Principles of Soil Stabilization

by

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A problem continually facing an engineer is that dealing with procedures and techniques by which otherwise unsuitable subgrades may be improved by means of stabilization. In many instances, subgrade soils which are unsatisfactory in their natural state can be altered by admixtures or quantities of aggregate, or by proper compaction, and thus made suitable for highway subgrade construction. In its broadest sense, soil stabilization implies improvement of soil so that it can be used for subbases, bases, and in some rare instances, surface courses. As in all engineering design problems, the economics of the problem in light of the benefits derived from the stabilization procedure will determine whether the stabilization process is warranted.

It is well at this point to review the basic principles of pavement design, so that stabilization can be put into its proper perspective. It is to be recalled that a rigid pavement derives its load supporting capacity primarily from the strength characteristics of the pavement proper. Therefore, the economic use of base courses from the structural standpoint is open to question. However, base courses may be used under rigid pavements for control of frost action, drainage, pumping, to prevent shrinkage and swell of the subgrade soil, and other reasons. Therefore, if a stabilized subgrade is to be used under a rigid pavement it should be one which imparts these useful qualities to the subgrade soil.

In contrast to rigid pavements, flexible pavements derive their load supporting capacities not from resistance to bending of the slab, but rather by distributing the load down through a finite thickness of pavement so that pressures on the subgrade will not be excessive. Stabilization for this type of pavement logically is one which will impart additional strength to the subgrade soil, or one which will improve a borderline subbase material so that the unsuitable materials can be used for subgrade or base course construction.

The high pressures exerted on the pavement and base course generally preclude the use of stabilized soil for bases and therefore stabilization, except for secondary roads, is centered around use in subgrades and subbases.

For secondary roads stabilization (particularly by mechanical means) can be used as the principal component of the pavement. These could include gravel surfaces of all types, soil-cement, or oiled earth surfaces.

Many types of stabilizers have been proposed for use in highway and airport construction. It is the purpose of this paper to categorize various types of stabilizers and to indicate how each affects a soil.

TYPES OF ADMIXTURES

For purposes of this discussion, the various types of stabilizers have been categorized depending upon the properties imparted to the soil. These are summarized in Table 1. The types of admixtures include cementing agents, modifiers, water proofing agents, water retaining agents, water retarding agents, and miscellaneous chemicals. The behavior of each of these admixtures is vastly different from the others and each will have its particular use and conversely, each will have its own limitations.

Considering first the cementing agents, the materials which may be used include Portland cement, lime, a mixture of lime and fly-

TABLE 1
TYPES OF STABILIZATION

TYPE OF STABILIZATION	ADMIXTURES
Mechanical	None
Cementing Agents	Cement
	Lime
	Lime-Fly Ash
	Sodium Silicate
Modifiers	Cement
	Lime
	Bitumen
Water Proofing Agents	Bitumen
	Membranes
Water Retarding Agents	Organic Cationic Compounds
Water Retaining Agents	Calcium Chloride
	Sodium Chloride
Miscellaneous Chemicals	Resin
	Calcium Acrylate
	Sulphite Lignin

ash, and sodium silicate. Portland cement has been used extensively in many states in the improvement of existing gravel roads as well as in stabilizing the natural subgrade soils. Its use includes base courses and subbases of all types. Soil-cement gains its strength by hydration of the cement.

Another cementing agent that is often used in the southern states is hydrated lime. Lime will impart strength to a soil primarily by a reaction between the free lime and the silica and alumina of the soil. This material is best used in granular materials and lean clays; the quantity required for a proper hydration generally is relatively low. Lime-soil mixtures are generally susceptible to freezing and thawing action, thus, limiting their use to regions of mild climate.

Another admixture that has come into rather extensive use in recent years is the use of lime and fly ash admixtures. Fly ash is a by product of blast furnaces and is generally high in silica and alumina; therefore, the addition of lime and fly ash will speed the reaction mentioned above. Generally, however, the quantity of fly ash required for adequate stabilization is relatively high, making its use restricted to areas which have available large quantities of fly ash at relatively low cost.

Many times, the use of a cementing material to cause actual hardening of a soil is restricted due to cost, and therefore, low quantities of the material may be added to the soil merely to modify it rather than to impart actual cementing action. Modifiers which are often used include cement, lime and bitumen. Cement and lime will change the water film on the soil particles, will modify the clay minerals to some extent, and will decrease the plasticity index. Small amounts of bituminous materials are often used in aggregates containing an excess of fines where the action of the bituminous material is merely to retard moisture absorption in the clay fraction in the soil-aggregate mixture. These modifying materials are generally best adapted to use in poor quality base course materials which can be improved to some extent by the modifiers.

The next category of stabilization includes the waterproofing materials. Foremost among these are the use of bituminous materials to coat the soil or aggregate grains, which will retard or completely stop absorption of moisture. Bituminous stabilization is best suited for sandy soils or poor quality base course materials and its benefit is derived by driving off the volatile constituents of the bitumen just prior to compaction. In recent years, the use of membranes for retarding or stopping movement of moisture in soil has come into popularity. These include enveloping a subgrade soil in a sheet of asphalt or wrapping the soil in a common plastic. Since the action of these waterproofing agents is merely to retard or hold back the movement of moisture, it is essential that these materials be compacted to relatively high densities, to take advantage of all the inherent stability of the soil which is to be stabilized.

In contrast to the above, some chemicals will increase the rate of water absorption. These include calcium chloride and sodium chloride. These materials will lower the vapor pressure of soil water, will lower the freezing point of the soil water, and thus, can be used with satisfaction for a construction expedient to retard evaporation of the soil water during construction or in some cases prevent freezing of the soil water mixture also during construction.

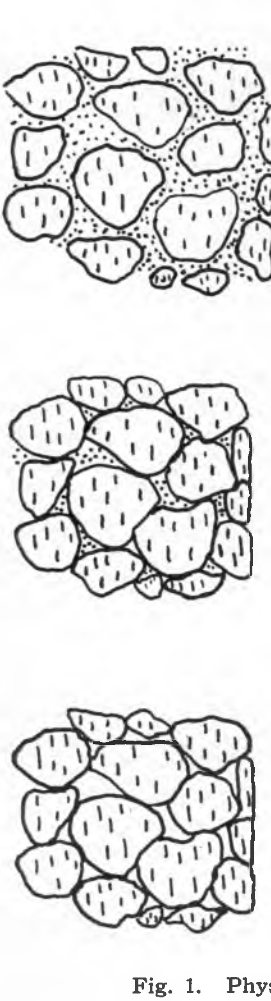
Many other chemicals are available for stabilization. These, by and large, include organic cationic compounds which will render a soil hydrophobic. These chemicals will decrease rate of water absorption to a minor extent, but in general are costly, thus limiting their widespread use. The following paragraphs will outline in detail various features of each of the above mentioned stabilizing materials. It should be kept in mind that the proper choice of an admixture will depend upon the use for which it is intended, and upon the mechanics by which the stabilizer will stabilize the soil.

PROCESSES OF STABILIZATION

Mechanical Stabilization

Mechanical stabilization is a process used to increase both the strength and the durability characteristics of soil-aggregate mixtures by the utilization of the proper combination of binder soil with coarse and fine aggregate. Mechanical stabilization is not only the earliest form of designed and controlled stabilization, but the techniques used in obtaining mechanical stabilization are frequently common to other types of soil stabilization.

Three principal factors controlling the stability of soil aggregate mixtures are: (a) the gradation of the aggregate, (b) the proportion of the soil (minus 200 sieve) to the aggregate, and (c) the plasticity of the fine constituents. Of these factors the proportion of the soil to the aggregate is perhaps most important. Fig. 1 shows three general states of soil-aggregate mixtures. As given in this figure the best gradation is one where the stability is derived by grain contact. Whenever an excess of fines is used the contact between individual grains is destroyed with resulting loss of stability.



(a) Aggregate With No Fines	(b) Aggregate With Sufficient Fines For Maximum Density	(c) Aggregate With Great Amount of Fines
Grain to Grain Contact	Grain to Grain Contact With Increased Resistance Against Deformation	Grain to Grain Contact Destroyed, Aggregate "Floating" in Soil
Variable Density	Increased Density	Decreased Density
Pervious	Practically Impervious	Practically Impervious
Non-Frost Susceptible	Frost Susceptible	Frost Susceptible
High Stability if Confined, Low if Unconfined	High Stability in Confined or Unconfined Conditions	Low Stability
Not Affected by Adverse Water Condition	Not Affected by Adverse Water Condition	Greatly Affected by Adverse Water Condition
Very Difficult to Compact	Moderately Difficult to Compact	Not Difficult to Compact

Fig. 1. Physical states of soil-aggregate mixtures.

Fig. 2 shows the relationship of density and stability and quantity of fines for a soil-crushed stone mixture. It is to be noted that density and stability are not necessarily related but that the quantity of fines is extremely important.

Soil-Cement

Stabilization of soil with cement consists of adding Portland cement to a pulverized soil, and permitting the mixture to harden by hydration of the cement. The factors which affect the physical

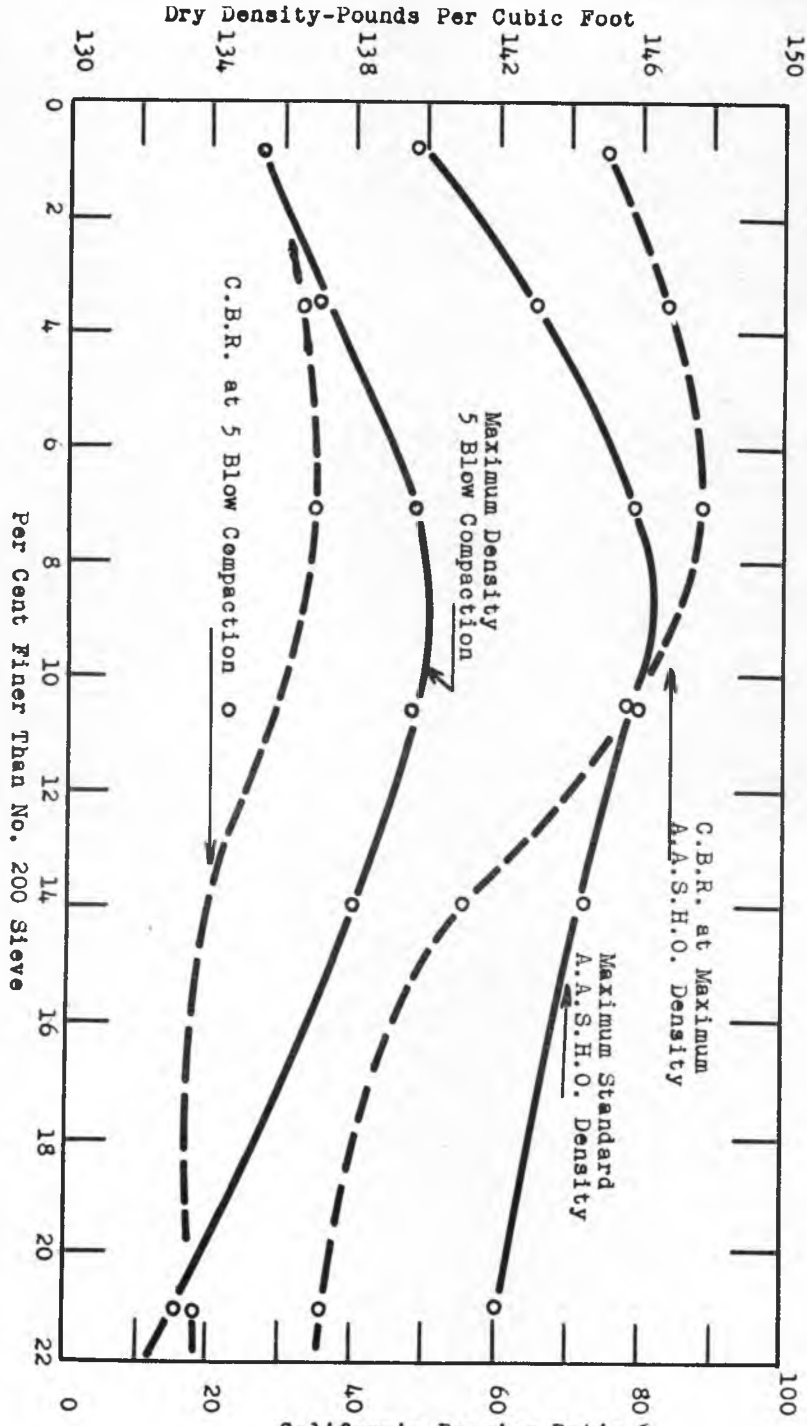


Fig. 2. Variation of density and California Bearing Ratio with quantity of fines (crushed stone).

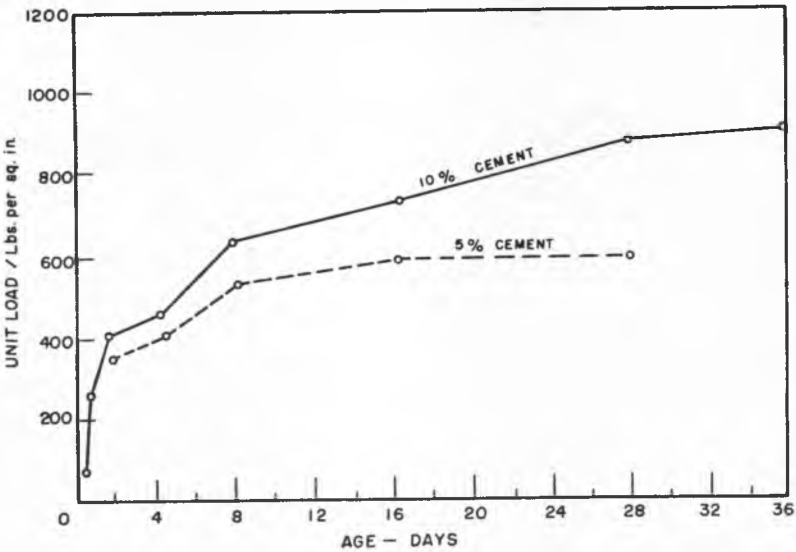


Fig. 3. Influence of curing time on compressive strength for a typical silty clay (A-4).

properties of soil-cement include soil type, quantity of cement, degree of mixing, time of curing and dry density of the compacted mixture.

Cement will generally result in decreased density when compared to the natural soil, although this factor is not significant when considering the physical characteristics of the mix since soil-cement if cured in the presence of moisture will hydrate much as concrete hydrates.

Since cement will hydrate, thus making the mixture of soil and cement a hard material, it can successfully be used as a base course in some situations. These include low-cost roads of all types. Soil-cement has been used extensively in stage construction where existing gravel roads are scarified and then recompacted. A most important factor that must be considered is curing time of the compacted soil-cement mixture. Fig. 3 shows the effect of curing time on strength of soil-cement. It is essential that the mixture be cured in the presence of water before it is opened to traffic.

Soil-Lime

Lime has been used with varying degrees of success by various highway departments. Generally, use of lime should be restricted to warm to moderate climates since lime stabilized soils may be susceptible to breakup under freezing and thawing.

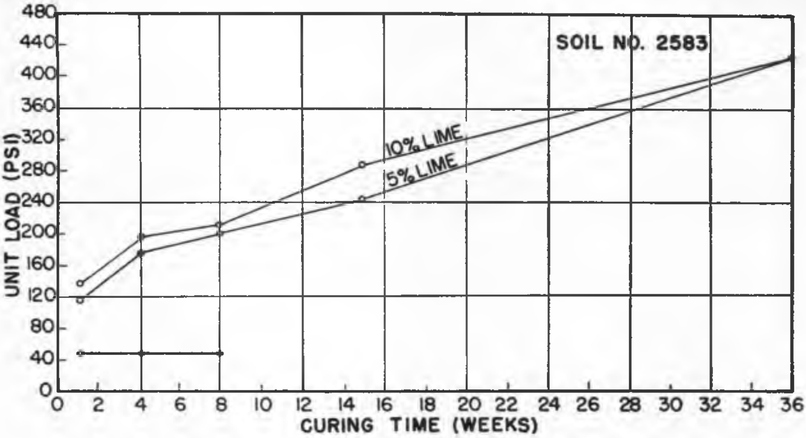


Fig. 4. Influence of curing time on compressive strength.

Lime will generally bring about a decrease in soil density, change the plasticity properties of soil, and increase soil strength. The action of lime in soil can be explained by three basic reactions. The first of these reactions is alteration of the water film surrounding the clay minerals. The strength of the linkage between two clay minerals is dependent on the charge, size, and hydration of the ion. The calcium ion, divalent, binds the soil particles close together, which in turn decreases plasticity and results in a more open and granular structure.

A second process by which lime will change a soil is that of coagulation, or floculation of the soil particles. The amount of lime ordinarily used in construction (5 to 10 per cent by weight) results in a concentration of calcium ion greater than that actually needed.

The third process by which lime affects soil is reaction of the lime with soil components to form new chemicals. The two principal components of soil which will react with lime are alumina and silica. This reaction is a long-term reaction (see Fig. 4) and one that results in greater strengths if lime-soil mixtures are cured for a period of time. This reaction is known by some investigators as "pozzolanic action."

Soil-Bitumen

Stabilization of soil with cut-back asphalts, road tars, and asphalt emulsions is quite satisfactory for coarse grained or granular soils. Its use in plastic soils, however, is difficult.

Two broad concepts may be used regarding bituminous stabilization. Both have a definite application, both also may have limitations in their application. These are as stated below:

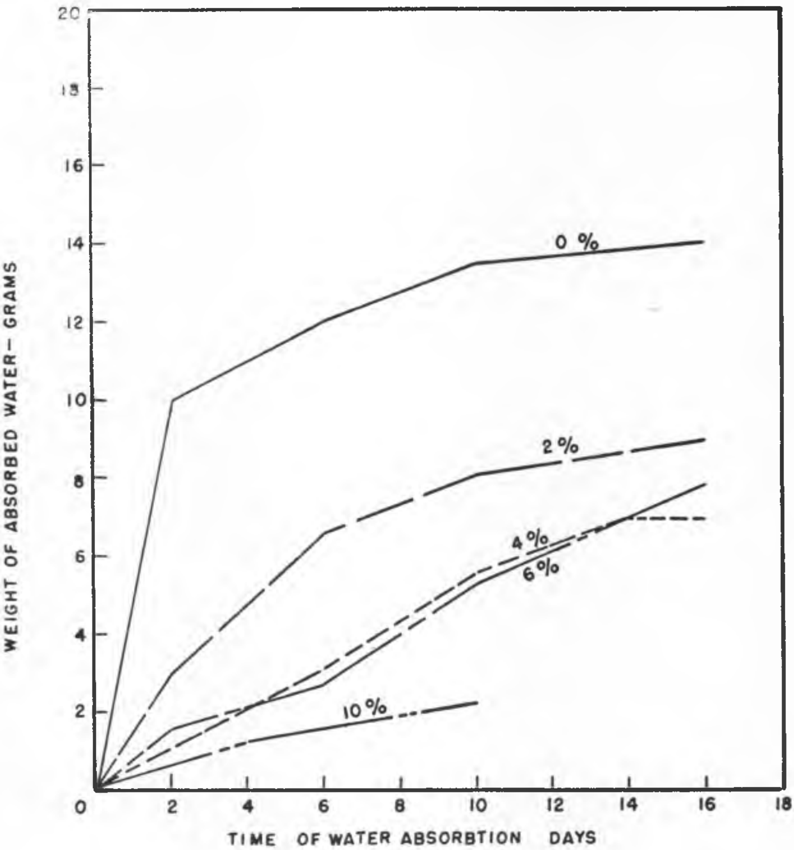


Fig. 5. Water absorbtion of a typical sandy clay with SC-1 admixture.

1. Use a design criteria based on cementation and thus use strength as a criteria.
2. Attempt only to waterproof the soil in order to maintain the inherent strength of the stabilized material under all conditions of weathering.

The advantage of the first concept is that one obtains maximum stability for continued traffic. This in effect is the type of stabilization utilized in road mix jobs where existing road metal on county roads is improved during stage construction. This type of stabilization is in most cases effective; however, one distinct disadvantage is the relatively high cost of stabilization.

The second concept of stabilization deals with low quantities of bituminous materials merely to waterproof the fines. For this case, stability of the mix is not used as a criteria, but rather water

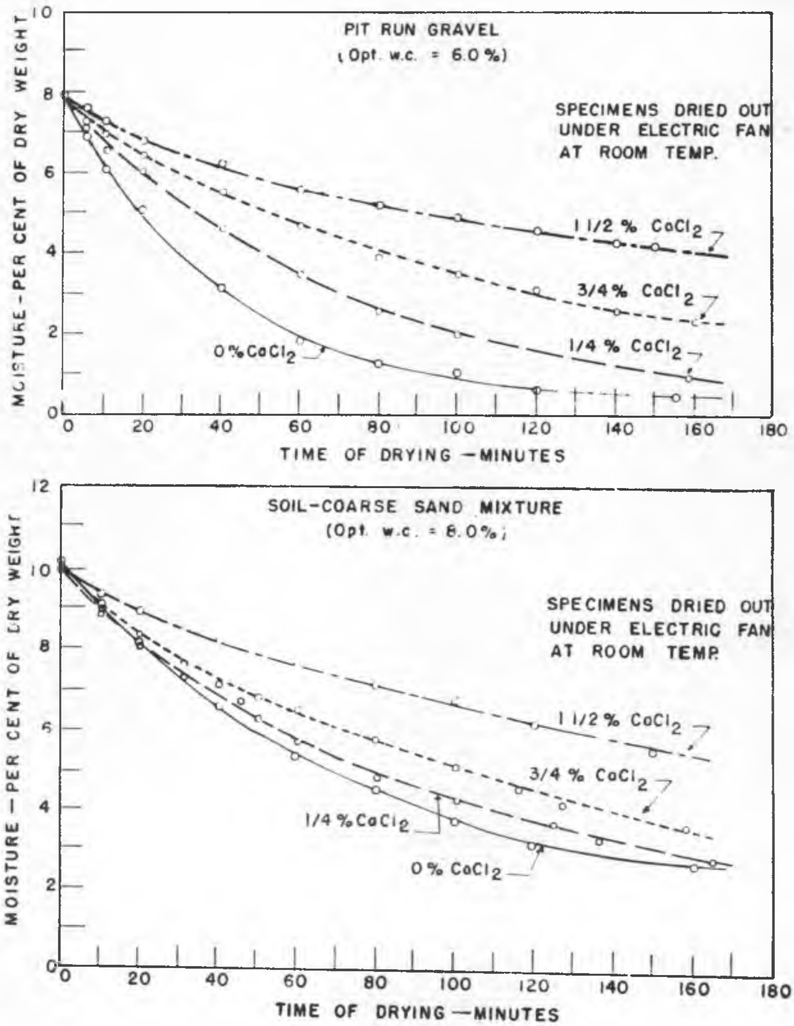


Fig. 6. Effect of calcium chloride on retarding drying of two granular materials.

absorption is the governing factor. This type of stabilization leans heavily on a thorough study of the inherent stability of the material with and without the admixture.

The principal advantage of this latter procedure is low cost of stabilization. As is the case in all types of stabilization, the ultimate criteria is benefit derived for the lowest cost. Therefore, it is essential that all of the inherent strength of the stabilized soil be utilized to its utmost so that the waterproofing process will result in appreciable retention of strength over that of the natural, unstabilized soil.

Fig. 5 shows the effect of the quantity of admixture on the water absorption characteristics of a typical sandy clay soil. Additions of small amounts of the admixture will alter the water absorption characteristics sufficiently. However, an apparent optimum amount can be used where the addition of increasing amounts of the admixture shows decreasing benefits derived.

Calcium Chloride

The reaction of chloride and soil is brought about largely, by changes in the soil water itself. Thus the beneficial effects of salts are realized by lowering the freezing point of soil water and decreasing the rate of evaporation of soil water. This later property is one of the most important properties of these admixtures.

Regarding the moisture attraction property of calcium chloride it has been reported that when used in soil binder of gravel roads it will take up four to ten times its own weight at night, and retain from ½ to ⅔ of this amount during the day.

The chlorides also lower the vapor pressure of water. This phenomenon results in a slower rate of evaporation of water from soil in which calcium chloride is used. This property is illustrated in Fig. 6 for calcium chloride.

Another property of these materials that helps reduce rate of evaporation is that of increasing the surface tension of water (see Fig. 6). This property is not only effective in reducing the rate of evaporation but the soil-moisture films are stronger than those of water. Aside from the changes in the properties of soil water, the chlorides also affect the soil to some extent from the standpoint of base exchange. Data on this particular point are meager at the present time.

Some saving in strength is realized over that of a natural soil during freezing and thawing. This is attributed to the lowering of the freezing temperature of the soil water. Since the addition of these admixtures imparts no cementing action to the soil and since the effect during freezing is merely that of reducing the freezing temperatures, the use of this type of admixture for freeze-proofing soils in extremely cold climates is not justified.

SUMMARY

In the final analysis, the choice of the admixture to be used will depend upon the economics involved. The first question that should be answered by the engineer is "Should stabilization be attempted at all?" In some cases it may be economical merely to increase the compaction requirements or, as a minimum, to resort to increased pavement thickness.

The purpose of the road is to carry the traffic across it under all climatic conditions. If an all-purpose road can be constructed utilizing locally available materials such as pit-run sand and gravel for subbases, the use of chemical admixtures is open to question. However, if border line materials are encountered, definite consideration should be given to stabilization. Faced with the problem of choosing the proper admixture may cause an inexperienced individual to become hopelessly confused by the vast amount of materials available for use.

However, if one considers the mechanics of stabilization, it is possible to determine whether stabilization should be attempted and types to use. Many of the miscellaneous admixtures will not impart sufficient strength to a soil to make the use of these justifiable unless they are available at low cost and in large quantities at a particular location. Too great an emphasis should not be placed upon the effect of admixtures upon soil density and plasticity, except in cases where some modification of the natural soil is indicated, such as for low grade sandy gravels. A series of laboratory tests made in a logical manner should be carried out before an attempt is made to choose an admixture. The strength characteristics of the natural material can be compared to the stabilized material and these data used in conjunction with durability tests. Cost data will form the basis of a logical choice. If this procedure is followed at all times, the most economical design from the standpoint of initial cost and future maintenance cost can be made. It must be emphasized that each individual problem must be analyzed on its own merits before this can be accomplished.

Even though some means of stabilization is indicated, this cannot be a substitute for proper drainage of the roadway, proper utilization of ditches and good compaction and other good sound construction practices.