

# Effect of Lime, Moisture and Compaction on a Clay Soil

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•IN AN EFFORT to use economically material otherwise unsuitable for subgrade construction, the State of Virginia is in many instances adding a small percentage of lime to improve such material. Much of this so-called lime stabilization or lime modification has been done in the southwestern part of the State where Virginia Polytechnic Institute is located. The purpose of this project was to investigate the change in engineering characteristics of a typical clay soil from this area, when different amounts of hydrated lime were added.

The testing program consisted mainly of studying the effect of three variables—percent lime, moisture content, and compactive effort—by fabricating CBR specimens and obtaining values of CBR, density, and swell. In addition, Atterberg limit determinations were made on the soil containing different percentages of lime. Use of the CBR test was particularly appropriate for this study because the State of Virginia bases the flexible pavement design on this test.

## TEST SOIL PROPERTIES

The soil, a reddish brown, plastic clay, had approximately 97 percent passing the No. 200 sieve and about 66 percent finer than 0.001 mm. The soil had a liquid limit of 71 and a plasticity index of 35. Standard AASHO density was 86 pcf at an optimum moisture content of 31 percent. Modified AASHO density was 97 pcf at an optimum moisture content of 27 percent. According to the AASHO classification system, the soil was classified as A-7-5(20). X-ray diffraction analysis was run on the soil with the following results: kaolinite group (but mostly halloysite), 30 percent; montmorillonite group, 10 percent; chlorite, 10 percent; illite, 10 percent; and amorphous ferrous and aluminum oxides and hydroxides, 40 percent.

## TEST PROCEDURES

CBR tests were performed on soil with the addition of 0, 5, and 10 percent (by weight of dry soil) hydrated lime. The compactive efforts used were 10, 25, and 55 blows per layer on five layers with a 10-lb hammer dropped 18 in. The underlying purpose of this procedure was to develop a family of curves showing the effect of variation in lime content, compactive effort, and moisture content on density, swell potential, and CBR values of the soil, and finally to show the relationships between CBR and density at different moisture contents. Knowing such relationships for subgrade soils would enable better compaction control in the field in order to obtain a required CBR value.

CBR values were obtained immediately after compaction and again after a 4-day soaking period with a 20-lb surcharge weight. Moisture content and density before soaking were determined. Swell measurements were taken during the soaking period and the percent swell after 4 days of soaking determined. Specimens were molded at about six different moisture contents for each level of lime content and compactive effort.

Liquid and plastic limit tests were performed on soil containing 0, 3, 5, 7, and 10 percent lime. In running these tests, the soil and lime were mixed thoroughly in the dry powdered state. Water was added to the mixture in sufficient quantity to approach the plastic limit. The liquid and plastic limit tests were then run in the ordinary manner.

EFFECT OF LIME ON ATTERBERG LIMITS

Table 1 summarizes the results of this part of the experiment and Figure 1 shows the effect of lime content on the liquid limit flow curve.

To illustrate the effect of lime content on the plasticity properties of the soil studied, the values in Table 1 are plotted in Figure 2. It is evident that these properties of the soil were improved by the addition of lime. There was a marked decrease in liquid limit by addition of lime. Also, the plastic limit was decreased from 35 for the natural soil to 18, 16, 13, and 11 with the addition of 3, 5, 7, and 10 percent of lime, respectively. With the addition of a small percentage of lime (3 percent), it was reduced drastically from 35 to 18. However, as the percent added increased, the rate of reduction was decreased.

TABLE 1  
ATTERBERG LIMITS FOR VARIOUS  
LIME PERCENTAGES

Lime Added (%)	Atterberg Limit (%)		
	Liquid Limit	Plastic Limit	Plasticity Index
0	71	36	35
3	66	48	18
5	65	49	16
7	63	50	13
10	62	51	11

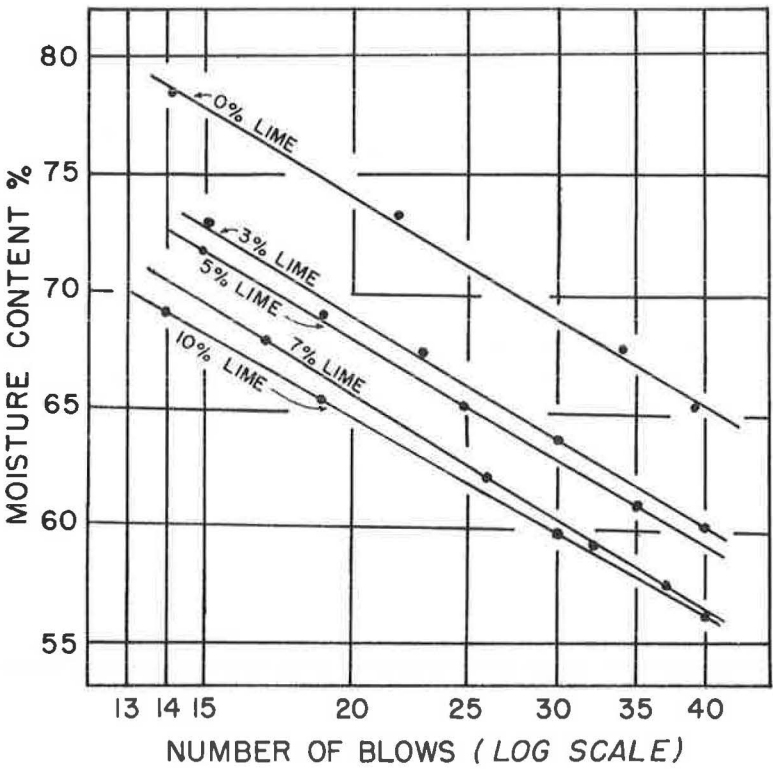


Figure 1. Flow curves for different percentages of lime.

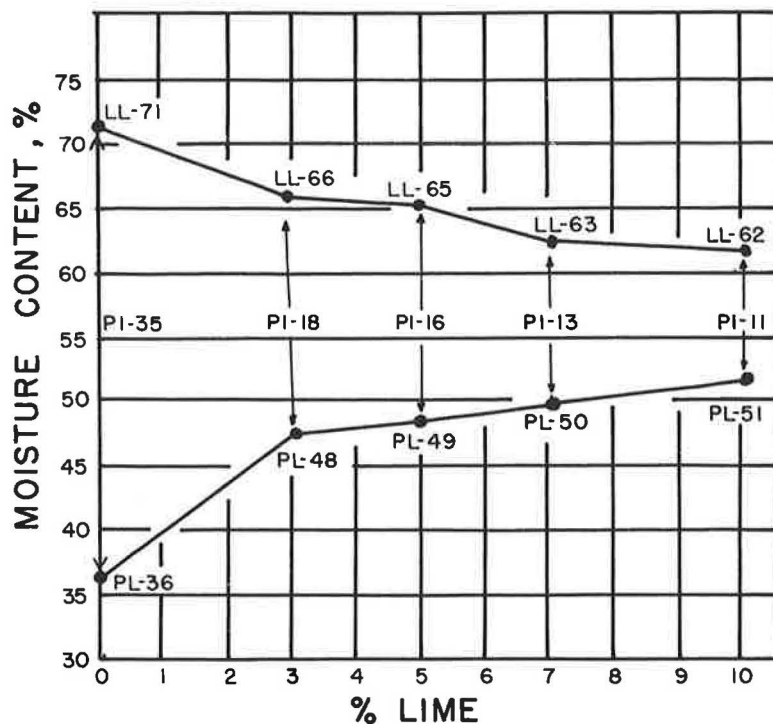


Figure 2. Effect of lime on plasticity indexes of soil.

TABLE 2  
CBR TEST RESULTS FOR 0 PERCENT LIME

Compactive Effort (blows/layer)	As-Molded Condition			Soaked Condition	
	Moisture Content (%)	Dry Density (pcf)	CBR (%)	CBR (%)	Swell (%)
10	19.8	73.3	6.7	0.7	4.0
	27.3	76.3	13.3	3.0	3.4
	29.2	82.0	25.0	3.3	2.6
	34.6	85.0	10.0	6.7	0.4
	38.6	80.4	1.7	3.7	0.2
25	22.0	85.8	46.7	3.7	6.7
	27.6	89.4	40.7	8.3	3.8
	32.2	87.2	21.7	10.0	0.6
	35.0	85.6	9.3	10.0	0.4
	37.0	82.5	3.3	7.3	0.2
55	41.9	77.3	1.7	3.7	0.1
	22.2	93.0	61.7	5.0	7.3
	26.9	94.2	75.7	11.7	5.1
	27.7	93.4	56.7	12.0	3.3
	31.4	91.0	20.0	13.3	0.5
	34.4	86.0	6.7	10.0	0.4
	38.6	81.9	3.7	3.3	0.3

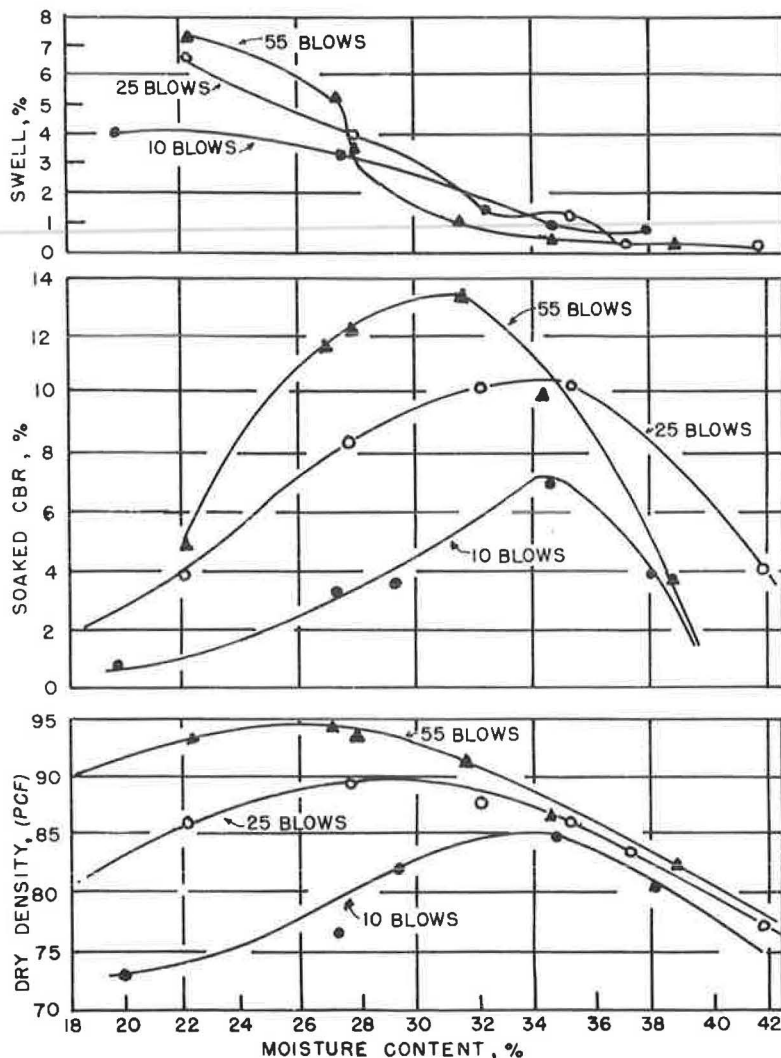


Figure 3. Density, strength, and swell vs moisture content in untreated soil.

### CBR TEST RESULTS

CBR tests were performed with the addition of 0, 5, and 10 percent of hydrated lime. The CBR load penetration values were recorded for the soil and soil-lime mixtures before soaking and also after 4 days soaking period.

The results obtained for CBR tests with 0 percent lime are given in Table 2. On the basis of these results, a family of curves was developed by plotting values of dry density, soaked CBR, and percentage swell against moisture content (Fig. 3).

To study further relationships that exist between strength, compactive effort, and moisture content, values of dry density were plotted against CBR soaked for arbitrarily selected moisture contents of 23, 27, 31, 36, and 39 percent in Figure 4.

CBR test results for 5 and 10 percent of lime added to the soil are given in Tables 3 and 4. Figures 5 and 6, and 7 and 8, are similar to Figures 3 and 4 for 0 percent lime.

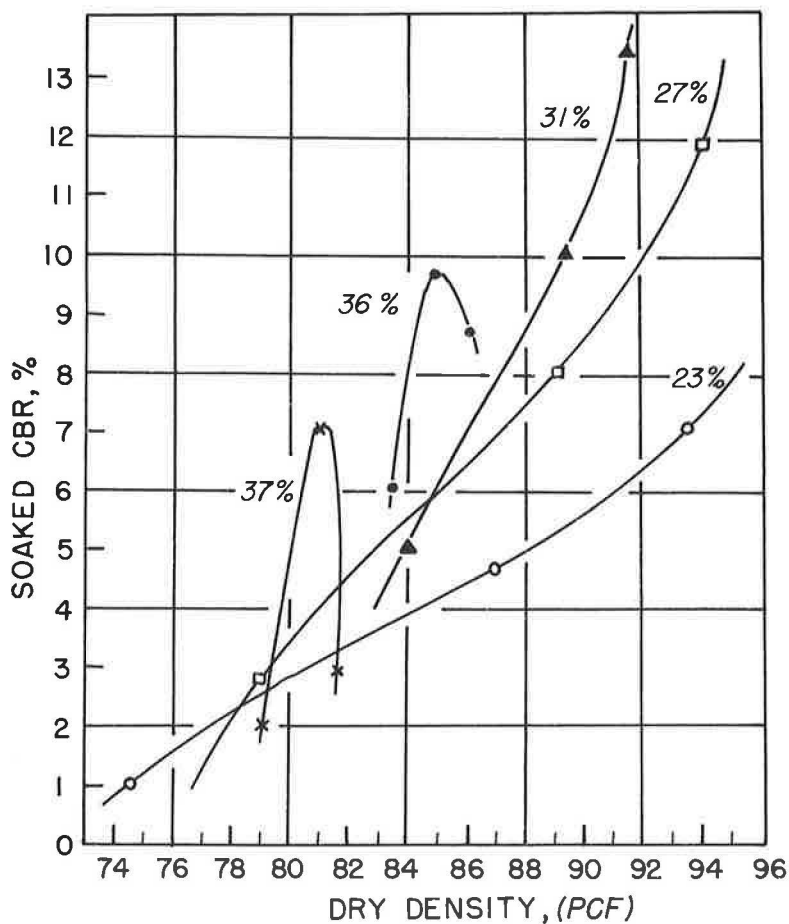


Figure 4. CBR-density relationships in untreated soil.

TABLE 3  
CBR TEST RESULTS FOR 5 PERCENT LIME

Compactive Effort (blows/layer)	As-Molded Condition			Soaked Condition	
	Moisture Content (%)	Dry Density (pcf)	CBR (%)	CBR (%)	Swell (%)
10	23.0	75.1	26.0	25.0	2.6
	26.6	79.2	31.7	36.2	2.1
	29.3	80.6	32.7	63.3	1.6
	32.4	83.3	28.3	83.3	0.9
	34.7	83.8	30.0	81.3	0.8
	37.4	82.6	11.7	45.3	0.4
25	18.7	81.2	25.0	26.0	3.3
	20.4	82.3	18.3	33.3	2.8
	26.1	87.4	38.3	44.7	1.1
	28.4	89.0	48.3	60.0	0.5
	30.0	90.5	48.3	80.0	0.2
	31.8	89.5	31.0	101.0	0.1
55	36.1	84.4	19.0	40.9	0.1
	16.4	87.6	41.7	45.0	3.9
	20.7	95.1	81.7	84.0	2.0
	24.8	96.7	81.7	131.7	0.4
	28.1	95.2	44.7	72.0	0.2
	34.2	87.2	10.0	39.0	0.0

TABLE 4  
CBR TEST RESULTS FOR 10 PERCENT LIME

Compactive Effort (blows/layer)	As-Molded Condition			Soaked Condition	
	Moisture Content (%)	Dry Density (pcf)	CBR (%)	CBR (%)	Swell (%)
10	20.0	78.9	12.7	23.3	1.3
	23.6	82.5	31.7	30.3	1.0
	27.9	85.2	33.3	66.7	0.4
	32.4	86.3	18.3	70.7	0.2
	36.7	80.0	5.0	28.2	0.0
25	20.8	85.0	53.3	60.0	1.8
	23.3	86.0	35.7	65.0	1.4
	27.0	88.3	33.3	115.0	0.2
	32.0	88.0	25.0	87.7	0.1
	36.8	82.6	6.7	56.7	0.0
55	18.6	89.3	43.3	75.0	2.3
	21.9	91.0	80.0	83.3	1.6
	26.3	93.2	86.7	153.3	0.4
	30.3	91.6	46.7	90.7	0.2
	34.9	86.4	10.0	56.7	0.1

### ANALYSIS

#### Strength-Density Moisture

Using Figure 4 as an example, strength is shown to be a function of both density and moisture content. The optimum strength of the soil (CBR=13.4) can be achieved by using the compactive effort to develop 91.5 pcf dry density at the moisture content of 31 percent. At moisture contents lower than 31 percent, even at high densities (achieved through increased compactive effort), this value of CBR could not be realized.

Again, at moisture contents higher than 31 percent, even with increased compactive effort, values of dry density and CBR soaked continued to decrease. This is due to the fact that, with the increase in moisture content beyond the optimum, the voids are gradually filled with water resulting in a loss of grain-to-grain contact. The structure of the soil is also affected. The flocculent structure is destroyed gradually, and the clay particles are oriented more and more with the increase in moisture content. Further, thickness of the water film continues to increase, causing a reduction in the attraction force between the clay particles.

Such relationships as shown in Figures 4, 6, and 8 can be used as an important tool in controlling compaction in the field by permitting the designer to choose intelligently a range of allowable moisture content and density in order to choose a design CBR.

#### Effects of Lime Additions

**Dry Density and Optimum Moisture Content.**—Maximum dry density and optimum moisture content values obtained from the CBR tests on natural soil and soil-lime mixtures with the various compactive efforts are given in Table 5. Unlike many studies, no distinct reduction in maximum density is shown by these data. However, some slight decrease is shown in the optimum moisture content with the addition of lime with only one value contradicting this trend.

**Soaked CBR.**—The maximum values of CBR soaked for the different percentages of lime and compactive efforts are given in Table 6. The values of soaked CBR are plotted against percent lime added in Figure 9. The following trends are observed:

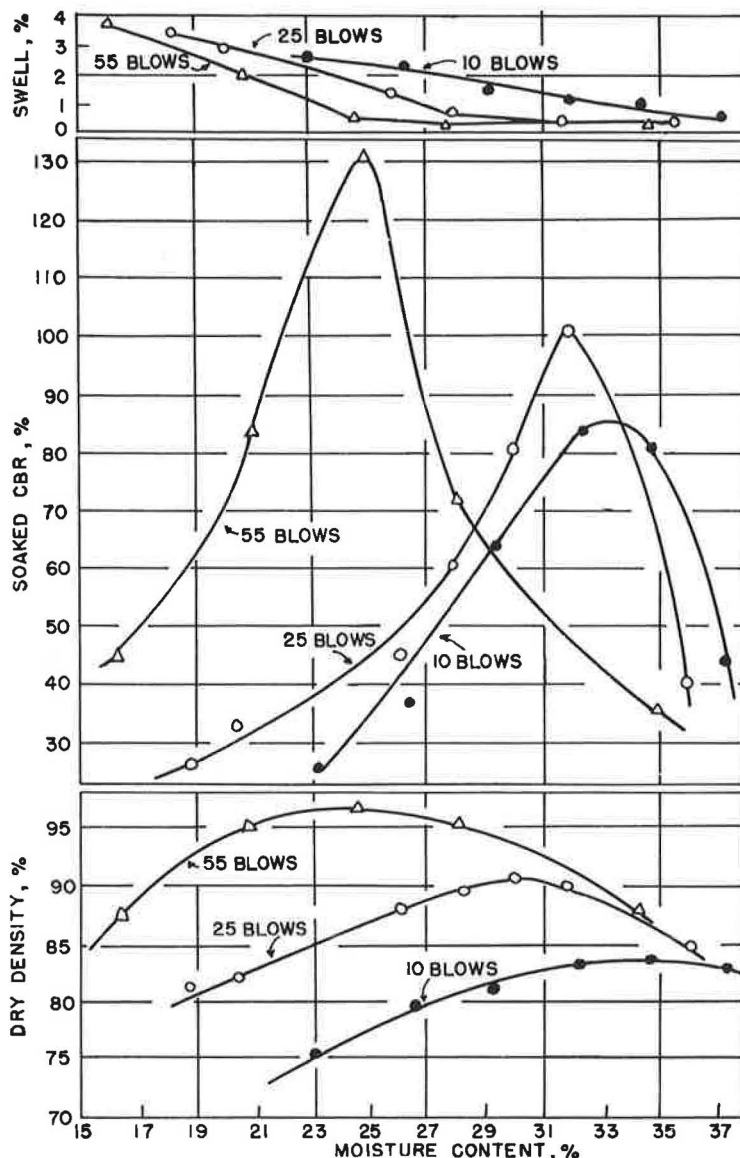


Figure 5. Density, strength, and swell vs moisture content for 5 percent lime.

1. Addition of hydrated lime materially increased the strength as measured by the CBR test. Addition of 5 percent lime increased the CBR value almost ten times, regardless of compactive effort. The CBR values were increased from 6.67 to 83.3, from 10 to 101, and from 13.3 to 131.7, for 10, 25, and 55 blows per layer compactive effort, respectively.

2. With the addition of 10 percent lime there was a further increase in the CBR value, but this increase was not as pronounced as those obtained initially with the addition of 5 percent lime. Figure 9 shows the addition of 10 percent lime relatively did not produce similar results.

3. For the natural soil, change in compactive effort did not increase the CBR value significantly (Fig. 9). But with the increase in lime percentage, the increased

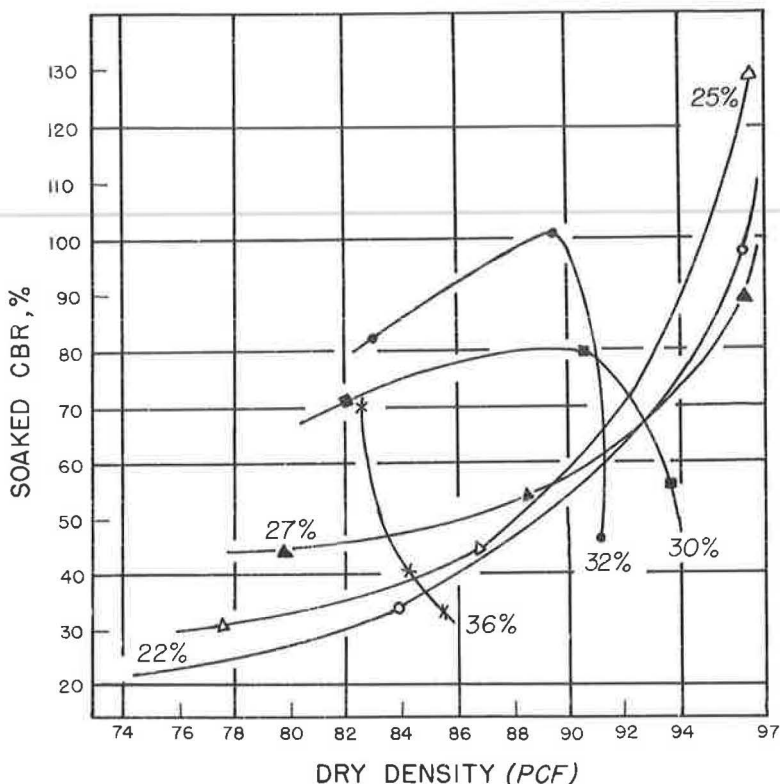


Figure 6. CBR-density relationships for 5 percent lime.

compactive effort increased CBR values significantly. For the natural soil, CBR soaked increased from 6.7 to 10 blows per layer compactive effort to 10.0 and 13.33 for 25 and 55 blows per layer, respectively. With the addition of 5 percent lime CBR soaked was increased from 83.3 for 10 blows per layer compactive effort to 101 and 132 for the next two compactive efforts. Similar increases in CBR soaked, due to increased compactive effort, are observed with the addition of 10 percent lime. Hence, the increased compactive effort produced more favorable results with the addition of lime to soil. Thus, increased rolling of a lime-treated subgrade should be more effective, as far as strength increases are concerned, than of an untreated subgrade.

4. For the development of maximum strength (CBR), compactive effort and moisture contents must be properly controlled. Without the proper density-moisture control, even addition of large amounts of lime (10 percent) will not develop maximum strength. Hence, it is imperative to make certain by proper checks during construction that the designed densities and compaction moisture contents are fulfilled.

**CBR As Molded.**—The values of maximum CBR as molded for various additions of lime percentage and compactive efforts are given in Table 6. The values of CBR as molded against percent lime added are shown in Figure 10. The following trends were observed:

1. For the natural soil, the unsoaked strengths were generally greater than those of soaked for 4 days (Table 6). But for the soil-lime mixture, the values of CBR soaked are greater than those of CBR as molded. This is probably due to the flocculation and aggregation of clay particles and cementing action which occur with lime addition. The absence of these reactions in natural soil results in lower values of CBR after 4 days soaking period. Loss in grain-to-grain contact and increase in



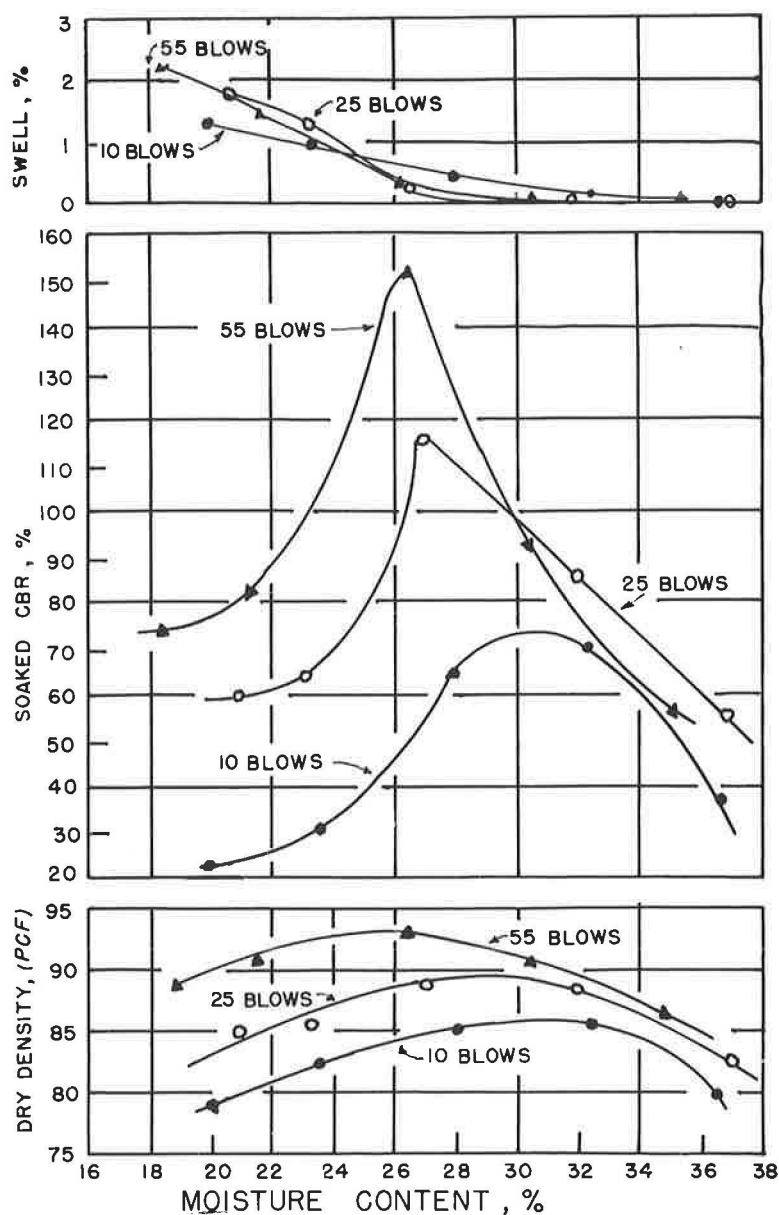


Figure 7. Density, strength, and swell vs moisture content for 10 percent lime.

water film thickness surrounding the clay particles further reduces the strength of the soaked CBR specimens.

2. Although the increase in lime content increases the CBR as molded, the change is not as pronounced as those of CBR soaked. It is probably due to the fact that aggregation of particles and cementation action, with the lime addition, occur most favorably when the soil-lime mixture is soaked in water.

Swell Potential.—The values of maximum swell as observed during the 4-day soaking period of samples for various lime contents and compactive efforts are given in

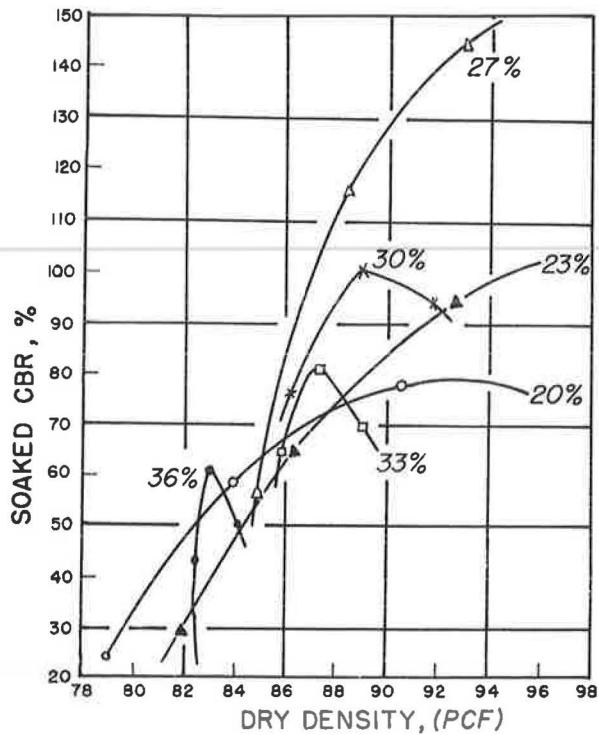


Figure 8. CBR-density relationships for 10 percent lime.

TABLE 5  
EFFECT OF LIME ADDITION ON DRY DENSITY AND OPTIMUM  
MOISTURE CONTENT

Lime (%)	10 Blows per Layer		25 Blows per Layer		55 Blows per Layer	
	Opt w (%)	Max $\gamma_o$ (pcf)	Opt w (%)	Max $\gamma_o$ (pcf)	Opt w (%)	Max $\gamma_o$ (pcf)
0	34.6	85.0	27.6	89.4	26.9	94.2
5	32.4	83.3	30.0	90.5	24.8	96.7
10	32.3	86.3	27.0	88.3	26.3	93.2

TABLE 6  
EFFECT OF LIME ADDITION ON CBR AND  
SWELL POTENTIAL

Compactive Effort (blows/layer)	Lime (%)	CBR		Maximum Swell <sup>a</sup> (%)
		As Molded (%)	Soaked 4 Days (%)	
10	0	25.0	6.7	4.0
	5	32.7	83.3	2.6
	10	33.3	78.0	1.3
25	0	46.7	10.0	6.7
	5	48.3	101.0	3.3
	10	53.3	115.0	1.8
55	0	75.7	13.3	7.3
	5	81.7	131.7	3.9
	10	86.7	153.3	2.3

<sup>a</sup>Generally occurs on dry side of optimum moisture; swell percentage at optimum moisture is much lower than these values.

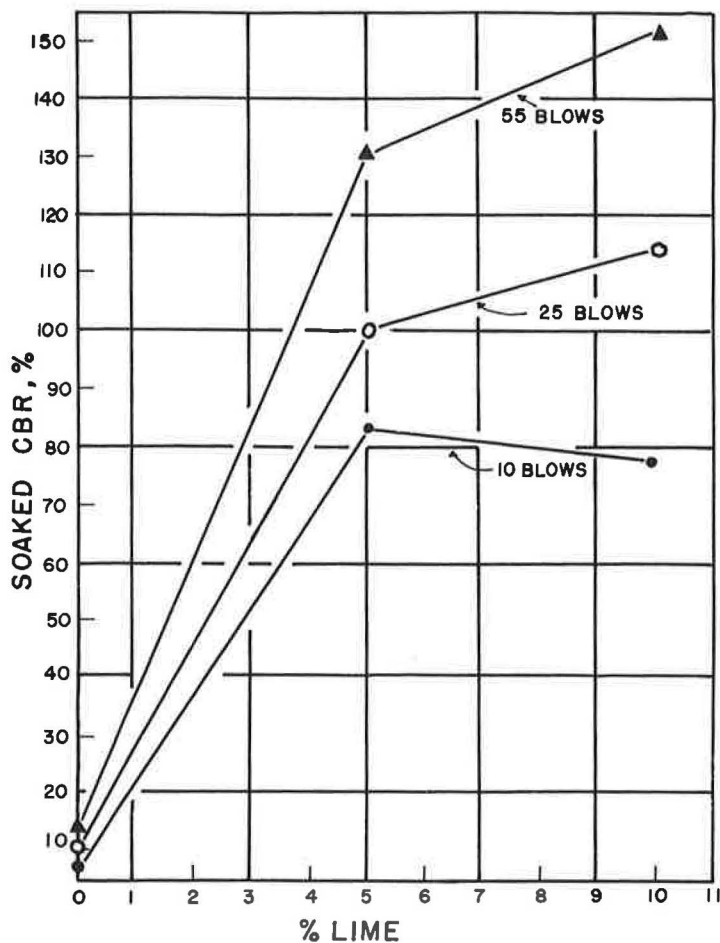


Figure 9. Effect of lime on CBR.

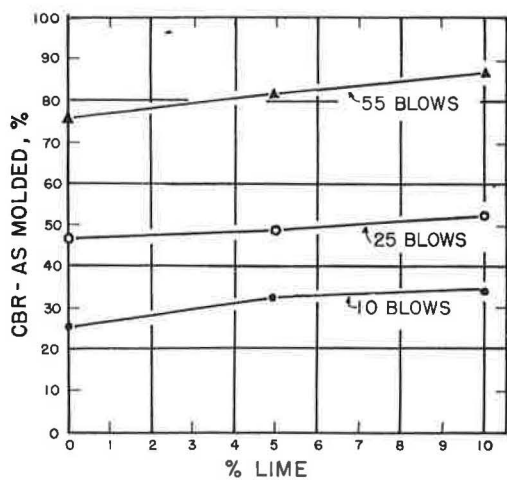


Figure 10. As-molded CBR vs percent lime.

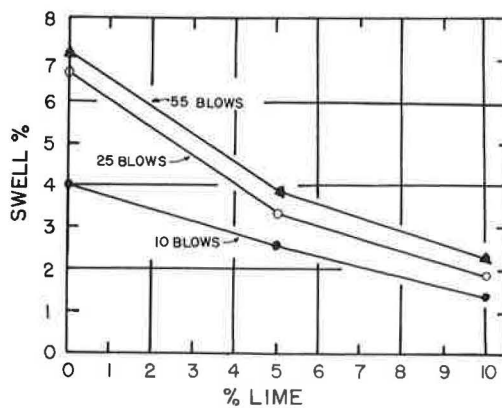


Figure 11. Effect of lime on swell.

Table 6. The values of percent swell against percent lime added are plotted as shown in Figure 11. The following trends are observed:

1. An increase in lime content decreases the percent swell. The reduction in swell percentage is relatively more significant with the addition of smaller percentages of lime.
2. Figures 3, 5, and 7 indicate that moisture content at which compaction is carried out has a very important influence on swell percentage. Appreciable swell is observed on the dry side of optimum moisture content with values decreasing as optimum moisture content is reached. Little decrease in swell results as moisture content is increased beyond optimum. Also, on the dry side of optimum, an increase in compactive effort causes an increase in amount of swell. However, on the wet side of optimum, the increase in compactive effort does not increase swell.

### CONCLUSIONS

The following represents a summary of the trends shown by this study:

1. The plastic properties of the soil were improved appreciably by the addition of hydrate lime. There was a marked decrease in liquid limit, and the plastic limit was decreased; consequently, the plasticity index was decreased considerably. Little change in plastic properties was obtained by adding more than 3 percent lime.
2. Addition of hydrated lime materially increased the strength of soil as measured by the CBR method. Five percent lime addition increased the CBR-soaked values more than ten times. With the addition of more lime (up to 10 percent), CBR values increased further. However, the addition of more than 5 percent lime produced relatively less significant increases.
3. Increases in compactive effort were more effective on lime-treated soil than on untreated soil.
4. For the natural soil, the values of CBR as molded were generally greater than those of CBR soaked for 4 days, but with the addition of lime the situation was reversed and the CBR-soaked values observed were greater than those of CBR as molded.
5. Although the increase in lime content increased the CBR as molded, the change was not as pronounced as for CBR soaked.
6. The addition of hydrated lime reduced the swell percentage of the clay soil appreciably. The effect of lime addition on dry density and optimum moisture was found to be negligible in this study.
7. The CBR test on natural soil and soil-lime mixture using varying compactive effort and moisture content indicated that strength is a function of both density and moisture content. Maximum strength can be developed only by exercising proper control over moisture content and density.