# CHAPTER II

# LITERATURE REVIEW

## 2.1 Lime Stabilization

There has been a growing interest in the use of lime for stabilizing soils in recent years. It is one of the oldest man-developed construction materials. Lime can be used with a wide variety of soils ranging from clays to gravel and has been used in the improvement of soft undesirable subgrades as well as in the construction of subbases and bases for highway and air-field pavements.

### 2.1.1 Effects of Lime on Soil

(a) Plasticity - The phenomenon that is mentioned in almost every article on lime stabilization is the ability of lime to change the plasticity of the soil. Both the plastic limit and the liquid limit of the soil are affected. Hilt and Davidson (1960) reported that adding a small amount of lime will increase the plastic limit until the lime content reaches "lime fixation point", after which there was little change in the plastic limit. In general, but not always, the liquid limit is reduced in the more plastic clays and is increased in the less plastic soils. Regardless of whether the liquid limit decreases or increases, the net effect of adding lime is always a mark decrease in the plasticity index of the soil. The effect is less significant for soils with low plasticity (Herrin and Mitchell, 1961).

(b) Grain size distribution - When lime is added to a fine-grained soil the agglomeration or flocculation of the clay particles will take place. This produces a coarser and more friable soil. The amount of agglomeration in a soil is influenced by the type of soil, which is the most important one. The fine clay particles are changed in size by lime as they tend to react with lime more than the larger individual sandy-like materials. In general, plastic soils tend to agglomerate more than silty or sandy soils. Lime cannot be successfully used with all types of soils, but is limited primarily to the stabilization of medium and highly plastic soils (Herrin and Mitchell, 1961). In addition, the amount of lime influences the agglomeration in the soil, with more lime is added to the soil as more aggromeration occuring.

(c) Strength - The strength of lime-soil mixtures increases as the lime content in the soil is increased, which depends on the characteristics of the soil. There appears to be no optimum lime content that will produce a maximum strength in a lime-stabilized soil under all conditions (Herrin and Mitchell, 1961). There may or may not be an optimum lime content, depending primarily on the length of curing. Pietsch and Davidson (1962) reported that there is usually an optimum lime content for maximum strength under a certain curing condition. Lime content higher than optimum will yield lower strength (Eades and Grim, 1962). The optimum lime content for strength is dependent upon the soil type and curing time (Woo Siu-Mun, 1971). The strength, the optimum lime content and the moisture content at maximum strength are increased with prolonged curing periods (Pongsit, 1975). The optimum lime content is well correlated with the clay content, the higher the clay content, the higher the optimum of lime.

(d) Compaction and optimum moisture content - As lime is added to a soil, the density of the mixture will be lower than the original soil whithout lime when compacted with the same effort. It is interesting to note that the unit weight of the mixture decrdase as the lime content is increased. Although the density of a soil tends to decrease with additional amounts of lime, it should not be assumed that the strength of the lime-soil mixtures is lowered. This is not true. Lime-soil mixture are one material to which the general thought "when the density increases the strength also increases" does not always apply. It usually applies, though, if at the same lime content additional compactive effort is used to produce higher density.

In addition to the amount of lime used in a soil, the optimum moisture content tends to increase. Usually the initial increase in moisture content is rather significant even when small amounts of lime are used. Woo Siu-Mun (1971) reported that the addition of lime reduces the maximum dry density and increases the optimum moisture content of the soil.

Compaction of lime-soil mixtures is influenced by the type of lime. Soils with quicklime usually have a slightly higher optimum moisture content than soils compacted with hydrated lime. On the other hand, the type of lime does not seem to influence the unit weight of soil-lime mixtures. A soil treated with either quicklime or hydrated lime in the same amount has about the same density.

(e) Volume change - Additional amounts of lime will produce decreasing volume changes that take place in soils up to an optimum lime content. Little additional reduction in volume change is produced by adding lime in amounts larger than the optimum value. Limes have a greater influence on reducing volume changes and the swelling of soils.

2.1.2 Factors Affecting Soil-Lime Strength

(a) Types of lime - There are five basic types of lime :

High - calcium quicklime, $CaO$

Hydrated high - calcium lime, $Ca\,(OH)_2$

Dolomitic quicklime, $CaO + MgO$

Normal hydrated or monohydrated dolomitic lime,
$Ca\,(OH)_2 + MgO$

Pressure hydrated or dihydrated dolomitic lime,
$Ca\,(OH)_2 + Mg\,(OH)_2$

The type of lime influence the strength of lime-soil mixtures. The dolomitic limes produce higher strengths in lime-soil mixtures than high-calcium lime at the higher lime contents of both two types of lime. In fact, some outstanding engineers believe that in the long run high-calcium lime will produces as high a strength as dolomitic lime. Laguros (1956) found that the quicklimes are generally more effective than the hydrated limes in improving soil properties. However, in practice, quicklime has not been used extensely as the hydrated lime.

(b) Soil types - The type of soil affects the improvement of engineering characteristics of soil-lime mixtures. Generally, the highly plastic soils are more reactive with lime, whereas soils with low plasticity react little with lime. Usually, clays are more reactive with lime than other soils and are generally increased in strength when lime is added (Herrin and Mitchell, 1961). Pietsch and Davidson (1962) noted that lime did not react with soil particles greater than silt size.

(c) Clay minerals - The reactivity of lime to various clay mineral is not the same. Eades and Grim (1960) found that the reactions of hydrated lime with pure clay minerals, for kaolinite, strength began to increase some of the calcium attacked the edges of the kaolinite particles, for illite and montmorillonite strength developed only after the clay was saturated with $Ca^{++}$ ion. Mateos (1964) reported that montmorillonitic and kaolinitic clay soils and clays contain halloysite attain the least strength.

(d) Curing - Lime stabilized soils increase in strength with age. Usually, there is a rapid increase in strength of these mixtures at the beginning of the curing period, but as the curing progresses the rate of increase in strength becomes less.

The temperature also affects the rate of reaction between lime and soil, and rate of gain in strength too. The higher temperature accelerates the reaction rate, thus, increasing the rate of strength.

### 2.1.3 Mechanism of Soil-lime Stabilization

When lime is added to a soil, some reactions will take place. The most important of these reactions in lime-soil mixtures can be classified to three categories :

(a) Ion exchange and flocculation - When lime and a moist cohesive soil are mixed together, the soil becomes friable. This phenomenon is due to ;

(i) exchange of strong calcium cations of the lime replace the weaker metallic ions on the surface of the clay particles.

(ii) crowding of excess calcium cations around the clay particles.

Both processes change the electrical charge density around the clay particles and then become electrically attracted to one another, causing flocculation or aggregation. The clay particles, now acting as aggregates, behave as a silt which has a low plasticity or cohesion.

(b) Pozzolanic reaction - Another important lime-soil reaction produces a cementing action between the soil particles. Apparently, the calcium in the lime reacts with certain soil minerals to form new compounds. Usually, aluminous and silicious minerals in the soil react with the lime to produce a gel of calcium silicates and aluminates that tends to cement the soil particles in a manner similar to that produced by the hydration of portland cement, and thus contribute to bond the soil particles together.

(c) Carbonation - The carbon dioxide from the air can be adsorbed to react with calcium hydroxide in the lime to form calcium carbonate which is a weak cementitious material. These carbonates will form weak cements and also deter pozzolanic action in soil-lime mixtures.

## 2.2 Cement Stabilization

Cement stabilization consists of a mixture of pulverized soil, amounts of portland cement and water compacted to high density and protected against moisture loss during a specified curing period. As the cement hydrates, the mixture becomes a strong, durable material having higher strength than the untreated soil.

### 2.2.1 Factors Affecting Soil-Cement Mixture

#### 2.2.1.1 Properties of soil

(a) Gradation - In the granular soils the cementing action approaches that in concrete, except that the cement paste does not fill the voids in the aggregate. The more densely graded the soil, the smaller the voids the more numerous and greater the contact areas, and the stronger the cementing action. At higher void contents, the greater amounts of cement motor are required to fill the void contents and thus increasing cement content.

(b) Clay content - When the clay content in a soil increases the cement requirement increase too.

(c) Organic matter - Undecomposed regetation such as roots and twigs, the carbon compounds and other water - insoluble compounds derived from vegetation do not cause an unfavorable reaction with cement.

(d) soil pH - Laguros and Davidson (1963) reported that the soil with low pH value might have caused a precipitation of a gel over the cement particles, thus delaying and possibly prohybiting the hydration of cement.

2.2.1.2 Types of cement

Two types of Portland cement available on the market for general use in soil - cement are Type I (normal Portland cement) and Type III (high early strength Portland cement). Type I cement is usually used in soil - cement, probably because it is usually most readily available and is lower priced than Type III cement. Davidson and Bruns (1960) reported that by using Type III, the cement requirement was 1 - 4 % less than that of Type I cement.

Soil - cement requires a definite curing period prior tò the construction of additional base or wearing courses. And because curing time affects total construction time, a reduction in curing time made possible by use of Type III cement could be advantageous.

2.2.1.3 Compaction and moisture content

Compaction method seems to have some effect on the strength of soil-cement possible because of the effect of particle orientation. El-rawi (1968) compared the kneading compaction method with impact compaction on three soils. He found that for the granular soil, impact compacted samples had higher unconfined compressive strength, and for the fine-grained soil, the kneading compaction produced stronger specimens. Unfortunately, there is not sufficient data to explain any conclusion.

When cement is added, increase in density usually occur for sands and sandy soils and sometimes in small degree for heavy clays. Little or no change occurs for the light to medium clays. Decrease in density may occur in silts. Decrease in optimum moisture content occur for clays. Increase occur for the silts and little or no change takes place for sands and sandy soils.

Davidson, Pitre, Mateos and Gorge (1962) found that the optimum moisture content for maximum density and the optimum moisture content for maximum unconfined compressive strength of cement - treated sand - clay mixtures are not necessarily the same. It also suggests that the optimum moisture content for maximum strength falls slightly on the dry side for sandy soils and slightly on the wet side for clays. As clay content increases, the optimum moisture content for both maximum density and maximum strength values decrease.

The variation between the optimum moisture contents for both maximum density and maximum strength may be related to the particle size of the soils. The surface area of sands is relatively small, and most of the lubrication water provided is available for hydration of the cement. Clays, on the other hand, have a large surface area and much of the water provided for lubrication may be adsorbed resulting in insufficient water available for hydration of the cement. Thus the optimum water content for maximum strength is greater than that required for maximum density when the amounts of clay are large.

2.2.1.4 Curing time

Generally, curing is an important factor in improving the properties, especially strength and durability in soil - cement. The strength of cement stabilized soils will increase with curing time.

2.2.2 Mechanism of Soil-Cement Stabilization

When water is added to a soil - cement mixture, hydration of cement occurs and the major hydration products as hydrated calcium silicates, hydrated calcium aluminates and hydrated lime are formed. Both hydrated calcium silicates and hydrated calcium aluminates are the main cementitious compound materials and the hydrated lime is deposited as a separate crystalline solid phase. The released hydrated lime cause an increase in the pH of the pore water. The strong bases dissolve the soil silica and alumina on the particle surfaces and become reactive with the calcium ions from the hydrated lime to form insoluble calcium silicate and aluminate hydrates, which harden on curing to stabilize the soil. This mechanism has been described by Herzog and Mitchell (1963), Lambe (1959), Moh (1962), Laguros and Davidson (1963).

The reactions in a soil - cement mixture can be expressed in a simplified form as the following (Moh, 1965).

$$\text{Cement} + H_2O \longrightarrow CSH + Ca(OH)_2$$

$$Ca(OH)_2 \longrightarrow Ca^{++} + 2(OH)^-$$

$$Ca^{++} + 2(OH)^- + SiO_2 \text{ (soil silica)} \longrightarrow CSH$$

$$+ Al_2O_3 \text{ (soil alumina)} \longrightarrow CAH$$

Notations of chemical terms ;

$C = CaO$ , $S = SiO_2$ ,

$H = H_2O$ , $A = Al_2O_3$

During curing, the soil-cement mixture tends to harden due to the hydration of cement. The cement particles bind the adjacent soil grains together during hardening and develop a continuous, hard and strong skeleton. This results in the formation of a matrix of hardened skeleton enclosing unaltered soil particles. The skeleton of the cementitious material plugs some of the voids in the soil, reducing permeability and swelling and increasing the shear strength of the soil-cement mixture.

## 2.3 Lime on Cement Stabilization

Generally, Portland cement is the chemical most successfully used in soil stabilization for road and air-field construction. Almost all soils respond to treatment with cement ; however, chemical conditions of some soils and high plasticity of others have limited the use of Portland cement. Another chemical widely used in soil stabilization is lime, which has been shown to improve greatly the workability of the soil and to increase the strength of the mixture.

The soils with liquid limits greater than about 35 and plasticity indexes greater than about 20 cannot be pulverized effectively, they are usually unsuitable for stabilizing with Portland cement. However, the soils can be easily pulverized and the plasticity is reduced by adding lime to these soils, then it can be stabilized with cement effectively. This combination stabilization with lime and cement has proved beneficial in the engineering properties of soils. It seems to be uneconomical but the effectiveness should be considered.

### 2.3.1 Effect of Lime on Cement Stabilization

When lime is added to a soil, the flocculation of the clay particles will take place. Flocculation results in easier workability of the mixtures, which can be observed during the preparation of specimens from plastic soils mixtures. The effect of lime in facilitating mixing should be more noticeable. In the field, addition of lime before the cement should facilitate the achievement of the specified degree of pulverization.

The amount of lime required for complete flocculation varies with the amount of clay in the soil and other soil characteristics, such as carbonates present. The optimum amount of lime for maximum strength is well correlated with the clay content - the higher the clay content, the higher the optimum amount of lime. However, the optimum amount of lime for strength in mixtures of soil-lime-cement is equal neither to the required amount of lime for complete flocculation nor to the lime fixation capacity to which the amount of lime required for flocculation is very close. An excess of lime is known to be harmful to the hydration of cement for soil-cement mixtures. The particles of soil can not be completely surrounded by particles of cement, thus decreasing in strength of soil-lime-cement mixture. The effect of lime by addition some amounts, has improved the cement reaction with some organic soils exhibiting retarded setting and low strength.

Pinto, Davidson and Laguros (1962) studied the effect of lime on soil-cement mixtures of montmorillonitic soils, they found that the addition of lime increased the compressive strength of the mixtures. The optimum amount of lime for some soils such as plastic Loess and Kansan Till increased with prolonged curing periods.

This increasing was due to additional pozzolanic reaction by prolonged curing times.

2.3.2 Factors Affecting Lime - Cement Stabilization

The retarding hydration of cement by lime or opposing the accelerated hydration caused by clay, may explain the results obtained in the study of prolonged mixing. The strength decreased with mixing time, primarily because of the reduction in density, due to the hardening of the aggregates. The addition of lime, by reducing the formation of aggregates and retarding their hardening, decreased the reduction of strength.

The results of effect of elapsed time between mixing and compacting, showed a decrease of density and strength with the time elapsed between mixing and compacting when the molding moisture content was below or near the optimum moisture content. Use of lime minimized both the density and strength reductions due to this time lag (Pinto, Davidson and Laguros, 1962).

2.3.3 Economics of Lime - Cement Treatment

The addition of lime to soil - cement mixtures present three advantages and one possible disadvantage.

Advantage

(1) Improve the workability of the mixture, with the reduced depreciation of equipment and time required to achieve the specified degree of pulverization.

(2) The advantage stems from the effect of lime on the mixing period. Because lime minimizes the loss of strength during

this period, either a reduction in the amounts of additives or a prolongation of the mixing time can be allowed when lime is added.

(3) The advantage concerns the cost of the additives. Because the cost of lime and cement are nearly equal, the total cost of the additives is in proportion to the total amount of additives.

Disadvantage

- The disadvantage is the possible increase of operational cost of incorporating two additives instead of one.

2.3.4 Mechanism of Combination Stabilization

The reactions of either Portland cement or lime with moist soils are complex and not yet completely understood; the simultaneous addition of lime and cement to soils makes the problem even more complex. However, an attempt is made to clarify some phases of the reactions. The process of stabilization can be divided into two phases :-

(1) The conditioning phase or treatment the soil with lime.

(2) The addition of cement to form lime-cement-soil mixtures.

The mechanism of the first phase (soil-lime mixture) has been reviewed in the previous stated.

The mechanism of the second phase (soil-lime-cement mixture) is more complex and less understood than the first phase. Although the important function of cement is to increase the strength, and that of lime to reduce plasticity and improve workability, there is some degree of interaction.