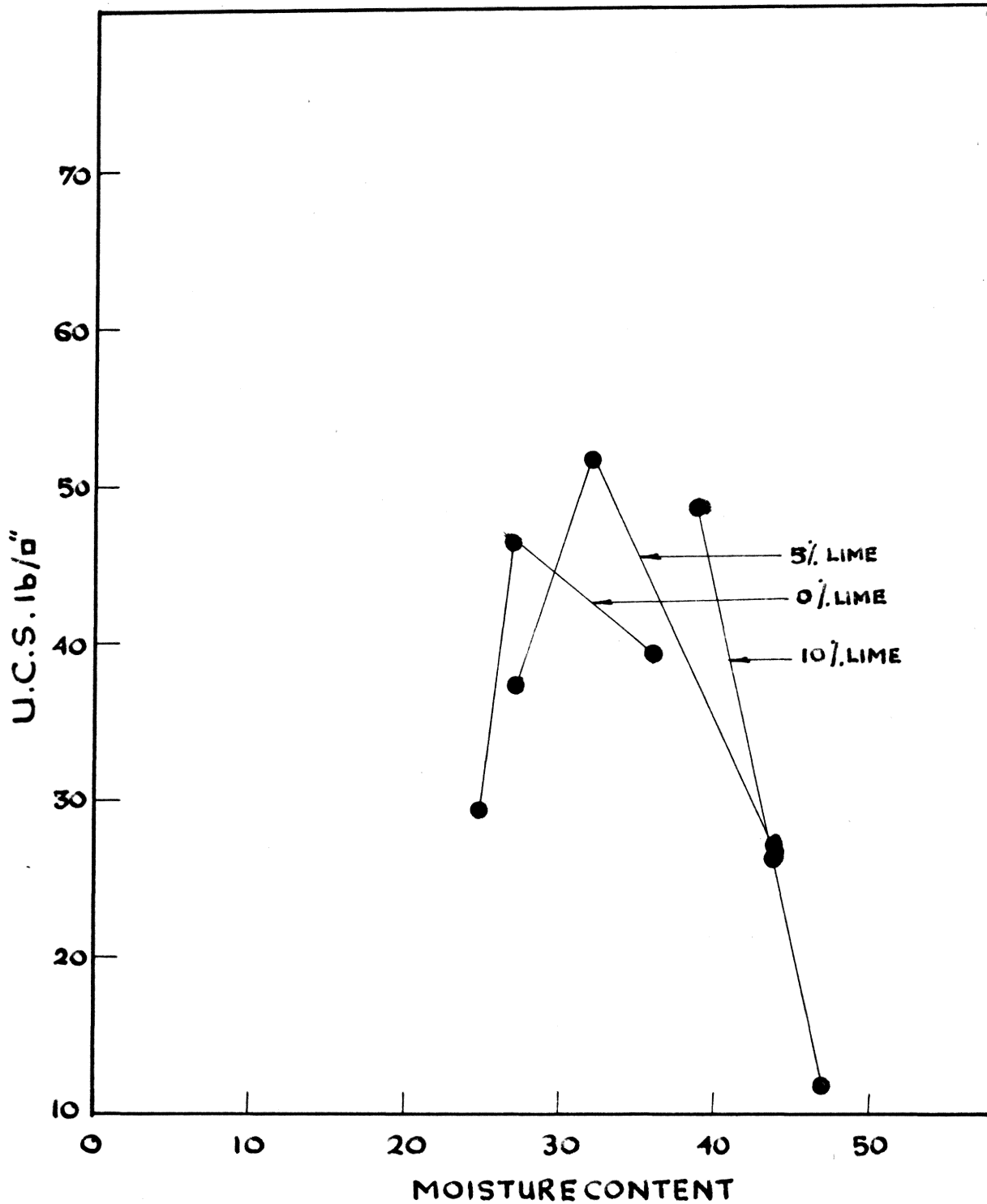


FIGURE 14  
DAMPCURED U.C.S.—PERCENT LIME

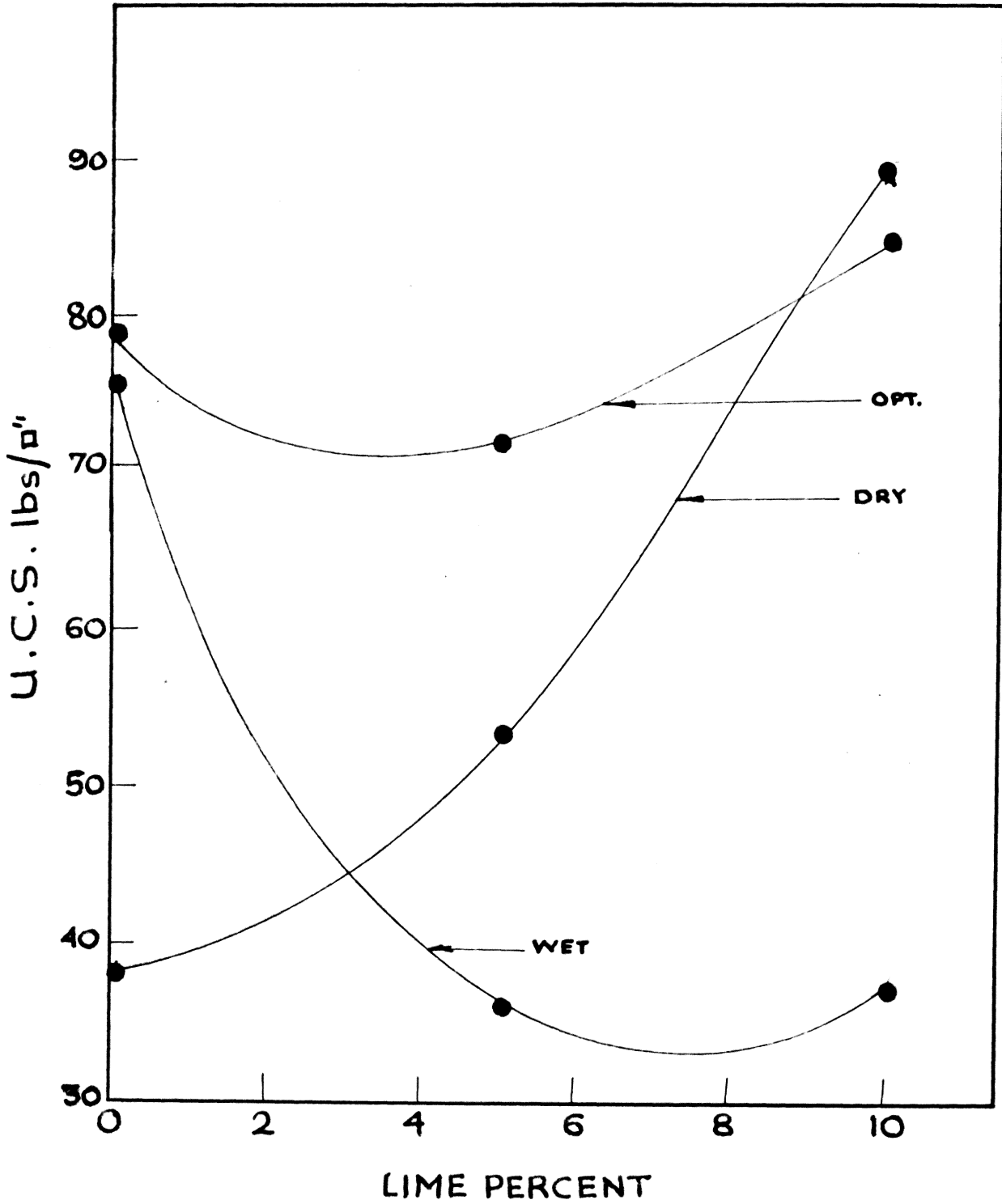
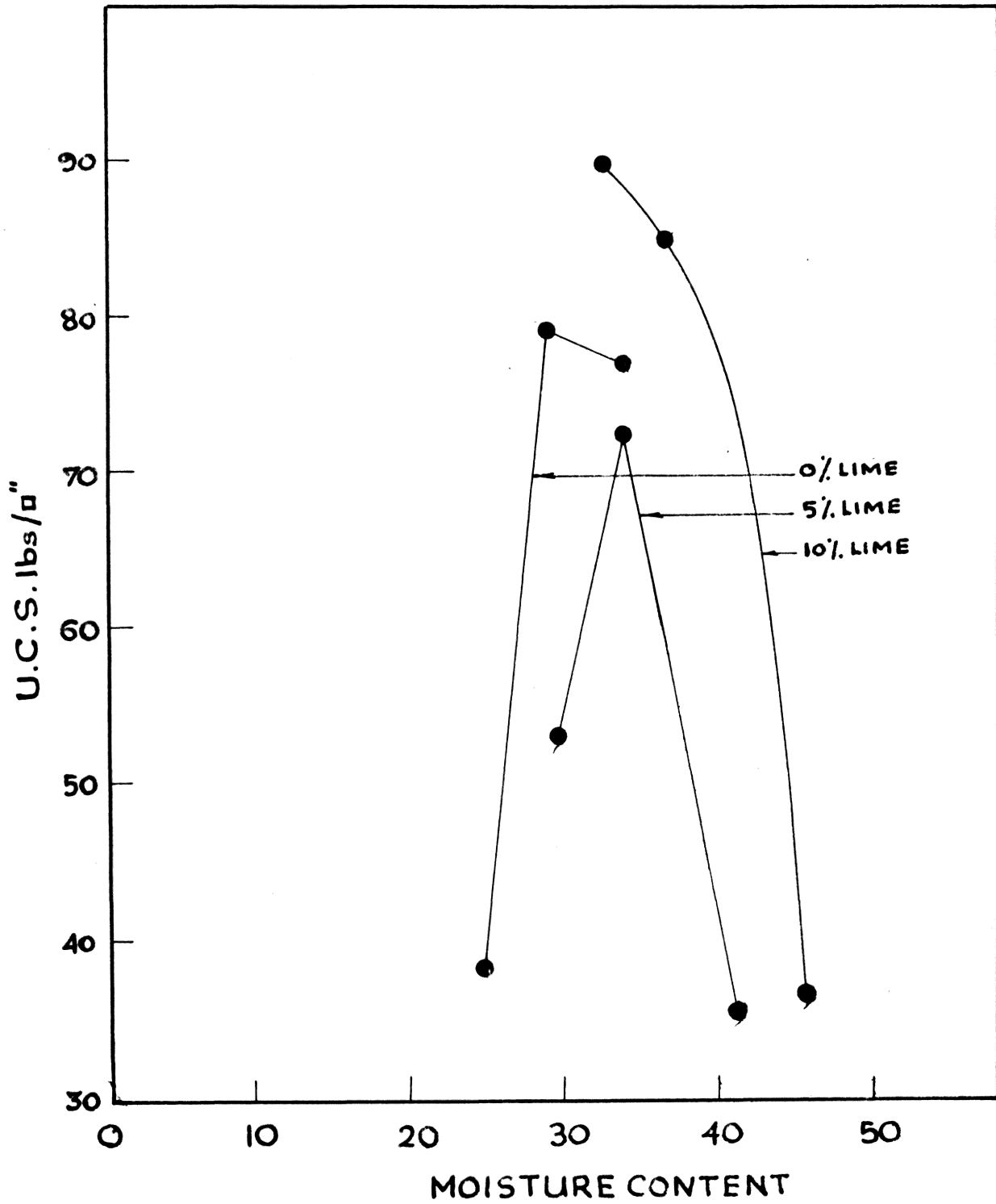




FIGURE 15  
DAMPCURED U.C.S.—MOISTURE CONTENT



### Oven Cured UCS Relationship

Figure 16 gives a plot of oven cured UCS and percent lime. It shows a significant increase in strength with the addition of 10 percent lime. From Figure 17 it appears that with oven curing 10 percent lime gives very significant increase in strength irrespective of moisture content.

Considering Figures 13, 15, 17 and 12, 14, 16, it appears that curing, regardless of method, generally increases the strength of the soil. This effect is most pronounced in the case of oven curing.

### Discussion

From the above results it appears that the lime increases the strength of the soil. However, the increase in strength is very significant at lower moisture contents. With increasing moisture it has little effect on the strength of the soil except in the case of oven curing.

Oven curing showed an appreciable increase in the strength. This increase is very significant with 10 percent lime as shown in Figure 17. By comparing the results of UCS for damp curing and oven curing it appears that four days soaking period is rather insufficient.

Table II summarizes all UCS results. Plot of as molded UCS and as molded OBR is shown in Figure 18. Plot of soaked OBR and damp cured UCS is shown in Figure 19, and that of soaked OBR and oven cured UCS in Figure 20.

Considering the above figures, it appears that no specific relation exists between as molded UCS and as molded OBR, damp cured UCS and soaked OBR and oven cured UCS and soaked OBR.

FIGURE 16  
OVENCURED U.C.S. - PERCENT LIME

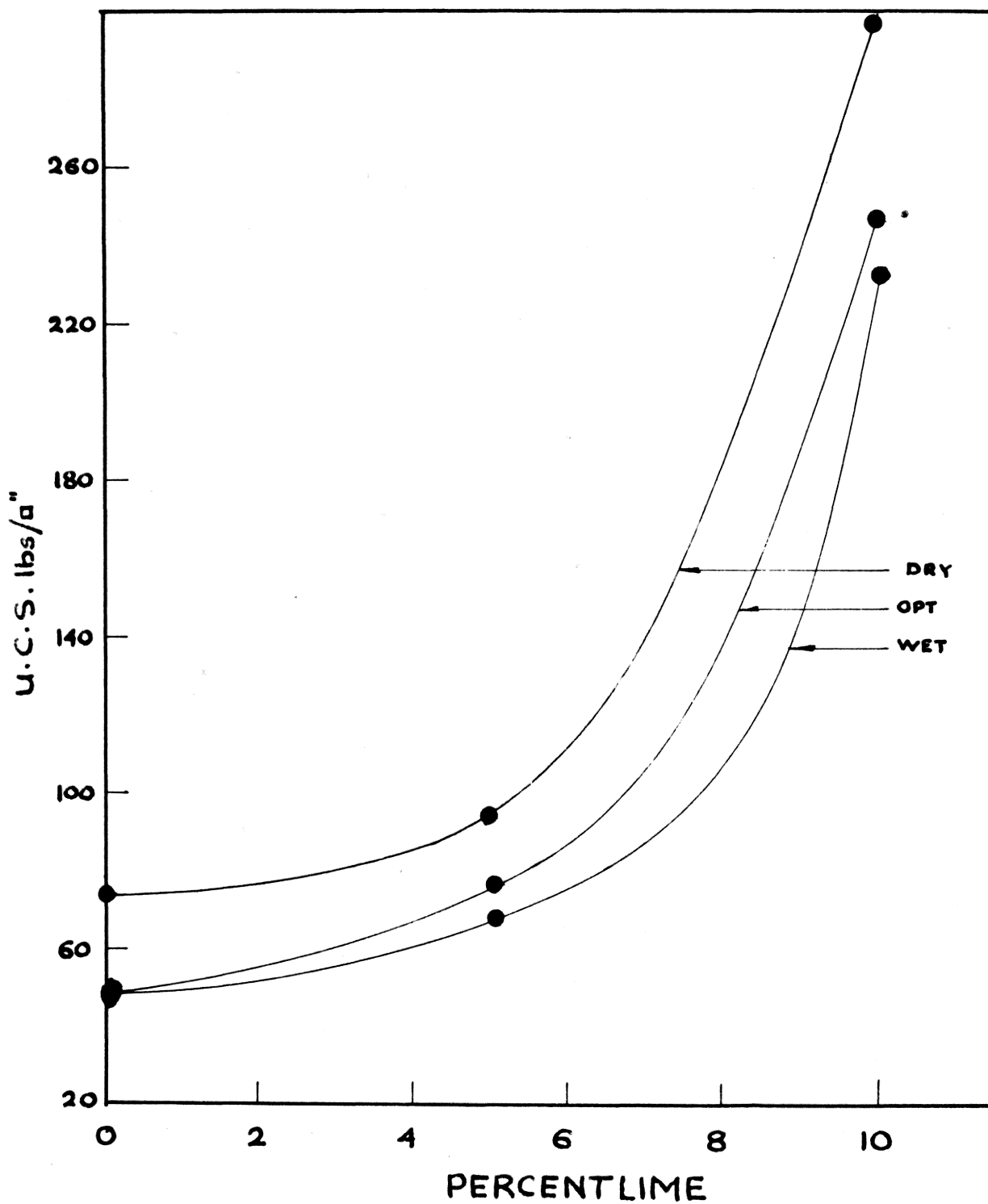


FIGURE 17  
OVENCURED U.C.S.—MOISTURE CONTENT

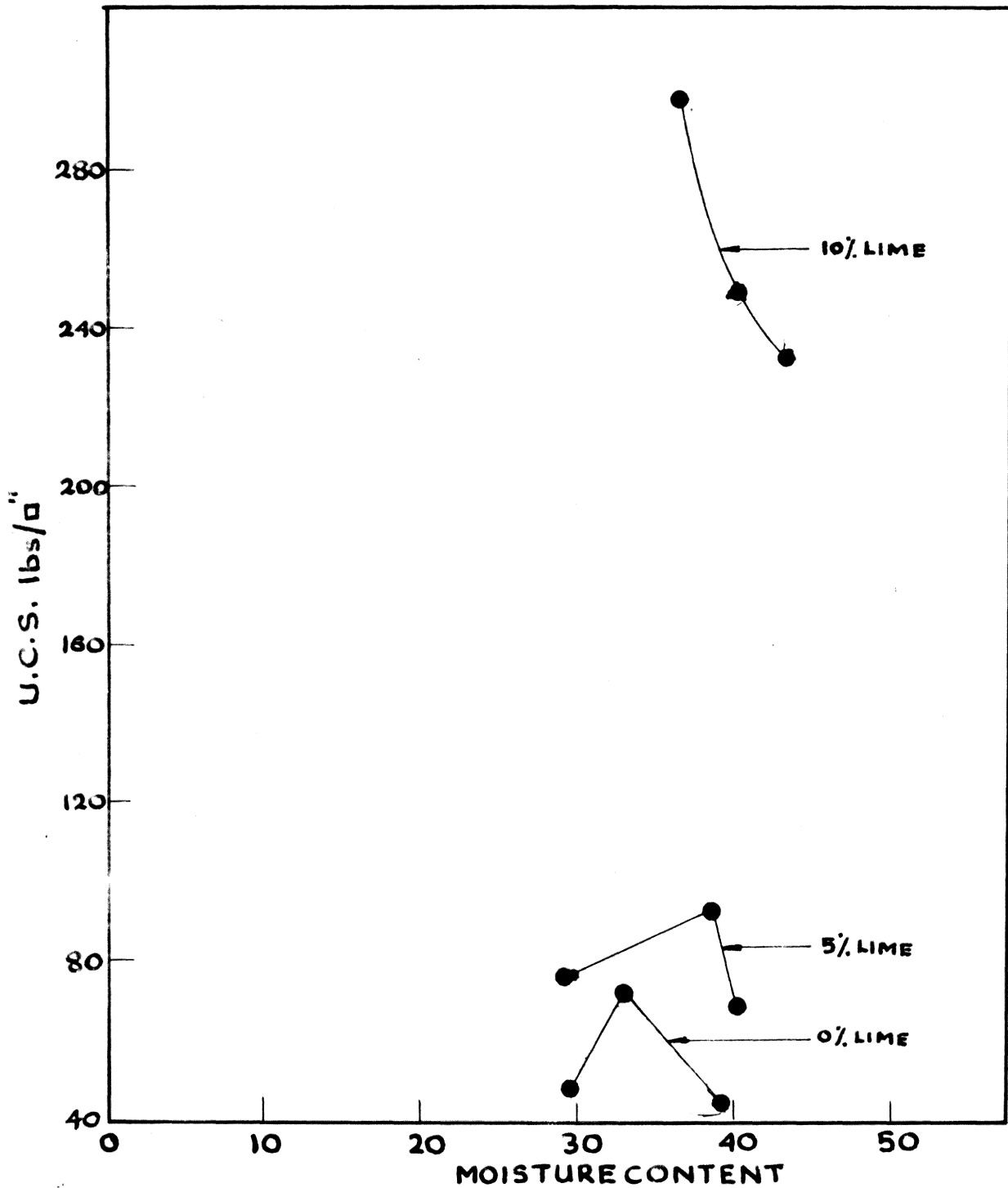


TABLE II

UCS in lbs./sq.in. for Different Curing Conditions,  
Percentages of Lime and Moisture Contents

UCS in lbs./sq.in.		10% Lime	5% Lime	0% Lime	Total
	Dry	47.2	33.3	30.3	110.8
		51.0	41.6	28.8	121.4
As Molded	Opt	24.6	47.0	47.0	118.6
		29.7	57.6	45.5	132.8
	Wet	13.6	24.8	34.7	73.1
		14.7	30.7	44.3	89.7
	Dry	76.5	48.3	40.6	165.4
		103.0	59.0	36.3	198.3
Damp Curing	Opt	82.4	75.7	89.0	247.1
		88.0	69.4	69.0	226.4
	Wet	38.9	25.2	88.0	152.1
		34.9	46.0	67.0	147.9
	Dry	311.0	69.5	33.7	414.2
		284.0	85.0	64.2	433.2
Oven Curing	Opt	267.0	92.5	67.0	426.5
		229.0	94.5	79.0	402.5
	Wet	267.0	61.0	44.0	372.0
		201.0	78.5	40.0	319.5
Total		2163.50	1039.6	948.4	4151.5

FIGURE 18

# AS MOLDED U.C.S. - AS MOLDED C.B.R.

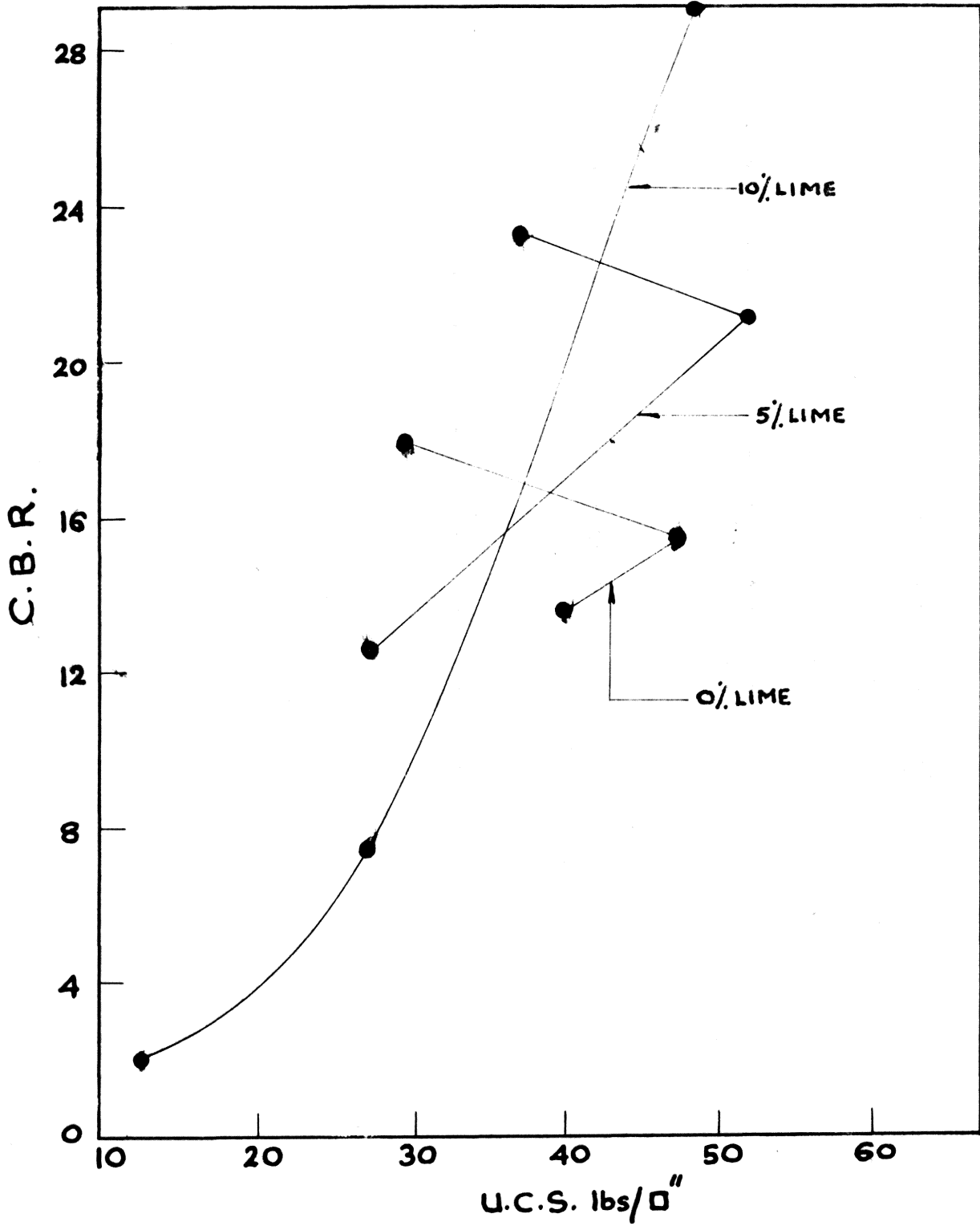


FIGURE 19

## DAMP CURED U.C.S - SOAKED C.B.R.

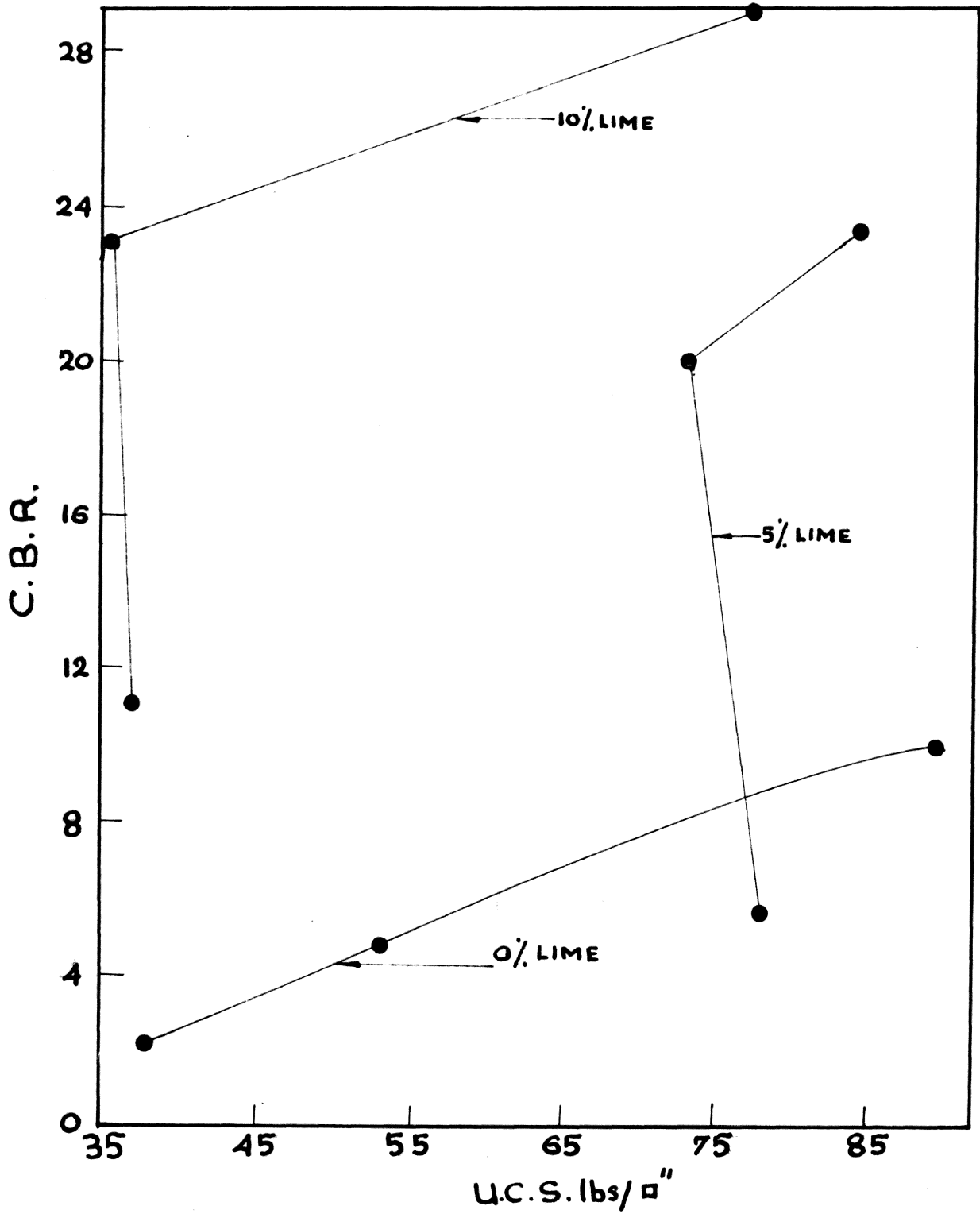
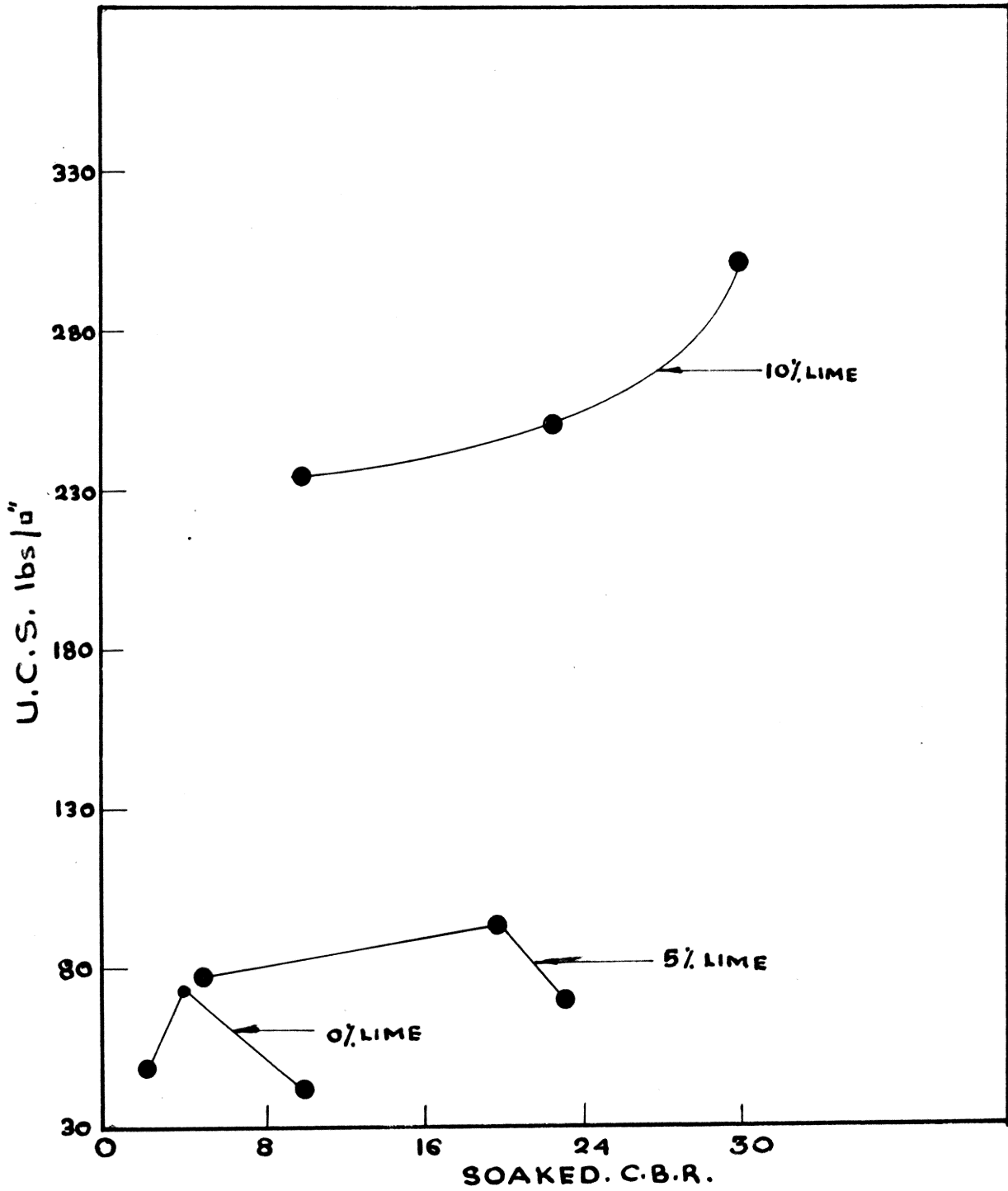


FIGURE 20  
OVENCURED U.C.S.-SOAKED C.B.R.





### Statistical Analysis

A statistical analysis of variance was carried out on UCS data (Tables II and III). The following conclusions were derived:

1. Lime concentration produces a significant effect on soil strength.
2. Changes in curing conditions produce a significant change in soil strength.
3. Moisture does not have a significant effect on soil strength.
4. There was no significant interaction between lime, moisture and curing conditions.

Although the above statistical results do not show any significant overall interaction, there appears to be a significant interaction between percent lime and curing method. The interaction between lime and moisture content and curing and moisture content does not appear to be very significant. If these interactions were treated separately in the analysis, it is believed that these differences would be borne out.

TABLE III

Analysis of Variance of UCS Data

Source of Variance	F	F <sub>0.05</sub>	F <sub>0.01</sub>	Significance
Lime	4.5646	3.49	5.85	*
Curing	7.8819	3.49	5.85	**
Moisture	0.35614	3.49	5.85	Not significant
Interaction	0.85925	2.04	2.78	Not significant

\* Significant to the 0.05 level.

\*\* Significant to the 0.01 level.

## CONCLUSIONS

As a result of this study, the following conclusions were derived:

1. Addition of lime increases optimum moisture content and reduces dry density of the soil.
2. Specific relation between OBR and dry density could not be found. Swell increases with higher values of OBR.
3. Lime considerably reduces the swell; soil with 10 percent lime shows practically no swell.
4. Lime increases the strength of the soil; this effect is very significant on dry side. With higher moisture contents lime has little effect on the strength of the soil; it mainly improves the workability.
5. Up to five percent addition of lime produces little increase in strength. This value may be roughly considered as a fixation value of lime for this soil.
6. Curing increases the UCS and OBR of lime treated soil.
7. Four days damp curing at 67°F appears to be insufficient.

8. Accelerated oven curing at 120°F for two days gives significant increase in strength, especially with 10 percent lime.
9. No definite conclusions could be derived between as molded OBR and as molded UCS, between soaked OBR and damp cured UCS and between soaked OBR and oven cured UCS.

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## A B S T R A C T

### OBR and Unconfined Compression Strength Tests on Lime Stabilized Clay Soil

The main purpose of this study was two-fold:

1. To show any existing correlation between OBR and UCS tests.
2. To show the variation in UCS due to various methods of curing.

Using a Harvard miniature apparatus, compactive curves were determined for standard AASHO compactive effort for 0, 5, and 10 percent lime. From these curves the moisture contents to be used for strength tests were determined. These were dry of optimum (optimum -6 percent), optimum, and wet of optimum (optimum +6 percent).

OBR specimens were fabricated at the above moisture contents for 0, 5, and 10 percent lime. In all, nine samples were prepared. This was repeated using the miniature apparatus for the unconfined compression test. Six samples were prepared for each test condition. Two of these were tested as molded, two after damp curing (four days 67°F), and two after oven curing (two days 120°F).

The results of this study indicated the following:

1. Lime increases the strength of the soil. This effect was very significant on the dry side.
2. Upto five percent addition of lime produced little increase in strength. This value may be considered as a fixation value of lime for this soil.

3. Curing increased the UCS and CBR of lime-treated soil. Accelerated oven curing of 120°F for two days gives significant increase in strength, especially with 10 percent lime.
4. No definite conclusions could be derived between as molded CBR and as molded UCS, between soaked CBR and damp cured UCS, and between soaked CBR and oven cured UCS.