

## Chapter II

### LITERATURE REVIEW

#### 1. Asphalt Emulsion Stabilization

The use of asphalt as a soil stabilizing agent has been quite extensive and is one of the older soil stabilizing method. It is useful for soil stabilization because of the cementing and waterproofing qualities. The cementing property is generally considered to be most effective in providing increased stability in non-cohesive or very slightly cohesive granular soils, such as gravels and sands. The waterproofing property is utilized to greatest advantage in the more cohesive soils or soil-aggregate mixtures. Waterproofing assists in the the preservation of the natural stability which these soils have in a dry and well-compacted condition. Two types of asphalts, at normal or slightly elevated temperatures, are suitable for mixing with soil; these are the cutbacks and the emulsions. In cutbacks, the viscosity of the asphalt cement is lowered by the use of a solvent such as naphtha, kerosene or fuel oil. In the usual emulsions, asphalt cement is reduced to colloidal size droplets and dispersed in water (8).

### 1.1 The Advantages of Asphalt Emulsion

Asphalt emulsions are widely used because they offer many advantages over cutback asphalts and paving grade asphalts. They can be used directly with damp or wet aggregates whereas, other types of asphalts are not suitable because poor coating and adhesion results unless the aggregate is thoroughly dry. Cutback and paving asphalts can be treated with additives in order to promote their adhesion to damp or wet aggregates, but this is usually expensive and often not truly effective. Asphalt emulsions are safer to use than cutback asphalts since they do not, as a rule, contain solvents nor do they have to be heated to extremely high temperatures as do paving asphalts. Asphalt emulsions possess a further advantage over cutback asphalt since mixes made with them develop cohesion in the field much more rapidly and thus are able to resist damage by traffic earlier. Another advantage of this type of asphalt for utilizing in the field of soil stabilization is that only simple mixing and spreading equipment are required. Special equipment is not needed to dry the aggregate nor is equipment needed to heat the emulsion, as is usually required with other asphalt products (3).

### 1.2 Theory of Asphalt Emulsions

An emulsion is a two-phase system consisting of two immiscible liquids, one of which is dispersed in the other in the form of very fine droplets. Where the dispersed, or internal, phase is an oil and the continuous phase is water, then the emulsion

is known as the oil-in-water type. The reversal occurs when the water is the internal phase and oil is the continuous phase, the emulsion is of the water-in-oil type. But the system is unstable, that is the internal phase will coalesce, unless an emulsifying agent (emulsifier) is present in the system. With the presence of emulsifier, an adsorbed film of the emulsifier is formed round each globule in the emulsion, this film acting as a protective coating which affords a considerable resistance to coalescence of the globules (3,15).

### 1.3 Types of Asphalt Emulsion

Asphalt Emulsions may be divided (according to the types of emulsifiers) into four main groups of which the first two are by far the most important :

- (a) Anionic emulsions.
- (b) Cationic emulsions.
- (c) Nonionic emulsions.
- (d) Colloidal emulsions.

Since nonionic emulsions and colloidal emulsions are of very limited use in highway constructions (3), the further discussion will be made only on anionic and cationic emulsions. The emulsions which have the negative charge on the emulsified asphalt droplets are defined as anionic emulsions. Cationic emulsions, conversely, are those which have the positive charge on the emulsified asphalt droplets (3,15). Cationic emulsions possesses many advantages over anionic emulsions. They can be used with nearly all types of aggregates; on the other hand, the anionic emulsions, though suitable

for use with limestone and similar aggregates, are difficult to use with silicious aggregates. Cationic emulsions extend the paving season for they can be used in cool weather, especially in the spring, and are not as easily damaged by sudden showers as are anionic emulsions because the cationic emulsifiers are natural adhesion agents for asphalt-aggregate systems (2,10,21).

#### 1.4 Electrochemical Property of Aggregates

It is commonly accepted that the electrochemical property of the aggregate determines whether good adhesion will be obtained with liquid asphalts and asphalt emulsions. This important property is the nature of the electrical surface that the aggregate possesses when it is in contact with water. By this condition, the aggregates may be classified into two groups (3). Those which bear the negative surface charge in the presence of water are known as electronegative aggregates. Silicious aggregates, including silty sand and beach sand, are examples of this type of aggregates. On the other hand, some types of aggregate (such as limestone and other calcareous materials), which bear positive charge on the aggregate surface are defined as electropositive aggregates. However, in most aggregates, both types of charges are present. These aggregates not only contain silicon which will permit a surface to have some negative charges, but also contain calcium, magnesium, aluminum or iron, which will permit the surface to have positive charges.

#### 1.5 Mechanism of Emulsion-Aggregate System

Whether a given asphalt emulsion-aggregate combination

will results in a mix that is well coated and has good adhesion is determined to a great extent by the charge on the emulsified asphalt droplet on the one hand and the aggregate on the other (10). Thus, if the charges are different, one may expect good coating and adhesion, but, if they are similar, the prospects of obtaining a good asphalt-aggregate bond are considerably poorer. By this concept, successful results could be obtained when anionic emulsions were used with the electropositive aggregates, such as many of the limestones. In these instances, the difference in surface charge between the emulsified asphalt droplet and the aggregate surface will promote cohesion (Figure 1 a). In this system, the anionic emulsifier functions as a "bridge" between the asphalt and the aggregate. On the other hand, anionic emulsions sometimes could not be used with electronegative aggregates, such as silica and quartz, because the charges on the emulsified asphalt droplet and the aggregate particle were similar. The asphalt and aggregate surfaces repelled each other, and, thus good coating and adhesion were difficult to obtain.

According to Mertens and Wright (10), good adhesion between the electronegative aggregates and an emulsified asphalt became feasible when cationic emulsifiers became available. These emulsifiers, because of the positive charge they place on the emulsified asphalt droplet, are attracted to the surface of the electronegative aggregate as shown in Figure 1 b. As the emulsifier is being drawn to the surface of the aggregate, the nonpolar tail of the emulsifier pulls the asphalt to the surface too. Consequently, the cationic emulsifier functions as the "bridge" or bonding agent,

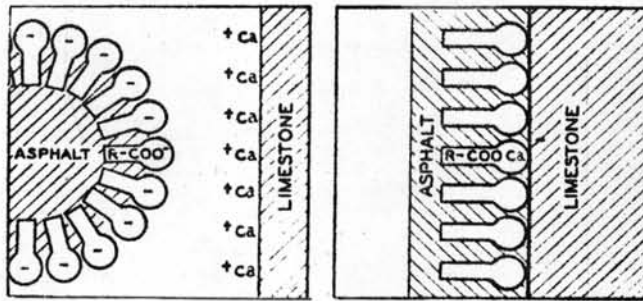


Figure 1a. Action of Anionic Asphalt Emulsion upon Calcareous Aggregates (10).

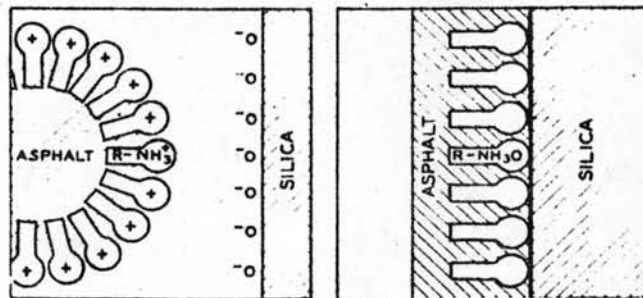


Figure 1b. Action of Cationic Asphalt Emulsion upon Silica Aggregates (10).

just as the anionic emulsifier serves the same purpose in the anionic emulsion-electropositive aggregate system.

#### 1.6 Effect of Emulsion on Shear Strength of Stabilized Sand

Because the shear strength of sand is due entirely to its frictional properties, its strength is a function of its porosity and the confining stresses to which it is subjected. The addition of bitumen as a binder has the effect of giving unconfined sand some cohesive strength; but, in general, it also reduces the angle of shearing resistance. Different proportions of bitumen in sand will result in varying values of cohesion and angles of shearing resistance, but it is important to realize that the strength exhibited by stabilized sand may also be influenced by numerous variables, both natural and manmade. For a given sand, stabilized with a particular percentage weight of emulsion, the strength actually measured can vary significantly with type of test used to measure strength; rate of loading; efficiency of mixing; density to which the material is compacted; moisture content; confining stresses to which the specimen is subjected; temperature at which it is mixed, cured, and tested; and age of the specimen. Because mixes containing different emulsion contents have their strength changed by different amounts of these variables, the optimum emulsion content for one set of conditions is generally different from that for another set of conditions.

Dunn and Salem (4) reported that small percentage of bitumen impart cohesive strength without preventing contacts being formed between sand grains, which are necessary to mobilize frictional resistance.

As the proportion of bitumen is increased, the effects are (a) to improve particle coating and increase the area of bitumen that has to be sheared and (b) to increase the VMA and, therefore, reduce the degree of particle interlock and the shearing resistance normally mobilized in dilating the sand. When the bitumen content exceeds the optimum for that set of conditions, the bitumen will tend to act as a lubricant separating the sand particles. Lees (9) has found that the angle of shearing resistance fell linearly with bitumen content.

## 2. Lime-Emulsion Stabilization

As it is found that stabilization by using asphalt alone does not much improve strength, the process of employing emulsion with lime as stabilizers have been developed. By so doing, the properties intermediate between those of soil-emulsion and soil-lime can be obtained. Thus, the material finally produced will possess some rigidity and be fairly waterproof. The literature indicates that this type of stabilization may prove to be an economical and effective method of upgrading certain fine-graded materials that do not react with lime, require large quantities of cement, or cannot be blended readily with bituminous materials (16).

Before making any other discussions about this type of stabilization, some attention should be firstly paid to such case of soil-lime mixture.

### 2.1 Lime Stabilization

Lime is relatively inexpensive and can often be used to produce both a chemical change and a cementing action that will improve the soils.



Lime-soil mixtures are soils that had their physical characteristics changed and/or the soil grains cemented together by action of lime with the aid of water.

2.1.1 Mechanisms of Soil-lime Stabilization When lime is added to a moist soil, several types of chemical reactions will take place. Some of these reactions have been identified and are understood to a certain extent. The most important of these reactions for stabilization seem to fall into three general categories (5).

(a) Ion Exchange and Flocculation - When mixed with a moist soil; lime will dissociate into  $\text{Ca}^{++}$  (or  $\text{Mg}^{++}$ ) and  $(\text{OH})^-$ . As a result, two processes will take place. One, known as a base-exchange reaction, occurs with  $\text{Ca}^{++}$  ions of the lime replacing the weaker metallic ions, such as sodium and hydrogen, on the surface of the clay particles. Another process is the crowding of excess  $\text{Ca}^{++}$  ions of the lime onto the surface of the clay. Both processes materially change the number of electrical charges on the surface of clay particles. As this chemical reaction between the lime and the soil takes place, the soil becomes more friable and the plasticity is lowered.

(b) Pozzolanic reaction - This reaction of lime and soil will produce a cementing action between the soil particles. The 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.

(c) Carbonation - This reaction is a reversal of the lime - processing process. The calcium hydroxide lime reacts with carbon dioxide ( $CO_2$ ) absorbed from the air to form calcium carbonate. Not only do these carbonates form weak cements but they also deter pozzolanic reaction and prevent normal strength development.

2.1.2 Effects of lime on soil It is generally agreed that lime influences the following physical characteristics of a soil : grain size distribution, soil plasticity, volume change, field moisture equivalent, soil pressure compaction and optimum moisture content, strength and durability (5). Only some of these physical changes are discussed herein.

(a) Grain size distribution - When lime is added to a fine-grained soil, the change in grain size distribution will take place. Through the process of agglomeration or flocculation of clay particles, a coarser and more friable soil is produced.

(b) Soil Plasticity - Another noticeable phenomenon that is mentioned in almost every article on lime stabilization is the ability of the lime to change the plasticity of the soil. The plastic limit of a soil is normally increased as additional amounts of lime are added to the soil. In the case of liquid limit, although the decrease in the liquid limit with increased amount of lime is usual, but it does not occur in all soil. In some soil distinct increase in the liquid limit is produced by adding lime. Regardless of whether the liquid limit decreases or increases, the increase in plastic limit is such that the plastic index is usually reduced with the addition of

small amounts of lime.

(c) Volume Change - As lime is added to a soil the volume change tends to be reduced. As the lime content in the soil increases, the shrinkage limit increases and the shrinkage ratio decreases. The shrinkage limit and the plasticity index of a soil appear to be related. As the plasticity index tends to drop when the lime content increases, the shrinkage increases; and where there is little further change in the plasticity index there is little change in the shrinkage limit.

(d) Compaction and Optimum Moisture Content - When compacted with the same effort, a soil-lime mixture has lower standard AASHTO T99 density than the original soil without lime, and as the lime content increases, the density tends to decrease even more. The decrease in unit weight is small and average about 2.5 percent for most soils. In the case of optimum moisture content, as lime is added to 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. Once the large initial increase in optimum moisture content takes place, additional lime produces only a slight increase in the optimum moisture content.

(e) Strength - In general, lime increases the strength of almost all types of soil, but the amount of strength increase depending on many factors, such as lime content, type of lime, density and the time and type of curing. Unlike many soil stabilizers, there appears to be no optimum lime content that will produce a maximum strength in a lime-stabilized soil under all conditions. Some data, however, have

been presented that indicate the relationship between the strength and the lime content in the soil to be such that an optimum lime content does exist. Such data were usually obtained for only one particular of curing time. If a different curing time was used a different optimum lime content would be indicated. Lime - stabilized soils increase in strength with age in a manner similar to Portland cement concrete. Usually, there is a rapid increase in strength of these mixtures at the beginning period, but as the curing progresses the rate of increase in strength becomes less and less.

## 2.2 Mechanisms of Soil-Lime-Emulsion Stabilization

The mechanisms of lime-emulsion stabilization may be divided into two phases: 1) the conditioning phase that results when the soil is treated with lime and 2) the waterproofing phase that occurs when soil-lime mixture is mixed with emulsion (16).

In the conditioning phase, a small percentage of lime (1-4%) is added and thoroughly mixed with the soil. As previously reviewed, the mechanisms of soil-lime stabilization are composed of three important processes : 1) exchange and flocculation, 2) pozzolanic reaction, and 3) carbonation. The changes in physical properties that take place through these processes of soil-lime stabilization have been already discussed in the previous section.

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The mechanism involved in waterproofing phase is the same as in soil-emulsion stabilization. Emulsion is mixed with the soil-lime mixture to preserve the compaction water content in order to retain natural compacted stability and prevent moisture content fluctuations

which can cause high volume changes in fine-grained soil.

### 2.3 Engineering Properties of Soil-Lime-Emulsion

A review of lime-bitumen combination stabilization indicates that with increased lime content at a constant bitumen content, the stability should increase and the percent swell and water absorption should decrease. When lime is added to a plastic soil, the soil becomes silty in texture, more workable, but the compacted soil also becomes more permeable. The bituminous material is added for the purpose of waterproofing the soil-lime mixture and also decreasing its permeability. It is therefore possible, that a highly plastic soil, if properly blended with only bitumen could be more impermeable and less susceptible to the adverse effects of water than the sand soil treated with a low percentage of lime and the same percentage of bitumen. The lime treatment may increase the permeability but yet not improve the workability to the extent that the bitumen can be properly blended to make the compacted soil reasonably impermeable (16).

Puzinauskas and Kallas (12) reported that the Maryland soil with 4 percent lime treatment would have about the same soaked strength as the with a combination of 4 percent lime and 5 percent asphalt treatment. This may be concluded that asphalt did nothing to increase stability of soil-lime mixture. However, the asphalt-lime combination was found to be more durable and less susceptible to water absorption than the lime-treated mixture. Robnett and Thomson (16) reviewed that the trends of strength and durability of soil-lime mixtures treated with cutbacks or emulsions are similar to

bitumen-treated soil mixtures.

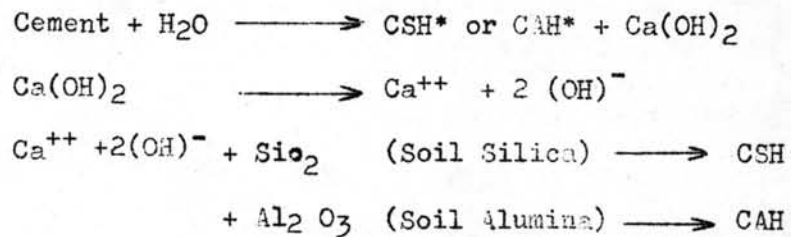
### 3. Cement-Emulsion Stabilization

The process of employing bituminous emulsion in conjunction with cement as stabilizers have been developed in Britain (18). The emulsion, which was specially developed for the purpose, will remain stable for a short time when mixed with fine-grained soils thus promoting good dispersion of the bituminous phase throughout the soil. The cement that is added subsequently: (a) causes the emulsion to break, (b) absorbs some of the resulting free moisture, and (c) give added strength to the processed and compacted soil when it has hardened. The proportions of admixtures generally required are 5 to 7½ percent emulsion and 3 to 5 percent cement. The final emulsion is said to possess properties intermediate between those of soil cement and true soil-bitumen.

#### 3.1 Mechanisms of Soil-Cement-Emulsion Stabilization

In the soil-cement-emulsion system, since cement is added later to the soil-emulsion mixture, the effective action of cement with silica and/or alumina will be partially prevented by the coating of emulsion. Unfortunately, there has been a few limited literatures concerning soil-cement-emulsion stabilization, some of them had not been discussed clearly and lacked data to support their idea. The mechanisms of soil-cement-emulsion may be expected to be divided into two phases. Waterproofing phase occurs after the soil is treated with emulsion. This is as same as in soil-emulsion stabilization. When

cement is added to soil-emulsion mixture, the reaction between cement and soil particles (which were partially coated with emulsion) will take place. This is known as cementation phase. The primary process of this phase is the hydration of cement, which calcium silicate hydrates and/or calcium aluminate hydrates are formed and the hydrated lime is released. In the secondary process, the reaction between calcium ions from the released hydrated lime and soil particles will produce additional cementitious compounds (6). The reactions occurred in the cementation phase are similar to those which take place when a soil is treated with cement. The reaction in a soil-cement mixture can be expressed in a simplified form as the following (11) :



### 3.2 Effects of Cement on Soil Properties

3.2.1 Soil Plasticity When cement is added to a plastic soil, its plastic properties will be reduced (7). Normally, cement changes the plasticity by increasing the plastic limit and thus reducing the range within the material is plastic. Cement may also change the liquid limit, but to a lesser degree. In the fine-grained silty and clayey soils, the cement, on hydration, develops strong linkages among and between the mineral aggregates and the soil aggregates to

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\* CSH : Calcium Silicate Hydrates  
CAH : Calcium Aluminate Hydrates

form a matrix that is effective in fixing the particles so they can no longer slide over each other. Thus the cement not only destroys the plasticity but also provides increased shear strength. The surface chemical effect of the cement reduces the water affinity and thus the water holding capacity of the clayey soil.

3.2.2 Volume Changes Admixing cement to cohesive soils reduces shrinkage because the cement matrix tends to restrain the movement of the soil. For noncohesive granular soils that in themselves exhibit little or no shrinkage, admixing cement results in small shrink, which is related to cohesion associated with the cementing action. Thus cement-treated mixture made with sand exhibit some slight shrinkage and cracking. Increasing the cement content decreases the total shrinkage of cement-treated mixtures made from soils that exhibit volume change without cement (7).

3.2.3 Compaction and Optimum Moisture Content. When cement is added to sands and sandy soils, the density tends to increase. Little or no change takes place for the light to medium clays. Decreases in density may occur in silts. Cement usually decreases optimum moisture content of clays, but for sands and sandy soils, little or no change occurs. The optimum moisture content of cement-treated mixture made with silts tends to increase.

3.2.4 Strength Cement-treated soil develops values of cohesion and internal friction that are markedly higher than values for the raw soil (19). Balmer (1) studies the shear strength characteristics of two granular and two fine-grained soils by using undrained triaxial tests. The triaxial shear results in terms of total stress,