RECENT DEVELOPMENTS IN THE DESIGN AND CONSTRUCTION OF SOIL-EMULSION ROAD MIXTURES

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This paper briefly reviews the theory of the stabilization of soils with emulsified asphalts The major part is devoted to a description of recent improvements in field operations which insure the success of the work and greater speed of construction These improvements are discussed under the following subjects, (1) proportions of soil and emulsified asphalt, (2) mixing soil and emulsified asphalt, (3) rolling, (4) drying, and (5) stabilization of sand with emulsified asphalt. The most outstanding improvement was that obtained by allowing the soil-emulsion mixture to dry out in thin layers of approximately 2 in. thickness. Based on a dehydration value of 25 per cent of the compaction moisture as being necessary for effective stabilization a 2-in. layer attained this value in 6 days, whereas a 4-in. layer required 17 days and a 6-in. layer needed 34 days with the drying environment a constant The greater ease of construction, coupled with the more effective drying in thin layers, has been so successful since its adoption that it has practically displaced all other construction methods

In the many past discussions of the stabilization of soils with emulsified asphalt, including the first one in the Proceedings of the Highway Research Board in 1935,[1] the main subject has been the technical and theoretical characteristics of the treatment. Too little has been said about the methods by which this process can be most effectively used. The growth in the use of emulsified asphalt in this work has naturally placed construction under the operations of many engineers who have been responsible for improvements in construction practices which are of great importance, and this report will attempt to present these improvements.

THEORY

Only sufficient theory need be mentioned here to explain the necessity for the construction improvements.

Stabilization by this process consists of mixing emulsified asphalt with earth in a proportion which will cause the binder, or clay, portion of the soil to lose its affinity for water, without causing it to lose its natural binding quality and become thermoplastic. At the time of making the mixture, the asphalt becomes dispersed in microscopic spheres among the soil colloids, but during drying of the mixture, these spheres are drawn into coatings on the soil grains by the force of surface tension. These water-resistant films prevent the soil from again taking up sufficient water to cause it to lose stability, and thereby permanent stabilization is accomplished.

To obtain this result, several operations are important:

1. The proportions of soil and emulsified asphalt must be within a range which has been proven satisfactory by preliminary tests If too little emulsified asphalt is used the desired water resistance in the mixture will not be developed. Too much will lubricate the mixture with asphalt, thereby causing loss of some of the naturally high supporting strength inherent in the dry, or damp, soil.
2. The soil and emulsified asphalt must be thoroughly mixed together, or the blend will be non-uniform in its characteristics, and will give poor results.

[1] C. L. McKesson, "Soil Stabilization with Emulsified Asphalt," *Proceedings*, Highway Research Board, Vol. 15, p 357.

3. The mixture must be compacted while at optimum moisture content to its greatest density, if the material is to develop its maximum load-carrying power.
4. (Probably most important) The mixture must be dried to the lowest water content possible, in order to convert the spheres of asphalt into protective films on the soil grains.

These four points are essential to high quality in a stabilized base or pavement, and the improvements in field operations affecting these four items will be the principal subject of this discussion.

PROPORTIONS

Little improvement has been made in this phase of the treatment since the early days of its development. Tests are made on each individual soil encountered, to determine its general characteristics. Each soil is then made into several mixtures, with quantities of emulsified asphalt covering a range predetermined on the basis of the grading and surface area of the soil. After these mixtures have been molded into cylindrical specimens and dried, they are tested for absorption of water and resistance to plastic flow. The lowest quantity of emulsified asphalt which results in satisfactory water resistance and high stability is found by these tests, and this quantity, plus a small safety factor, is used. Four percent of emulsified asphalt has been set as a minimum requirement for soils where tests indicate a lesser quantity. This minimum requirement affords a factor of safety to compensate for minor variations in mixing, gradation of soil and placing under field conditions.

This method of determining proper proportions has proven entirely satisfactory, and is quite rapid. No very costly equipment is required, and any experienced and capable soils laboratory can readily set up the necessary control for stabilization work.

MIXING

All types of mixing equipment continue to be used in stabilization work. Large jobs, however, are usually done with large, mechanical traveling mixers, because of their great capacity and efficiency. Control of materials has been improved through the use of windrow eveners, and this has resulted in more dependable proportioning. One definite improvement in traveling mixers merits comment. Formerly, most of these machines were equipped to pump only one liquid material to the mixing chamber, and this made dilution of the emulsified asphalt, or pre-wetting of the aggregate, necessary. The present use of two proportioning pumps now makes it possible to add the emulsified asphalt and water separately to the mixer, thereby controlling the consistency of the mixture, regardless of variations in the aggregate.

Proper preparation of the subgrade is of maximum importance to every mixing operation, as well as to the other operations to follow. There has been a tendency in the past to stabilize material in place, without exposing the subgrade so that it could be satisfactorily prepared. This has resulted in subgrades of non-uniform character, many times improperly compacted, and having no true plane. A great improvement can be made by so arranging the work that the subgrade can be entirely cleared of material at one stage of the operation, as this develops a uniformly firm foundation upon which to build the pavement

Where the mixing is to be done with traveling mechanical mixers, it has been found preferable to move all of the material to be stabilized outside of the area during preparation of the subgrade. Where possible, mixing, also, is carried on outside the pavement area, so that the already mixed material may be pulled over the subgrade and spread in layers without damage to the foundation. At first glance, this would appear to complicate the work, thereby making it more costly. This has not proven to be the case, however, as the cost has actually been reduced on those jobs where this method has been used. Even where large areas, such as airport runways, are to be constructed, it has proved more economical to completely remove all soil for use in the base, so that the subgrade could be properly prepared and primed.

Where the soil in place is to be mixed with blades and harrows, mixing is generally partially done during removal of the soil from the grade, after which the subgrade is prepared and primed. The additional mixing may then be carried on outside the area, or may be accomplished as the partially mixed material is moved back into place in the road. It is not always possible to completely remove the base aggregate, due to lack of space In this case, it is usually advisable to mix half-widths, leaving the other half of the area for storage, or mixing of the base material.

ROLLING

Very substantial improvements have been made in methods of handling stabilized mixtures during spreading and rolling. This phase of the construction of stabilized pavements has caused some trouble in the past, and improvements along this line are important.

When a stabilized mix is made, sufficient water is generally used to separate the individual soil grains and break up all agglomerations of clay or soil binder. When this is done, the mixing is much more easily carried out, and the asphalt is distributed more evenly throughout the aggregate. The consistency of the mix at this water content is usually somewhat softer than the consistency of the soil at its plastic limit The mix, therefore, when freshly made, is usually too soft to be handled expeditiously by ordinary road-building equipment Mixes containing a high proportion of cementing material of fine nature are generally somewhat sticky at this stage, making finishing difficult. Even mixtures containing quite a large proportion of coarse particles are soft enough to rut badly during spreading, resulting in a poor surface finish.

Rolling at this stage is impossible, except with sheeps-foot rollers, and even these furnish no satisfactory compaction until they have agitated the mixture enough to cause it to dry to somewhere near optimum moisture content. If the mixture is merely leveled and allowed to dry in place, without sheeps-foot rolling, a crust forms on the top which breaks up and crumbles if rolling is attempted when the average of the mixture reaches optimum moisture content. It may be seen, therefore, that difficulties have occurred in this phase of the process which could cause considerable worry to the contractor.

These difficulties have now been overcome by drying the mixture to optimum moisture content, prior to attempting to spread or roll it into place. This is rather easily accomplished by roughly spreading the windrow to expose a large drying surface. After an hour or two of drying under normal conditions, a $1\frac{1}{2}$-in. to 3-in. thickness of the surface can be cut off with a blade, and placed in a windrow. The surface thus exposed is allowed to dry in a similar manner, and is then cut into the new windrow, as was the first layer. This operation is repeated until all of the fresh mix constituting the flattened windrow has been dried to an average of optimum moisture content, and moved into the new windrow.

This method of drying is very rapid and effective. The surface of the freshly exposed mixture tends to crust during the short drying period, but this over-dry material is mixed with over-wet material during its movement into the new windrow, where a mixture of uniform consistency is formed.

Where this method is used, it has been found possible to dry a rather sticky clay-bearing soil from an average of 13 percent water content to an optimum of 7 percent, in as little as 5 hr., when handling sufficient material for a 6-in. stabilized base, 10 ft. wide. Where the former method of using sheeps-foot rollers was employed, rolling had to continue for more than that length of time merely to dry the mixture, prior to compacting it. It can therefore be seen that a great saving in equipment and power can be made by the use of this new process.

Once the mixed material has been dried to optimum moisture content, and placed in windrows, it can be readily handled by the use of ordinary road equipment. It has been found, however, that spreading and rolling in relatively thin layers is most effective, and that the use of pneumatic-tired rollers gives optimum results, both as to density and ease of operation.

It is now the practice to lay out the mixture in sufficient thickness to result in a compacted layer of not over 2 in., and roll it immediately with pneumatic-tired rollers, so that maximum density can be obtained before the soil can dry beyond the proper moisture content for best compaction. Several pneumatic-tired rollers on a large job can handle a large quantity of material, due to the speed at which the rollers operate, and their efficiency in obtaining density. This speed of rolling prevents excessive drying of the surface layer, and eliminates much trouble from the formation of a pulverized surface layer, particularly in the case of friable soil.

Some sprinkling of the mixture with water during rolling improves the bond and finish of the surface of each layer, but even this operation can sometimes be eliminated.

A pneumatic roller furnishes a hard, well-bound surface of superior toughness. By using such rollers on relatively thin layers, densities are obtained which, in most cases, exceed those obtained using the Proctor method of molding On one job of this type constructed last summer, densities as high as 110 percent of Proctor were obtained by this method.

Sheeps-foot rolling in greater thicknesses furnishes very satisfactory results, also, but as rolling cannot be accomplished as rapidly, a loosely bound layer is sometimes formed on the surface. Where the sheeps-foot roller is used, a very satisfactory method of finishing to a firm, hard surface is to roll the material to approximately one inch greater thickness than the thickness of base desired, and after completion of the rolling, to cut off the upper layer and move it into the next windrow of material to be spread. In the spreading of the next windrow, this material is worked into the wetter mixture, where it can be satisfactorily used.

DRYING

Drying a stabilized mixture is probably the most important step in the process of emulsified asphalt stabilization. Each of the three foregoing processes can be perfectly carried out, but if the mixture is not sufficiently dried, stabilization will not be fully effective

As explained previously, the asphalt in a mixture of this type is present as small microscopic spheres, distributed among the soil grains, until drying has pulled these spheres into protective coatings. Drying accomplishes this result by thinning the water films around each soil particle until the films develop strong surface tension. It is this surface tension which pulls the asphalt into protective coatings, and until these coatings have formed and adhered to the soil grain surfaces, stabilization has not been obtained Too much stress cannot, therefore, be placed on the necessity for thorough drying of the mixture after it is laid in place.

The drying time, as well as the completeness of drying of a mixture of soil and emulsified asphalt, like everything else, varies with its thickness. Thin layers of stabilized soil dry very rapidly under normal atmospheric conditions, but the greater the thickness of the layer, the slower the rate of dehydration.

An examination of Table 1 in which all conditions were held constant, except thickness, will better explain the difference in this regard. The conditions under which these tests were made are those available to the soil laboratory. They are not so effective as drying conditions in the field, where direct sunlight and air motion develop a much more rapid rate of dehydration. The figures in this table indicate, however, the difference in rates of dehydration for 2-in., 4-in. and 6-in. thicknesses of stabilized mixture, compacted and dried from the surface only. These tests do not take into consideration the infiltration of moisture from the subgrade which, unless prevented, also retards the drying rate.

TABLE 1

DRYING RATE OF 2 IN , 4 IN. AND 6 IN. THICKNESSES OF STABILIZED SOIL UNDER LABORATORY CONDITIONS

(Drying from Surface Only)

Drying Time	Percentage of Moisture Contained		
	2-in Thickness	4-in Thickness	6-in Thickness
	%	%	%
Start of Test	14 3	14 3	14 3
1 Day	10 0	11 9	12 6
2 Days	8 1	10 7	11 7
3 Days	6 6	9 4	10 8
6 Days	4 6	7 8	9 6
13 Days	2 2	5 7	8 1
17 Days	1 6	4 5	6 9
24 Days	1 2	2 7	5 6
34 Days	1 1	1 7	4 3

It will be seen from Table 1 that a 2-in. thickness of stabilized mixture, under the conditions of the tests, dried in 34 days to 1.1 percent water, while a 4-in. thickness dried to 1.7 percent water, and a 6-in. thickness dried to 4.3 percent.

From these data, it appears that the 2-in. layer of soil could be dried to 4.6 percent of moisture in 6 days, while it required 17 days for the 4-in layer, and 34 days for the 6-in. layer to reach approximately this same moisture content. It seems, therefore, that the drying time increases as approximately the square of the layer thickness, making it logical to construct a multiplicity of thin layers in preference to one thick layer, thus reducing the drying time to one third, or less, of that required for single layer construction.

That complete drying is essential will be shown by Table 2, where appear tests for absorption and stability on samples containing zero percent moisture and on samples containing 5 percent moisture at the time of placing them in the absorption cabinet. It will be seen that a very effective stability of 25,000 lb., or more, remained after absorption, where the specimens were completely dried, but that only about one-fifth the stability was obtained where the samples were dried to 5 percent moisture content before absorption. That drying to 5 percent moisture content still furnished substantial improvement as compared to the untreated soil does not alter the fact that better results were obtainable through more complete drying.

Effective stabilization is always accomplished when mixtures are dehydrated to 25 percent, or less, of the moisture indicated by the Proctor Test to be optimum for compaction. This degree of drying is obtainable under all field conditions when proper construction methods are used. In the case of the soil used in the tests shown in Tables 1 and 2, the Proctor optimum moisture content was 16 percent, and 25 percent of this amount would have been 4 percent. Drying to this degree, or less, would have greatly improved the results shown in Table 2, moisture, as shown in Table 1, was accomplished in six to eight days for the 2-in. layer. This same extent of drying in the 6-in. layer required 34 days.

Based upon the foregoing findings, it will be seen that drying in thin layers

TABLE 2

THE EFFECT OF DRYING AND MOISTURE CONTENT ON STABILITY
SAN FRANCISCO CLAY SOIL

Description	Stabilizer	Water Absorbed in 7 Days	Total Water at Test	Stability		
				1st ½ in.	2d ½ in	3d ½ in
	%	%	%	lb	lb.	lb
Specimen Dried at 140° F. Regular Absorption and Stability Procedure	0	13.3	13 3	500	500	750
	0	12.7	12 7	500	500	750
	0	12 5	12 5	750	1000	1000
Average	0	12 8	12 8	583	666	833
Specimen Dried at 140° F. Regular Absorption and Stability Procedure	10	1 2	1 2	25000	37000	40000+
	10	1 4	1 4	24000		
	10	1 3	1 3	24000		
Average	10	1 3	1 3	24333		
Specimen Air-Dried to 5% Moisture Content, then Absorption and Stability	10	1 9	6 9	5000	8000	9500
	10	2.1	7 1	4000	5500	6500
	10	2 1	7.1	5500	8500	10000
Average	10	2.0	7.0	4833	7332	8666

Mechanical Analysis of S. F Clay Soil

Sieve Size	Passing	Sieve Size	Passing
	%	%	%
½ in		No. 80	72 1
¼ in		No. 200	52 0
No 10	100 0	005 mm.	19.3
No. 40	95 5	.001 mm.	10 3

Plastic Index, 10
Optimum Moisture (Proctor) 16%

and would have furnished a margin of safety which is very desirable.

Comparison of the results obtained in Table 2 and those in Table 1 will give an idea of the differences in drying time necessary to accomplish proper stabilization. Drying to less than 4 percent should be substituted for drying in full base thickness, if rapid and complete dehydration is to be obtained.

Tables 3 and 4 show the results obtained on jobs in which layer construction and layer drying were used. Table 3 shows the results where construction

TABLE 3

DRYING TIME OF EMULSIFIED ASPHALT BASE WITH LAYER CONSTRUCTION (FAVORABLE WEATHER CONDITIONS)

Sampled	Consistency	Moisture Content
First 3-in. Layer of Stabilized Base		
		%
1st Day 9 30 a.m.	As Mixed	10 0
1st Day 2.00 p m	As Laid	6 3
2nd Day 2·00 p m.	During Drying	4 6
3rd Day 2.00 p m	During Drying	4 0
4th Day 4·00 p m.	During Drying	3 2
7th Day 9.30 a m ..	Drying Completed	2 3
Second 3-in Layer of Stabilized Base		
		%
1st Day 8:30 a m.	As Mixed	9 0
1st Day 2·00 p.m	As Laid	7.6
2nd Day 4.00 p m.	During Drying	5 3
3rd Day 2.00 p m	During Drying	3 9
4th Day 4 00 p m	During Drying	3 7
5th Day 8:30 a m	Drying Completed	2 6

Typical drying rate of 3-in layers of stabilized soil under favorable weather conditions. Six-inch base completed, dried and ready for surfacing 10 days after construction started.

was carried out under favorable climatic conditions, and Table 4 shows results where climatic conditions were less favorable, because of high humidity and frequent showers. The data shown in Table 3 were obtained through the use of two-layer construction, each layer being of 3-in. compacted thickness A 6-in. stabilized base was constructed under these conditions, satisfactorily dried, and ready for the construction of a wearing surface in 10 days. In Table 4, three 2-in layers were constructed and satisfactorily dried in 22 days. In both cases the time required for construction and drying of the pavement was very materially reduced from that formerly necessary where a full 6-in. base was constructed at one time.

The greater ease of construction, coupled with more effective drying in thin layers, has been so outstandingly success-

TABLE 4

DRYING TIME OF EMULSIFIED ASPHALT BASE WITH LAYER CONSTRUCTION (UNFAVORABLE WEATHER CONDITIONS)*

Sample from	Moisture when Laid	Time of Drying	Water Remaining
	%	*days*	%
1st Layer 2 in Thick	15 0	4	2 83
2nd Layer 2 in Thick	13 0	10	2 56
3rd Layer 2 in Thick	11 0	8	3 41

Total Time of Drying 6-in Thickness, 22 Days

* Drying rate of stabilized soil under weather conditions of eastern seaboard where high humidity and showers produce slow drying. Drying accomplished in 22 days as compared with two months or more where the 6-in layer is rolled into place at one time The variation in drying time of successive layers was due to variations in weather during this period which ranged from medium to very unfavorable

ful since its adoption that it has practically displaced all other construction methods. These new developments have almost completely eliminated the once serious difficulty of slow drying in emulsified asphalt stabilized bases, making the process workable and rapid. Combined with this development, has been the use of an asphaltic prime on the subgrade which, by retarding the infiltration of moisture into the drying layers placed on it, also aids in rapid dehydration

STABILIZATION OF SAND WITH EMULSIFIED ASPHALT

In the foregoing discussion, only the treatment of cohesive soils and aggregates has been covered. There is another form of stabilization which has come into general use that is differentiated from the more widely known type by the designation, "sand stabilization".

This process can be used with non-cohesive soils with very satisfactory results, but it depends for its success upon a different method of design. In soil stabilization, the coarser materials in the soil are bound together by the cohesive matrix already present therein. Sandy soils lack this binder portion, and must be cemented together by other means.

A number of years ago considerable laboratory work was carried on in an attempt to form a cohesive mixture of asphalt and sand by the usual methods of design, but the inherent stability of the aggregate proved to be too low to give satisfactory results. A new theory of design was therefore worked out which, seemed to function satisfactorily.

It was remembered that very unstable sands found on the ocean beach usually remain stable for a period of time after the tide has gone out, due to their retention of a water film.

The idea, therefore, of manufacturing a highly cohesive mixture was discarded, and an attempt was made to better the result furnished by Nature in the case of the wet beach-sand. Sands were tested with various thicknesses of water films, to determine the percentage of water which provided the greatest stability. After this amount was determined, the same thicknesses of films of ductile, sticky asphalt were substituted through the use of the proper quantities of emulsified asphalt. The results were very satisfactory. Although the mixtures thus formed lacked the degree of cohesiveness formerly believed desirable, they were found extremely stable under direct loading, and it proved possible to protect the surface from abrasion by the use of relatively thin surface treatments The amount of emulsified asphalt required to accomplish the desired result was found to vary somewhat, depending on the character of the sand, itself. Average sand could be well stabilized with approximately 50 percent of the amount of binder required for fully binding the sand together, or the amount indicated by the usual design formula for sand-asphalt surface mixtures. In some cases, as much as 60 percent, and even 70 percent of binder was found desirable on this basis. Apparently, these thin films of asphalt, as furnished by these small quantities of emulsified asphalt, accomplish stability by increasing the frictional resistance of the sand surfaces to sliding over each other. Some cohesiveness naturally is also obtained, but it is believed that the treatment is less dependent upon cohesion than upon increased friction.

A large amount of this type of construction has been done in the past several years which, under service conditions, has well proven the soundness of the theory of design. The use of emulsified asphalt has some distinct advantages in that the sand need not be dried prior to mixing. It can be dampened in advance of the mixing operation, in which form it is sufficiently stable to allow the use of large traveling mixing machines, without their miring down in the normally unstable material; and quick showers do not delay the work.

GENERAL DISCUSSION

In the foregoing, four very essential steps in the stabilization of cohesive soil have been discussed. The proper handling of each of these important steps is necessary to the success of stabilization with emulsified asphalt. The recent improvements discussed are strongly recommended to engineers interested in using this form of stabilization.