# L I M E S T A B I L I Z A T I O N
# O F S O I L S



B Y

B A Y H A N E R O L

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# PART I

## LITERATURE SURVEY

## INTRODUCTION

Certain types of soil are not suitable for engineering. They either must not be used and replaced by suitable materials, or their engineering properties must be improved to make them suitable.

Until recently the general solution to the problem was removal of the unsuitable material and replacement of it by suitable material. This solution consequently brings up economic considerations. When the bed of suitable material is far away from the construction site the transportation cost amounts to large sums. The second problem which is encountered in this solution is the lack of suitable material. This problem has gained more importance lately as aresult of increased rural population demanding more highways.

The engineer faced with the problem was urged to to find a solution, and he came up with the idea of improving the properties of soil by using additives. So far stabilization of soil with additives has proved to be the best solution

In stabilization of soil, portland cement, lime and several chemical additives have been investigated as stabilizers. Of these, portland cement and lime have proved to produce improvement in engineering properties of soil, and have successfully been used in practice.

Lime stabilization is more favorable for under developed countries because of the fact that lime is readily available and costs much less than portland cement while having almost the same beneficial effects on soil.

This project consists of two parts. In the first part a literature surveyis presented providing information about the history of lime stabilization, mechanisms involved and the beneficial effects of lime addition on soil. Aside from these, the effect of different types and amounts of lime is summarized. A short method of construction of lime stabilized roads is also given.

The second part is a report of the research done to investigate the changes in engineering properties of a typical clay when treated with different percentages of hydrated lime. As the characteristics to be investigated, the unconfined compressive strength and Atterberg limits were chosen. 1, 2, 3, 4, 5, 8% lime by dry weight were mixed with soil.

## HISTORY OF LIME STABILIZATION

### APPLICATIONS

Hydrated lime has been used for stabilization of road construction material for the first time in 1924, in the state of Missouri, U.S. They laid short experimental lengths of road. The result of these experimental sections and other experiments run by Burea of Public Roads in Iowa and Dakota showed that addition of from 3 to 6 % of hydrated lime made earth roads on clay soils more stable.

In spite of the promise shown by these experiments the process was not applied to large scale until the Second World War, when rapid construction of airfields was a necessity. The first large scale application appears at this period both in U.S. and Germany.

The Texas State Highway Department had taken an interest in the method and in 1945 commenced using lime from 3% to 8% on public roads. By 1953 250 miles of lime stabilized roads were constructed in Texas.

In 1954 National Lime Association published a booklet describing methods of evaluating lime soil mixtures in laboratory and construction methods of roads. U.S. Corps of Engineers published specifications for construction of bases for roads using lime alone or together with cement in 1951.

In 1947 Freeborough reported that both gravels and clay can be satisfactorily stabilized with lime.

INFORMATION ON PROPERTIES OF LIME-SOIL MIXTURES

Johnson(1948) and Woods (1949) in laboratory studies found that addition of lime in the order of 5 % by weight reduced plasticity index and increased the strength under similar conditions of pore water pressure of both fine and coarse grained soils. They also stated that calcitic limes were superior to dolomitic limes in these respects.

Galloway and Buchanan (1951) suggested that the effect of lime on soil was due to the exchange of adsorbed ions on clay particles. They found that the reactivity of soil towards hydrated lime increased as plasticity index and ion exchange capacity increased.

Effect of lime addition on swelling was first studied by Goldberg and Rhein (1952). They added 2% to 6% hydrated lime and found that this reduced swelling pressures considerably, and that calcium hyroxide was converted to other compounds. As a result of X-ray diffraction and DTA of mixtures of soil and lime they concluded that the conversion was to calcium carbonate and not to calcium silicate. This was because their samples were air dried which favors carbonation. Their conclusion has been questioned by Lambe.

The question of permanencyof improvement in soil properties brought upon lime stabilization was studied by Whitehurst and Yader (1952). They used freezing-and-thawing tests and found that addition of 2% lime had almost negligible effect on durability but addition of 5% lime increased durability considerably. They also found that durability increased with the age of the mixtures. McDowell in 1953 reported that the cores taken from a seven year old lime stabilized road showed twice the strength found in laboratory at an age of 20 days. Ardamen (1953) as a result of laboratory tests suggested that the maximum durability willbe obtained by compaction to the highest density at low moisture content.

The first experiments in Soviet Union were made by Okhotima in 1926, and he found that the plasticity of Cambrian clay reduced by addition of 5% hydrated lime. The Russian workers have suggested that there was an optimum quantity of lime for satisfactory stabilization, within the range of 5% to 12%. They have also stated that the optimum lime content varies with the texture of the soil. The real criterian which this judgement is based on is unknown.

Tentative specifications have been prepared by Soviet Union for construction of lime stabilized roads (Gushosdor 1951). The resistance of lime stabilized soils is not very high against frost, therefore they are only recomended for certain climatic zones of USSR.

Levchanoyski (1953) stated that the use of unslaked lime was more economical than using slaked lime because calcium hydroxide formed in situ in damp soil is said to have a greater binding capacity due to its colloidal nature. Borosiva (1953) suggested that mechanical strength of soil lime mixtures is due to crystallization and subsequent carbonationof calcium hydroxide, the crystallization resulting from saturation of soil water solution with lime. As a result of drying of the soil crystals of calcium hydroxide were believed to interlock with each other and with soil particles, cementing the

the mixture into a monolithic mass.

Nature of the reaction product responsible for the gain of strength has been a question unanswered for a long time. Hilt and Davidson (1961) have done an X-ray analysis for this purpose. Their work showed that the reaction products, crystals, were detectable at high water contents but undetectable at optimum moisture content of Proctor compaction. They have extracted the crystals and have done physical and chemical analysis on them.

Recent research on lime stabilization is concentrated on the problems of construction and to find a correlation between laboratory results and actual field performances. As yet no dependable correlation has been found between laboratory results and field performance and the gradation problem which is met in construction have not been solved.

## MECHANISM OF LIME STABILIZATION

Mechanism of lime stabilization consists of three reactions. The first reaction, which takes place immediately after lime is added, is replacement of adsorbed ions by calcium ions, the second is formation of a series of new minerals, the third is carbonation of hydrated lime. The second reaction is of pozzolanic character.

### BASE EXCHANGE

Clays are primarily aluminosilicate minerals and as a result they carry a negative charge. If placed between two electrodes of unlike sign they will migrate to the positive pole. The greater the migration velocity, the higher is the negative potential. If this potential is sufficiently great the clay particles will repel each other when they collide during their Brownian motion in the suspention.

On the surface of these negatively charged anions there are positively charged cations. Thus it may be concieved as a negatively charged nucleus surrounded with cations. This electrical arrangment is an electrical double layer. The inner layer is a part ofthe wall of the particle, and negatively charged. The outer layer is of opposite sign and is at a distance of molecular dimensions from the inner layer.

The magnitude of the electrical potential of clay particles will depend upon the number of charges per unit surface and the degree of activity of these charges. Thus, the stability of the clay suspention increases directly with cation exchange capacity of the clay and inversely with which the adsorbed ions are held against the inner layer.

The adsorbed cations are not steady and they exhibit Brownian movements. The amplitude of these oscillations are in the order of the thickness of the electrical double layer which in turn is in the order of molecular dimensions. During these oscillations another ion of the same sign may come in between the anion and the cation and may replace the particular cation.

When a solution of lime comes into contact with clay particles, the divalent positively charged calcium ion tend to occupy the exchange positions of the clay particle. This may be manifested either as a reversible or a complete reaction. The reaction is of the form:

$$AOK_2 + Ca(OH)_2 \rightarrow AOCa + 2KOH$$

$$AOH_2 + Ca(OH)_2 \rightarrow AOCa + 2H_2O$$

Clay particles which are hydrophibic in its real nature may manifest hydrophilic characteristics because of ions attached to them. By replacing some of these cations by calcium, the amount of adsorbed water will be far less, thus the electrical potential of repulsion will diminish and the grains by coming together will form flocculated masses.

Ion crowding serves the same purpose as ion exchange and some investigators think that it is more important than ion exchange. Since certain calcium saturated clays could be lime stabilized it is not hard to see the importance of ion crowding. In lime stabilization the calcium cancentration of the suspention is increased thus more ions are fixed on the clay particle reducing the potential of repulsion. This is known as ion crowding.

The effect of base exchange is immediate most of which is accomplished during the first few hours, reaction being almost complete during the first or second day.

Plasticity properties of the soil is improved by base exchange. We get lower plasticity index and also a coarser gradation.

In many research work it has been shown that the addition of small percetages of lime changes the consistency of the soil but has very little effect on strength properties. Thus comes up the probability that the lime added must first satisfy the affinity of the soil for lime, and would not be available for the pozzolanic reaction with soil constituents needed to produce the gain of strength. Because this lime is fixed that is, not available for other reactions, the process by which the lime becomes fixed, may be termed as "lime fixation". The percentage amount of lime by oven-dry weight of the soil which can be fixed by a given soil may be termed as the "lime fixation capacity" of the soil. The term "lime fixation"is not approved by some authors who prefer "lime retention" with the argument that the term "lime fixation" is similar to fixation which is irreversible whereas lime fixation is reversibleduring the early stages although the change in plasticity index is immediate.

The examination of figure and figure shows that the lime fixation theory is reasonable. Up to the lime fixation point consistency changes rapidly so the reaction is either base exchange or ion crowding. After lime fixation point strength increase is obvious and the reaction must be pozzolanic. Itmeans that there is enough lime in the mix that it satissfies the affinity of soil for lime and it goes into pozzolanic reaction.

POZZOLANIC REACTIONS

This is the reaction of calcium with silica and alumina present to form monocalcium silicates and aluminates. The reaction product forms a cementitious layer. For further reaction calcium must diffuse through this layer. Thus the mechanism of pozzolanic reaction is a simultaneous diffusion and chemical reaction of calcium. The rate of compressive strength development is directly related to the rate of lime adsorbtion which in turn is related to the rate of diffusion.

Bradfield and Russel of Cornel University suggested that the formation of natural cements are due to the high pH value given to the solution by calcium. They suggested that the high pH value helps break the alumina and silica complexes thus increasing the amount of material from which the natural cements form.

Examining the DTA data for the pozzolanic reaction, it is observed that the reaction is endothermic. Thus increasing the heat of curing increases the reaction rate. This has been termed as Aerhenius effect.

Although almost every investigator believed that a reaction product was responsible for the strength gain not untill recently anybody could detect the product by X-ray diffraction methods or by DTA. As a result many theories were developed as to the nature of strength increase. I will give imformation about the two most important of these theories

The X-raydiffraction data obtained by J.L.Eades And R.E.Grim for montmorillonites demonstrate that there is destruction of the mineral structure with little new crystal formation. However, compressive strength test results show that there is a reaction after the addition of enough lime, the reaction product being the added strength. Then the above mentioned investigators suggested the possibilty of formation of calcium silicate hydrate gels which can not be detected by X-ray deflections and which could interlock the particles together giving added strength without a crystaline structure.

DTA curves obtained by the same investigators for a sodium montmorillonite untreated showed a single peak between 100 degrees Centigrade and 200 degrees Centigrade. When the same soil was treated with lime and cured for three days there were two endothermic peaks which is characteristic of calcium clays.

G. H. Hilt and D. T. Davidson ran X-ray diffraction analysis for the same purpose. They changed the three variables of water-lime-soil system one by one keeping the other two constant.

When water was the variable they found that the X-ray diffractrometer traces showed well defined peaks belonging to the reaction products for high water content. When the percentage of water fell below 40% by dry weight the peaks disappeared. They suggested that this might be the reason why specimens compacted at the optimum moisture content do not give indications of the products. Tests run by them showed that only clay particles entered the reaction becaus the fraction passing 270-mesh and retained on 325-mesh sieve treated and cured in the same way showed no peaks.

When lime was the variable they found that the peaks grew larger as the amount of lime was increased.

The investigators were able to extract the crystals. They studied the crystals and found them to be transparent, colorless, platy and hexagonally shaped. Specific gravity, determined by heavy liquid method foud to be 2.07 0.01. In this method crystals are immersed in a liquid. If they are denser they will sink and otherwise they will float. At some density of the liquid they neither float nor sink. The density of the liquid is then equal to the density of the particles. In their study they used a mixture of bromoform and carbon tetrachloride.

Chemically the crystals were soluble in most dilute acids and the chemical composition showed the presence of calcium, aluminum, silica, and sodium. It was shown that iron was absent.

Pozzolanic reaction is the source of strength increase. It is slow and the rate of reactionincrease with increased amount of lime.

## CARBONATION

Some of the added strength is due to carbonation. This the reaction of lime with carbon dioxide adsorbed from atmosphere. Its influence is not important.

## EFFECTS OF LIME STABILIZATION GENERAL

Before discussing the effect of lime stabilization on different engineering properties of the soil itis beneficial to see the influence of type and amount of lime used.

## INFLUENCE OF TYPE AND AMOUNT OF LIME

Chemically lime are divided into two groups: quick limes and hydrated limes. Quick limes are furher divided into two groups: calcitic (CaO) and dolomitic (CaO MgO). Hydrated limes are of three types: calcitic ($Ca(OH)_2$) dolomitic monohydrate ($Ca(OH)_2$ MgO) and dolomitic dihydrate. Dolomitic limes have from 25% to 45% MgO, and the ratio of MgO to CaO determines the degree to which the lime is dolomitic.

In a comparative study[6] it was found that calcitic limes lowered plasticity index to the greatest extend. The compound which is chiefly responsible for lowering plasticity index is $Ca(OH)_2$. $Mg(OH)_2$ causes no effect and MgO is between the two.

Quick limes lower plasticity index more than the equivalent amounts of hydrated limes. Quick limes are better in improving shrinkage properties than the corresponding hydrated limes. Among the hydrated limes calcitic lime is better than the rest.

Results of many research has proven that dolomitic limes ( quick lime and monohydrate) are better than calcitic limes in imparting added strength except in kaolinitic clays in which both types of lime gave exactly the same result.

One disadvantage of dolomitic limes is that different results were obtained when different brands were used whereas with calcitic limes brand had almost no effect on the results.

Quick limes were found to give greater strength when applied in slurry form. Hydrated limes gave the same results whether applied in slurry form or in powder form.

As to the amount of lime, so far no definite criteria has been established to determine the amount of lime necassary for optimum strength gain. Test results show that it depends on the type of soil and curing conditions. With different curing conditions different optimum values were obtained.

With low amount of lime all the possible strength gain is obtained within a few days. With higher percentages of lime, the reaction is slow and continues for a long time but the overall added strength is greater.

The minimum amount of hydrated calcitic lime for montmorillonitic clays for a maximum decrease in the plasticity index was found to be:

$$L_{o_m} \quad \frac{\% 2}{35} \quad 1.25$$

EFFECT OF LIME STABILIZATION ON ENGINEERING PROPERTIES

The effect oflime stabilization on engineering properties is manifold and they will be taken up one by one.

PLASTICITY PROPERTIES

Results of many research show that both plastic limit and liquid limit are effected. Plastic limit is increased upon addition of lime. Liquid limit normally decreases with increasing amount of lime. This is not a definite pattern, in some soils it increases. The increase in plastic limit is so defined that the net result in all cases is a decrease in plasticity.

The amount of decrease in plasticity index is mainly depended on the type of soil. Plasticity index of highly plastic soils are reduced most.

The reduction is also time depended. Most of it occures in the first few hours and almost allof the reaction in plasticity is complete within 2 or 3 days.

Further reaction time causes some more reduction but it is negligible compared to overall reduction.

Reduction in plasticity index is also a funtion of type of lime used. Quick limes are better in this respect than hydrated limes.

Lime stabilization has shown improvement in shrinkage properties of soil. Results of one research showed that a gumbottil soil with shrinkage limit of 9.5 increased to 29.0% upon addition of 4% lime and the volumetric change of the soil was reduced from 59.5% to 13%.

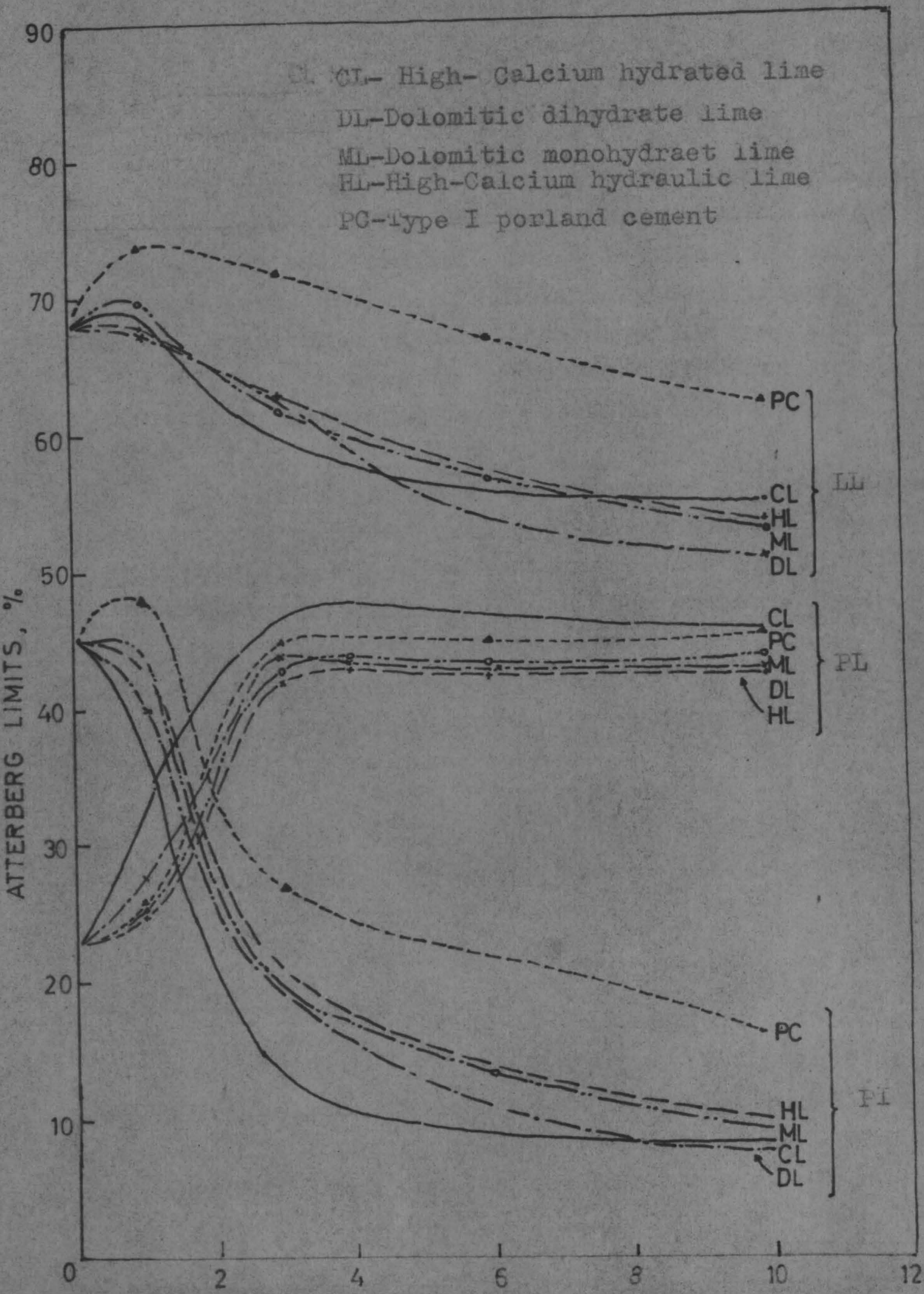


Fig. 1 Amount of additive (After D.T.Davidson)

STRENGTH

Evaluation of strength of lime stabilized soils have been done by different tests: unconfined compressive strength, CBR and triaxial. The trends in the results of different tests have been similar although the percentage changes in strength were not the same. In some instances the percantage changes in different tests were so out of order that wrong conclusions could have been drawn.

Although there appears to be an optimum lime content for a certain curing period and curing conditions different optimum lime contents were obtained for different curing conditions. This brings up the probability that there might not be a general optimum lime content. Thus strength tests can not be used to obtain a general optimum lime content, but to show whether the mix hardens sufficiently and the influence of various factors.

Major factors influencing the strength of lime soil mixtures are: type and amount of lime, type of soil, density and time and type of curing.

TYPE AND AMOUNT OF LIME

This is discussed previously but here as a conclusion we can say that strength increases as lime content inthe soil is increased. Also dolomitic limes are superior than calcitic limes in this respect.

TYPE OF SOIL

Increas in strength in lime stabilization depends on the pozzolanic material present in the soil. When desirable pozzolans are present in the soil they readily react with lime to improve the strength of the soil. If the soil has no or a small amount of desirable pozzolans the improvment obtained upon addition of lime is little.

Recently it has been shown that only the clay fraction of the soil enters the reaction which causes an increase in strength. In many cases, however, only a small amount of clay is necessary for the reaction. Higher strengths but not necessarilyhigher percentages of increase are obtained with coarser grained soils with some clay in them.

Plasticity is not a measure of reactivity of soil for lime, strength gain wise.

TIME AND TYPE OF CURING

Lime soil mixtures' increase in strength shows a similar manner as Portland cement. There usually is a rapid increase at the beginning and a gradual increase as curing progresses. It seems that the gain of strength with time is indefinite in the laboratory but it is not so in the field. In one instance cores taken from an actual road seven years after construction showed similar strength obtained after two years.

Gaining strength under field curing conditions are gradual and slow. Atleast four to six months are necessary for the mix to gain most of its strength.

The rate of gain is directly related to temperature. Mixes cured at higher temperatures show a higher rate of strength gain.

Humidity of curing does not seem to show a clear trend in strength gain. Sometimes the gain is greater at high humidity and at other times it is higher at low humidity.

The question of similarity between results of laboratory experiments and actual performance in the field always arises. M. C. Anday has run experiments to corrolate a relation between the accelerated laboratory curing and field curing. He has cured two samples at 140 degrees Fahrenheit and at 120 degrees Fahrenheit respectively. Comparing the strength obtained in laboratory curing to the 45 day field curing he found that 45 day strength could be predicted by 18 hour curing at 140 degrees Fahrenheit and two days at 120 degrees Fahrenheit. His conclusion has been questioned by other investigators. The general idea is that it is not possible to corrolate laboratory results with field performances and there is too much data to support this argument.

DURABILITY

Another factor, which is as important as the gain of strength, of lime stabilization is durability of the mixes under field conditions. Determination of the durability in laboratory has been very difficult because it is not possible to create all the detrimental conditions in the laboratory.

Durability of the mixes are examined by the use of several tests. The three most popular tests employed to stimulate weathering conditions are:

1) Freezing-and-thawing
2) Wet-and-dry
3) Heating-and-cooling.

The procedure of each test, asto the length of cycleand number of cycles vary from investigator to investigator. In most cases the check is made by loss in weight which has a large personal skill involved. Of the nondestructive testsemployed till now the most promising is the one that use soniscope to measure the change in velocity of pulse propogation. Also this method is not limited to laboratory and can be used on projects in service with little modifications.

Up to now the results of durability tests have shownthat lime soil mixes were not durable to weathering. As an example we can give the research done by Çetin Karabulut. He has studied the effect of freezing and thawing on unconfined strength. He has used a clayey and a silty soil and found that clay gains strength upon addition of limebut lose most of it after freeze and thaw cycles. Silty soils' strength was very little effected both by addition of lime and freeze and thaw cycles.

The conclusion that lime siol mixtures are not durable to weathering is not true because actual projects which has been in service usually show good performance. In one instance a road seven and a half years after construction was classified as excellent.

Larger amount of lime, longer curing period before actual weathering and higher density give greater resistance to weathering.

COMPACTION

General trend in lime stabilzation is a decrease in maximum dry density accompanied with a slight increase in optimum moisture content. The afore mentioned changes are more pronounced when the amount of lime is increased. In only one instance it was found that the maximum dry density increased upon addition of lime.

Water content increases and the amount of the increase is caused by the first amount of lime added. Additional lime has small effect on water content.

Type of lime also effects the compaction. Soils treated with quick lime usually have a slightly higper optimum moisture content than soils treated with hydrated lime. On the other hand type of soil does not seem to influence unit weight.

Maximum is not necessarily obtained at obtimum moisture content. For plastic soils maximum strength is obtained on the wet side and for the sandy soils on the dry side of the optimum moisture content.

If no water during curing the compaction must be done with moisture content higher than optimum to obtain maximum strength. Increasing the compactive effort increases the strength. The increase in strength obtained by changing from Standard Proctor to Modified AASHO is from 50 to 160%.

OTHERS

Apart from the major effects, lime stabilization has the following secondary effects.

Increased permeability and decreased capillarity was observed is explained by the flocculation of soil mass.

In one instance the permeability increased from the order of $10^{-8}$ to $10^{-5}$ and the capillarity adsorbtion was decreased by 25%.

It's effect on volumetric changes has already been statedy.

## CONTSTRUCTION METHOD FOR ROADS

National Lime Association has suggested the following method for lime stabilized roads.

### 1. SCARIFYING ROAD BASE

The road base is scarified to the required depth with preferably an adjustable rooter attached to a power grader. At every 10 or 5 feet the scarifiying depth must be checked carefully.

### 2. PULVERIZATION OF SOIL

The loosened soil is pulverized with either a rotary speed pulverizing mixer or a disc harrow. The depth of pulverization must correspond to depth of scarrifiying. The pulverization equipment is operated up and down the length of the road project. Some soils may require a small amount of water for proper pulverization.

### 3. SPREADING LIME

The bags of lime are first placed on the road way in comformity with the individual lime requirements for the particular job. This can easily be done by using hydrated lime bag spacing tables. The paper bag of lime is split open by showels and the contents emptied on the road. Proper protective measures should be taken for the workers.

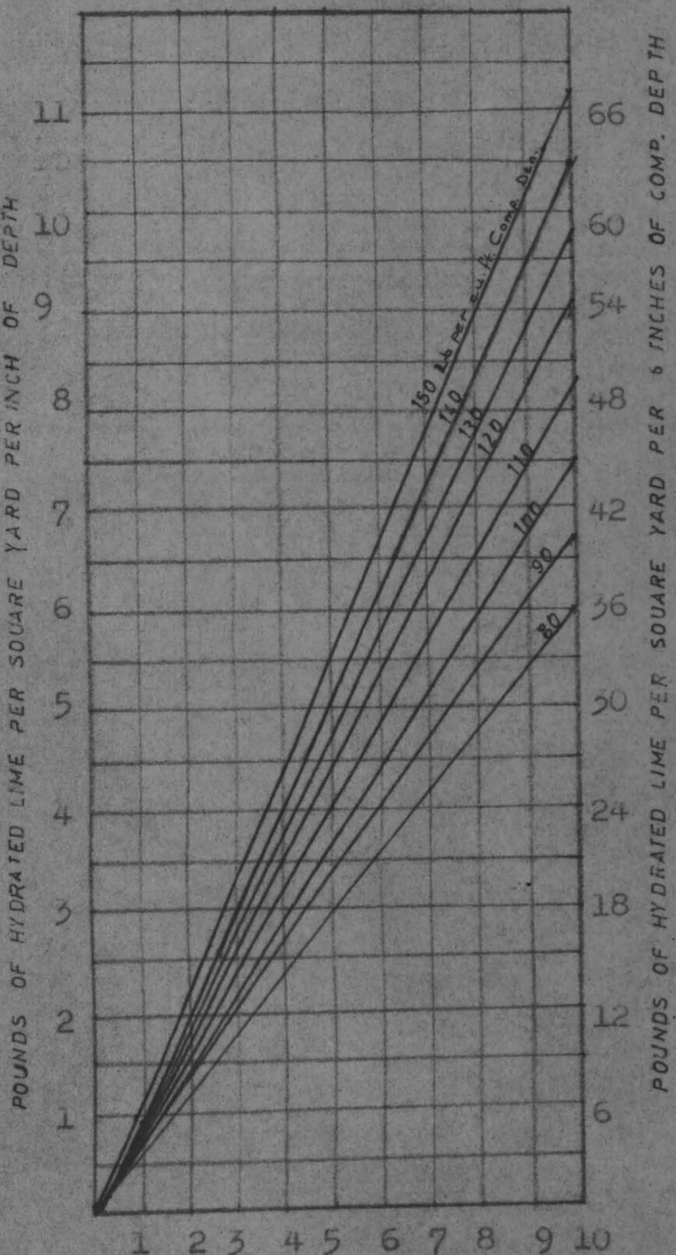


Fig. 2 Lime spreading diagram of National Lime Association

4. MIXING LIME AND SOIL

Mixing can be done either by a motor grader or by the use of pulverizing mixer or a disc harrow. Great care should be taken in mixing.

5. MIXING TO OPTIMUM MOISTURE CONTENT

Careful laboratory determination of optimum moisture should be done from these tests, the amount of water and the rate of application should be calculated. Water is usually applied by distributers and can be added in as large increments as the equipment will permit.

6. COMPACTION

Compaction is done with sheep foot rollers or pneumatic rollers depending on the type of soil. The degree of compaction is checked by moisture-density tests performed. These tests should be done frequently. Before compaction is finished the motor grader should shape the road bed to desired cross section.

7. FINAL SHAPING

Multiple-wheel pneumatic tire rollers, usually carrying ballast are used for final shaping.

8. CURING

The road is closed to any traffic for at least 5 days. During this time additional water sprinkled on the surface to ofset the effects of evaporation.

## 9. ADDING BITUMINOUS WEARING SURFACE

After the initial curing bituminous wearing coat can be applied. It is a necessity because the waterpoofing effect increases the durability.

In the actual construction the greatest problem met was the gradation requirement. This requirement states that at least 80% must pass number 4-mesh sieve before addition of any additive. This has been found to be economically impossible without lime pretreatment. Requirements were not met even then.

Pulverization and aeration for a whole day increased the amount passing number 4 sieve from 65 to 67%. The best results were obtained upon lime pretreatment with 4% lime. Upon addition of 2% , the amount passing number 4 increased from 17% to 62.6%. When the remaining 2% was added a further increase to 71% was obtained which was still below 80%. Later the requirements were lowered to 65%

Lime stabilized road construction is a new process. As with any new process the technique improves with new experience. I believe that more refined methods and more realistic specications are soon to come.

LIME STABILIZED TEST ROADS CONSTRUCTED BY KARAYOLLARI GENEL MÜDÜRLÜĞÜ

I- SORGUN- AKDAĞMADENI

1- Farness of base material beds to the construction site and insufficiency of these beds.

2- Various sections of the highway pass over marsh and even though select material was used the select material was burried in the marshand passage was impossible during winter and early spring.

For the above reasons it was decided to create a semi-rigid surface by stabilizing the soil with lime.

LABORATORY STUDIES

The soil to be stabilized was obtained from the construction site and had a dry density of 79-86 lb/cuft and optimum moisture content of 30-40%.

Amount of lime to be used was determined by CBR and 4.25 % quicklime was used as the design lime content. The stabilized layer had a thickness of 30 cm constructed in two layers. A blanket of select material of 15cm thickness was laid on the stabilized layer.

SECTIONS AND AMOUNT OF LIME USED

| Km | Thickness | Length | Amount of Lime |
|---|---|---|---|
| 40 100-41 850 | 30cm | 1750 m | 343 |
| 41 850-44 050 | " | 1250 m | 242 |
| 44 050-45 000 | " | 1000 m | 191 |
| 47 500-48 500 | " | 1000 m | 191 |
| | Sum | 5000 m | 967 |

For lime and transportation 1160.40 TL was spent. Construction started at 6.6.1959 and ended at 14.10.1959.

RESULT

All of the 5 km which was lime stabilized is on marsh and under water most of the time. As of today no damage has been reported and the road is in perfect condition. Because the surface is semi-rigid ondulations do not occure.

II- ADANA PASS

It was necassary to haul the base material from a newly found bed on Adana-Karataş route for construction of

Adana Pass and Adana-Ceyhan road. Transportation from Karataş to Adana-Pass site required passage through the city which increases the cost and delays the operation. To minimize the amount of material used lime stabilization was decided on.

LABORATORY WORK

Soil for the laboratory work was obtained from the construction site. Characteristics of the soil are as follows: Liquid limit 59, plastic limit 21, plasticity index 38. The soil belongs to A-7-6. The lime which was obtained from Ceyhan had 75% activity.

To determine the optimum amount of lime, mixes of different lime percentages was compacted to give maximum dry density and optimum moisture content. Unconfined compression test samples were prepared at maximum dry density. The samples were cured in different ways. Together with unconfined compression test CBR was used to determine lime content.

Test results showed that optimum lime content for quick lime was 3.8% and for hydrated lime 5%. For 1000m section with 15 cm thickness 150 tons of lime were used and the construction was completed in 10 days.

CONSTRUCTION METHOD

The soil was stabilized with 3.8% lime to a depth of 30 cm in two layers. On the stabilized layer a blanket consisting of 10 cm of select material and an asphaltic concrete of 7.5 cm thickness were laid.

RESULT

1. Laboratory results showed that the CBR value would be 120. Too much time was spend to pass the mix through number 4 sieve. During this time the activity of lime decreased and as a result a CBR value of 20 was obtained.

2. To improve the effect of lime 8% was used instead of 3.8%.

III- PINARBAŞI- GURUN- DARENDE

Purpose of stabilization was to improve the plasticity of the subbase.

LABORATORY WORK

To determine the optimum lime content 1.5, 2, 2.5, 3, 3.5 % lime was used. The soil to be stabilized had the following characteristics: liquid limit 39 plastic limit 21, plasticity index 18. Plasticiy index decreased to 12 with 1.5% lime to 11 with 2%, to 10 with 2.5%, and to 8 with 3.5% lime.

Based on above data and the results of unconfined compression test, CBR 1.5% was determined to be the optimum lime content. Taking into consideration losses in transportation and uneven mixing 2% was chosen as the lime content.

CONSTRUCTION METHOD

A layer of 10cm was stabilized and covered with asphalt. It is in good condition today. Unsoaked CBR values of 30-70 and soaked 40-80 were obtained after three months of construction.

# P A R T II

## PROPERTIES OF SOIL TESTED AND LIME USED

### SOIL

The soil to be tested was obtained from Baltalimanı quarries. It is a reddish brown plastic clay and has a liquid limit 45, and plasticity index 16. In Casagranda's plasticity chart it is above the A-line and classified as inorganic medium plastic clay. It has a maximum dry density of 93.5 lb/cuft and an optimum moisture content of 20%. It has 0.4% calcium in its composition.

### LIME

The lime is hydrated calcitic lime with an activity of 91.6%.

## TEST PROCEDURES

### ESTIMATION OF CALCIUM IN SOIL

Ten grams of soil is shaken occasionally by the hand in a stoppered bottle with 100 cc of a solution N with

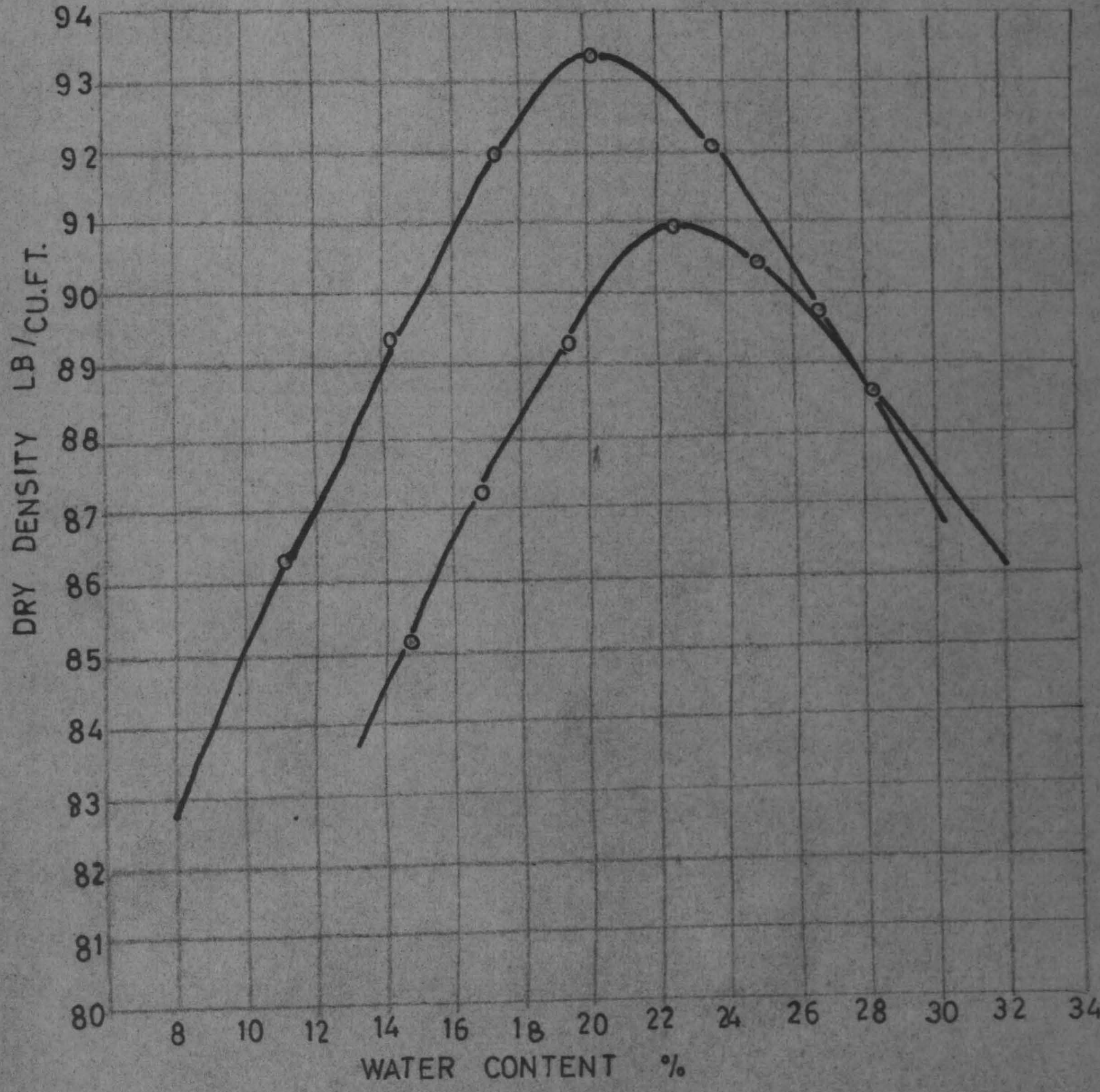


Fig.3 Dry Desity vs moisture content

respect to potassium acetate, 0.1 N with respect to potassium oxalate, and 0.015 N with respect to $K_2CO_3$, filtered and 50cc of the filtrate titrated with 0.1 N $KMnO_4$. The total decrease in the concentration of oxalate ion is equivelant to calcium in the soil. (The procedure has been taken from Puri, Soils: their physics and chemistry)

ESTIMATION OF ORGANIC MATERIAL

The presence of organic matter was tested by boiling 100 gm of soil with 6% hydrogen peroxide. After boiling to dryness, the oven dry weight is compared to the oven dry weight of the untreated soil. There was no considerable change in the weight.

The absence of organic matter was further proved by performing Atterberg limit tests on the soil which was treated with 6% hydrogen peroxide. If there had been organic matter then the plasticity would be lowered but there was no change in the plasticity which proves that the soil is inorganic.

PREPARATION AND CURING OF SPECIMENS

The tests were performedon soil with 1, 2, 3, 4, 5, 8% hydrated lime by dry weight. All soil was previously air dried and grounded to pass number 10 sieve. The maximum density and the optimum moisture content of untreated soil and 8% mix were determined in accordance with AASHO t99-57 Method A. The optimum moisture content for inbetween percentages were estimated by linear approximation.

The soil and the predetermined amount of lime were first hand mixed, then the necessary amount of water coresponding to the lime content in the mix was added. The mix was further mixed by hand and then it was transfered to the mechanical mixer. In the mechanical mixer it was mixed for 15 minutes.

The mix then was molded to standard compaction in the Proctor compaction device in three layers with 25 blows to the layer using 5.5 lb hammer dropping from a 12 in height. Then 3.5 cm diameter samples were obtained by pushing the sampler into the mold using a hydraulic jack. 6 specimens were prepared for each lime content, 3 to be tested after 7 day humid curing and the other three to be tested after 28 days.

STRENGTH TESTING

In determining strength, unconfined compression was used with a loading rate of 0.1 in per min. After curing periods three specimen from each percentage were tested to failure in the unconfined compressive strength apparatus. The average strengthof the three specimens was taken as the strength of that mix. When one of the specimens gave a result which was not comparable to the other two, it was discarded.

ATTERBERG LIMITS

ASTM methods D423-59 and D424-59 were used. The procedure was followed on samples passing number 40 sieve and the tests were done at the end of curing periods. Three liquid limit tests and three plastic limit tests were done for each percentage of lime. Average of the three values is recorded as the limit for the mix.

## DISCUSSION OF THE RESULTS

### EFFECT OF LIME ON WORKABILITY

The first effect of lime on soil properties was observed to be increased workability. The mix was observed to stick to the mixer in decreasing amounts as the percentage of lime was increased. At high percentages it did not stict at all. Since the mix was transfered to the mixer immediately after hand mixing the effect of lime on workability must be immediate.

The increased workability was again observed in moldin the specimens. When material was taken out of the mold tobe grounded for further molding less effort was exerted as lime content increased.

After seven days curing , when samples were grounded to pass number 40 sieve the workability was observed to have increased further but no more improvement after 28 days.

This is in accordance with the theory because increase in workability is a result of base exchange and ion crowding. Many investigators have shown that these reactions occur in the first few hours and reach complition within 2 or 3 days.

This knowledge is important for improving construction methods. Many investigators have reported ot have difficulty in pulverizing the mix to meet the specifications. Since the effect of lime on workability requires very little time the soil may first be treated with lime. Actually a method of construction employin pretreatement with lime has been suggested and successfully applied.

EFFECT OF LIME ON ATTERBERG LIMITS

The effect of lime on Atterberg limits is summarized in tables I and II and the changes in the limits as a function of curing time and lime content are shown by graphs.

The results show that curing time has negligible effect on plasticity properties since the greatest difference between the 7 day cured specimen values and 28 day cured specimen values is less than 5%. This shows that the changes in the plasticity properties take place during the early stages of curing and further curing is not beneficial.

It is evident from the tables and the graphes that plastic properties of soil were improved by the addition of lime. Actually a medium plastic clay has been trasformed to a nonplastic soil.

| % Lime | LL | PL | PI |
|---|---|---|---|
| 0 | 45.0 | 29.0 | 16.0 |
| 1 | 40.0 | 28.6 | 11.4 |
| 2 | 40.5 | 36.0 | 4.5 |
| 3 | 44.5 | 41.8 | 2.7 |
| 4 | 44.0 | 44.0 | 0.0 |
| 5 | 44.0 | 44.0 | 0.0 |
| 8 | 44.0 | 44.0 | 0.0 |

7 Day Plasticity Values
TABLE I

| % Lime | LL | PL | PI |
|---|---|---|---|
| 0 | 45.0 | 29.0 | 16.0 |
| 1 | 39.5 | 28.4 | 11.1 |
| 2 | 41. 0 | 36.7 | 4.3 |
| 3 | 43.5 | 40.9 | 2.6 |
| 4 | 44.0 | 44.0 | 0.0 |
| 5 | 44.0 | 44.0 | 0.0 |
| 8 | 43.0 | 43.0 | 0.0 |

28 Day Plasticity Values
TABLE II

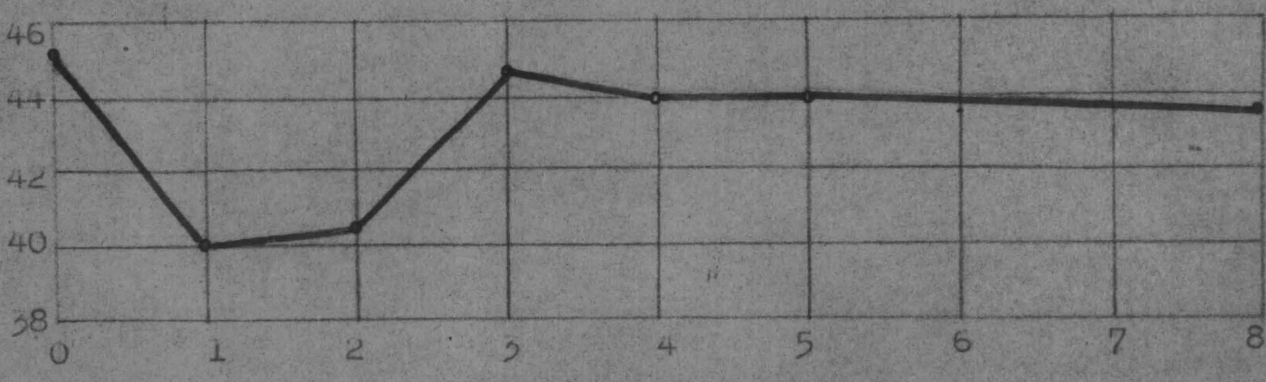


Fig4. 7 Day Liquid Limit Lime Cotent Relation

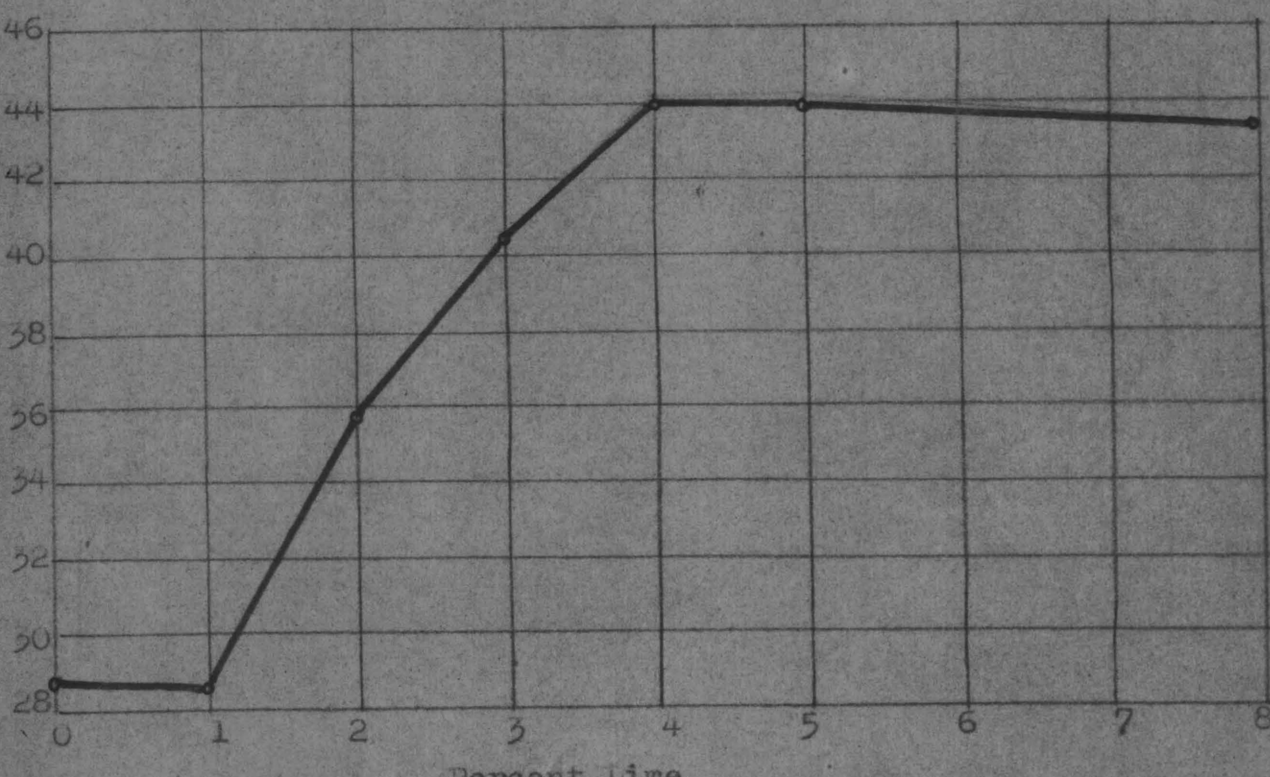


Fig. 5 7 Day Plastic Limit Lime Content Relation

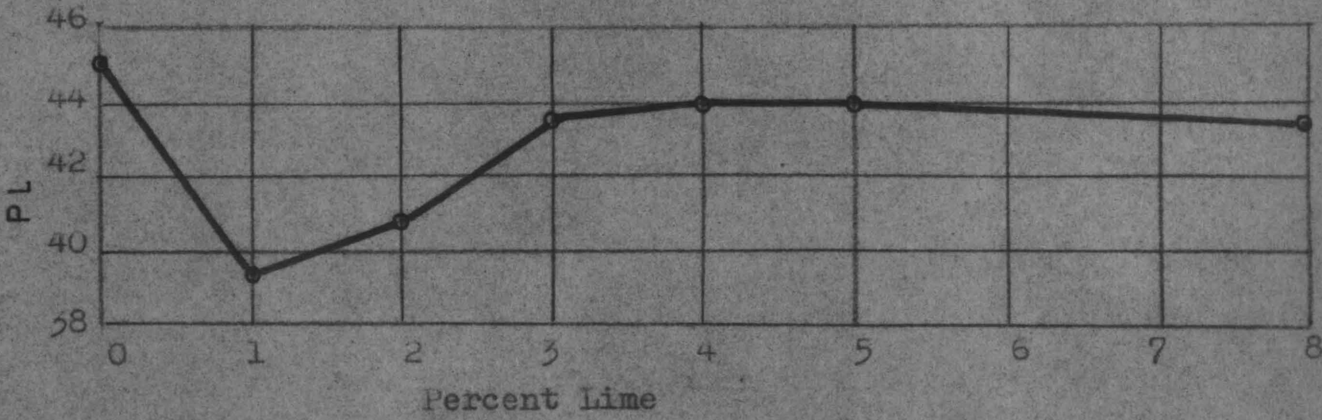


Fig.6 28 Day Liquid Limit Lime Content Relation

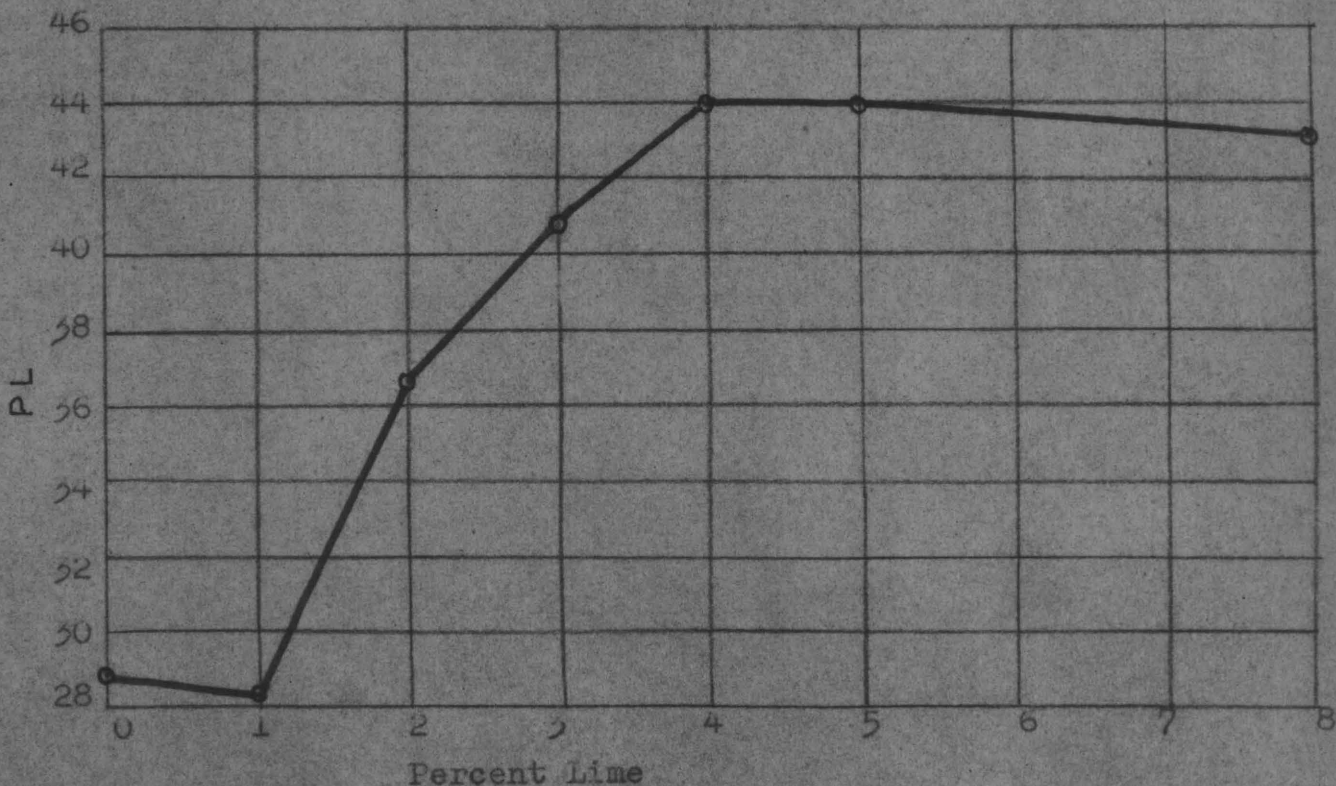


Fig.7 28 Day Plastic Limit Lime Content Relation

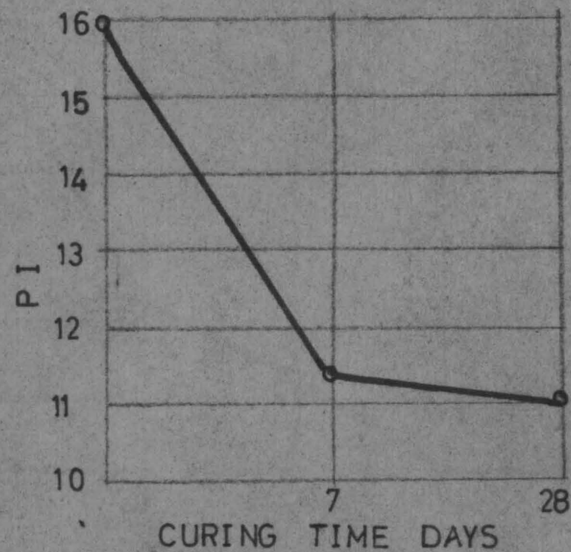


Fig.8 Variation of PI
with Curing Time of 1% Mix

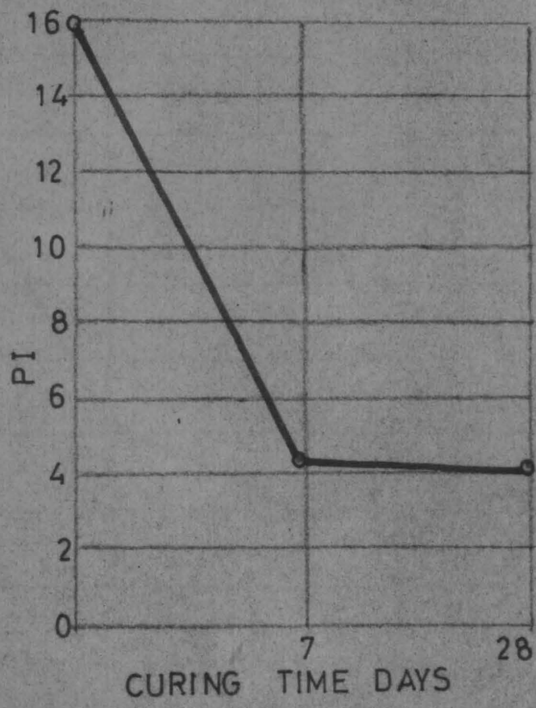


Fig.9 Variation of PI
with Curing Time of 2% Mix

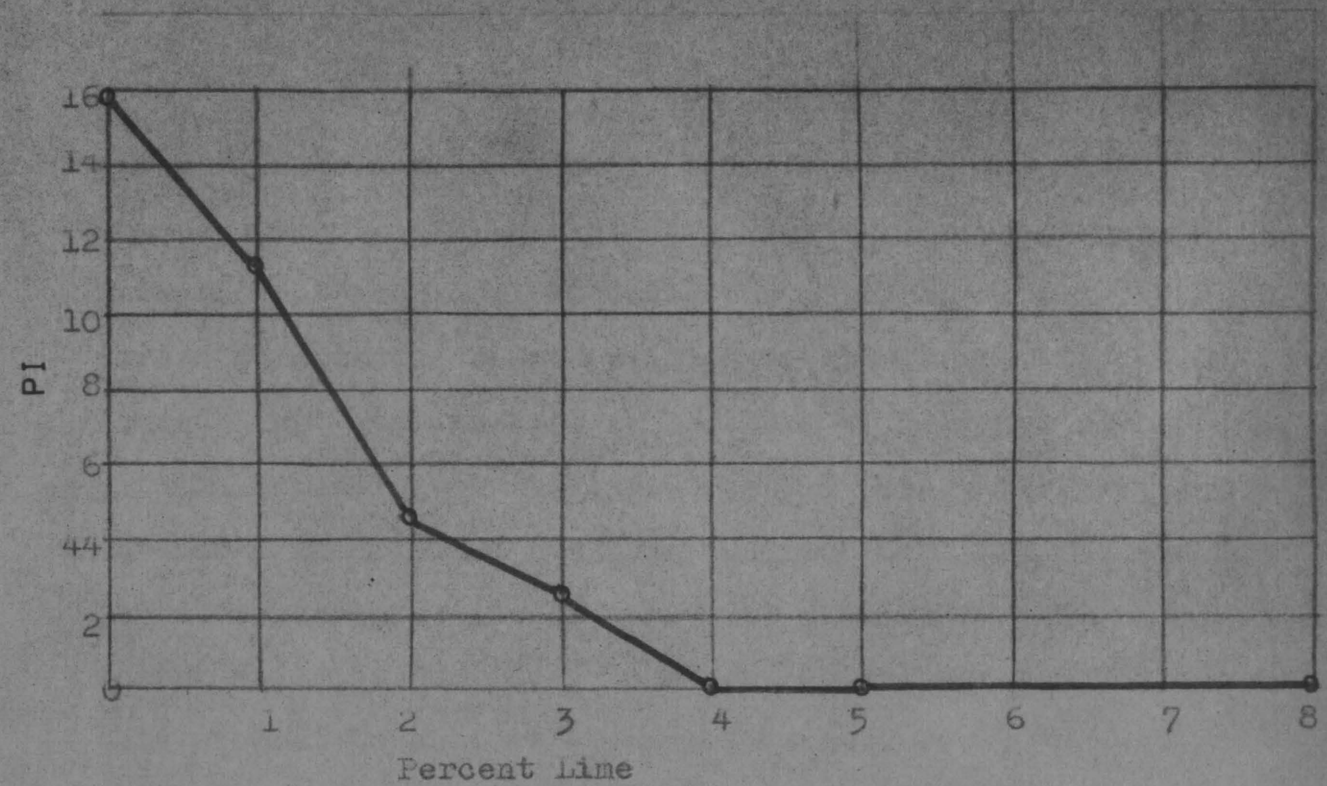


Fig.10 7 Day Plasticity Index Relation

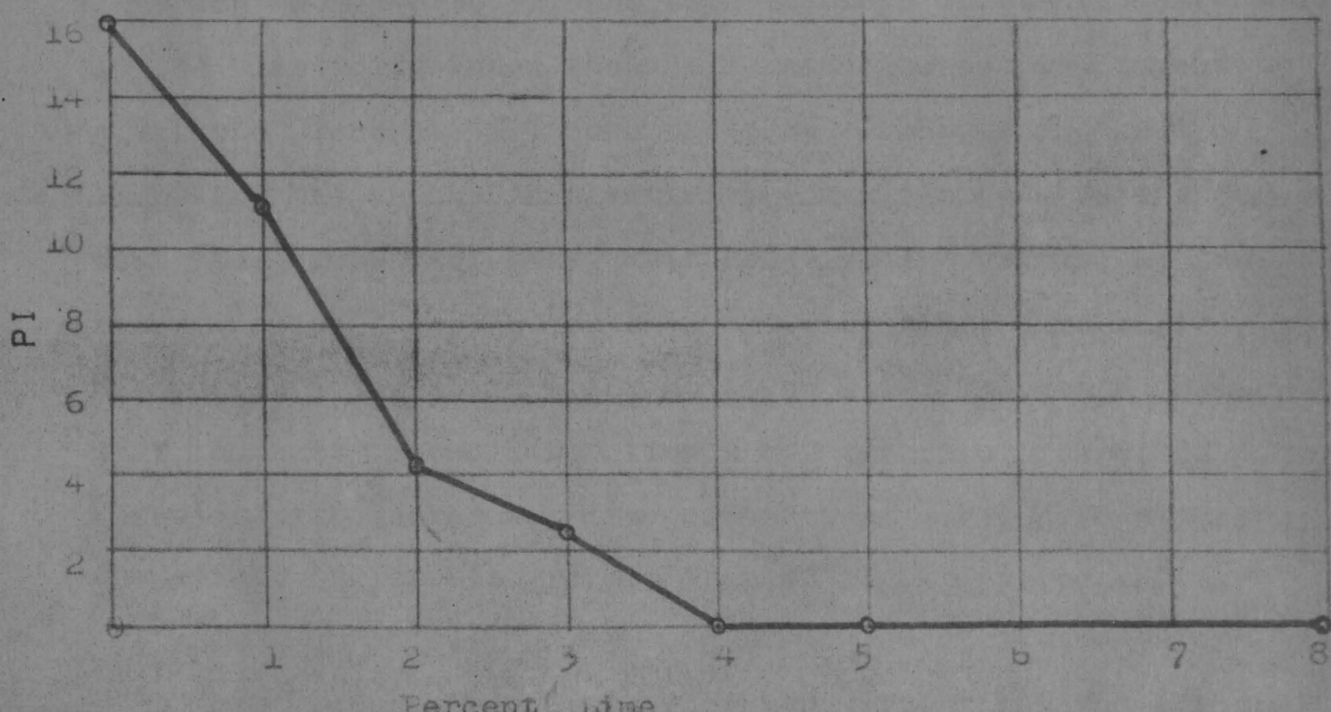


Fig.11 28 Day Plasticity Index Relation

With increasing lime content the liquid limit shows first a decrease and then it increases and stays constant, close to its untreated value. The inconsistency in the pattern that liquid limit shows has also been observed by other investigaters. The common opinion on this matter is that the liquid limit may increase or decrease or may have no definite pattern depending on the type of soil. Some soils have shown no change in liquid limit upon addition of lime. The reason for different patterns of variation of liquid limit for different soils has not been found and it is beyond the scope of this project to suggest a possible solution.

The plastic limit shows a marked increase for the lime contents, up to 3%, and then it stays constant. Consequently the plasticity index shows a marked decrease and reaches a value of zero at 4% . Both the rate of change in plastic limit and the change in plasticity index decrease as the percent lime added increases. This behavior is verified by the lime fixation theory which says that the lime added must first satisfy the affinity of soil for lime. The graph shows that affinity of soil for lime shows almost a hyperbolic behavior with increasing lime content. At small percentages the effect of lime is greater than at higher percentages.

It has been argued by many investigators that the changes in the plasticity properties of soil is only a result of base exchange. Some investigators have disagreed with this argument and have proposed another mechanism which helps improve plasticity properties together with base exchange namely ion crowding. The results of this investigation seems to provide more data for the second group of investigators since the raw soil 20me per 100gm of soil calcium. The change in the plasticity properties is so great that the base exchange alone can not account for it.

EFFECT OF LIME ON STRENGTH

The effect of lime on strength of soil is summarized in table III. The variation of strength with percentage and curing time is shown by graphs.

Gain of strength is a result of pozzolanic reactions. Since pozzolanic reactions are slow the strength gain after seven days curing is considerably less than the strength obtained after 28 days curing.

After seven days of curing there is very little strength gain at low lime contents. For examble when 3% lime is added the strength gain is only 40 psi. As the percentage of lime added is increased the rate of strength gain increases and at 8% lime content it shoots up from 298 psi to 470 psi.

28 days cured specimens show a similar behavior. There is only 21 psi difference between 1% lime mix and 3% lime. The rate of gain of strength starts to increase at 5%. There is only an increase of 90 psi when lime content is increased from 5% to 8%.

An optimum lime content could not be obtained in the range of percentages used. The strength increases with increasing lime content. The optimum lime content must be greater than 8%.

Examination of the figures will show that 5% lime appears to be the most suitable lime content to be used in lime stabilization of this soil in any project. The strength gain obtained using 8% lime instead of 5% is 90 psi. There is no improvement in plastic properties by using 8% lime. The small strength gain will not compansate the added cost of lime.

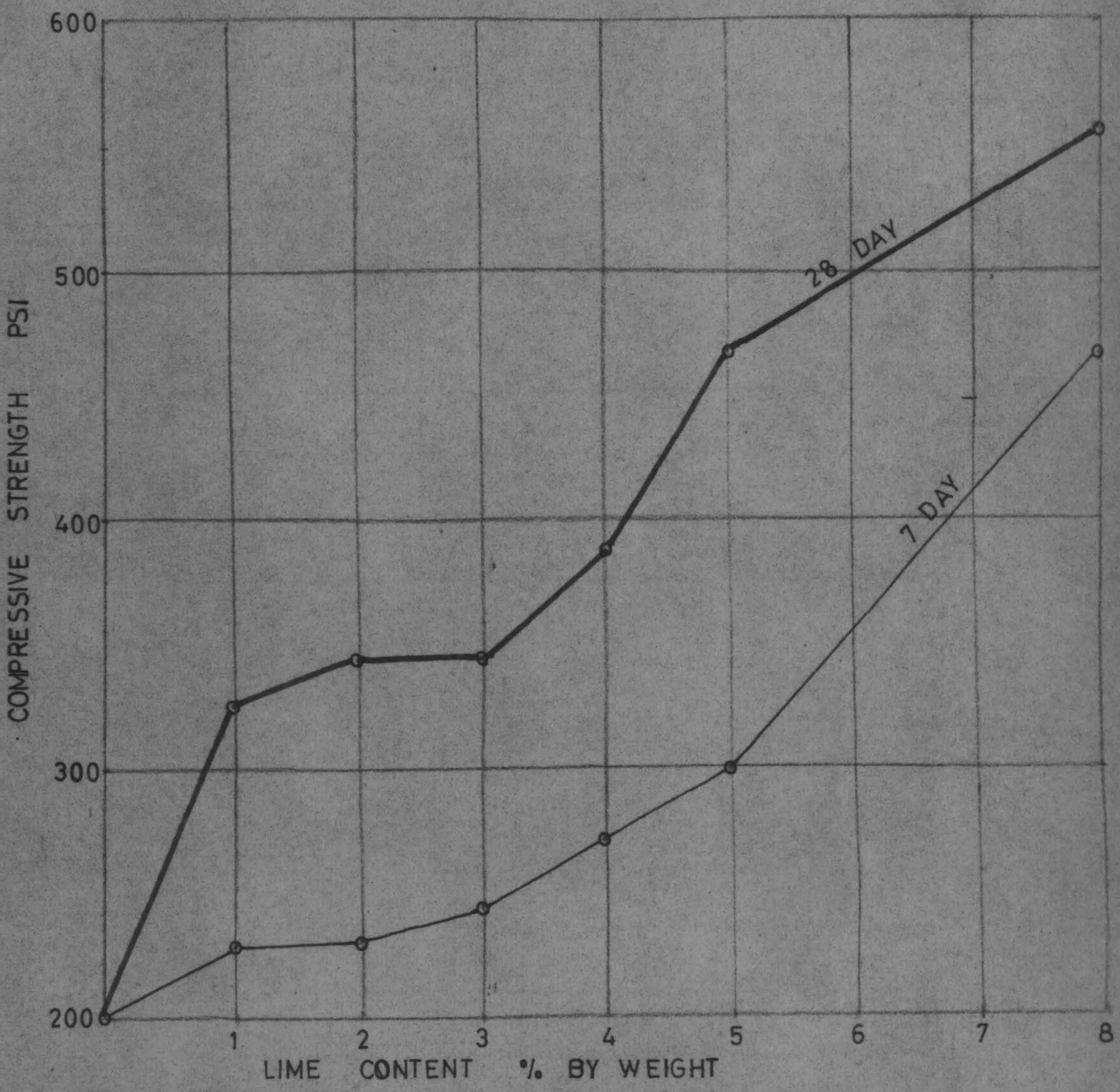


Fig.12 Compressive Strength vs Lime Content

Unconfined Compressive Strength

| % Lime | 7-Day psi | 28-Day psi |
|---|---|---|
| 1 | 230 | 325 |
| 2 | 250 | 345 |
| 3 | 240 | 346 |
| 4 | 274 | 388 |
| 5 | 298 | 470 |
| 8 | 470 | 560 |

TABLE III

| % Lime | 1 | 2 | 3 | 4 | 5 | 8 |
|---|---|---|---|---|---|---|
| Water Con. | 25.0 | 25.3 | 25.6 | 25.9 | 26.2 | 27.1 |

TABLE IV Water Content for Compaction

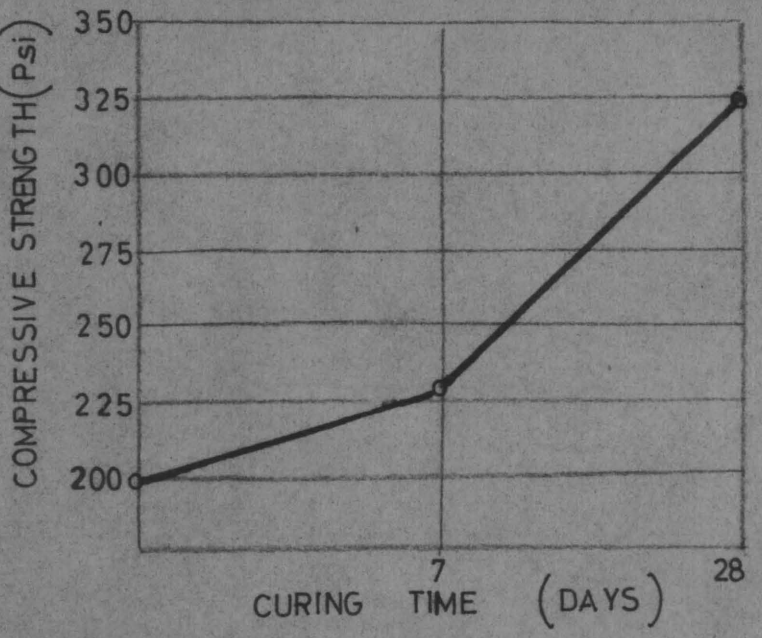


Fig.13 Variation of Compressive Strength with Time of Curing for 1% Mix

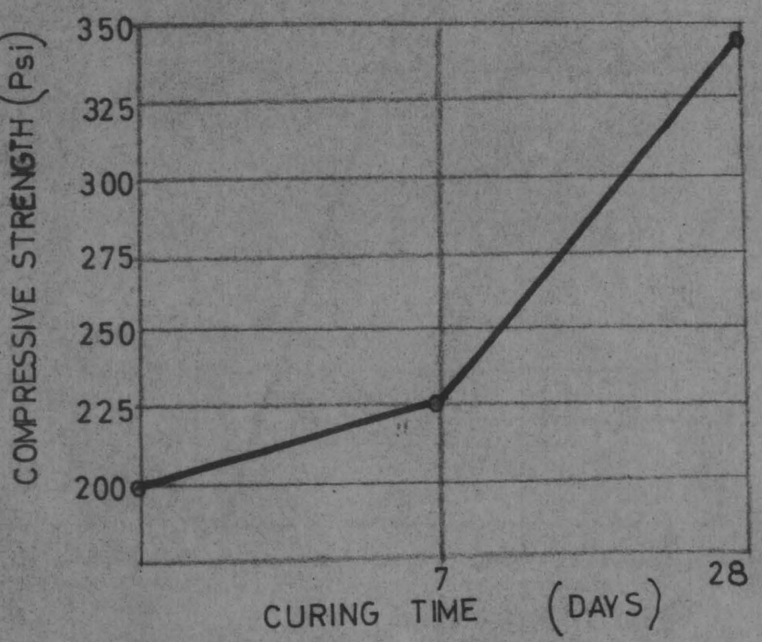


Fig. 14 Variation of Compressive Strength with Time of Curing for 2% Mix

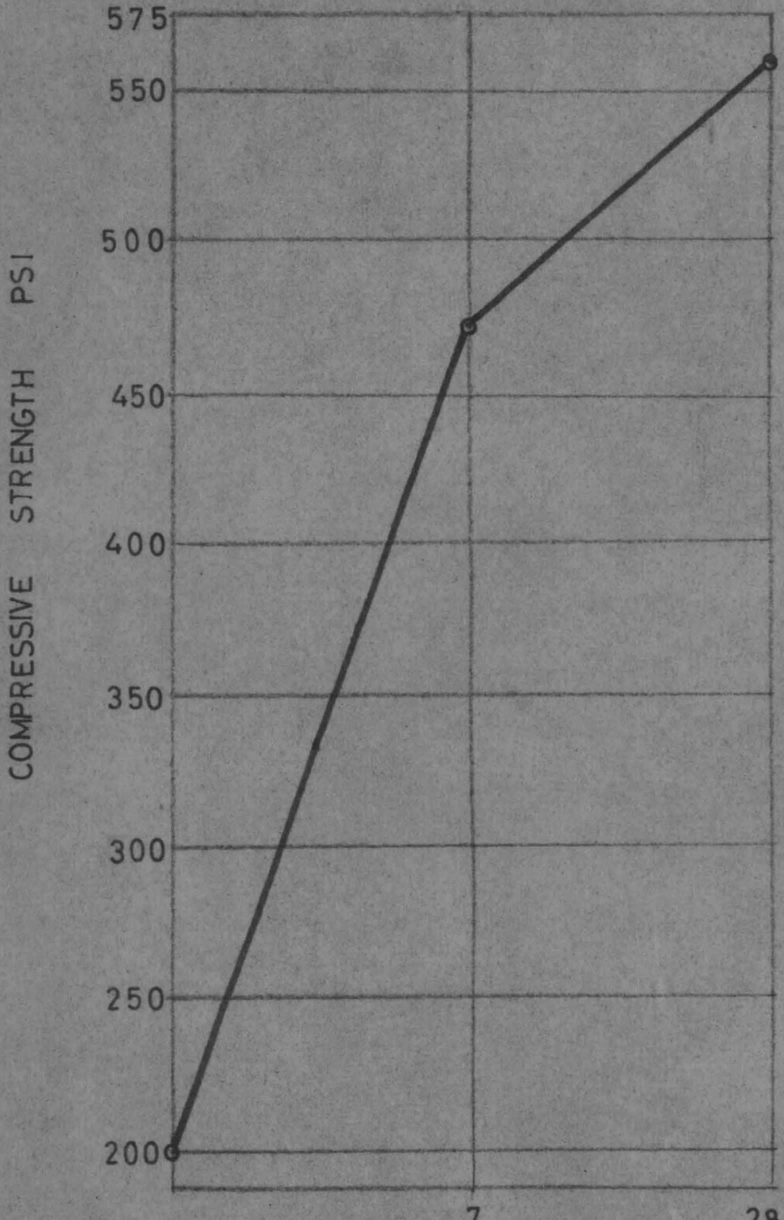


Fig. 15 Variation of Compressive Strength with Time of Curing for 8% Mix

## CONCLUSIONS

1- Plasticity properties of soil are improved with addition of lime.

2- Variation of liquid limit with lime content is not definite.

3- Plastic limit increases with increasing lime content up to 4% and stays constant at greater percentages.

4- Plastic limit increase is so dominant that regardless of the change in liquid limit the plasticity index decreases to 0.

5- The rate of decrease in plasticity index decreases with increasing percentages of lime.

6- The changes in plastic properties occur in short time and values after 7 days curing are almost same as values after 28 days curing. Curing time has no effect.

7- The strength increases with increasing lime content.

8- The rate of strength gain is increasing with increased lime content.

9- Longer curing time gives greater strength.

10- Optimum lime content could not be obtained in the range of percentages used.

11- 5% lime is suggested as the design lime content for this soil.

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