CHEMICAL STABILIZATION OF COHESIONLESS OKLAHOMA SOILS

By

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CHEMICAL STABILIZATION OF COHESIONLESS
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CHAPTER I

INTRODUCTION

Chemical treatment of subgrade soils to improve strength and reduce total highway costs is an accepted procedure. Cohesive soils are commonly stabilized to eliminate the cost of purchasing and hauling aggregate. Furthermore, density and compressive strength of granular soils are often improved by the use of a clay binder to fill the voids and supply additional cohesion.

Statement of the Problem

The purpose of this study was to find a method of stabilizing three cohesionless Oklahoma soils, to provide suitable base course material for use with a nominal thickness asphaltic concrete surface coating (armor coat) on light traffic roads. The selected method was required to be inexpensive, so that the Oklahoma Highway Department engineers could use limited maintenance funds to purchase materials, with existing maintenance personnel accomplishing all work utilizing available equipment. The selected mix design should also be suitable for all three soils.

Portland and asphaltic cement have been used very successfully as stabilization agents for cohesionless soils. The purpose of this study was not to confirm or discredit Portland and asphaltic cement stabilization, but to seek a possible alternative which may be lower in total cost or at least in material cost. Sodium chloride was given prime consideration because of its low cost and availability in the area where the soils were encountered.

Scope of the Investigation

The scope of this thesis included the investigation of the effects of sodium chloride and sodium chloride-lime admixtures on three Oklahoma cohesionless soils. To gain a better understanding of the reactions occurring, it was necessary to accomplish the testing in two phases, with and without the use of a clay binder. Testing was directed towards investigating those properties of the given soils and soil mixtures which affected their stabilized strengths, with special interest in evaluation of both total strength and strength increase.

CHAPTER II

A LITERATURE SUMMARY AND STRENGTH DESIGN CRITERIA REVIEW

Introduction

The purpose of this Chapter is to provide a brief review of some of the existing theories and test results related to salt and salt-lime treatment of both cohesive and cohesionless soils. Existing design criteria as related to highway base and subbase course selection is also reviewed.

Chemical Treatment of Soil Mixtures

Sheeler (Ref 1) reported that sodium chloride-aggregate stabilization is used quite extensively in Iowa. The effects are primarily a hard surface crust when dry, reduced dust, and increased aggregate retention.

Marks and Haliburton (Ref 2), in a study of salt-lime treatment of cohesive Oklahoma soils, found that the addition of sodium chloride in conjunction with lime increased compacted unit weights and reduced optimum moisture contents, as compared to values obtained by lime treatment alone. Additionally, salt-lime modification not only produced higher strengths than lime modification, but also increased the rate of strength gain during curing.

The Illinois Department of Highways (Ref 3) suggests lime treatment will only induce large strength increases when used on soils which display good pozzolanic reactivity, while Shen and Li (Ref 4) suggested that the effectiveness of lime-soil stabilization is related to the fine-grain fraction/lime (FGF/L) ratio. For the particular clay-sand mixtures within the scope of their investigation, the optimum FGF/L ratio for maximum strength was from 12 to 14.

Miller and Sowers (Ref 5) conducted an investigation of the optimum percent of clay binder for use with cohesionless soils. They reported the mixture with the highest density occurred at 26 percent binder and 74 percent granular soil by weight. They further suggested that maximum density should be the criteria on which to base optimum mix design, since both strength and incompressibility are influenced by density. The ideal maximum density would be obtained if the air voids in the compacted granular soil were just filled with compacted binder and this ideal mix could be computed from the void ratio and densities of each soil when compacted at optimum moisture.

Review of Strength Design Criteria

Unfortunately, very little design criteria are available for consideration of chemically treated base materials. The most popular method of evaluating cohesive soils treated with lime appears to be unconfined compressive strength, while untreated granular material is evaluated by the California Bearing Ratio (CBR) test.

The Illinois Department of Highways (Ref 3) indicated that for fine-grained soils subjected to freeze-thaw conditions a minimum unconfined compressive strength of 150 psi is required for lime stabilized soil used as a base course. It was also suggested that lime-stabilized soil used as a subbase for flexible pavements should have a minimum unconfined compressive strength of 100 psi. According to the Illinois flexible pavement design criteria, a granular material with a CBR of 44 would be equivalent to a 100 psi lime stabilized soil.

McDowell (Ref 6) indicated lime stabilized soils should have a minimum unconfined compressive strength of 100 psi to be suitable for base material, while an unconfined compression value of 50 psi would be required for a subgrade or subbase material. This lower strength requirement appears reasonable since Texas soils are not subjected to the extreme freeze-thaw conditions that soils in Illinois undergo.

The Asphalt Institute (Ref 7) recommends that in light traffic areas a minimum CBR value of 80 should be required for granular base materials, while subbase materials should have a minimum CBR of 20. For light traffic conditions, a minimum surface course of 1 in. thickness is to be used in combination with 4 in. of granular base.

CHAPTER III

MATERIALS AND SAMPLE PREPARATION

Introduction

This Chapter provides information describing geological origin, physical characteristics, and sample preparation procedures for the tested soils. Standard sample preparation and testing procedures were established and used throughout the study in order to minimize variations resulting from test sample nonuniformity.

Soil Location and Description

The soil samples used in this study were provided by the Oklahoma State Highway Department. All three samples were obtained in Harper County from the unsurfaced roadbed of State Highway 46 southwest of Buffalo, Oklahoma. They will be referred to as Buffalo 1, Buffalo 2, and Buffalo 3. Buffalo 1 was taken 8.4 miles north of the U.S. 270, SH 46 junction, while Buffalo 2 and 3 were respectively 9.7 and 13.3 miles from the same point. The parent geological material is of the Guadalupean Series of the Permian deposits of Oklahoma. Buffalo 1, which overlies the Ogalla geological unit, is a brown sand with aggregates of poorly cemented sandstone. Buffalo 2 and 3 are both of the White Horse group. Buffalo 2 is a red silty sand with aggregates of siltstone and overlies the Rush Springs Unit. Buffalo 3 overlies the Marlow Unit and is an orange-brown fine-grained sand with particles of poorly cemented sandstone.

Soil Physical Properties

Grain size distribution curves as determined by wet sieve and hydrometer analysis are shown in Fig 3.1. The various index properties and other physical characteristics are shown in Table 3.1, for comparative purposes. All three soils were nonplastic for the minus 40 fraction; however, the minus 200 fraction of each soil exhibited a low degree of plasticity. Although Buffalo 1 had the smallest percentage passing the number 200 sieve, its fines had the greatest plasticity.

TABLE 3.1

SOIL PHYSICAL PROPERTIES

	Buffalo 1	Buffalo 2	Buffalo 3
% Finer than 2.0mm(-10)	97.7	88.0	98.4
% Finer than .42mm(-40)	87.0	77.0	87.0
% Finer than .074mm(-200)	9.7	37.0	20.0
% Finer than .002mm	3.8	11.9	5.0
D_{60}	0.30	0.15	0.27
$D_e \doteq D_{10}$	0.08	0.001	0.019
Uniformity Coeff. Cu	3.75	150.0	14.2
Specific Gravity	2.62	2.67	2.64
Plastic Index	NP	NP	NP
Lineal Shrinkage (Percent)	0	1.95	1.25
Unified System Classification	SP-SM	ML-SM	SM
AASHO System Classification	A-3(0)	A-4(.4)	A-2-4(0)
Index Properties on Minus 200 Fraction			
Liquid Limit	33.1	27.7	25.3
Plastic Limit	22.7	24.6	24.3
Plastic Index	10.4	3.0	1.0
Flow Index	13.0	9.2	3.1
Toughness Index	0.8	0.4	0.3
Lineal Shrinkage (Percent)	5.8	3.3	4.0
Activity Number	0.27	0.09	0.04
% < .002mm	39.0	33.0	25.0

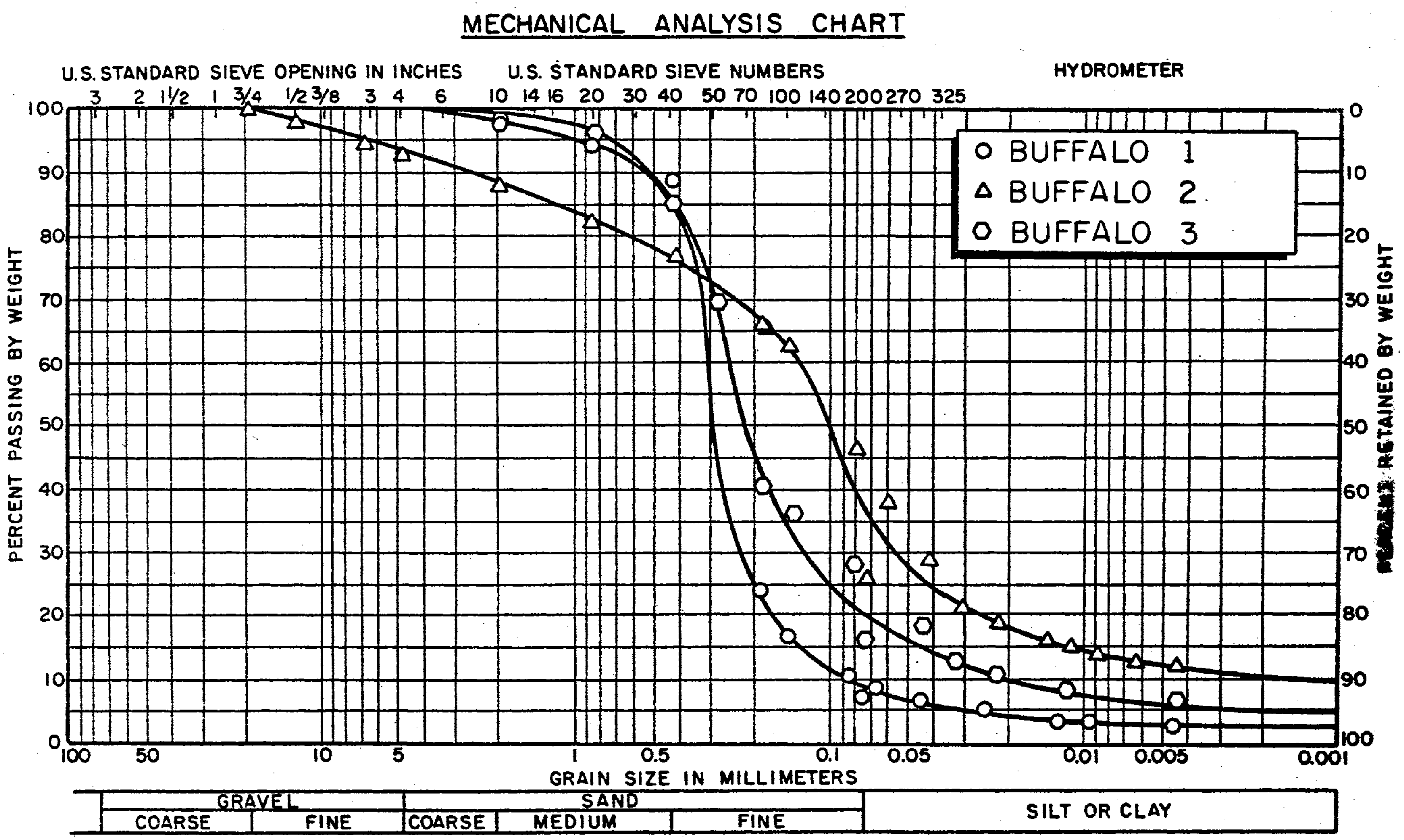


Figure 3.1. Grain Size Distribution Curves for Buffalo 1, 2, and 3.

Additives

A red Permian clay (PRC) which had been oven dried, pulverized and ground to pass a US No. 40 sieve was used as a binder.

Marks and Haliburton (Ref 2) found PRC to contain 38% by weight finer than 0.002mm. The plasticity index and plastic limit were determined to be 21.0 and 17.6 respectively, the lineal shrinkage was 17%, and the unconfined compressive strength (compacted at optimum) was found to be 16 psi.

PRC was added as a percentage of the dry weight of Buffalo soil passing the US No. 40 sieve. For those tests using the minus (-) 10 fraction an adjusted percentage of clay binder was used to make the percent equivalent to that percentage used with the -40 fraction. This equivalent percentage was found by multiplying the original clay percentage used with the -40 fraction by the percentage, expressed as a decimal, of Buffalo soil passing a US No. 40 sieve. Table 3.2 shows the relationship of the percentage used on the -40 fraction and -10 fraction.

Sodium chloride in the form of rock salt was used throughout the study. The salt was approximately 99.0% sodium chloride by weight. Before it was used, the rock salt was ground and passed through a number 40 sieve.

Quicklime which was 97.5% calcium oxide by weight was used for lime treatment. The commercial lime was passed through a U.S. No. 40 sieve to remove any large carbonated fractions, and then stored in sealed containers.

Commercial Portland cement, Type I, was used in the soil-cement mixtures.

TABLE 3.2

CLAY PERCENTAGES USED ON MINUS 40 AND MINUS 10 FRACTIONS OF BUFFALO SOILS

	Percent Used On Minus 40 Fraction	Equivalent Adjusted Percent Used On Minus 10 Fraction
Buffalo 1	20	17.75
	25	22.19
	30	26.63
Buffalo 2	20	15.35
	25	19.19
	30	23.01
	40	30.70
	60	46.06
Buffalo 3	20	17.07
	25	21.34
	30	25.60

Material and Sample Preparation Techniques

Prior to testing, the raw soil required processing to remove natural moisture and break clods into individual soil particles. The processing included oven drying for 24 hours at 105° C and pulverizing in a Straub Model 4E Laboratory Mill.

A standard procedure for preparing soil mixtures was adopted and used throughout the study. Dry Buffalo soil of sufficient quantity was weighed into shallow mixing pans. The clay binder and chemical additives were added in dry form as a percentage of the dry weight of Buffalo soil. The soil and additives were thoroughly mixed and blended by hand. The soil mixtures were then leveled in the pans and brought to the desired moisture content by sprinkling the required weight of distilled water evenly over the soil. All moisture contents were expressed in terms of the percent of total weight of the dry soil mixture. In those tests where a special moisture content was not desired a moisture content of 10 percent was used. Throughout the mixing all weights were measured to the nearest .1 gram. The mixtures were sealed and allowed to cure at room temperature for 16 to 24 hours. At the end of the curing period the moisture content was checked by weighing the moist soil mixture and pan. The mixture was again brought to the required moisture content and reblended as quickly as possible to minimize further moisture evaporation. The soil-cement mixtures were an exception to this standard procedure in that moisture was added to the dry mixture just prior to sample compaction.

Thoughout the study a miniature Standard Proctor compaction method was used for the compaction test and also sample preparation for both the unconfined compression test and determination of the California Bearing Ratio. The miniature test was accomplished using a Harvard miniature mold and specially designed 0.825 pound impact hammer which was proportionally scaled down from that used in the Standard Proctor test. Before compaction, the soil was sieved through a US No. 10 sieve to remove the coarse sand and gravel. The samples then were compacted in three lifts at 25 blows per lift, producing a sample 2.8125 inches long with a diameter of 1.3125 inches, at a compacted density equivalent to that obtained from the full-scale Standard Proctor Compaction test.

CHAPTER IV

TESTING PROCEDURE AND RESULTS

Introduction

This Chapter describes the various laboratory tests conducted on the Buffalo soils and their results. The testing procedure was designed to investigate the effect of chemical treatment on both the physical and engineering properties of the three soils, which would in turn provide some insight as to the most suitable method of chemical stabilization.

As a general procedure, physical properties of the raw soil were investigated using the tests for Atterberg limits. The optimum sodium chloride percentage was determined by the compaction test. After a series of unconfined compression strength tests on the Buffalo soil and salt mixtures, it was determined that a single additive in the form of sodium chloride would not noticeably improve the strength, but instead a cohesive binder should be considered. The optimum clay content was established through a combination of Atterberg limit and compaction tests. Strength gain was then evaluated using first the unconfined compression test and then the California Bearing Ratio (CBR) test.

Atterberg Limits and Indices

Liquid limit tests were conducted in accordance with ASTM-D-423-66; plastic limit test and determination of plasticity indices complied with ASTM-D-424-59(65) (Ref 8).

The -40 fraction of all three soils was found to be nonplastic. Limit tests were then conducted on the -200 fraction of the three soils for an indication of the plasticity of the fines. Buffalo 1 had a plasticity index of 10.4 while Buffalo 2 and 3 were comparatively lower, being 3.1 and 1.0 respectively, as shown in Table 4.1.

TABLE 4.1

ATTERBERG LIMIT DATA ON BUFFALO SOILS PLUS VARIOUS PERCENTAGES OF CLAY BINDER

		Buffalo 1	Buffalo 2	Buffalo 3
0% PRC		NP	NP	NP
0% PRC (-200 Fraction)	Liquid Limit	33.1	22.7	25.3
	Plastic Limit	22.7	24.7	24.3
	Plastic Index	10.4	3.1	1.0
15% PRC		NP	NP	NP
20% PRC	Liquid Limit	NP	23.3	NP
	Plastic Limit		21.7	
	Plastic Index		1.6	
25% PRC	Liquid Limit	17.2	23.5	18.9
	Plastic Limit	12.7	19.3	15.8
	Plastic Index	4.5	4.2	3.1
30% PRC	Liquid Limit	18.8	23.8	21.5
	Plastic Limit	10.6	17.5	16.0
	Plastic Index	8.2	6.3	5.5

Both the limit tests and grain size distribution curves indicated Buffalo 1 had only 9.67% finer than .074mm, the least percentage of fines. However, when comparing only the fractions finer than .074mm for the three soils, Buffalo 1 had the greatest plasticity index and percentage finer than .002mm.

The plasticity index of various Buffalo + PRC mixtures was used to determine the optimum percentage of clay binder. PRC was added to the -40 fraction of Buffalo soil in 5% increments based on dry weight of the Buffalo soil. Results are shown in Table 4.1. The 5%, 10%, and 15% mixtures were nonplastic; however, Buffalo 2 + 20% PRC had very low plasticity. All three soil mixtures were plastic at the 25% level, and Buffalo 1 + 30% PRC had a PI of 8.2.

Soil mixtures containing 25% PRC and 30% PRC were selected for further study, on the criteria of adding the maximum amount of binder, but not exceeding a PI of 6.

Linear Shrinkage

Linear shrinkage tests were conducted in accordance with a procedure developed by the Texas Highway Department (Ref 9). This procedure involved mixing the soil with sufficient water to exceed the liquid limit. The samples were then placed in lubricated bar molds and air dried until a color change occurred; they were then oven dried at 105° C for 24 hours. The dried soil bars were measured and the linear shrinkage taken as a percentage of the original wet sample length. Two samples were prepared and the results averaged.

Table 4.2 lists the linear shrinkage values of the various soil fractions and mixtures. The linear shrinkage test again confirmed that the minus 200 fraction of Buffalo 1 contains more plastic material than either of the other two soils. The addition of 25% PRC caused the linear shrinkage to double, but the values were still small when compared with that of PRC (17%) as reported by Marks (Ref 2). The addition of 1% salt to the Buffalo PRC mixture reduced the shrinkage by only a very slight amount. Buffalo 2 + 25% exhibited the greatest linear shrinkage of 5.8%;

adding 1% salt reduced this value to 4.6% where linear shrinkage of the raw soil was 2.1%. Marks found PRC to have a linear shrinkage of 17%; the addition of 6% salt reduced the linear shrinkage to 15%; the addition of 6% salt and 4% lime reduced the linear shrinkage to 9%.

TABLE 4.2

LINEAR SHRINKAGE RESULTS FOR BUFFALO SOILS

Soil Condition	Buffalo 1	Buffalo 2	Buffalo 3
Raw (-40)	0	2.1%	1.3%
Raw (-200)	5.8	3.3	4.0
Buffalo + 25% PRC (-40)	3.4	5.8	3.9
Buffalo + 25% PRC + 1% Salt(-40)	3.3	4.6	2.8

Compaction Properties

Standard Proctor moisture-density curves were developed using the modified Harvard miniature test previously described.

Basically, two series of compaction tests were conducted to select soil-salt and soil-binder-salt mixtures which would provide maximum strength. The optimum salt content was taken as that percentage providing maximum dry density and minimum optimum moisture content.

It was first desired to investigate the effect of salt on the engineering properties of the Buffalo soil. One percent salt was the optimum for all three soils. However, the salt gave relatively little increase in dry density. The maximum compacted dry density of Buffalo 3 was increased from 115.6 pcf to 117.8 pcf. Dry density of Buffalo 1 was increased only 1 pcf to a value of 116.0 pcf, while the density of Buffalo 2 remained constant at 108.0 pcf for the various salt percentages.

After the completion of the first series of compaction tests and unconfined compression tests (to be discussed in a later section) the effect of a clay binder was then investigated. Mixtures of 25% PRC and 30% PRC were selected for the study, based on Atterberg limit tests. Since it was desired to select one mixture which would be most suitable for all three soils, this series of tests was accomplished on Buffalo 2 and 3, extrapolating results to Buffalo 1. All three soils behaved quite similarly with Buffalo 3 data usually representing the mean behavior and properties of the three soils. The results were again plotted with maximum density and optimum moisture versus salt content. The maximum density-optimum moisture-percent salt curves are shown in Figs 4.1, 4.2, and 4.3. For Buffalo 3 the 25% PRC mixture definitely had greater densities than 0% and 30% PRC; while the moisture contents were less than the 30% but greater than the 0% PRC mixtures. Maximum density for 25% PRC was at 0.5% to 1.0% salt with minimum optimum moisture at 1% salt; therefore, the optimum mixture was taken as 25% PRC and 1% salt. Buffalo 2 behaved differently in that the 30% PRC + 1% salt mixture was .5 pcf more dense than the 25% mix at the same salt content. Since 30% PRC provided no significant benefit for Buffalo 2 and the density for Buffalo 3 + 25% PRC was noticeably higher than 30% PRC, 25% PRC and 1% salt was selected as the optimum moisture for all Buffalo soils.

Another series of compaction tests was used to further investigate soil mixture properties. The maximum density and optimum moisture curves for these tests are shown in Figs 4.4, 4.5, and 4.6. Figure 4.4 shows the effect of varying clay percentages with no chemical additives. The 13% PRC mixture had a dry density of 110.7 pcf, which was significantly greater than that of the other mixtures.

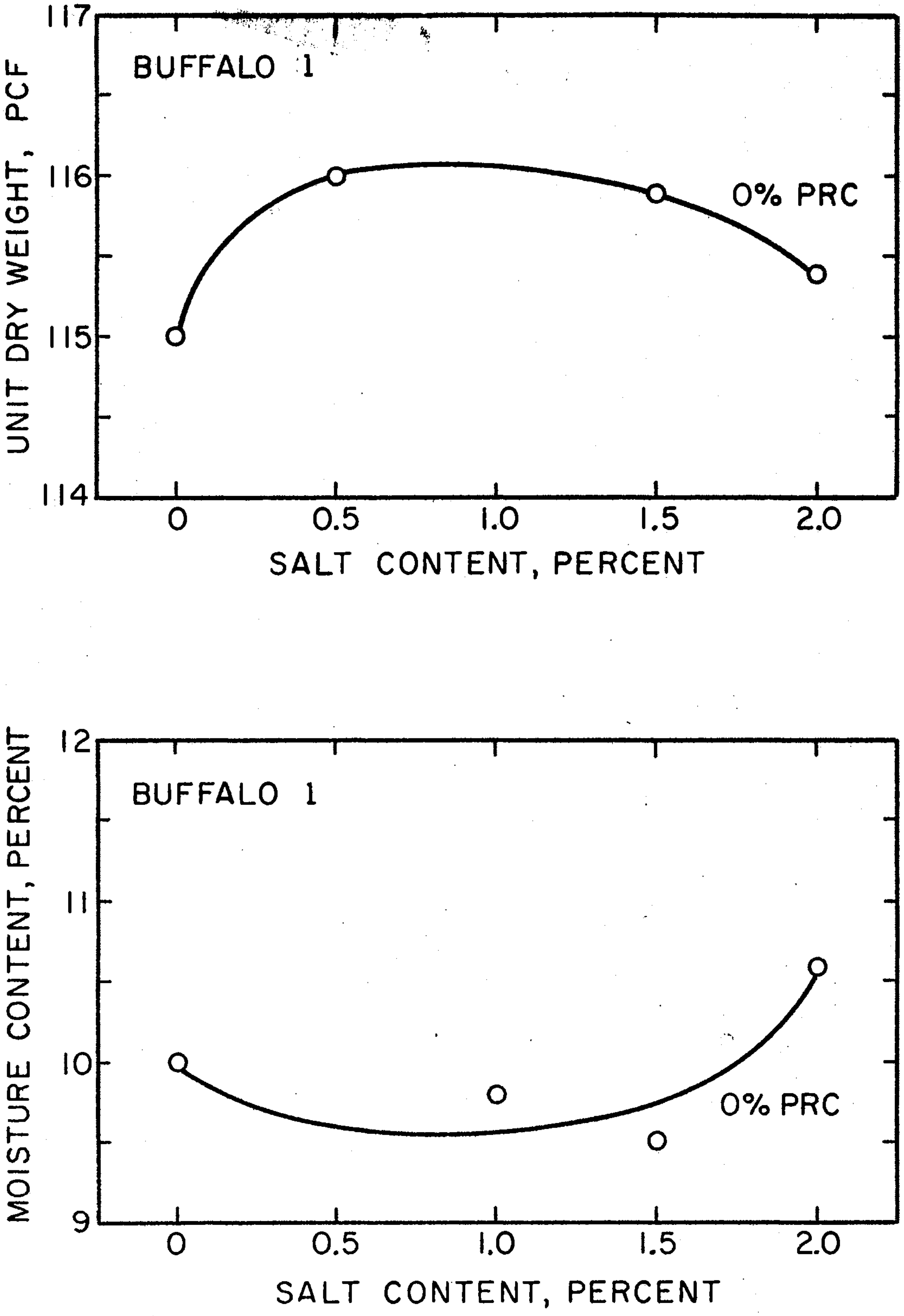
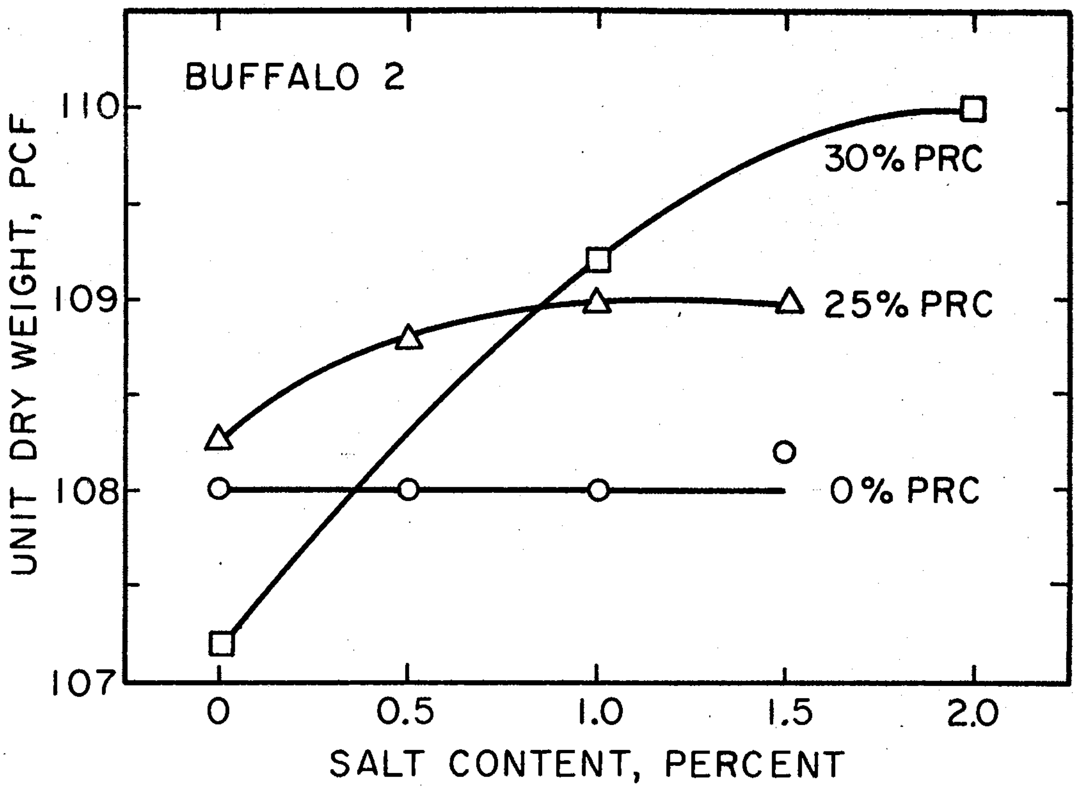


Figure 4.1. Effect of Salt Treatment on Maximum Dry Density and Optimum Moisture of Buffalo 1.



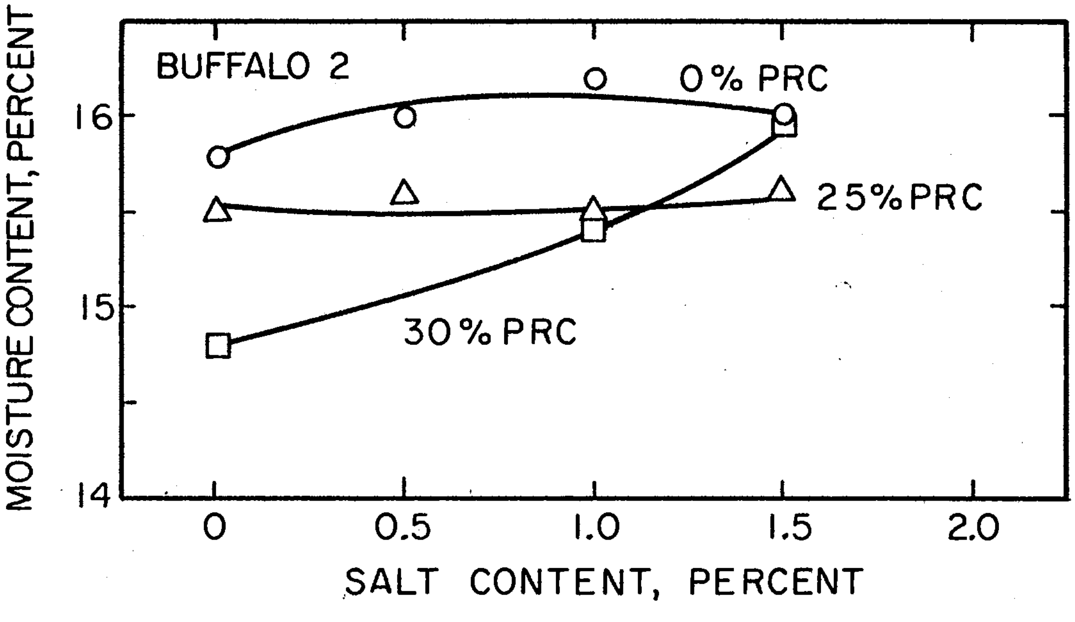
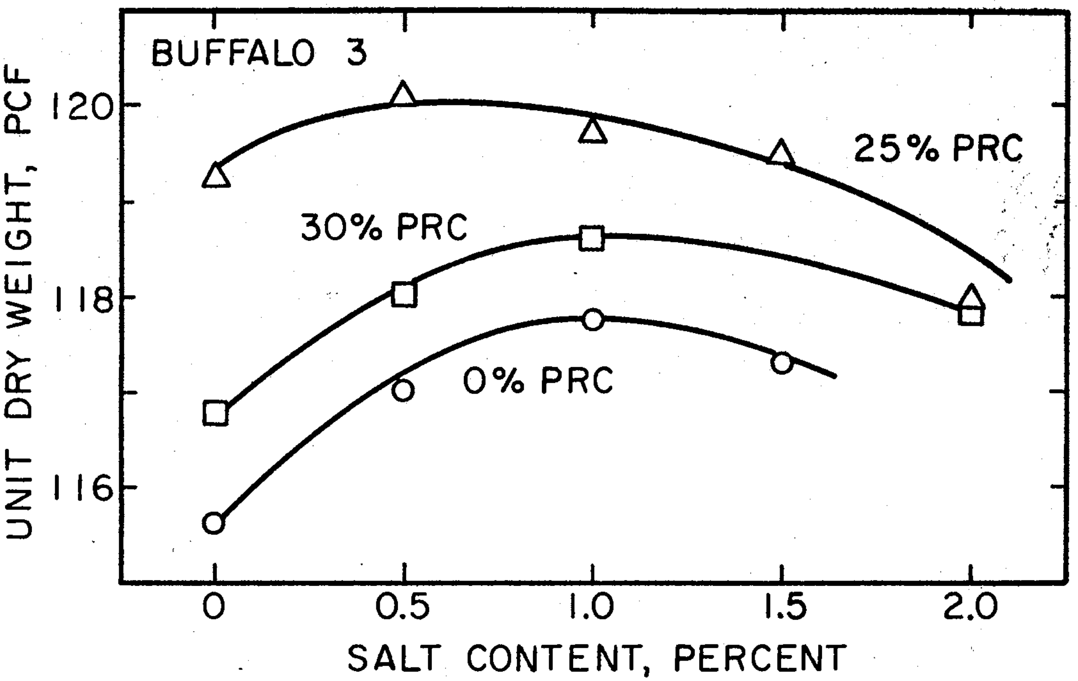


Figure 4.2. Effect of Salt Treatment on Maximum Dry Density and Optimum Moisture of Buffalo 2 and Buffalo 2 + PRC.



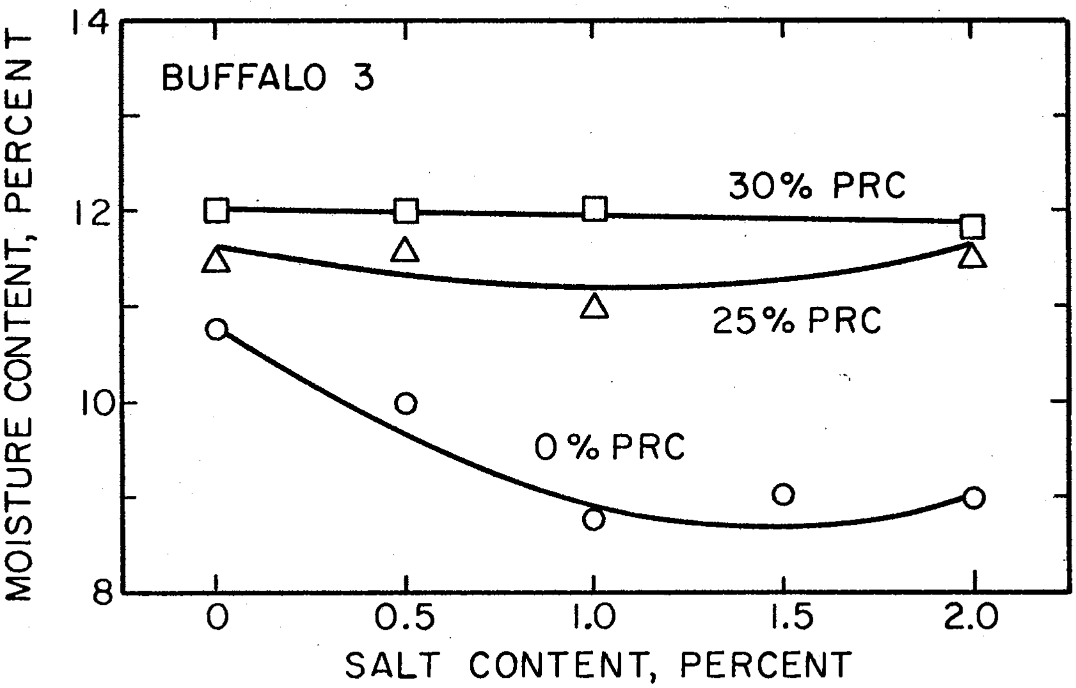


Figure 4.3. Effect of Salt Treatment on Maximum Dry Density and Optimum Moisture of Buffalo 3 and Buffalo 3 + PRC.

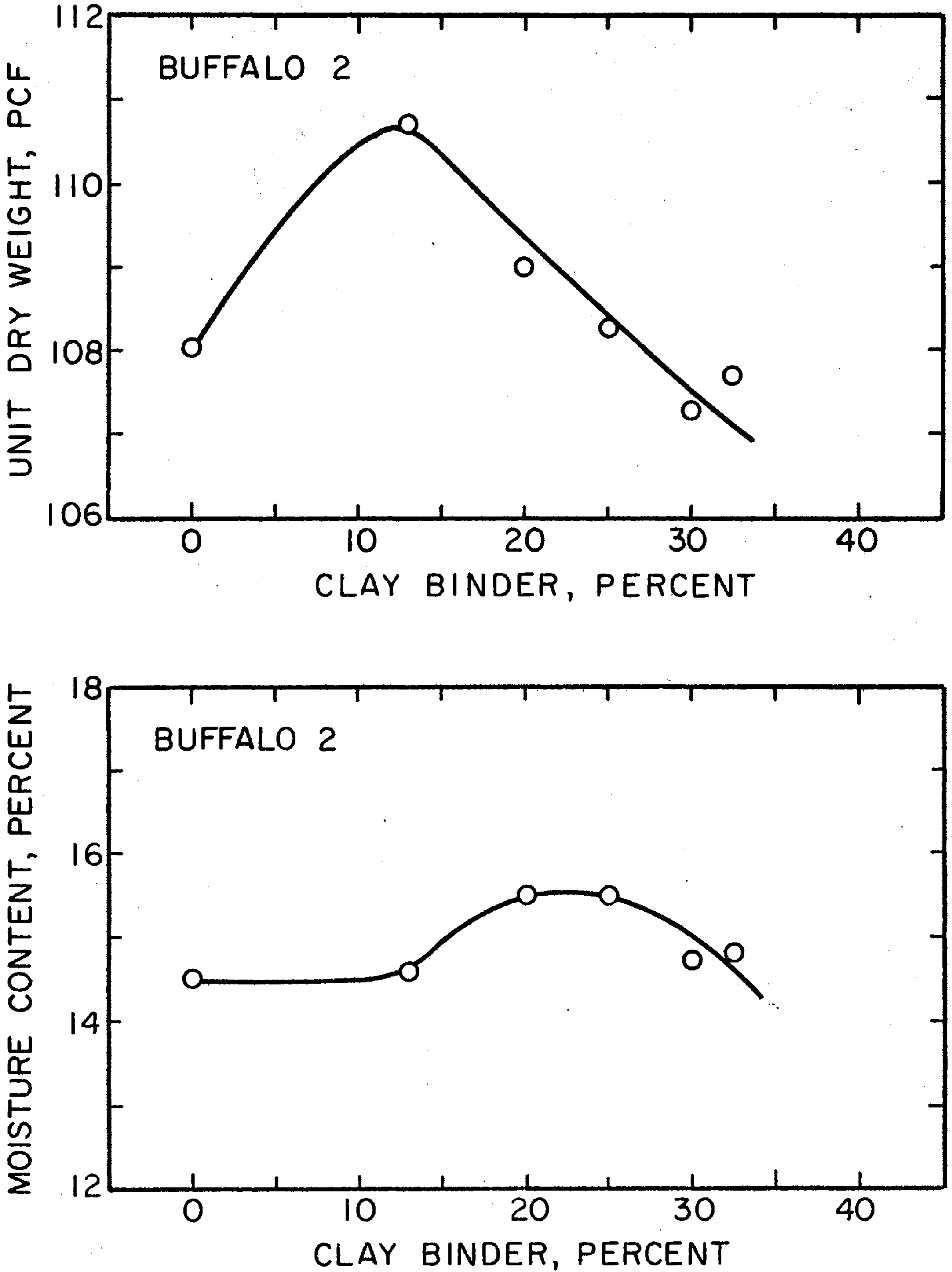
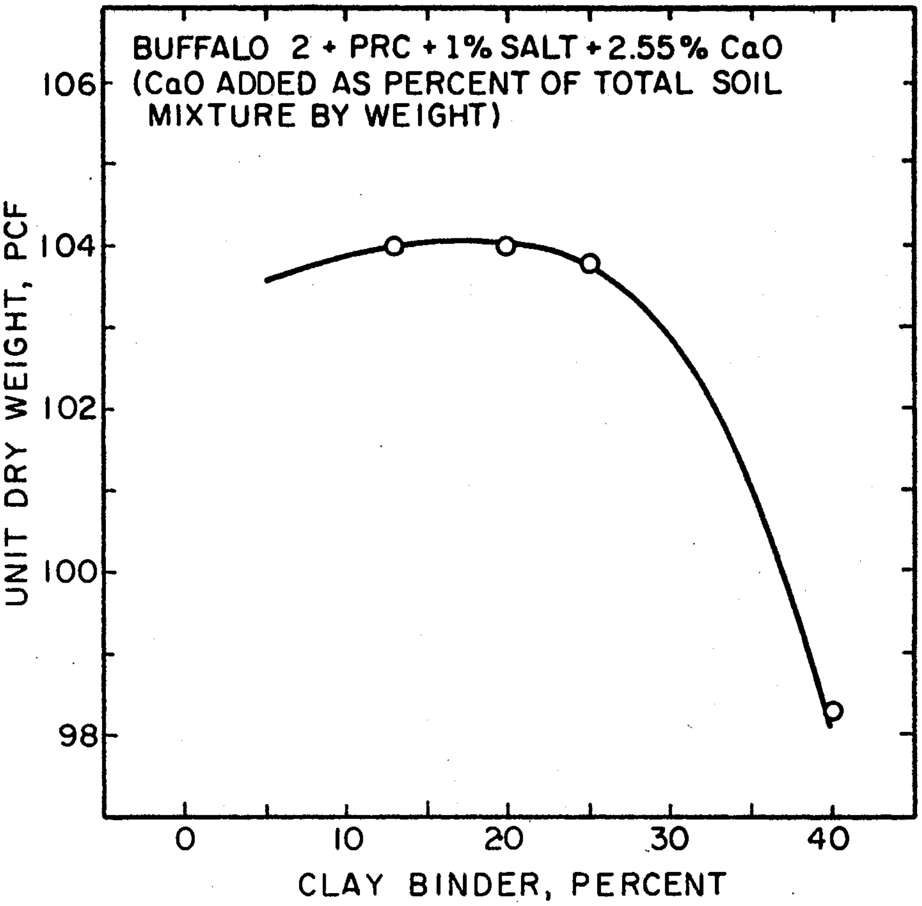


Figure 4.4. Effect of Clay Binder on Maximum Dry Density and Optimum Moisture of Buffalo 2.



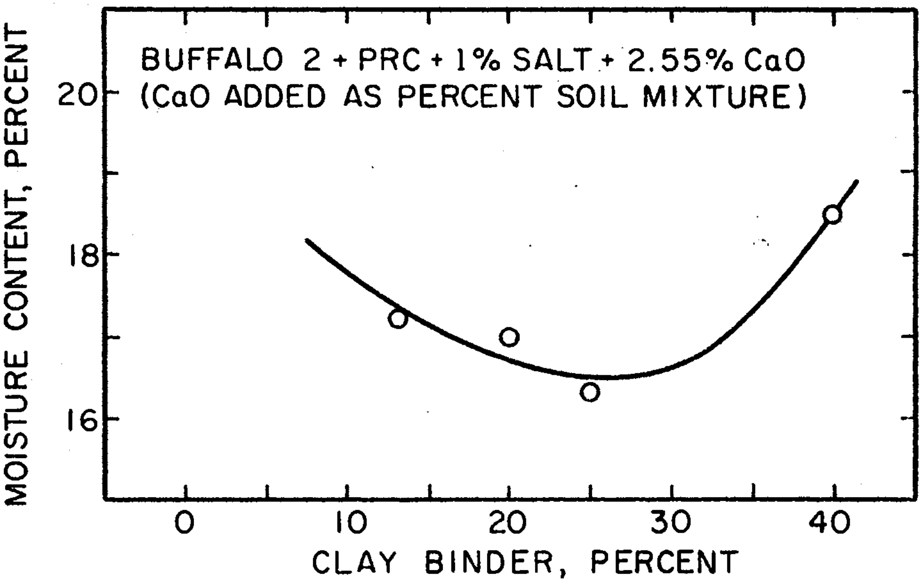


Figure 4.5. Effect of Clay Binder on Maximum Dry Density and Optimum Moisture of Buffalo 2 + 1% Salt + 2.55% CaO Mixture.

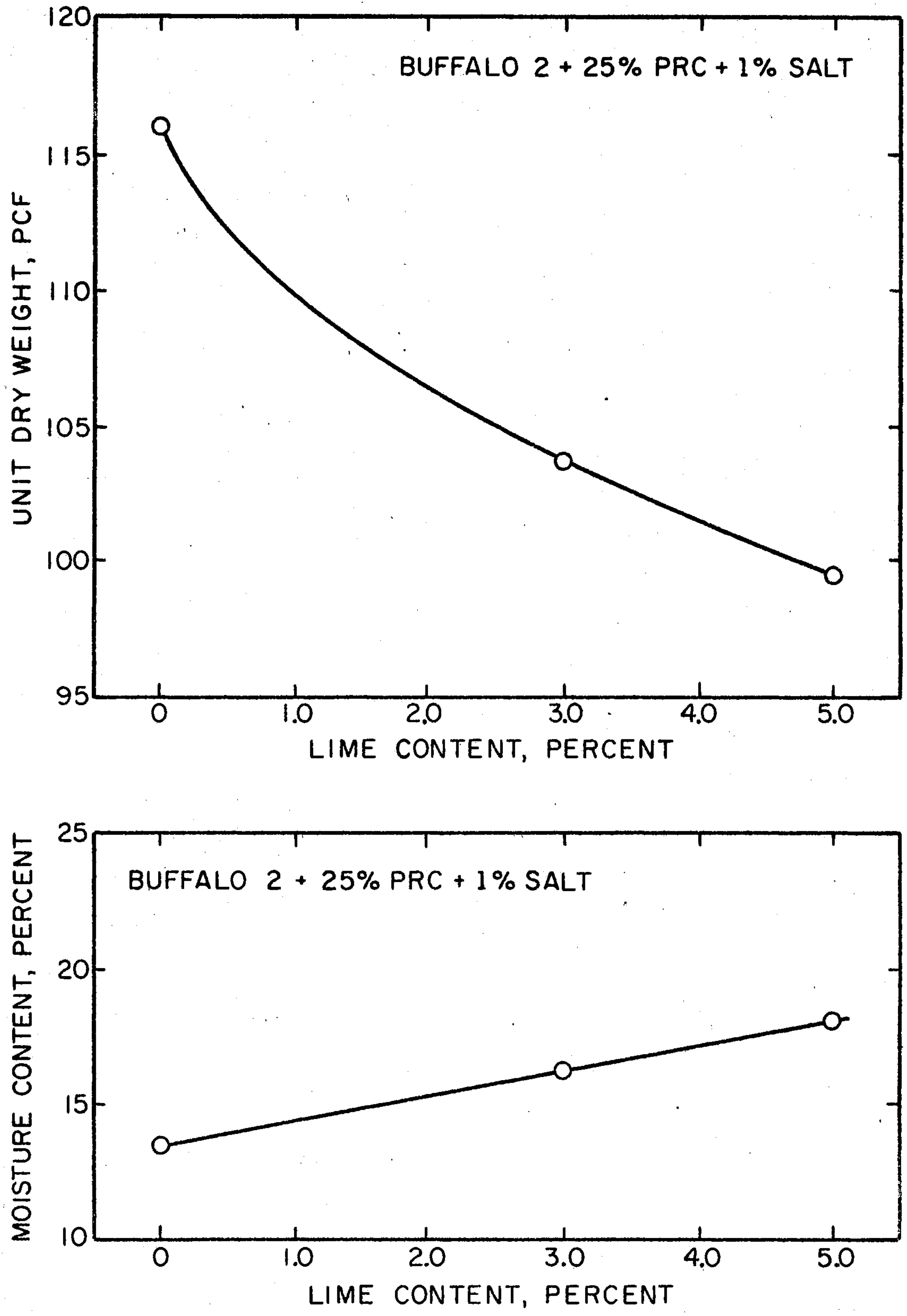


Figure 4.6. Effect of Lime Treatment on Maximum Dry Density and Optimum Moisture of Buffalo 2 + 25% PRC + 1% Salt Mixture.

Figure 4.5 shows the effect of varying clay percentage on a mixture of Buffalo 2 + 1% salt plus 2.55% CaO. The lime percentage in this case was based on the total dry weight of Buffalo 2 and PRC. In this case the 13%, 20%, and 25% PRC mixtures had approximately the same densities; however, the optimum moisture content of the 25% mix was lowest.

Figure 4.6 shows the effect of varying lime percentages for a soil mixture of Buffalo 2 + 25% PRC + 1% Salt, lime percentages being based on dry weight of Buffalo soil. As was expected, the maximum compacted density decreased and the optimum moisture content increased with increasing lime percentages.

Lime Stabilization of Buffalo Soils

The lime stabilization optimum was obtained through use of the pH test suggested by Eades and Grim (Ref 10). The pH versus percent lime curves for Buffalo 1 and Buffalo 1 + 25% PRC are shown in Fig 4.7. Curves for Buffalo 2 and 3 were quite similar. Stabilization optimum was taken as 2% lime for raw Buffalo soil and 3% lime for Buffalo + 25% PRC and Buffalo + 30% PRC.

Unconfined Compressive Strength

Samples were prepared for unconfined compression testing using the standard procedure previously described. All samples were compacted at optimum moisture to the maximum density as determined from previous compaction tests. The specimens were compacted using the Harvard miniature mold and 0.825 pound impact hammer. After compaction the samples were wrapped in plastic wrap and sealed with a thin wax coating to prevent moisture gain or loss during the curing period. The test samples were

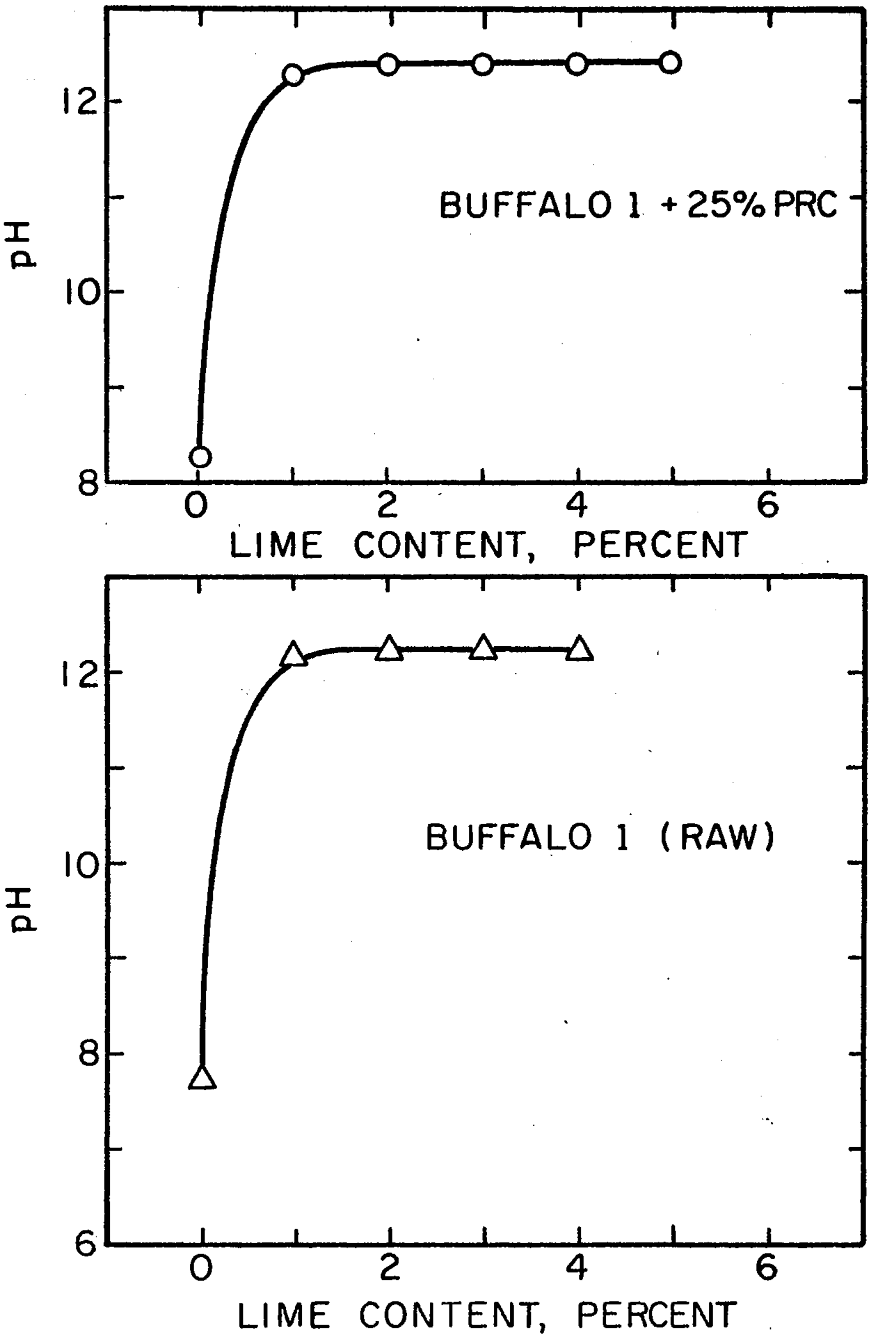


Figure 4.7. Results of pH Test for Determination of Lime Stabilization Optima for Buffalo 1 and Buffalo 1 + 25% PRC.

allowed to cure in a moist room at 75° F and 100% relative humidity. The samples were removed from the moist room after the desired curing period and loaded in the unconfined compression machine at a rate of 0.02 inches per minute or approximately 5% strain developed in 10 minutes. The average compressive strength was obtained by testing three samples.

Unconfined compression tests were first conducted on the raw Buffalo soil and Buffalo + salt mixtures. In addition to those samples cured in the moist room, samples were left unwrapped and placed on a shelf in the laboratory to air-dry and cure at room conditions. The air-dried samples exhibited a very high dry strength, ranging from 70.5 psi for Buffalo 3 + 2% Salt to 209 psi for Buffalo 2 + 0% Salt. The 0.5% salt mixtures for Buffalo 1 and 3 had much higher compressive strengths than the other mixtures of the same soil, while the dry strength of Buffalo 2 was considerably reduced by adding salt. The time strength curves are shown in Figs 4.8, 4.9, and 4.10. The moist cure samples had very low compressive strengths and again showed very little strength increase with time. The samples ranged in strength from 1 psi to 9 psi, with the .5% salt mixtures showing the highest strengths. The various strength-time data for these moist cure samples are shown in Fig 4.11.

A pilot study was conducted using a rapid cure time of 72 hours at 105° F and 95% relative humidity to provide information regarding relative strength gain of various mixtures. The pilot study results are listed in Table 4.3. Buffalo 3 raw and Buffalo 3 + 0.5% Salt had approximately the same strength, also Buffalo 3 + 25% PRC showed a slightly higher strength than Buffalo 3 + 25% PRC + 1% Salt. Part of the difference in strength was attributed to the fact that the three samples of

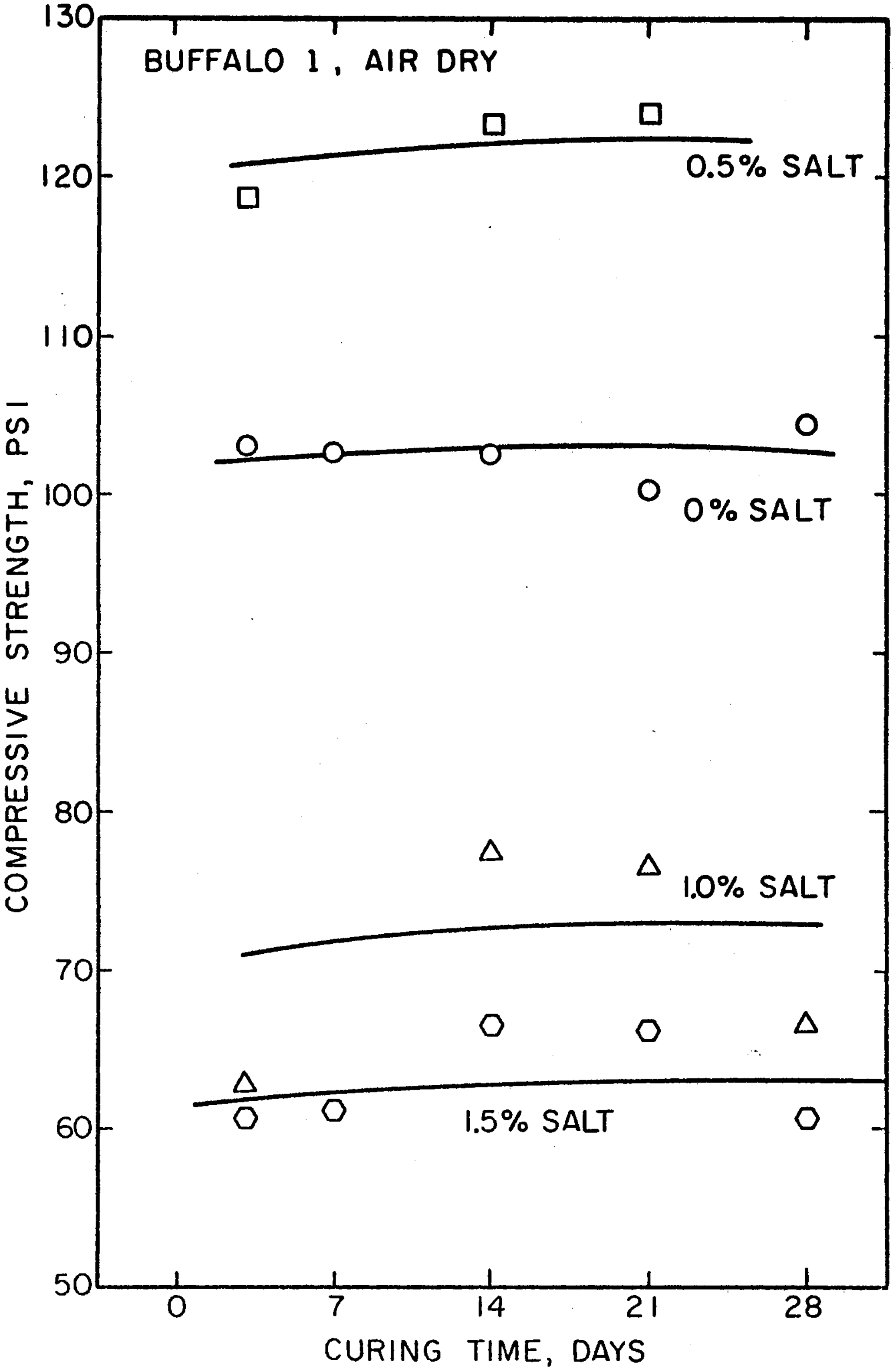


Figure 4.8. Effect of Salt Treatment on Unconfined Compressive Strength of Air-Dried Samples of Buffalo 1.

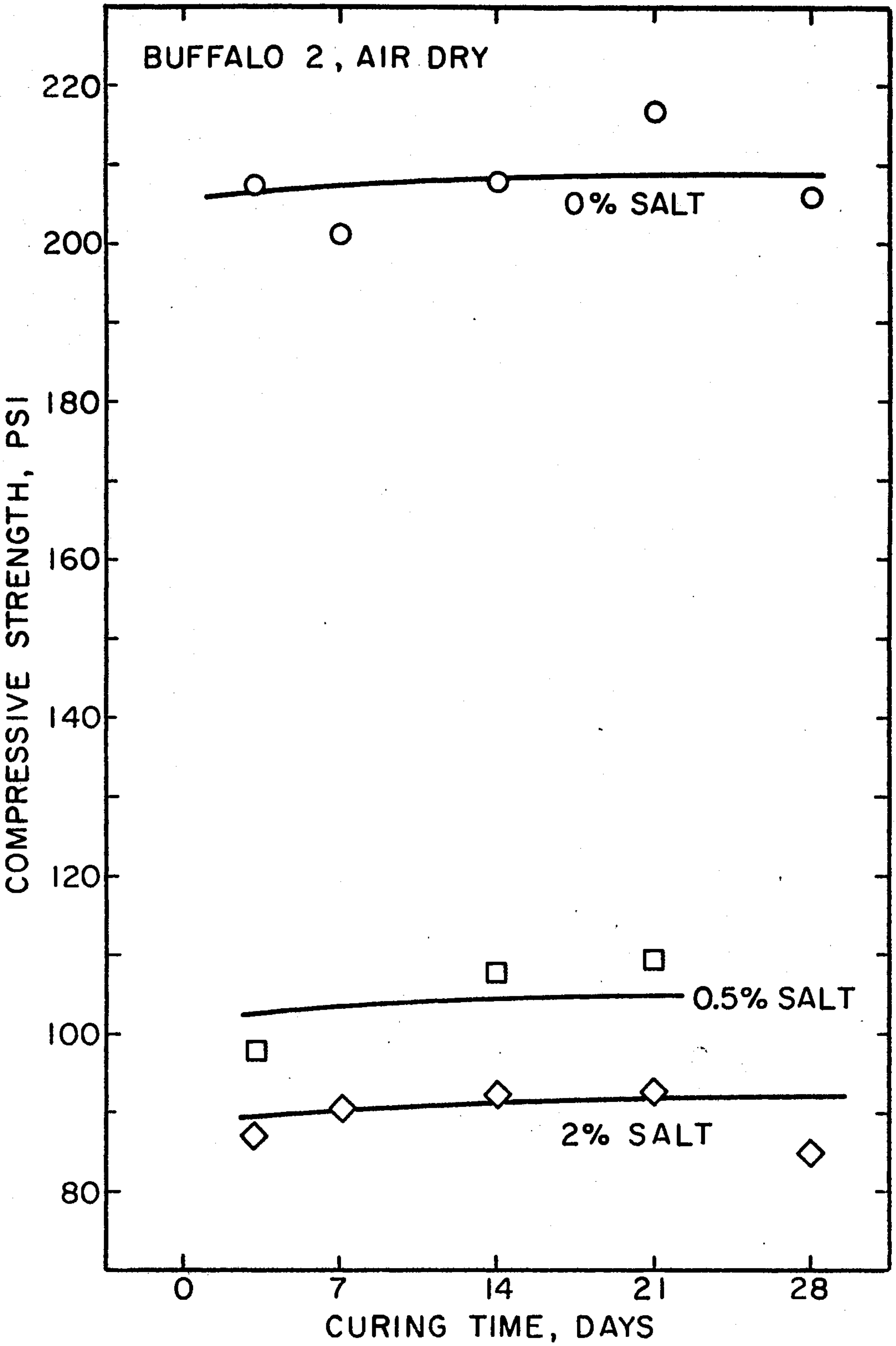


Figure 4.9. Effect of Salt Treatment on Unconfined Compressive Strength of Air-Dried Samples of Buffalo 2.

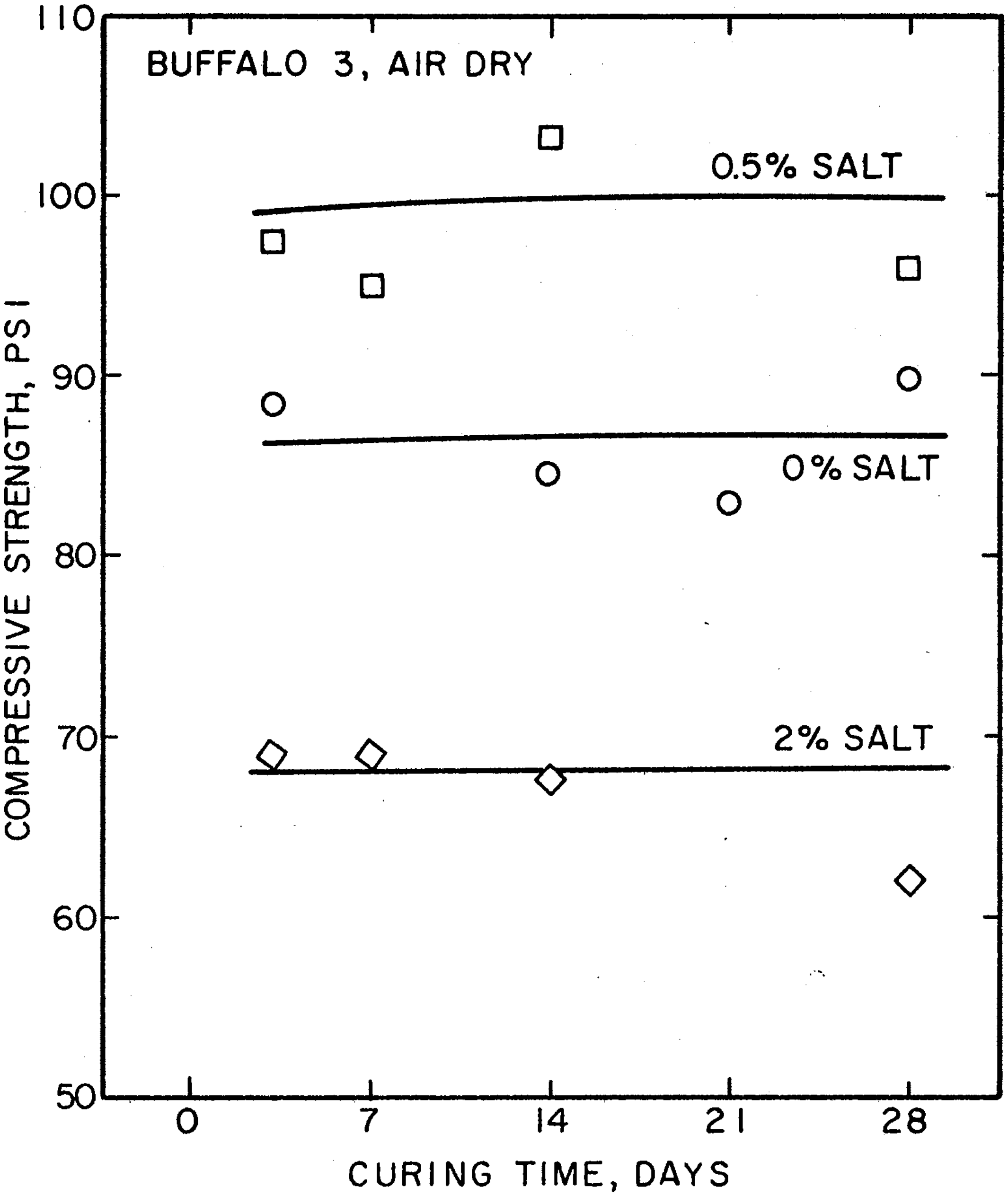


Figure 4.10. Effect of Salt Treatment on Unconfined Compressive Strength of Air-Dried Samples of Buffalo 3.

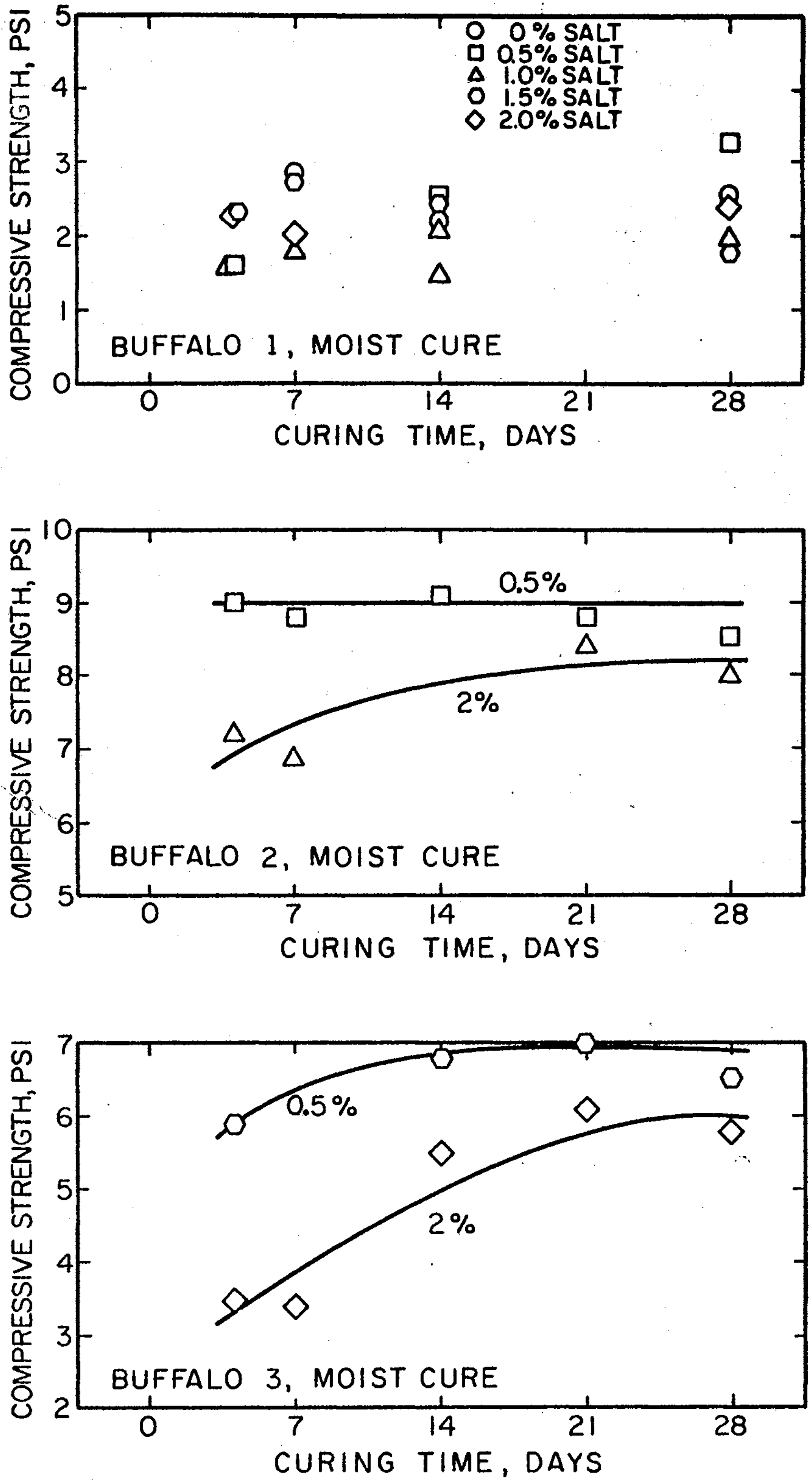


Figure 4.11. Effect of Salt Treatment on Unconfined Compressive Strength of Moist Cured Samples of Buffalo 1, 2, and 3.

Buffalo 3 + 25% PRC + 1% Salt were accidentally compacted slightly wet of optimum. The addition of salt and lime provided some strength increase for the raw Buffalo 3; however, the strength was still insufficient for use as base course material. Although salt alone provided no strength gain, Buffalo 3 + 25% PRC + 1% Salt + 3% CaO had significantly higher strength than the Buffalo 3 + 25% PRC + 3% Lime mixture.

TABLE 4.3

UNCONFINED COMPRESSIVE STRENGTH RESULTS FOR

BUFFALO 3 PILOT STUDY

Soil Mixture	Unconfined Compressive Strength (PSI)
Buffalo 3	6.1
Buffalo 3 + 0.5% Salt	5.7
Buffalo 3 + 25% PRC	18.1
Buffalo 3 + 25% PRC + 1% Salt	16.1
Buffalo 3 + 1% Salt + 2% CaO	31.7
Buffalo 3 + 25% PRC + 3% CaO	59.7
Buffalo 3 + 25% PRC + 3% CaO + 1% Salt	82.8

Although the purpose of this study was to find an alternate to cement stabilization, a series of Buffalo soil plus 5% cement samples were compacted to provide a basis for strength comparison with the salt-lime stabilized samples. The samples were compacted at the optimum moisture for the raw soil and cured for 24 hours in a humid curing jar prior to wrapping and sealing. The samples were then stored in the moist room and tested at 3 days, 7 days, and 28 days; the test results are shown in Fig 4.12, and all 28-day cure samples easily satisfy the 100 psi base material criteria of McDowell (Ref 6).

Since unconfined compressive strengths of 100 psi were desired, it

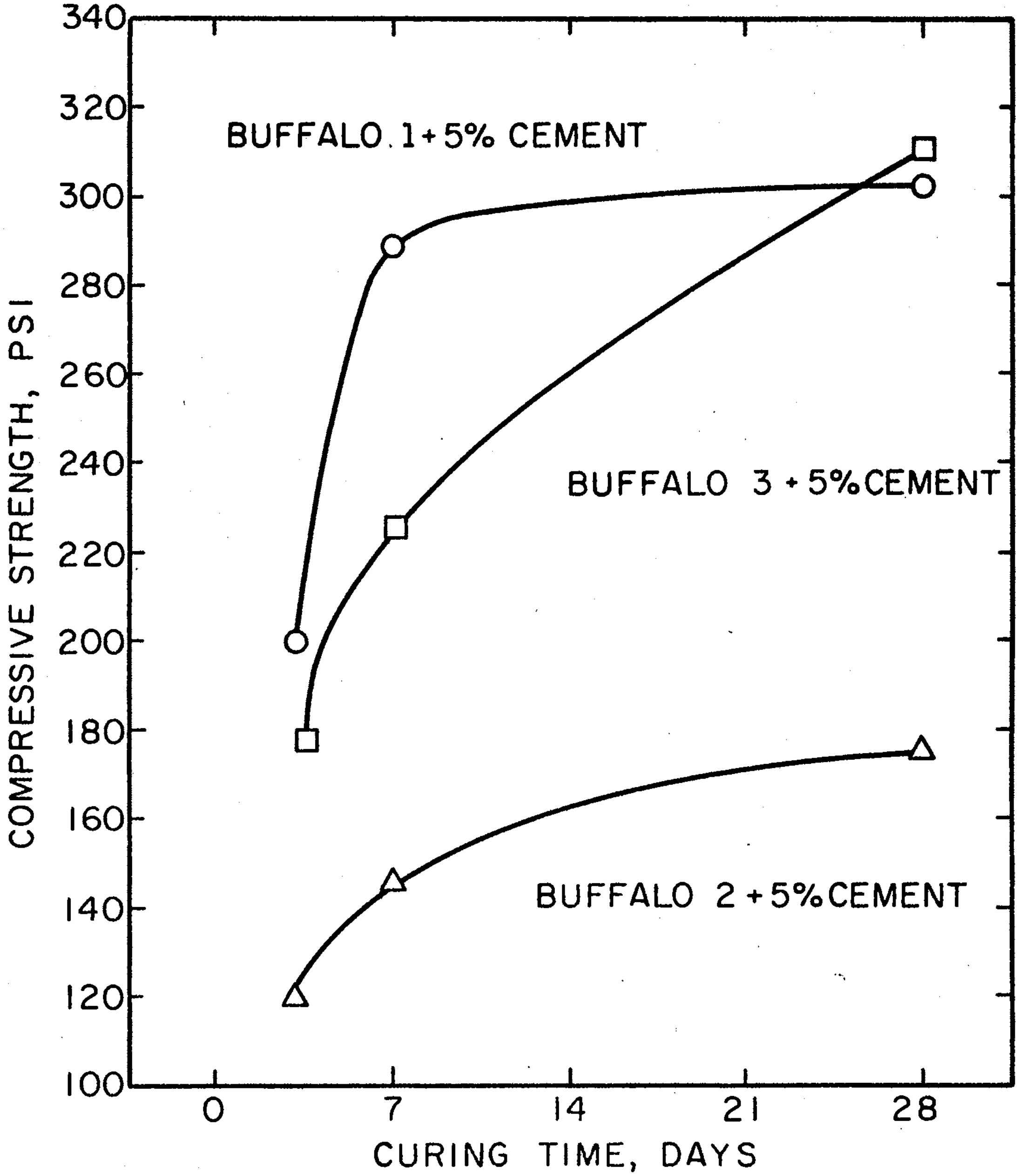


Figure 4.12. Effect of 5% Cement on Unconfined Compressive Strength of Buffalo 1, 2, and 3.

was concluded that salt-lime treatment on raw soil alone would be insufficient. The balance of the testing was then directed towards selecting the proper percentage of clay binder and evaluating the effects of chemical treatment.

Marks and Haliburton (Ref 2) found that the compressive strength of PRC lime mixtures was greatly increased by the addition of small percentages of sodium chloride. Also, as previously mentioned, the raw Buffalo soil was affected very little by salt-lime treatment. It was, therefore, concluded that any strength increase would come from the salt-lime reaction with the clay binder and that salt should be used in addition to lime for maximum strength. Samples of each of the three Buffalo soils + 25% PRC + 1% salt and 1% salt + 3% lime were prepared for testing, the results of which are shown in Fig 4.13. As was expected, the 1% salt samples showed little or no strength gain, while the 3% lime + 1% salt samples exhibited strength gain. The 28-day strengths of the salt-lime mixtures ranged from 49 psi for Buffalo 1 + 25% PRC + 1% Salt + 3% Lime to 71 psi for Buffalo 3 + 25% PRC + 1% Salt + 3% CaO.

Miller and Sowers (Ref 5) indicated the optimum percent of clay binder (for strength purposes) should be based on the volume of voids of the compacted soil. Shen and Li (Ref 4) further suggest that the ratio of fines to percent lime is the controlling factor for optimum sand, clay, and lime mixtures. To confirm that 25% clay binder and 3% lime were optimum values, a series of tests on varying PRC and lime percentages were conducted.

Compaction test results (Fig 4.4) and computations of the volume of air voids indicated the optimum mix would be 13% PRC; however, the 28-day strength of the Buffalo 3 + 13% PRC + 3% CaO + 1% Salt was definitely

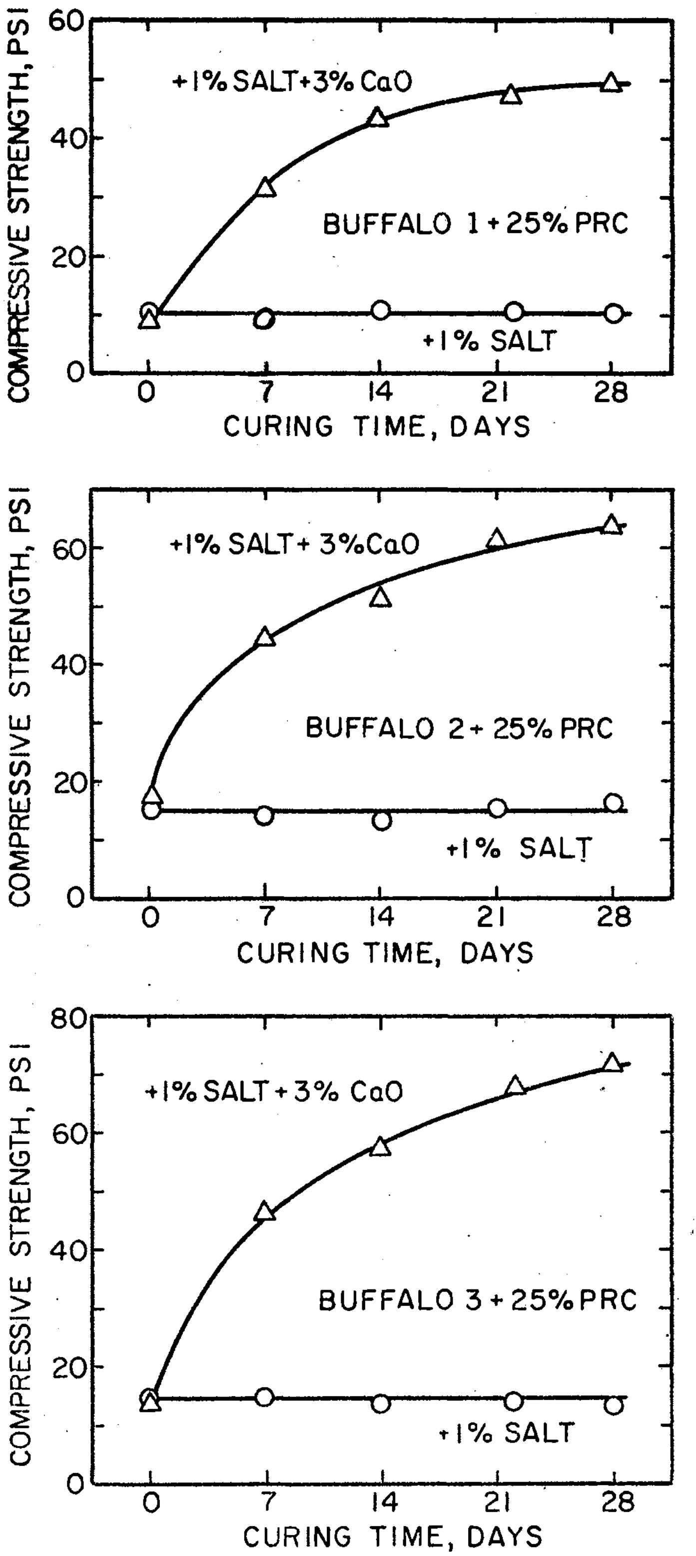


Figure 4.13. Effect of Salt and Salt Lime Stabilization on the Unconfined Compressive Strength of Buffalo + 25% PRC Mixtures

lower than that of the Buffalo 2 + 25% PRC + 1% Salt + 3% CaO mixture. The mixture of Buffalo 2 + 20% PRC + 3% CaO + 1% Salt was higher in strength than the 13% mixture, but lower than the other mixtures. The next highest strength mixture was Buffalo 2 + 25% PRC + 5% CaO + 1% Salt. The four remaining samples, Buffalo 2 + 25% PRC + 1% Salt, + 3% CaO, Buffalo 2 + 32.5% PRC + 3% CaO + 1% Salt, Buffalo 2 + 40% PRC + 3.5% CaO + 1% Salt, and Buffalo 2 + 60% PRC + 1% Salt + 8% CaO had approximately the same strengths for all practical purposes, ranging from 63 psi to 67 psi, the highest being the 60% PRC + 8% CaO mixture and the lowest being 40% PRC + 3.5% CaO. The conclusion of this brief study was that a minimum of 25% PRC was required for the optimum mixture and little or no practical increase in unconfined compressive strength could be derived from increasing clay and/or lime percentages. For the samples tested and strengths obtained, no deduction could be made regarding the optimum ratio of percent fines to percent CaO.

California Bearing Ratio Testing

The California Bearing Ratio (CBR) for the various soil mixtures was determined using the Oklahoma State University Harvard miniature CBR test. The soil was mixed using the standard mixing procedure, then six samples were compacted using the 0.825 pound hammer and Harvard molds previously described. A spacing block was used to extrude one inch of the sample, producing a 1.3125 inch diameter and 1.8125 inch high sample. At this point the unsoaked CBR was determined on half the specimens while three samples were placed in a soaking tank for four days (96 hours). A swell plate and weight of 172 grams were used to place a surcharge on the sample. A dial gage was also attached to measure swell during the soaking period. After the soaking period, the samples were drained 15 minutes and then tested using a center drilled surcharge weight and miniature CBR piston of .438 inch diameter. The load was applied at a rate of .05 in/minute with load values recorded in increments of 0.025 inches from 0 to .35 inches of penetration. The load-deformation curve was plotted and offset corrected as required. The sample CBR was taken as the average of the corrected value at .1 and .2 inches penetration. Scale-down ratio was 20:1, thus the standard load at .1 inch penetration was 150 lb and at .2 inches penetration was 225 lb. The average CBR of the three samples was recorded as the CBR of a particular mixture and moisture condition. In those cases where chemical additives were used, the specimens were left in the mold, wrapped, sealed, and rapid cured for 30 hours at 105° F and 95% relative humidity, which is believed to approximate the 28-day strength. After curing, both unsoaked and soaked CBR tests were run.

Test results are shown in Table 4.4. In all cases the salt-lime treated Buffalo PRC mixtures exhibited the highest CBR while the next highest was the raw soil. The lowest soaked CBR for each soil was Buffalo 1 + PRC + Salt, Buffalo 2 + PRC, and Buffalo 3 + PRC. Although sodium-chloride provided increased unconfined compressive strength it showed no significant CBR improvement. Negligible volume change occurred in all the samples. *On the basis of the soaked CBR, the raw soil would be suitable as a subbase while the salt-lime treated soil would be considered suitable as a base course, complying with recommendations of the Asphalt Institute (Ref 7).*

TABLE 4.4

CALIFORNIA BEARING RATIOS FOR BUFFALO SOILS AND VARIOUS SOIL MIXTURES

Soil Mixture	Soaked CBR	Unsoaked CBR	% Swell
BUFFALO 1			
+ 25% PRC + 1% Salt	11.2	15.2	+.055
+ 25% PRC	13.4	22.6	-.073
Raw	31.2	45.1	-.165
+ 25% PRC + 1% Salt + 3% CaO	88.6	78.5	0
BUFFALO 2			
+ 25% PRC	6.4	39.0	+.88
+ 13% PRC	11.3	32.3	+.44
+ 25% PRC + 1% Salt	11.8	32.2	+.22
Raw	24.0	49.9	+.44
+ 25% PRC + 3% CaO	84.5	88.1	+.02
+ 25% PRC + 1% CaO	90.0	87.5	-.18
BUFFALO 3			
+ 25% PRC	13.7	34.0	0
+ 25% PRC + 1% Salt	18.3	31.3	+.037
Raw	20.0	26.7	-.22
+ 25% PRC + 1% Salt + 3% CaO	126.0	125.0	0

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

Conclusions

The following conclusions are based directly on the analysis of collected data from the various soil tests performed on the three Buffalo soils:

1. Salt as a single additive to a cohesionless soil will provide an increase in the compacted dry density, but negligible strength increase.
2. The cohesionless soils had a high dry strength at low salt percentages. However, after rewetting all strength was lost.
3. The addition of a clay binder will substantially increase the unconfined compressive strength of cohesionless soils. However, the CBR value is equally reduced.
4. Salt provided negligible strength increase for all the Buffalo soil/clay binder mixtures, and in some cases, i.e., the CBR values for Buffalo 1 + PRC, the strength was reduced by adding salt.
5. Salt used in conjunction with lime treatment provides a higher unconfined compressive strength than the use of lime as a single additive; however, little improvement was observed in the CBR value.
6. The cohesionless Buffalo soil has a very low pozzolanic reaction potential, and therefore large strength increases resulting from lime treatment should not be expected.

7. When used in conjunction with a clay binder, salt-lime admixtures will suitably stabilize cohesionless soils, providing a significant increase in both the unconfined compressive strength and the CBR value.
8. The four day soak period significantly reduces the CBR value, except for lime treated soils which have slightly higher CBR values after soaking. The reduction was more noticeable in the clay binder mixtures than in the raw cohesionless soils.
9. An optimum percentage of clay binder may be established by use of the plasticity index; selecting a mix with a PI between 2 and 6. For the soils within the scope of this study the percentage of binder providing the greatest dry density prior to the addition of chemicals will not necessarily produce the highest strength after chemical stabilization.
10. Since freeze-thaw conditions are not a hazard to Oklahoma highway subgrades, the criteria established by McDowell (Ref 6) may be applied. The mixture of Buffalo soil + 25% PRC + 1% Salt + 3% CaO would qualify as an excellent subbase material, but fall short of the 100 psi unconfined compressive strength required for base material.
11. Using the criteria suggested by the Asphalt Institute (Ref 7) and based on the soaked CBR value, the raw Buffalo soils would be suitable as subbase material. The mixtures of Buffalo soil + 25% PRC + 1% Salt + 3% CaO would be suitable for use as base material.

Evaluation and Final Conclusion

The CBR test rather than the unconfined compressive test better describes and evaluates the strength properties of the Buffalo soils and soil mixtures since they are basically granular and have little cohesion, even with the addition of 25% PRC binder. It is thus concluded that the mixtures of Buffalo soil + 25% PRC + 1% Salt + 3% CaO would be suitable for use as base material.

Recommendations for Further Research

1. A definite need exists for detailed design criteria to evaluate strength of chemically treated soils. Research to indicate which standard test best evaluates the strength of a stabilized soil for design purposes and if a valid correlation can be established between unconfined compressive strength and CBR value would be of great benefit.
2. Further studies on various methods of selecting the optimum percent binder to be used with granular soils in conjunction with chemical additives are also recommended.

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VITA

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