

Stabilization of Fine-Grained Soils with Cutback Asphalt and Secondary Additives

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● **GROWING SHORTAGES** of quality road-building aggregates in many areas of the United States, coupled with the ever-growing need for roads, undoubtedly will result in greater use of inferior aggregates and soils. Inasmuch as present standards governing the quality of roads will not be downgraded, the means must be found to upgrade these inferior materials. This is evident in the report of Highway Research Board Special Committee on Highway Research Priorities (Special Report 56), which regards improved knowledge of aggregates and soils as a research area of critical importance. This committee estimates that almost one-third of the total \$34 million of highway research expenditures over the period of five years should be spent for that purpose.

Because soil stabilization falls in this research area, it can be expected that the stabilization of soils with asphalts will increase in significance and importance.

The stabilization of soils with asphalts (as with any other stabilizing agent) can be defined as a treatment of a natural soil so that, after compaction or consolidation, it will provide a water-resistant and stable structural pavement layer of adequate load-bearing qualities under the anticipated traffic and environmental conditions.

A variety of materials has been used to stabilize natural soils. Depending on the mechanism of stabilization these stabilizers may be subdivided into three general groups:

The first group includes materials which cement the soil particles. These materials, capable of reactions within themselves or with certain soil constituents in presence of water, produce strong interparticle bonds which can support high intensity loads. Typical representatives of this group are portland cement limes, and more recently acidic phosphorus compounds. The soil stabilized with these materials may possess high initial strengths. But, because of inherent nature of the bonds formed, it lacks desirable durability characteristics when exposed to such environmental conditions as drying-wetting or freezing-thawing. Additionally, in the case of fine-grained soils, the quantities of such stabilizers required to produce adequate initial strengths often are economically prohibitive.

A second group of stabilizers could be termed the soil modifiers or conditioners. Cement and lime at low concentrations, calcium or sodium chlorides, and a number of surface active materials are typical of this group. These chemical compounds, because of the surface reactions with the soil minerals (and particularly with fine fractions of soil), change soil texture and structure, thereby altering its physical or engineering properties. Depending on the character of the soil, improvements in mixing, drying, compaction, strength and other wet soil properties can be realized with relatively small quantities of these modifiers. But just as in the case of the cementing agents, soil masses treated with these modifiers are often highly susceptible to the climatic and environmental changes.

The third group embraces the waterproofing agents. Asphalts, certain resinous materials, and coal tars are representative of this group. The basic mechanism of stabilization by these agents is radically different from the two groups previously mentioned. These stabilizers coat individual soil particles or their agglomerates, and thereby prevent or hinder the penetration of water into the stabilized soil layer.

The role of the asphalt film in stabilizing a soil mass depends to a great extent on the properties of the soil. In the case of coarse, non-cohesive soils (such as sands

or silts) the asphalt film serves a double purpose. First, it waterproofs the soil mass. Second, it binds the soil particles together, contributing materially to the load-bearing qualities of the stabilized layer. In the case of fine-grained, cohesive soils, on the other hand, waterproofing is the principal role of the asphalt film. Cohesive soil, when compacted at proper water content, possesses high strength. This strength, attributed principally to the cohesive interparticle forces, is highly sensitive to the action of water. Asphalt films distributed throughout the soil protect these bonds and, partially at least, preserve the strength of the soil.

Stabilization of soils with asphalts is probably the oldest road-building process using admixtures as soil stabilizers. With the advances in soil mechanics during the last several decades, long strides have been made toward a better understanding of soil-asphalt systems. Yet, asphalt soil stabilization remains largely an art form rather than science. Knowledge of the basic properties of such systems remains relatively sparse. Little is known, for instance, about determining the composition of the mixture or thicknesses of the stabilized compacted layer to be used. Many test methods, empirical formulas and recipes, although practiced for a long time and suitable for given local conditions often confuse rather than clarify the problem. This applies particularly to the soil-asphalt systems involving cohesive, fine-grained soils.

Many secondary admixtures have been tried with varying degrees of success in soil stabilization with asphalts. Their principal purpose is to condition the soil and improve asphalt adhesion to the mineral surfaces. Again, because of the variety of soils and the many different evaluation methods used, it is difficult to compare results submitted in random reports, often limited in scope.

In view of this, The Asphalt Institute is engaged in soil stabilization studies with the purpose of increasing basic knowledge of soil-asphalt systems and their effective use. The effects of secondary additives on asphalt-stabilized fine-grained soils constitute a partial report of these investigations.

DESCRIPTION AND PREPARATION OF MATERIALS

Soils

Three soils—Massachusetts clayey silt, Maryland sandy clay and Mississippi loess—were used in these investigations. Maryland soil was used in most of the testing because it was readily available. The properties of the three soils are summarized, as follows:

	Mass. Clayey Silt	Md. Sandy Clay	Miss. Loess (1)
Specific gravity	2.74	2.72	2.69
Liquid limit (%)	21.2	31.6	31.6
Plasticity index (P.I.)	5.9	11.8	8.3
Shrinkage limit (%)	16.9	21.0	24.5
pH	5.8	5.9	6.9
Surface area ¹ (sq m/gm)	17.5	33.2	54.7
AASHTO classification	A 4(6)	A 6(9)	A 4(8)

¹By glycerol retention.

Figure 1, showing the grain size distribution for the soils, indicates that these materials represented a wide range in gradation. Also, the mineralogical composition varies widely. However, the three major clay minerals were represented by these soils. Maryland soil contains kaolinitic clay minerals, the clay in the Massachusetts soil is composed predominately of illitic clay minerals and the Mississippi loess contains montmorillonitic clay minerals. Figure 1 shows gradations for two samples of Mississippi loess (continuous and broken lines). The majority of tests were made

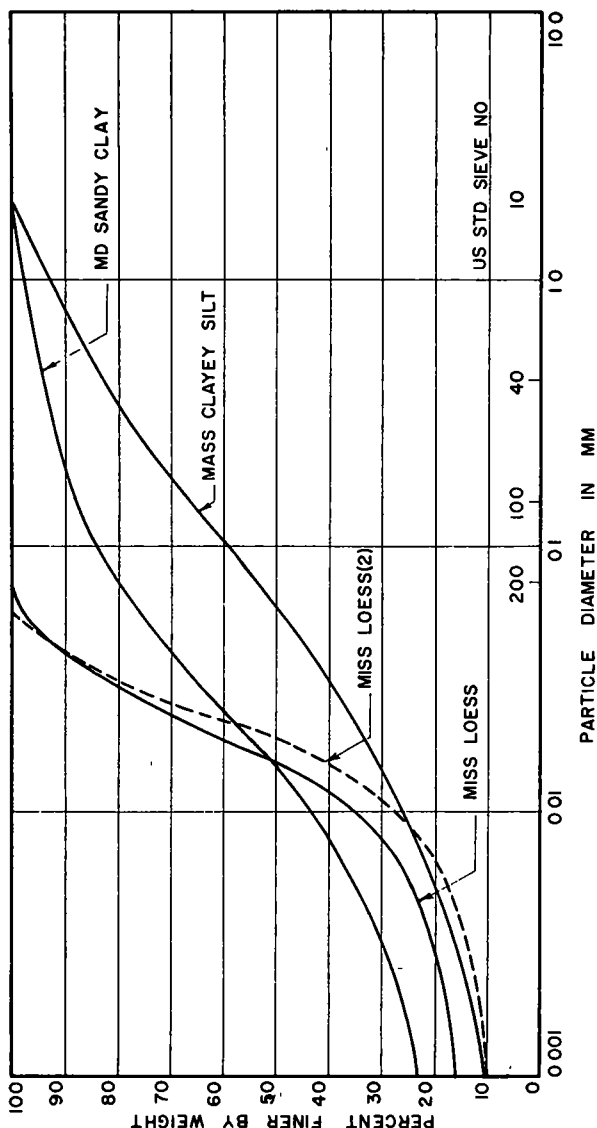


Figure 1. Grain size distribution of soils.

using material represented by the continuous line. Inasmuch as densities varied appreciably for compacted specimens of these two soil samples, gradations of both are shown. Accordingly, both soil samples are identified in the presentation and discussion of the results.

All soils, before testing, were air dried, broken down and sieved through successively smaller size sieves until a soil fraction passing the U. S. Standard Sieve No. 10 was obtained. This fraction was used for the preparation of specimens and testing. To prevent the degradation of the original soil particles minimum crushing or grinding was used.

Asphalt Cutback

Asphalt cutback used in this study was prepared in the laboratory by mixing on a weight basis two parts of 85-100 penetration asphalt cement with one part of light petroleum naphtha. These ingredients were placed in a 1-gal glass jar and rotated on ball mill rollers until the solution appeared completely homogeneous. A low boiling

range solvent was used to facilitate the evaporation and thereby to reduce or eliminate the effects of the organic solvent on the properties of compacted soil-asphalt mixture.

The properties of the prepared liquid asphalt are as follows:

Specific gravity	0.89
Kinematic viscosity, at 77F (centistokes)	160
Kinematic viscosity, at 140F (centistokes)	70

<u>Distillation characteristics:</u> Temp, (deg. F)	<u>Distillate (% by vol.)(Based on Tot. Dist to 680F)</u>
320	68.8
374	81.7
347	88.3
500	94.3
600	98.7
680	100.0

Residue from distillation to 680F by vol. % of total cutback	61.5
Penetration of residue (77F, 100 gm, 5 sec)	99
Ductility of residue (77F) cm	100+
Spot test on residue	Neg.

Tests made on this liquid asphalt and on the residuum obtained from distillation indicate that, according to Asphalt Institute specifications, this material could be classified as a Rapid Curing (RC-0) asphalt cutback.

Secondary Additives

Following is a list of the secondary additives used in this investigation:

<u>Material</u>	<u>Concentration Used % (based on dry soil)</u>	<u>Effect of Additive on Soil</u>
Hydrated lime (calcitic)	4.0	Cementing and modifying
Normal portland cement (Type III)	3.0	Cementing and modifying
Phosphoric acid (ortho) 84% solution	2.0	Cementing and modifying
Quicklime (calcitic)	3.0	Cementing and modifying
Calcium carbide	3.44	Cementing and modifying
Octodecyl amine (Armeen 18D)	0.3	Modifying and waterproof- ing
Sodium chloride	3.0	Modifying
Calcium chloride	3.0	Modifying

Commercial grades of these chemical compounds were used in all cases. The concentrations for quicklime and calcium carbide (3.0 and 3.44, respectively) were selected to obtain direct comparison with the effects of hydrated lime. After reaction with water, these additives produced approximately four percent of hydrated lime.

EXPERIMENTAL PROCEDURES

Mixing of Water, Additives and Asphalt with Soils

The air-dried soils were pre-mixed with the varying amounts of water and stored in the polyethylene bags for at least 18 hours before being mixed with stabilizers and compacted in specimens. Depending on the amount of soil required for testing, pre-mixing was done either with a Hobart Model C-100, 10-qt capacity or an LW Lancaster Mueller type 5/8-cu ft capacity laboratory mixer. Water content was always determined before mixing wet soil with the secondary additives or liquid asphalt. Usually, at least five water contents for a given type of compaction were used. Every effort was made to distribute the water contents on both sides of optimum in order to obtain well developed, density vs compaction water content curves.

Quicklime, calcium carbide and octodecyl amine were pre-mixed with liquid asphalt prior to mixing with soil. All other secondary additives were blended in before the liquid asphalt was mixed with the wet soil. Preliminary testing indicated that 1-min mixing in a Hobart mixer equipped with a flat beater was sufficient for the even distribution of the additive.

After mixing the additive, the mixer was stopped and a weighed amount of liquid asphalt was added. The mixing process continued for $1\frac{1}{2}$ min. Then the mixture was scraped from the sides of the mixing bowl and additional mixing continued for 1 min. By weighing the mixing bowl and the mixture ingredients before and after mixing, it was possible to determine the amounts of volatiles lost in the mixing process. Approximately 90 percent loss of liquid asphalt solvent occurred during a total $2\frac{1}{2}$ min mixing at room temperature. Tests made on the mixture indicated that only negligible amounts of water were lost during mixing.

Compaction and Stability Determination

Four different compaction and stability determination methods were used in this study. The methods and the pertinent characteristics of these methods are given in Table 1.

In order to obtain comparisons between these different compaction and stability determination methods, some changes in the standard methods were necessary. These changes and the references to the standard test methods are outlined in the following paragraphs.

Specimens compacted by the AASHTO T 180 method (see Highway Materials Part III, American Association of State Highway Officials) were tested in unconfined compression. The dimensions of the specimens were not ideally suited for this test. Inasmuch as the trends in the test results approximate closely the results obtained by the other test methods, it is believed that this test was valid.

Marshall compaction and stability determination procedures used in this testing were essentially as described in The Asphalt Institute publication, "Mix Design Methods for Hot-Mix Asphalt, Paving" (Manual Series No. 2). Compaction and testing at room temperatures constituted one deviation from the standard procedures. Modification of the sample mold was another deviation from the standard procedures. A sample mold $2\frac{1}{2}$ in. high equipped with an extension collar was used. Trimming the compacted specimens to that height resulted in the elimination of the height correction for the measured stabilities.

Compaction of the specimens with the mechanical kneading compactor and the determination of stabilometer resistance values were made by the procedures described in the "Materials Manual, Volume I," Department of Public Works, State of California. Deviation was made in the use of the leveling load after kneading compaction. These leveling loads were necessary to obtain parallel faces of specimen. Care was exercised not to obtain additional compaction by these static leveling loads and not to exclude the water from the specimens. A split mold similar to that used in Marshall testing was used to obtain specimens of constant volume.

TABLE 1
PERTINENT CHARACTERISTICS OF COMPACTION AND STABILITY METHODS¹

Method	Compaction Type	Specimen Size (in) Diameter	Height	Compactive Effort	Type of Stab Determination	Loading Rate (in /min)
AASHTO T 180	Dynamic-impact and kneading	4.0	4.8	10-lb ham., 18 in drop., 5 layers, 25 tamps/layer	Unconf comp strength	0.24
Marshall	Dynamic-impact	4.0	2.5	10-lb ham., 18 in drop, 50 tamps on each end of specimen	Semi-confined (Marshall)	2.0
Mechanical kneading compactor	Dynamic-kneading	4.0	2.5	Init 15-psi ft pressure, 30 tamps, Final 350 psi, 100 tamps	Triaxial (Hveem stabilometer)	0.05
ASTM D 915	Static	2.0	2.0	Total load 6,000 lb maintained for 1 min	Extrusion (punch shear)	1.0

¹All specimens compacted and tested at room temperature

Compaction and testing of ASTM D 915 test specimens closely followed methods prescribed in American Society for Testing Materials publications (see Procedures for Testing Soils, sponsored by ASTM Committee D-18). The major deviation from these test procedures was in the curing of the test specimens. Curing conditions for all test methods are described in the following section.

Curing and Water Immersion of Compacted Specimen

After compaction, the specimens were removed from the compaction moles and exposed to different curing conditions. Curing was always done in a closed chamber through which an air stream, saturated with water vapor, was passed. The saturation of air with water was obtained by passing the air stream at low velocity through two water scrubbers, and a water layer at the bottom of the curing chamber. Curing the specimens in the water-saturated air, it was believed, permitted further evaporation of organic solvent left after mixing while minimizing or even eliminating the evaporation of water from the compacted specimens. Weight losses of specimens cured under these conditions never exceeded one percent of the total weight of the compacted sample. Curing periods of one and four days were selected as standard in these investigations.

Total immersion of specimens at room temperature was used to determine the effects of water on the properties of compacted mixtures. Specimens were immersed in water after four days of curing in a 100 percent relative humidity chamber. In the case of all immersed specimens, changes in volume and water content after immersion were determined. Curing at 100 percent relative humidity and complete immersion in water, it is believed, represent by far a more severe condition than usually encountered in the field. In this study, four days complete immersion in water was used as a standard immersion time.

RESULTS AND DISCUSSION OF RESULTS

The results and discussion of the results of this study are divided in two parts. The first part is concerned with the basic consideration and description of the effects of asphalt on mixtures of cohesive, fine-grained soils and water. Properties of soil-water mixtures compacted with and without asphalt are compared. In the second part, the effects of a number of secondary additives on cohesive soil-water-asphalt systems are described and compared with wet soil systems treated only with these secondary additives.

Description of Cohesive Soil-Water-Asphalt Systems

Figure 2 shows dry density (soil + residual asphalt) and unconfined compressive strength of three different soils compacted over a range of water or volatiles (water + asphalt solvent) contents, with and without five percent of residual asphalt. It is seen

that when these soils are compacted by applying the same compactive efforts a wide range of densities was obtained. Furthermore, it is evident that densities (or the shapes of density-compaction water content curves) are not materially affected by the presence of five percent asphalt. When these compaction efforts are used, densities of compacted specimens of these three different soils are related to grain size distribution of the soils (Fig. 1). Although other factors undoubtedly influence the compaction characteristics of soils, in the case of these three soils, it appears that higher densities were achieved when coarser and better graded materials were used.

The major difference in compaction characteristics of these two systems appears in the water and volatiles content required to attain the maximum compacted densities. Systems containing five percent asphalt required approximately $2\frac{1}{2}$ percent less liquid than the systems without asphalt. This applies for all three soils used in this investigation. In the case of all three soils one part water used for compaction was replaced by two parts of asphalt.

In contrast to the density characteristics, Figure 2 shows that the unconfined compressive strengths of these soils are markedly affected by the presence of five

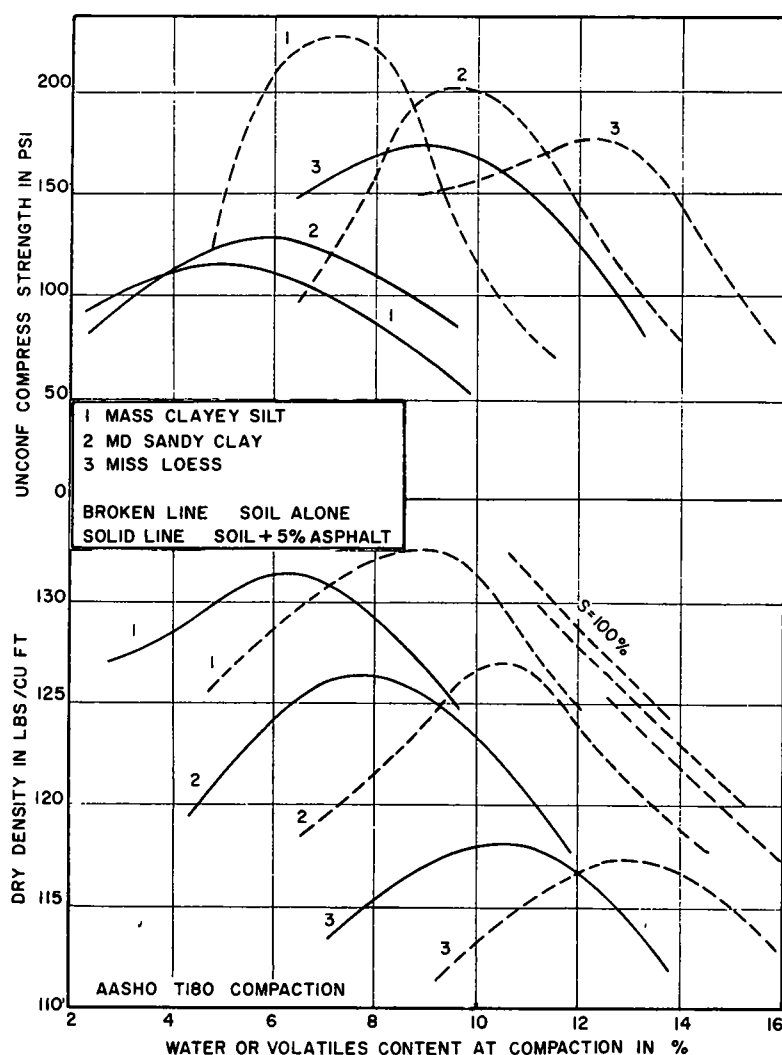


Figure 2. Density and strength of different soils with and without asphalt.

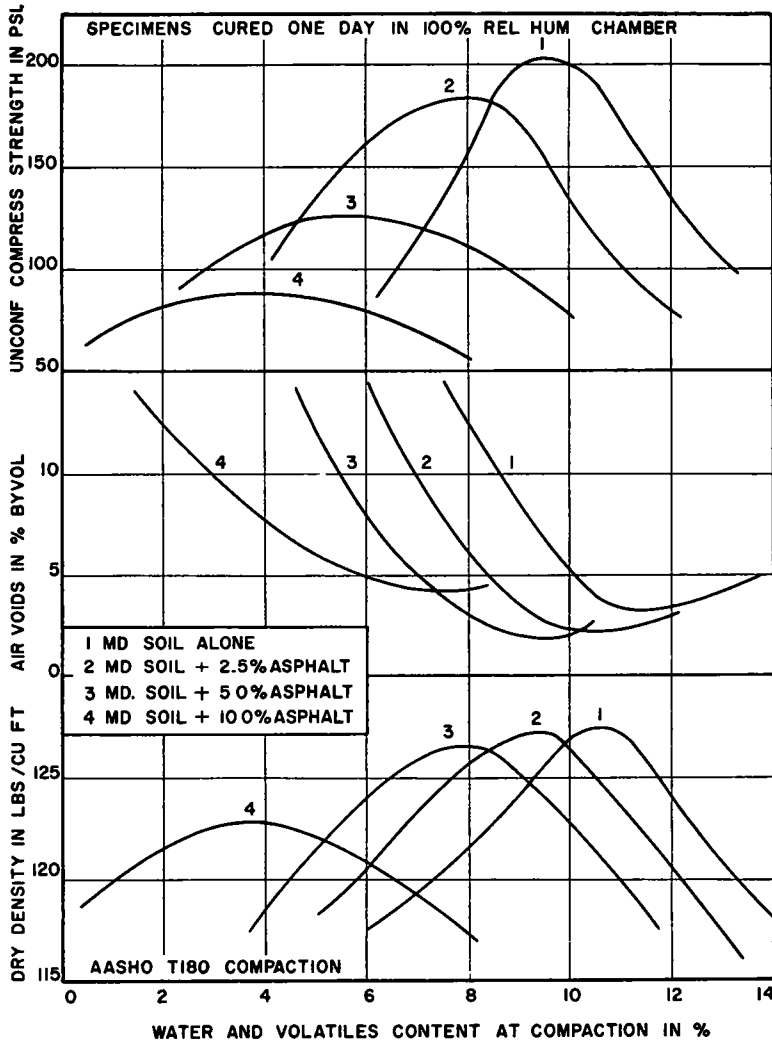


Figure 3. Density, voids and strength of Maryland sandy clay at different asphalt contents.

percent asphalt. In general, asphalt tends to diminish the strength of compacted soil. This loss of strength is more pronounced with more uniformly graded soils. In the case of poorly graded soil, such as Mississippi loess, the strength is virtually unaffected by the presence of five percent asphalt.

This loss of strength in fine-grained cohesive soils may be attributed to the reduction of cohesive interparticle bonds by the asphalt films distributed through the compacted soil mass. Asphalt films, of lower polarity than water, are not attracted to the same extent by the polar clay surfaces.

These films may act as an interparticle lubricant, resulting in a weakening of the compacted mass. Because, in the case of well-graded soil, the number of contact points (and therefore cohesive bonds) is larger, it can be expected that a given amount of asphalt films will proportionately destroy more of such bonds. This, therefore, results in a more pronounced reduction of compressive strength.

Another interesting observation can be made from the comparisons of strength characteristic of the two systems: the curves obtained by plotting strength against compaction water or liquid content are considerably flatter when asphalt is present

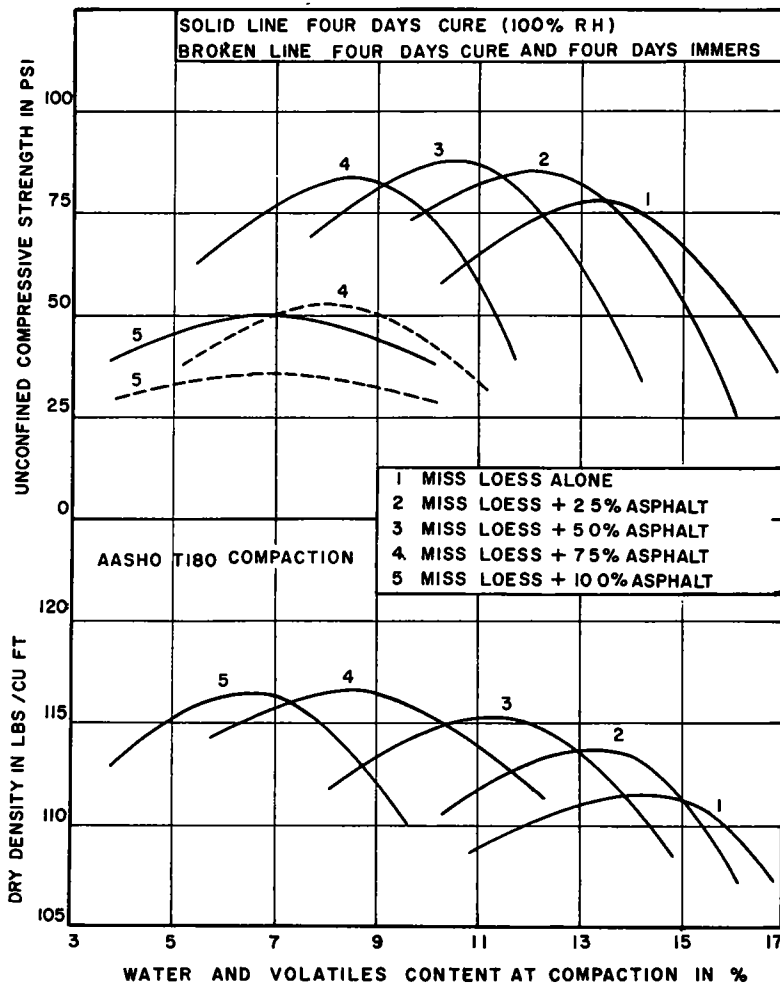


Figure 4. Density and strength of Mississippi loess (2) stabilized with different asphalt contents.

in the mixture. This means that the strengths of such asphalt-containing systems are affected less by the variations in the compaction liquid content. Considering such behavior from a practical viewpoint, it indicates that the mixtures containing asphalt will compact to a layer of more uniform strength even when the water is distributed less uniformly throughout the soil mass (as may often be the case in actual soil stabilization construction).

Figure 3 shows the effects of varying amounts of asphalt on density, air voids and strengths of Maryland soil compacted by the AASHO T 180 compaction method. It is evident that gradually increasing asphalt content in the mixture results in decreasing density of the compacted specimen. It should be noted that mixtures containing higher amounts of asphalt require less compaction liquid to obtain maximum densities. Additionally, it is evident, that when more asphalt is used, replacement of compaction water or volatiles by the asphalt is more pronounced. This means that when more asphalt is used in the soil-water mixtures, drier soil must be used in order to obtain the maximum compaction densities. Undoubtedly, the ratio indicating the substitution of compaction water or volatiles by the asphalt will be affected by factors such as soil properties, viscosity of residual asphalt, compactive efforts used, and others. Nevertheless, the general trend (as indicated by Fig. 3) will prevail, pro-

vided that the soil is sufficiently cohesive; therefore, some water is necessary to facilitate the compaction process.

Figure 3 indicates that gradually increasing amounts of asphalt progressively lower the compressive strengths of the specimens. The reasons for such behavior were described previously and it is believed that the results represented in Figure 3 confirm these reasons. It must be kept in mind, however, that such trends may be reversed when non-cohesive or cohesive soils of poor gradation are used. This is illustrated by Figure 4 showing density and strength vs compaction liquid contents of Mississippi loess (2) at various asphalt contents. Maximum dry densities and strengths of this quite poorly graded soil (Fig. 1, broken line) increase even when relatively high amounts of asphalt are used.

It is interesting to note that the maximum strengths for the systems with or without asphalt are obtained at less than optimum compaction liquid content, whether asphalt is present or not (Figs. 3 and 4). This points out the similarity in physical behavior of these two (with and without asphalt) systems.

Figure 3 also shows that a slight decrease, followed by an increase in the volume of air voids in the mixture, is caused by increasing asphalt content. Because these changes are small, it can be said that the influence of asphalt on the mixture air voids is negligible.

Figure 5 shows a more detailed picture of void properties of these mixtures and contains three families of curves, each consisting of four lines. The lower group of

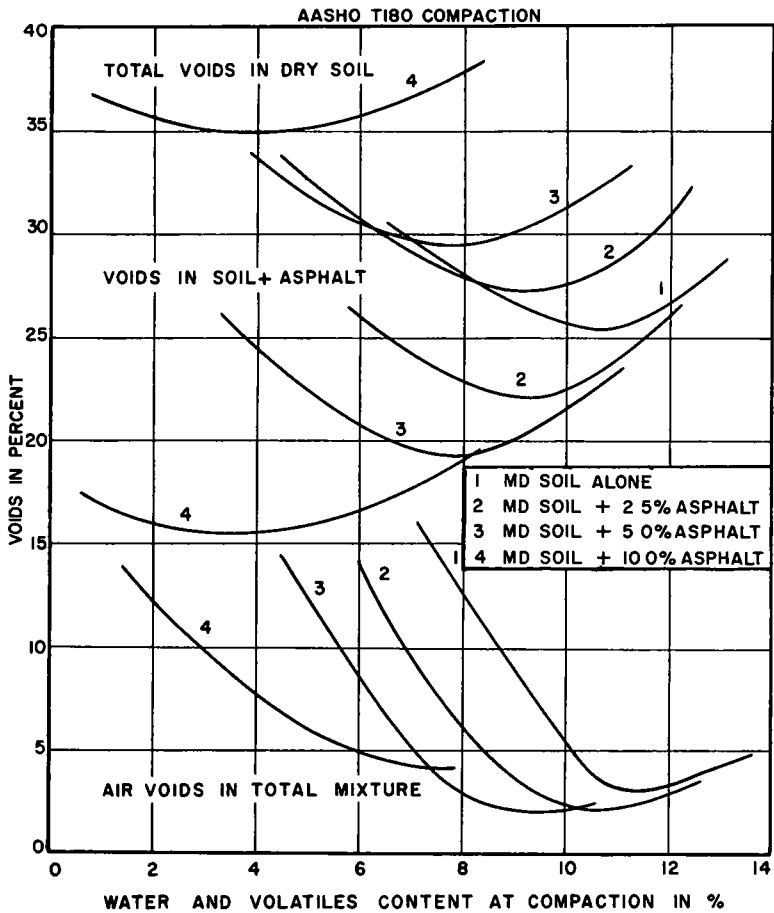


Figure 5. Void properties of Maryland soil and asphalt mixtures.

curves represents the air voids in the mixture (as shown previously in Fig. 3). The middle group of curves shows the voids composed of air and volatile liquids, and the upper curves show the mixture voids composed of air, volatiles and asphalt. These curves indicate that volatile compounds are replaced by the non-volatile asphalt and that the relative distances between the individual soil particles or agglomerates of these particles are gradually increased as progressively more asphalt is added to the mixture. The upper family of curves in Figure 6 indicates that gradual separation of soil particles by increasing amounts of asphalt is also evident when a poorly graded soil such as Mississippi loess (2) is used. It is evident, however, that the separation of soil particles is less pronounced than for a better-graded Maryland soil (Fig. 5).

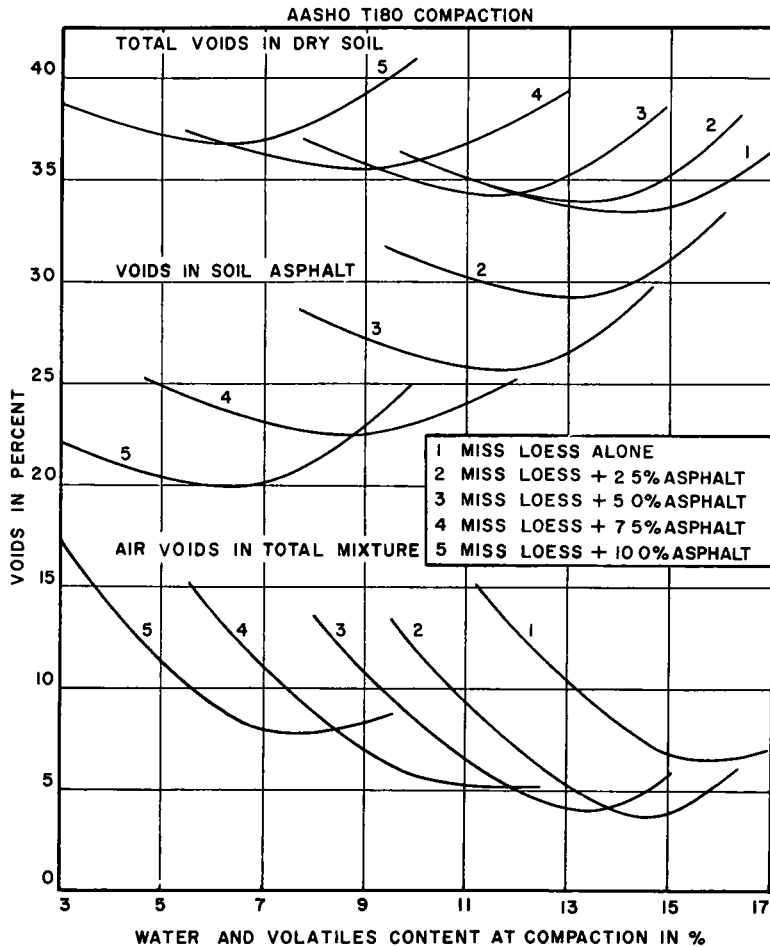


Figure 6. Void properties of Mississippi loess (2) and asphalt mixtures.

In the case of fine-grained water-sensitive soils, the major role of asphalt is to waterproof the compacted soil mass. Figure 7 shows the effects of water immersion on the properties of Maryland soil stabilized with different amounts of asphalt, and Figure 8 shows these properties of three different soils stabilized with five percent asphalt.

In these two figures, three factors are considered in evaluating the waterproofing effects of asphalt: (1) strength characteristics as affected by immersion in water; (2) water absorption; and (3) volumetric changes of specimens when immersed in water.

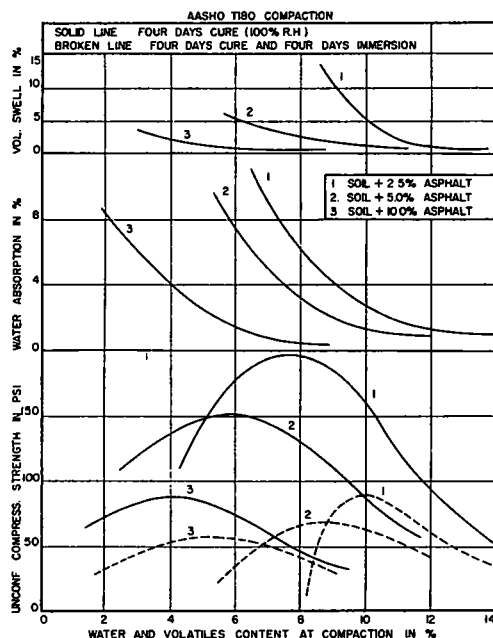


Figure 7. Strength, water absorption and volume swell of Maryland soil stabilized with varying amounts of asphalt.

Before considering the results presented in these two figures, it should be remembered that the numerical values of these properties depend on the size of the specimens (or more exactly, on the relative proportion of their external exposed surfaces and their bulk volume). For small specimens, the values for these properties would be larger than for large specimens.

These figures show that the strengths of immersed specimens, regardless of asphalt content or soil used, diminish more noticeably when compacting water contents are decreased. The loss of strength is sharply reduced by increasing the asphalt contents. Nevertheless, even when ten percent of asphalt is used, the reduction in strength by immersion is evident. (It should be kept in mind that compacted soil-water specimens without asphalt disintegrate rapidly when immersed in water.)

Although no experimental data are presented, it is safe to assume that specimens which retain greater strength during immersion also will behave more favorably when exposed to environmental weathering conditions (that is drying and wetting or freezing and thawing). This is substantiated by the generally lower rate of water absorption or by lower volumetric expansion values of the specimens which decrease less in strength after immersion in water.

Strength data as obtained for the curing conditions used and shown in Figures 7 and 8 indicate that compaction water contents at or somewhat above optimum may be more favorable. At such water contents—although the initial strengths (after curing) are considerably lower than maximum strengths at the lower water contents—a greater measure of the original strength is retained. It should be noted, however, that when a mixture contains more asphalt, the amount of compaction liquid becomes less important, because Figures 3 and 4 indicated that increasing asphalt contents replace progressively greater amounts of compaction liquid.

For the design of cohesive soil-asphalt mixtures, it is believed that the change in strength of the soil during immersion should be considered. The immersed strength could be used as an indication of the load-bearing qualities of the stabilized soil layer, and the change in strength upon immersion would indicate the waterproofing effects of asphalt which in turn would also reflect to the weathering properties of the stabilized layers. Additionally, the use of immersed specimen strength would provide a certain

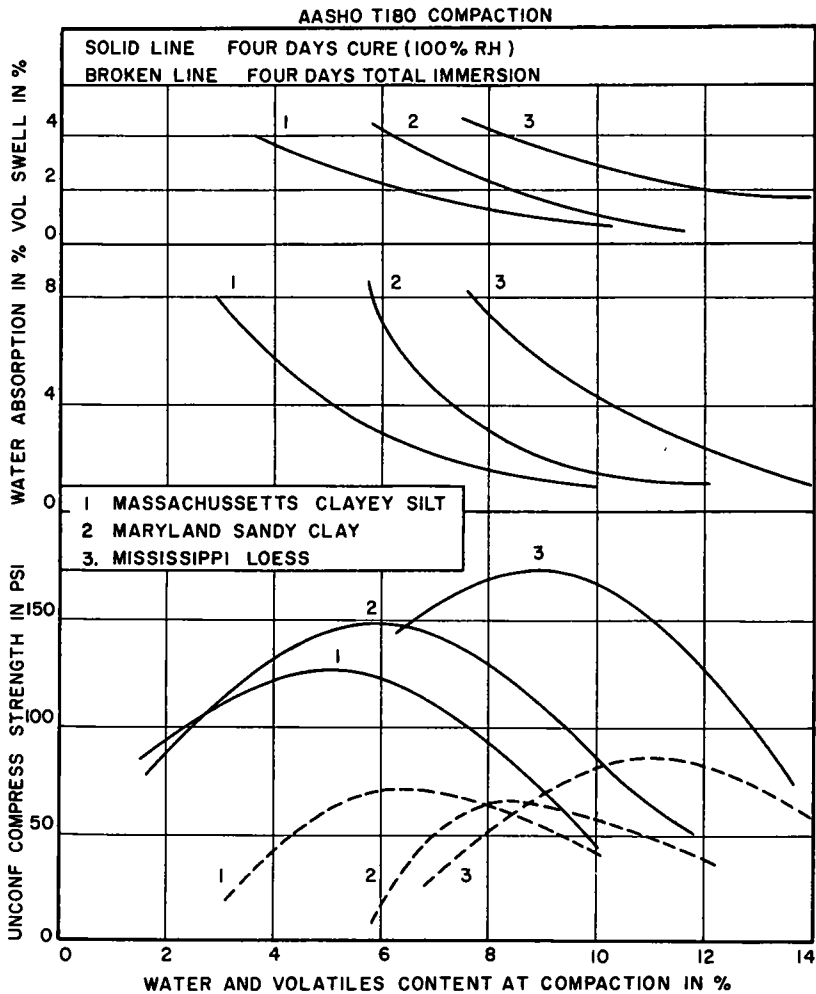


Figure 8. Strength, water absorption and volume swell of different soils stabilized with five percent asphalt.

factor of safety because, in actual use, a stabilized layer of soil is seldom subjected to such a severe condition. Normally, the stabilized soil layers are covered with layers relatively impervious to water (such as asphalt paving or surface treatments) and are provided with adequate drainage.

Comparisons of water absorption, volumetric expansion, and changes in strength of immersed specimens demonstrate the effectiveness of stabilizing the three soils with five percent asphalt (Fig. 8). These values for the Mississippi loess are highest, next highest for Maryland soil, and lowest for Massachusetts soil. It is interesting to note that the magnitude of these values corresponds to glycerol retention or to the specific surface areas for these soils as shown in the table describing the properties of the three soils.

An attempt was made to determine the suitability of different compaction and strength determination methods for testing cohesive fine-grained soil, water and asphalt mixtures. Figures 9 and 10 show density and strength of soil-water mixtures, with and without the asphalt, as determined by four different testing methods commonly used for the testing of asphaltic mixtures. The compaction methods used in this testing differ in two ways—in the manner of applying the compactive loads, and in the

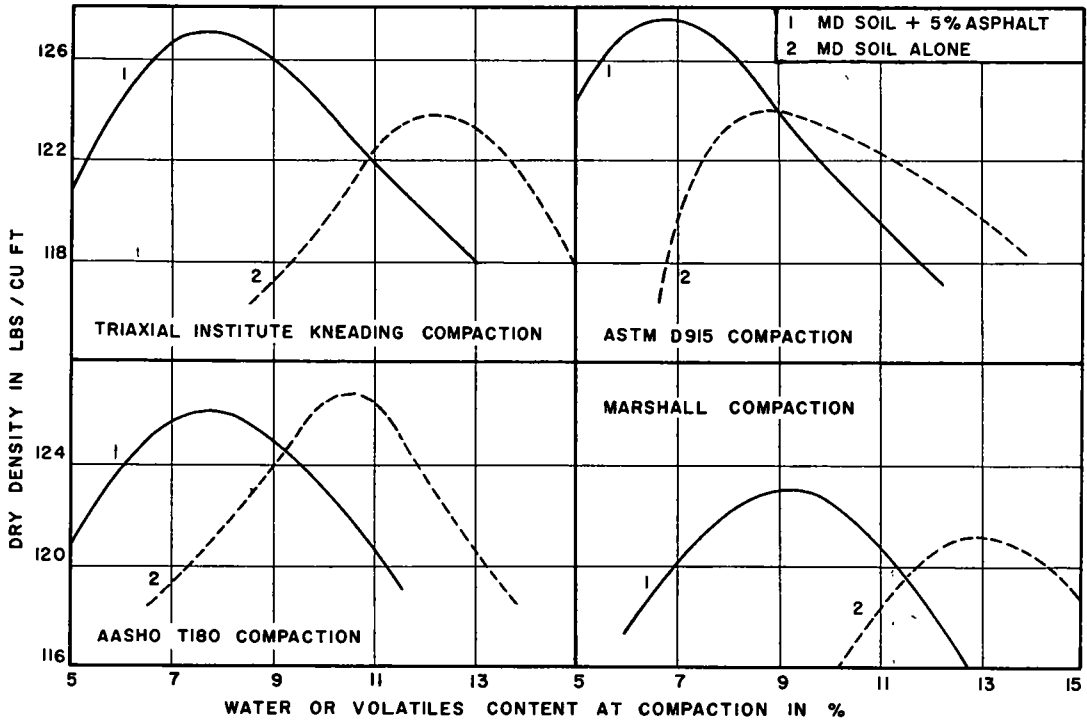


Figure 9. Effect of compaction method on density of stabilized and unstabilized soils.

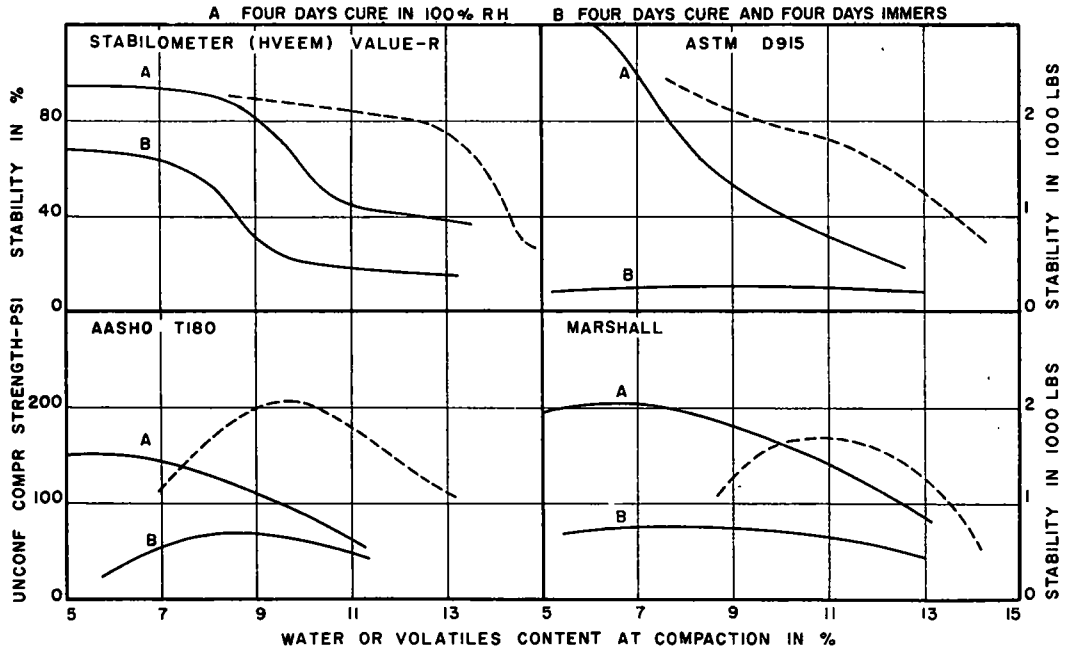


Figure 10. Stability of Maryland soil compacted and tested by different methods (solid line: Maryland soil + 5 percent asphalt; broken line: Maryland soil alone).

amount of compactive energy expended per unit weight or volume of soil mixture. The results (Fig. 9) indicate that all methods except the AASHTO T 180 method produced higher maximum densities when the mixture contained asphalt. AASHTO T 180 compaction, on the other hand, produced approximately the same specimen densities with and without asphalt. The reasons for this are not too obvious. Probably it can be attributed to the manner in which the compactive loads are applied, rather than to the difference in compactive energy between different compaction methods. During AASHTO compaction, the soil mixtures are subjected to the combined efforts of impact and kneading action; other compaction methods lack such combined effects.

Regardless of the compaction method used, optimum water content always is lower when asphalt is present in the mixture. It appears that replacement of compaction water or liquid by asphalt depends somewhat on the density of the compacted specimen. No definite conclusions can be drawn from these data in this respect because the difference in specimen density, as obtained by the different compaction methods, is not sufficiently large.

Figure 10 shows the strengths or stability at different water or volatiles content during compaction and indicates that any of these methods may be used for testing soil-asphalt mixtures. Typical curves for each stability determination method are obtained for cured or immersed specimens. It is, therefore, believed that the choice of method should be based on convenience and expediency until a laboratory test method can be correlated with field performance. In this respect, it appears that the unconfined compressive strength and Marshall stability determinations may be the most convenient of presently available methods.

Additionally, it is apparent that the strength or stability curves for immersed specimens, as developed by these two methods, are sloping downward on the dry side of the optimum compaction liquid content. It is believed that this represents a more complete and realistic picture, because mixtures at such low compaction liquid contents are less stable against water action than the mixtures compacted at optimum liquid content. The two other methods fail to show these effects.

Effect of Secondary Additives on Properties of Asphalt-Stabilized Fine-Grained Soils

The required load-bearing qualities of the individual pavement layer depends not only on the intensity of loading and the strength of other layers, but also on the position and depth of the layer in relation to the other layers.

Very often, as in the case of secondary roads, surface-treated or seal-coated asphalt-stabilized soil constitutes the upper layers of pavement structure. This means that such stabilized soil layers must not only resist weathering but also must be strong enough to support and transmit fairly intense loadings.

In the case of water-sensitive, fine-grained soils, occasions may arise when such soils will not satisfy these conditions even when stabilized with proper amounts of asphalt. Conditions may be encountered where the soil-asphalt layer, although sufficiently waterproof, may not possess adequate strength. Or conversely, it may be strong enough but not sufficiently waterproof.

Earnest efforts were made to improve the waterproofing and load-bearing qualities of asphalt-stabilized cohesive soil mixtures. These efforts invariably concentrated on using materials which would be suitable for such purposes at relatively low concentrations.

In spite of such efforts, little is currently known about the basic factors affecting the behavior of such complicated systems. The purpose of the tests described here was to learn more about these systems and weigh the merits of using a secondary additive with asphalt in the stabilization of fine-grained, water-sensitive soils. In this study, only those secondary additives were used which have been introduced to some extent and with varying degrees of success in actual field applications or field tests.

With some of the more promising additives, all three soils and other tests in addition to the Marshall (for determining compaction and stability) were used. Inasmuch as the results obtained with different soils and test methods developed very similar

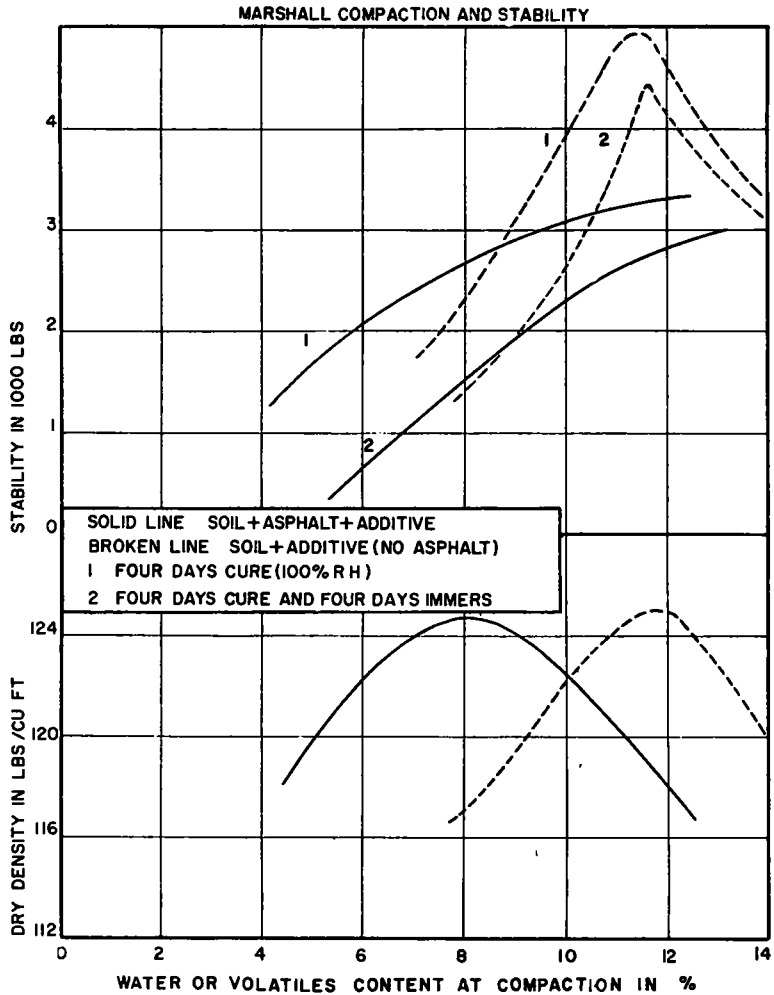


Figure 11. Density and stability of asphalt-stabilized and unstabilized Maryland soil treated with 3 percent portland cement.

trends, the accompanying graphs are limited to data from Marshall test results obtained with the three soils. The effects of secondary additives on soil-water mixtures with and without asphalt were studied. In the case of mixtures without asphalt, specimen density and strength properties are shown only for more effective additives. In all these tests only a single concentration of a given additive was used. Emphasis was placed on determining the effects of the single additive concentration over a range of water contents rather than on the effects of a wide range of additive concentrations. Although the effects of curing time on the properties of soil-additive and soil-additive-asphalt systems were investigated, the main portion of the results shows the properties of these mixtures after four days cure, and after a subsequent four-day complete immersion in water.

Effects of several environmental conditions on specimen properties (such as different immersion times or wetting and drying) also were studied and a part of the results as obtained for the more effective additives are shown in Figures 14 and 15.

Figures 11, 12 and 13 show the effects on Marshall density and stability of Maryland soil treated with normal portland cement, ortho-phosphoric acid and hydrated lime—stabilized and unstabilized with asphalt. Water absorption of specimens also was de-

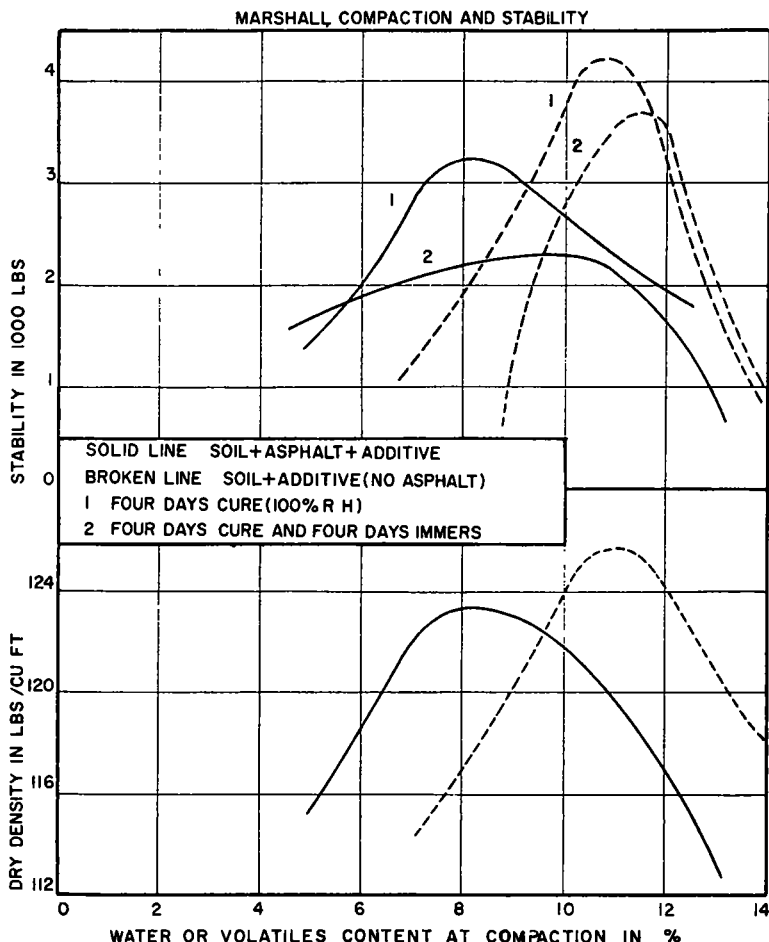


Figure 12. Density and stability of asphalt-stabilized and unstabilized Maryland soil treated with 2 percent H_3PO_4 .

terminated. Although these data are not shown, it should be noted that the presence of five percent asphalt reduced water absorption values of compacted mixtures by approximately 50 percent. Although in general the volumetric changes were small in the case of all additive-treated, immersed specimens, it was evident that asphalt also tended to reduce the specimen expansion values.

Comparison of Marshall dry densities of soil-water-additive mixtures (broken lines in Figs. 11, 12 and 13) with the densities of soil-water (no additive) systems (shown in the lower right corner of Fig. 9) reveals that different additives affect differently the densities of soil and water mixtures. This can be attributed to the structural or textural changes of soil-water mixtures caused by different additives. For example, soil particles suspended in water are dispersed by the addition of phosphoric acid. On the other hand, the same soil in the presence of hydrated lime exhibits strong aggregation or flocculation tendencies. In the case of normal portland cement, such changes are not as pronounced. These changes in soil particle structure can be seen visually or can be determined by measuring the sedimentation rates or final sedimentation volumes of soil particles suspended in water. Changes caused by different additives also are evident at lower water contents and can be detected by measuring changes in plasticity indices. These differences in soil structure also are reflected in compaction characteristics of different mixtures. It is evident that dispersed systems compact to a higher

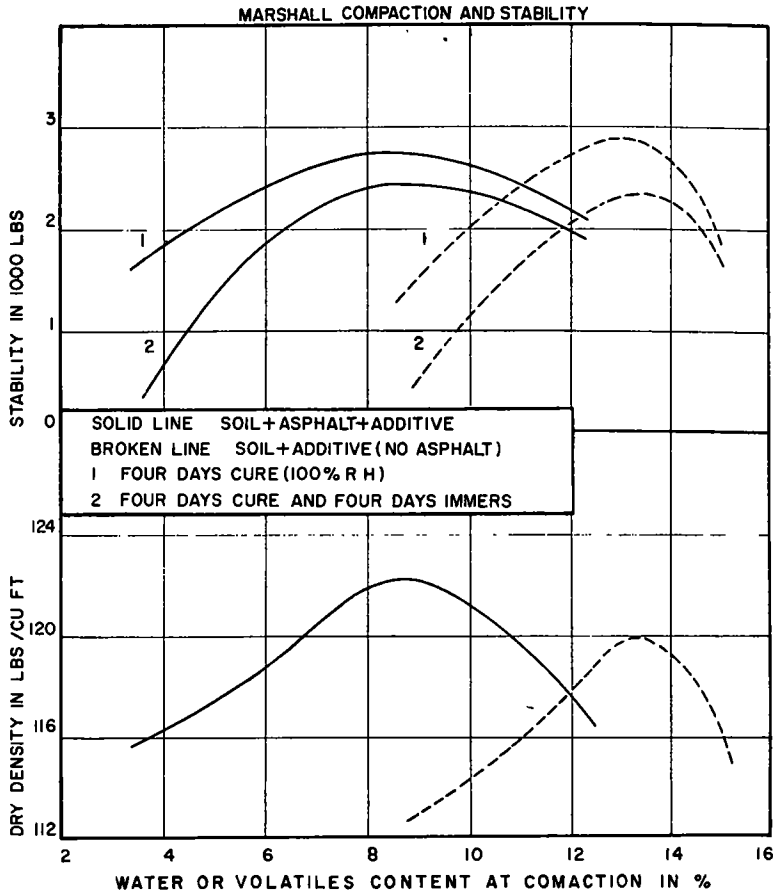


Figure 13. Density and stability of asphalt-stabilized and unstabilized Maryland soil treated with 4 percent hydrated lime.

density than the flocculated systems when an impact compaction method, such as Marshall, is used. These density differences are reduced when, for example, a compaction method such as AASHTO T 180, having more kneading action, is used. Evidently, the changes in soil structure as caused by different additives are accompanied by the changes in elastic or plastic behavior of the soil mass.

As shown in Figures 11, 12 and 13, the use of different additives in Maryland soil-water (no asphalt) mixtures results in a difference in maximum specimen density for standard Marshall compaction of approximately 6 pcf. On the other hand, these figures also show that, when five percent asphalt is present in these mixtures, differences in maximum densities are reduced to $2\frac{1}{2}$ pcf. Thus, it appears that asphalt tends to minimize the effects on compaction characteristics caused by different additives. This does not necessarily mean that asphalt promotes a reversal of soil-structure changes caused by different additives. It merely indicates that, particularly in the case of flocculated soil systems, the lubricating effects of asphalt films are more important for densification than the changes in soil structure caused by an additive such as hydrated lime.

Typical reduction of optimum compaction liquid content when asphalt is present in the mixture is also clearly shown in these figures. The magnitude of this partial replacement of compaction water by asphalt varies only slightly for different secondary additives.

The upper graphs of Figures 11, 12 and 13 indicate that approximately three-fold increases in the strengths of immersed specimens can be realized by using different

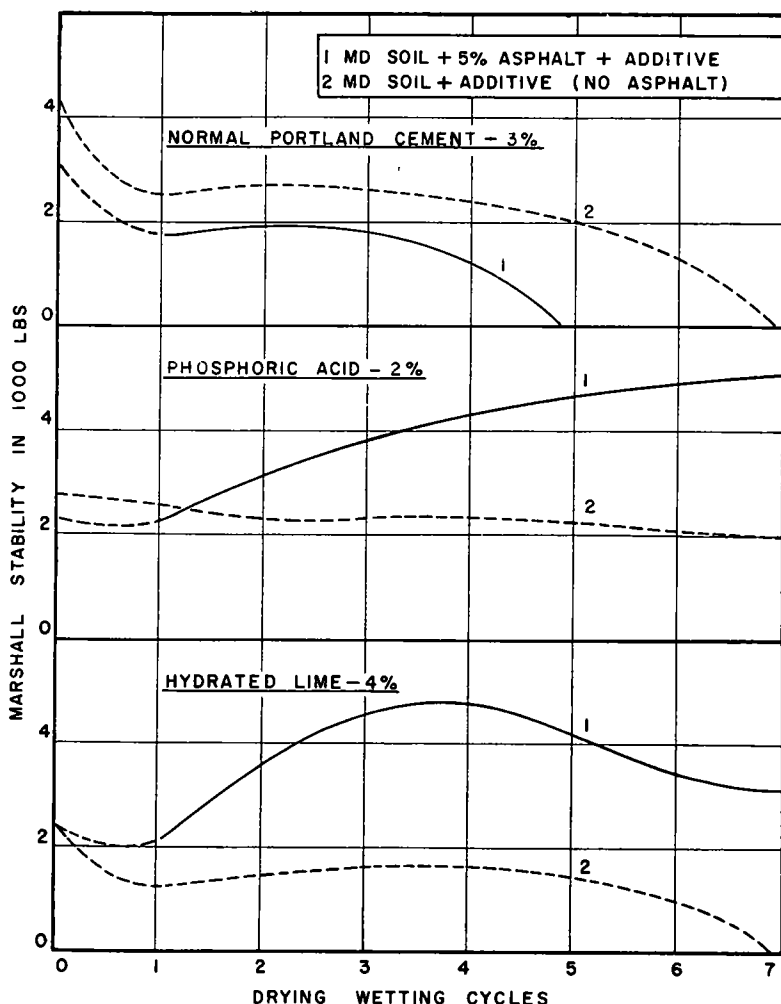


Figure 14. Effect of drying and wetting on stability of asphalt-stabilized and unstabilized Maryland soil treated with different cementing additives.

cementing additives in cohesive soil and asphalt mixtures. These figures also indicate that the additives reduce the water sensitivity of compacted soil-asphalt mixtures. In general, it appears that the reduction in strengths caused by complete immersion in water is lower in the specimens that are compacted at, or higher than, the optimum compaction liquid contents.

Comparison of stability characteristics of soil-additive mixtures reveals that maximum strengths of mixtures without asphalt are often higher than the maximum strengths of mixtures containing five percent asphalt. In the case of phosphoric acid and portland cement these differences appear to be more pronounced than in the case of hydrated lime. Additionally, it is evident that, with the exception of portland cement-asphalt systems, the maximum stabilities occur at the optimum water or liquid contents (that is, also maximum dry densities). The optimum water or liquid contents and maximum densities represent the points on density curves at which the distances between individual soil particles are the shortest. It may be assumed that such a condition is more favorable for the occurrence of cementing reactions between soil constituents and cementing additives. The reasons for the different behavior of portland cement-asphalt mixtures are not entirely clear. Perhaps asphalt retards hydration of cement more pronouncely

at optimum compaction liquid content, or perhaps the water content at such a point is not sufficient for complete hydration of the cement.

Another significant difference in strength characteristics of soil-additive systems in the presence of asphalt is the shape of the strength curves of cured and immersed specimens. In the presence of asphalt, these curves flatten out over an extended range of water contents. Conversely, in the absence of asphalt, these curves have pronounced peaks at optimum water or volatiles contents. This, as in the case of soil-water (no additive) systems, suggests the moderating effects of asphalt. Flat stability curves indicate that the compacted mixtures are less susceptible to variations in compaction water or liquid contents. This may represent a considerable asset in construction and performance of such mixtures.

In addition to the density and strength properties and the effects of water on these properties, the influence of the environmental conditions, such as may be encountered during the pavement service, is of great importance for complete evaluation of stabilized soils. Drying and wetting is one environmental condition. Figures 14 and 15 show the effects of drying and wetting on Marshall stability and water absorption of Maryland soil treated with three different cementing additives. In these tests, specimens with and without asphalt were compacted at slightly higher than optimum water or liquid con-

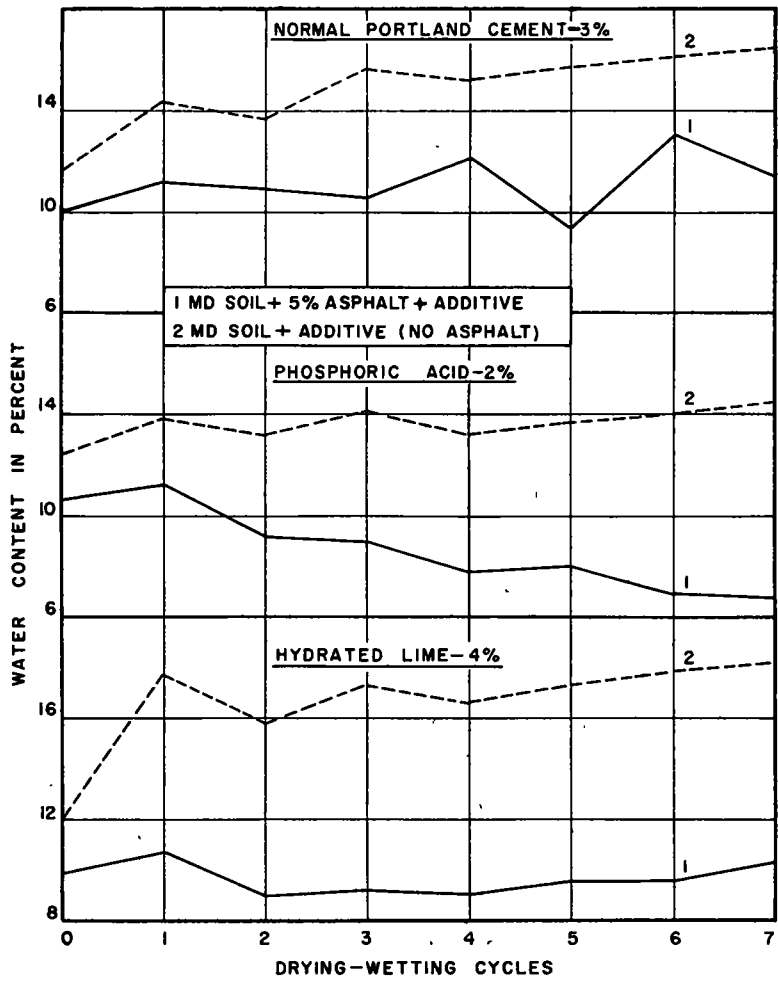


Figure 15. Changes in water content during drying and wetting of asphalt-stabilized and unstabilized Maryland soil treated with different cementing additives.

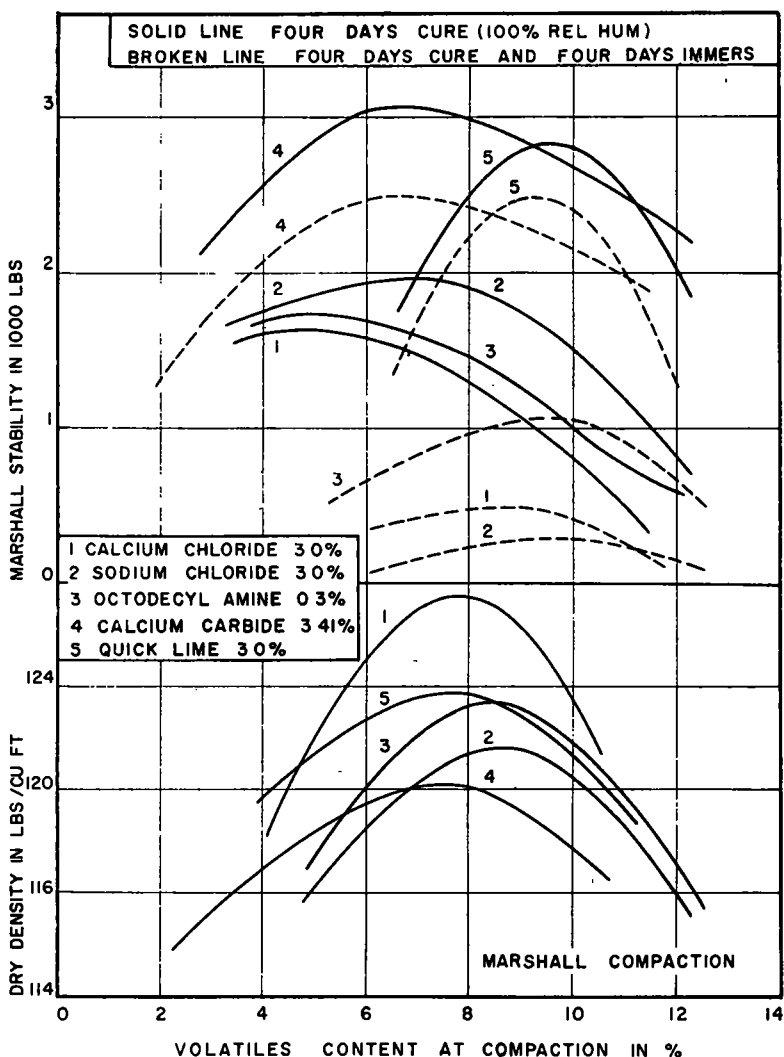


Figure 16. Effect of different additives on Maryland soil stabilized with five percent asphalt.

tent. All specimens were subjected to drying and wetting after curing for four days in 100 percent relative humidity chamber. Four days drying followed by four days complete immersion in water at room temperature constituted one drying-wetting cycle. Stability and water absorption were determined after four days immersion.

The results thus obtained illustrate definite advantages which can be derived from the conjunctive use of asphalt and phosphoric acid or hydrated lime.

Marshall stabilities of phosphoric acid-asphalt specimens actually increased with drying and wetting and after seven such cycles reached the level of 6,000 lb. Stabilities of specimens treated with phosphoric acid (no asphalt) when wetted and dried did not change appreciably and remained at approximately 2,000 lb strength level.

Specimens containing hydrated lime and asphalt increased in strength up to three or four cycles and then tended to weaken with subsequent wetting and drying. Specimens containing lime alone disintegrated after seven drying and wetting cycles.

Specimens containing portland cement at the compaction water contents investigated did not benefit by the presence of asphalt. In fact, they became less stable against

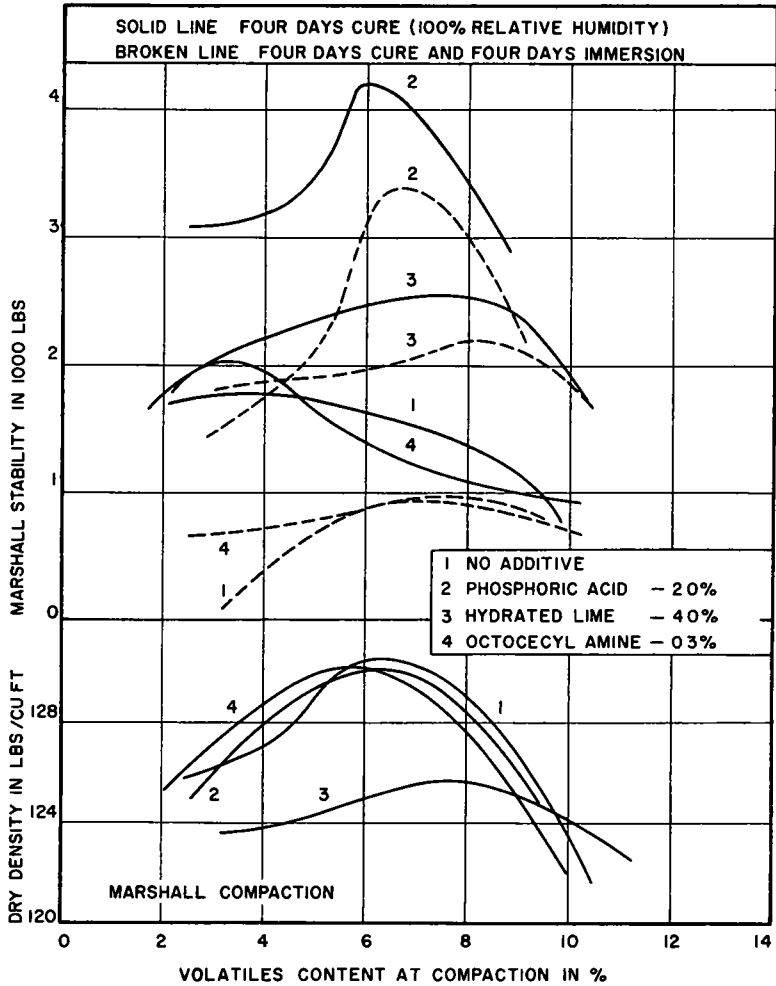


Figure 17. Effect of different additives on Massachusetts soil stabilized with five percent asphalt.

drying-wetting when five percent asphalt was present in the mixture. These specimens were completely destroyed after four cycles, as the specimens containing portland cement alone were destroyed after six or seven drying-wetting cycles.

It is interesting to note that the water absorption (Fig. 15) followed closely the strength changes as affected by the drying-wetting cycles. In all cases, water absorption of specimens containing asphalt was always lower than water absorption of specimens without asphalt.

The findings of this drying-wetting study were substantiated by a small-scale test section constructed on the grounds of The Asphalt Institute. This test section consisted of eight different test panels containing three cementing additives each, with and without asphalt. A somewhat coarser Maryland soil (although similar in mineralogical composition to that used in laboratory tests) was used in the test panels. Determinations of strength and water content, made over a period of several months, indicated that, with the exception of portland cement-asphalt mixtures, panels containing asphalt were considerably more stable against natural weathering elements. Water fluctuations in test panels with asphalt were reduced by approximately 50 percent.

Figure 16 shows the effects of five other additives on Maryland soil stabilized with five percent of residual asphalt. Dry densities and stabilities of cured and immersed

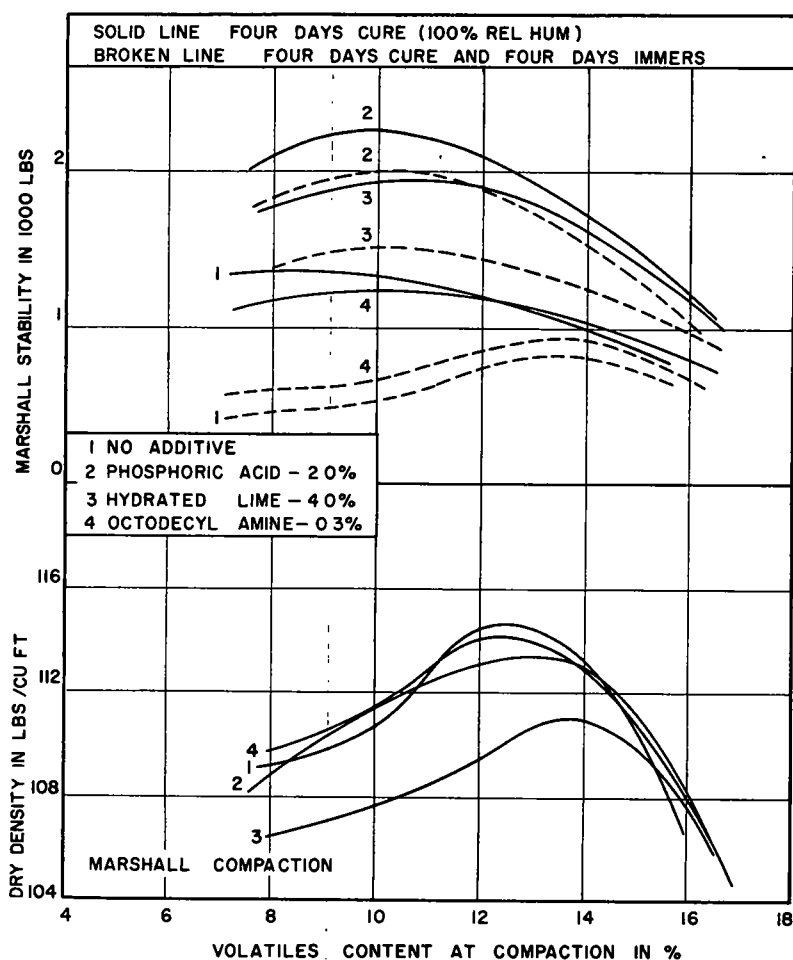


Figure 18. Effect of different additives on Mississippi loess stabilized with five percent asphalt.

specimens compacted by standard Marshall procedures are shown. With the exception of sodium and calcium chlorides, the other three additives were pre-mixed with asphalt cutback before being added to the soil.

It is evident that specimen densities, as affected by different additives, vary over a wide range. It should be noted that the variations in density were much more pronounced when these additives alone (no asphalt) were used with the same soil.

Stability data again indicate that cementitious additives (quicklime and calcium carbide) are far more effective for stabilizing fine-grained soils. These two additives, after reaction with water, produce hydrated lime (calcium hydroxide) which then reacts with the soil constituents.

It should be noted that, for these two additives, the optimum water contents (as shown in the lower half of Fig. 16) are considerably lower than the water contents used in mixing. The reason: some water is consumed in the instantaneous reaction with the additives and some is evaporated due to heat generated by these reactions. Because of the reactions with water, these two additives could conceivably be used advantageously with very wet soils. Compaction of soils treated with these materials should be delayed until the reactions are complete.

Stabilities of immersed specimens indicate that no benefits can be derived from the conjunctive use of asphalt and additives such as calcium or sodium chlorides. In fact,

in the case of these two additives, and particularly in the case of sodium chloride, detrimental effects on soil stabilization with asphalt are evident.

Figures 17 and 18 show the effects of a few selected additives on the properties of two other soils; namely, Massachusetts clayey silt and Mississippi loess stabilized with five percent of asphalt. Although other additives were tried with these two soils, only the effects of hydrated lime, ortho-phosphoric acid and octodecyl amine are shown. For comparison, densities and strengths of soils stabilized with five percent asphalt (without additives) are also included (Line 1).

It is evident that the effects of different additives are very similar for all three investigated soils. For example, it is seen that ortho-phosphoric acid and octodecyl amine do not affect the densities of asphalt-stabilized compacted soils, whereas hydrated lime tends to lower these densities. Although the data for the Massachusetts and Mississippi soils are not shown, tests indicated that the presence of asphalt tended to minimize the effects of different additives on the density of compacted specimens, just as in the case of Maryland soil.

From the viewpoint of stabilities, it appears that ortho-phosphoric acid is the most effective additive. Maximum stabilities of more than 4,000 lb were obtained for Massachusetts soil stabilized with five percent asphalt and treated with two percent of this additive. In the case of Mississippi loess, stabilized in the same manner, maximum stabilities of more than 2,000 lb are shown. Similar trends are shown for asphalt-stabilized, hydrated lime-treated specimens, although the cured and immersed specimen stabilities are generally lower than for ortho-phosphoric acid. As far as octodecyl amine is concerned, only moderate stability benefits are evident for the concentration levels used. Additionally, it appears that these benefits are somewhat more pronounced when drier than optimum water content soils are mixed and compacted.

SUMMARY AND CONCLUSIONS

On the basis of results presented in this paper the following conclusions are offered:

1. Cohesive soil-water mixtures with and without asphalt respond similarly to compactive loads. Typical compaction curves (plotting density against water or liquid content) are obtained for both systems when a range of compaction water contents is used. Increasing the amount of asphalt in the mixture reduces proportionately the amount of water required to obtain maximum densities of compacted mixtures.

2. Effects of asphalt on density and strength of compacted mixtures appear to depend on the gradation characteristics of soil. With well graded soils, asphalt—even at low concentration levels—tends to lower the values of these properties. In the case of poorly graded soils, a decrease in density and strength becomes evident only at relatively high asphalt contents.

3. The principal function of asphalt in a cohesive soil is to waterproof the consolidated soil mass. This is achieved by coating soil particles, or aggregations of these particles, with water-repelling asphalt films rather than by plugging the void spaces in the soil mass. In more granular soils the asphalt may perform both these functions, and—in addition—it acts as an adhesive between soil particles.

4. Waterproofing effects are improved by the use of more asphalt. The amount of asphalt to be used in a given soil should be governed by the waterproofing effects as reflected in the strength changes of specimens subjected to the action of water. Different soils require different amounts of asphalt for most effective waterproofing.

5. In view of different effects of asphalt on different cohesive, fine-grained soils, each soil should be tested individually to determine the most suitable composition of mixture. Different water and asphalt contents should be tried.

6. Because no correlation between test properties and performance of asphalt-stabilized fine-grained cohesive soil is available at the present time, and because all four testing methods used in this study indicated the same or similar trends in test results, the selection of a laboratory testing method should be based on simplicity and expediency of the method. On this basis it appears that unconfined compressive strength measurement of specimens compacted by AASHO T 180 method and Marshall density and stability test methods are more suitable.

7. Pronounced benefits can be derived from the conjunctive use of asphalt and certain secondary additives in the stabilization of fine-grained soils. Use of asphalt with cementitious additives, such as ortho-phosphoric acid, hydrated lime and normal portland cement, appears to be most suitable for such purposes. In such systems, the additive strengthens and the asphalt waterproofs the compacted soil mass.

8. Asphalt-stabilized, additive-treated fine-grained soil is far stronger and more waterproof than the same soil stabilized with asphalt alone. In general, it is believed that the strengths of soil-asphalt-additive mixtures are more than adequate for use in base courses or, when surface-sealed, for secondary roads.

9. With the exception of portland cement, the systems containing asphalt and cementitious additive respond to severe drying-wetting conditions more favorably than the similar soil mixtures with the additive alone. At compaction water contents around optimum these systems actually increase in strength when repeatedly wetted and dried, as the systems without asphalt tend to disintegrate.

10. Asphalt may tend to retard the additive-soil reactions, but the results indicate that soil-additive systems containing asphalt are less sensitive to variations in compaction water contents. Such moderating effects of asphalt could be useful during construction operations. It may mean that use of asphalt would permit more time for mixing and compaction of soil-additive mixtures and also would minimize the detrimental effects of inadequate distribution of mixture components.

11. The effects of additives which modify the soil structure or are intended to enhance the waterproofing qualities of asphalt are far less pronounced than the effects of cementitious additives. In some cases, some of these additives actually may be detrimental to stabilization of soil with asphalt.

12. Careful laboratory testing is a prerequisite to determining the proper asphalt, additive and water contents to be used with a given cohesive soil. Provided the compaction characteristics of soil are known, on the basis of information presented in this paper, the number of specimens and tests required to determine a satisfactory mixture composition could be appreciably decreased.

Discussion

MANUEL MATEOS and CARLOS de SOUSA PINTO*, Research Associate and Graduate Assistant, respectively, Soils Research Laboratory, Engineering Experimental Station, Iowa State University, Ames — This discussion presents the results of a limited investigation on the use of lime as an auxiliary additive for improving the stabilization of soils with cutback asphalts. The testing procedure used differed from that described in the paper, and it is felt that the data obtained present additional information on the subject of asphalt stabilization.

The soil was a Kansan-age glacial till from southwestern Iowa. Characteristics of the soil are given in Table 2. The lime was commercial calcitic hydrated, Ca(OH)_2 , from U. S. Gypsum Company. The asphaltic materials were MC-0 and MC-2 cutbacks from Texaco, Inc.

The amounts of cutback asphalt were calculated as a percentage of the weight of the oven-dry soil. The amounts of fluids were determined by oven drying and samples at 110 C; they include the weight of water plus volatiles.

Tests specimens were prepared from batches mixed in a Hobart C-100 kitchen mixer at the lower speed. The required amount of soil and lime was first machine mixed for 1 min, after which water was added and machine mixed for 2 min. The asphaltic material was poured into the bowl and premixed by hand. The cutback MC-0 was used at room temperature; MC-2 was previously heated to 150 F. Next, the materials were machine mixed for 1 min, the sides of the bowl hand scraped, and the materials mixed again for 1 min.

Immediately after mixing, 2-in. diameter by 2-in. high specimens were molded to near standard Proctor density (2). The specimens were cured as indicated in Table 3, then tested in unconfined compression with a load travel rate of 0.1 in. per minute.

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TABLE 2

PROPERTIES OF SOIL USED

Textural:	
Sand (2 to 0.074 mm)	32.7%
Silt (0.74 to 0.005 mm)	30.8%
Clay (less than 0.005 mm)	36.5%
Consistency limits:	
Liquid limit	42%
Plastic limit	15%
Plasticity index	27
Chemical:	
Organic matter	0.1%
Cation exchange cap.	20 me/100g
A. A. S. H. O. Classification	A-7-6(13)

The most favorable type of curing for compacted soil-asphalt mixtures is air drying to permit evaporation of moisture and other volatile products. For soil-lime mixtures it is best to retain the moisture, essential to the formation of cementitious reaction compounds. To properly evaluate the stability of a mixture after the required period of curing, it should be submitted to unfavorable conditions which simulate what may occur in the field. One of the most unfavorable conditions that may affect the stability of a stabilized soil base or subbase is water saturation.

The soil-lime-cutback combinations tested and the results obtained are presented in Table 3. The mixing water added was suggested by a previous investigation made with the same soil (3).

It should be mentioned here that during the process of mixing 6 percent MC-2 cutback with the soil, without lime, at a moisture content of 16 percent, slightly below the optimum for maximum density, the materials formed an unyielding paste and mixing was discontinued. In previous tests a similar mixture gave such high resistance to mixing that it broke the mixer (3). When lime was added, even in the smallest amounts, the mixing process proceeded normally. These difficulties were not experienced with MC-0 cutback. This may be explained by the fact that MC-0 has a lower viscosity than MC-2. It is also possible that MC-2 lost its heat-induced fluidity when it came in contact with the unheated soil.

Taking into account that only one soil was used in a limited number of mixtures, the observation of mixtures and the results obtained suggest the following comments:

1. With respect to the mixing: The addition of small amounts of lime improves the mixing of asphaltic materials with cohesive soils. In the case of MC-2 cutback, it was impossible to mix it with the moist clay soils, but previous addition of 1.5 or 3 percent lime to the soil made it possible to obtain a uniform mixture with the asphalt. Visual observations show that uniform mixtures were obtained when lime was used as additive, regardless of the quantity of lime used. With 6 percent MC-0, a good mix was obtained with and without lime as an additive.

2. With respect to strength: It was observed that only the specimens of mixtures with MC-2 stood one day immersion after 7 days of air curing. However, the specimens that withstood immersion did not retain much strength, the maximum being 87 psi for the mixture with 3 percent lime and 10 percent MC-2. Seven-day air cured specimens of mixtures with MC-0 failed during immersion. On the other hand, soil-lime specimens containing as little as 2 percent lime showed about 90 psi after 7 days moist curing and one day immersion. This may indicate that lime alone is more effective for soil stabilization than cutback asphalts with or without lime additives. There

TABLE 3
DATA AND RESULTS OBTAINED^a WITH SOIL-LIME-ASPHALT MIXTURES

Mixture No	Lime	Asphalt		Dry Density (pcf)	Fluids Content (%)			Unconfined Compr 7 Days Air Cured ^b	Str (psi) 7 Days Moist Cured ^b
		%	Type		At Molding	After 7 Days Air Curing	After Immersion in Water		
1	3	6	MC-2	105 0	14 8	2 8	14 9	30	ND
2	3	6	MC-2	103 2	16 2	2 6	20 0	20	ND
3	3	6	MC-2	102 5	18 4	2.8	15 0	60	ND
4	1 5	8	MC-2	105 8	15 6	2 5	20 0	15	ND
5	3	8	MC-2	105 3	16 0	2 5	10 6	60	ND
6	3	10	MC-2	102 0	16 8	3 0	11 5	87	ND
7	3	6	MC-0	105 2	17 2	2 0	ND	0	ND
8	1	6	MC-0	104 4	17 5	1 8	ND	0	ND
9	0	6	MC-0	104 7	17 5	1 8	ND	0	ND
10	6	0	None	102 2	15 0	ND	ND	ND	88
11	6	3	MC-2	102 0	15 0	ND	ND	ND	64
12	2	0	None	107 7	18 0	ND	ND	ND	99

^aND=not determined

^bPlus one day immersion

was also come correlation between the fluids content of the mixtures, after immersion, and the decrease in immersed strength. This shows the beneficial effects of the water-proofing characteristics of asphaltic materials.

A comparison of strengths for mixtures 1, 2 and 3 shows that higher strengths were obtained when the amount of fluids was 18.4 percent, which is greater than the optimum for maximum density. This does not correspond with previous findings using a different test to evaluate stability (3).

Additions of small amounts of cutback asphalt to soil-lime mixtures (compare mixtures 10 and 11) may decrease strength by interference with the formation of the cementitious compounds. The consequent reduction of strength apparently is not compensated for by the beneficial effects, if any, of the asphalt.

The following conclusions are based on the observations and test results obtained in this investigation:

1. Lime can be used in asphalt stabilization of cohesive soils as a mixing aid.
2. However, the stabilization of Kansan till with cutback asphalts does not appear to be promising, even when the soil is treated with lime to facilitate mixing. The same strengths can be obtained with small amount of lime at a lower cost than using cutback asphalt.
3. The addition of small amounts of cutback asphalt to clayey soil-lime mixtures to improve stabilization does not appear promising with conventional methods of mixing. It is possible that lime pretreatment of soils might be promising in connection with techniques of mixing using foamed asphalt (1,4).

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CLOSURE, V. P. Puzinauskas and B. F. Kallas— The authors welcome the comments by Messrs. Mateos and de Sousa Pinto. These comments were generated by their laboratory studies involving a single, highly plastic soil stabilized with lime and asphalt separately and, also, by both stabilizers conjunctively.

Their tests indicate that in regard to strength of stabilized compacted soil, lime alone may be a more effective stabilizer for the fine-grained, plastic soil than the asphalt alone. This agrees with the authors' findings, even when soils less plastic than the Kansan ageglacial till were used. However, the discussers' hypothesis that lime alone may be a better stabilizer than asphalt-lime mixture does not agree with the authors' findings. Laboratory studies and outdoor test panels have indicated that soil-water mixtures strengthened by the lime treatment and waterproofed by asphalt films are stronger, or at least equal in strength, and more durable against weathering effects produced by environmental conditions.

Perhaps the basis for the disagreement lies in the discussers' assumption that drying is the most favorable type of curing for compacted soil-asphalt mixtures. Although this is true for granular, nonplastic soils, it is not necessarily true in the case of fine-grained, plastic soils. The validity of this point is illustrated by the curves submitted in the paper. It is seen that, because of greater water absorption, soil-asphalt mixtures compacted at lower than optimum water contents weaken considerably more than the same mixtures compacted at optimum or higher than optimum water contents.

Similar effects could be expected with dried, plastic soil-asphalt mixtures even when compacted at optimum water conditions. This is substantiated by some unpublished test results obtained in the authors' laboratory. Such effects appear to be more pronounced when insufficient amounts of asphalt are used to stabilize mixtures of fine-grained soils and water.

Furthermore, the authors believe that the comparison of dry-cured, soil-asphalt-lime with wet-cured soil-lime systems is not warranted. We agree with the discussers that whenever lime is present in the stabilized soil system, regardless of whether asphalt is present or not, wet-cure is necessary to achieve the optimum beneficial effects of this additive. The tests indicate that asphalt films in the compacted mixture reduce the rate of water evaporation, thereby allowing more time for the occurrence of the cementitious, pozzolanic reactions of lime.

To reiterate, although strength is an important property of the stabilized soil, it does not necessarily reflect the durability of weathering characteristics of the stabilized compacted soil mass. The authors' studies indicate, at least as far as the effects of wetting-drying are concerned, that soils stabilized conjunctively with lime and asphalt or with phosphoric acid and asphalt behave far more favorably than the same soil treated with these cementitious additives alone.