HIGHWAY RESEARCH BOARD
DIVISION OF ENGINEERING AND INDUSTRIAL RESEARCH
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Wartime Road Problems

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No. 5

GRANULAR STABILIZED ROADS

HIGHWAY RESEARCH BOARD
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DEPARTMENT OF SOILS INVESTIGATIONS

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Wartime Road Problems

There are two major wartime road responsibilities; to keep the traffic essential to the war effort moving, and to carry the existing roads through the war period in as good condition as possible. Discharge of these responsibilities entails consideration of many new factors in view of the limitations on time, money, labor, equipment and use of critical materials imposed by the exigencies of the national situation. Obviously, changing emphasis from devising better and more economical methods to a program, within the wartime limitations of wartime traffic movement and conservation of the existing roads confronts highway engineers with many new problems and new aspects of old problems.

The Highway Research Board believes that it can be helpful by aiding in disseminating in usable form the best available information on those phases of highway technology in which common practice has not become established or in which practice must be modified during the war. To this end a series of bulletins on WARTIME ROAD PROBLEMS will be prepared by qualified committees and published by the Highway Research Board. Recommendations in this series of bulletins are based upon wartime restrictions and needs and are only intended for use as guides during the periods in which these conditions prevail.

This program has been endorsed by the Executive Committee of the American Association of State Highway Officials.

Suggestions for suitable subjects will be welcomed.

The following report on granular stabilized roads is of immediate emergency importance. The recommendations, however, are general and need not be restricted to wartime practice as they are applicable whenever the described conditions prevail. The section on Maintenance of Granular Stabilized Surfaces has been reviewed and approved by B. R. Downey, Maintenance Engineer, Michigan State Highway Department and W. H. Root, Chairman of Maintenance Department, Highway Research Board; Maintenance Engineer, Iowa State Highway Commission.

GRANULAR STABILIZED ROADS
(Soil-Aggregate Mixtures)

Granular stabilized roads are those which have been made usable in all weather by means of a mixture of soil and aggregate. They may or may not have a bituminous cover as traffic and weather may require.

Common Knowledge of Soil

The stabilized soil road has not completely emerged from the realm of research and yet because of its potential advantages it is called upon to play a most important part in the nation's war effort. Rapid expansion, due to the present emergency, of agencies concerned with its use has suddenly thrown upon many engineers the responsibility of directing work according to specifications which include terminology and test data limits entirely familiar only to a relatively few who have had the opportunity of delving extensively into the study of soil.

On the other hand, close and more or less continuous contact with soil in everyday life has furnished almost everyone with a fund of knowledge on its performance, which is directly applicable in the construction of the so-called stabilized road.

It is, therefore, pertinent to recall points of contact between common knowledge on soil, and the technical aspects of its use as an engineering material in road construction.

What is Soil Stabilization?

The word "Stabilization" in connection with road work has been used rather loosely and at least in some instances has suggested complex and mysterious processes. As generally accepted, however, it conveys a definite idea without much need for special definition. Simply stated a stabilized fill, subgrade, road surface or road base is one that will stay put, and stabilization is the process by which it has been made that way.

In practice native fine soil may be stabilized by the addition of coarse granular material (aggregate), naturally occurring granular material may be stabilized by the addition of plastic soil, or a suitable mixture of soil and aggregate may be prepared and placed on the road.

Similar methods may be used to prepare stable foundations for any type of pavement.

Granular Stabilized Roads Illustrated

The granular stabilized road is by far the oldest and most commonly used type. Consider a path in any garden or a road on any farm. If in wet weather the path or road becomes muddy, it is customary for the housewife or farmer to apply some kind of readily available granular material such as ashes, cinders, sand, gravel or crushed rock. These applications are, as a rule, continued until the path or road becomes usable under all weather conditions.

On the other hand, if the natural soil is very loose and sandy, small additions of clay soil over a period of time would likewise have produced a satisfactory path or road. These two simple procedures involve all the underlying principles of granular soil stabilization. They may be termed the "cut and try" methods.

By this means, surfaces of appreciable thickness, having natural soil and granular material in the right proportion to produce the desired firmness or stability, have been imposed on the underlying soil.

Recent Progress Concerns the Length of Time of Attainment

Thus, it can be seen that the essential features of granular soil stabilization have long been utilized. The value of soil tests and specifications, which are of relatively recent origin, lies in the fact that by their use the stability, obtainable by "cut and try" methods over long periods can be secured with confidence during construction or shortly thereafter.

STRUCTURE OF GRANULAR STABILIZED ROADS

The road structure consists of two parts; the road surface and the foundation.

Road Surface

The road surface may consist of a granular stabilized surface course with or without chemical treatment or of a granular stabilized base course also with or without chemical treatment, covered with a bituminous top. As defined here the road surface may also be called a pavement, although that term is not commonly used unless the road surface is given an impervious top.

The road surface should have adequate structural strength as this is the component of the total road structure which has to withstand the complex stresses produced by the wheels of vehicles. The weight of the wheel at rest causes stresses through the pavement—into the foundation—which tend to produce settlement or deformation of the loaded part of the pavement in a vertical direction. When the speed of the wheels in motion is being accelerated a horizontal shear is produced which tends to push the top of the pavement backward. When the wheels are braked, a similar tendency is produced in the opposite direction. Also rolling wheels produce vibratory or dynamic stresses which tend to destroy the bond between bituminous surfacing and base course.

The Road's Foundation

The foundation may consist of the subgrade soil, if suitable in quality, or of the subgrade soil covered with a subbase, subgrade treatment or blanket layer. Essentially the road's foundation must satisfy two requirements. It must be adequately resistant to vertical pressures and it must be of such character that the danger of detrimental volume changes due to climatic variations and moisture fluctuations will be eliminated.

Distinction Between Parts of the Road Structure Helpful

Making a distinction between the two principal parts of the total road structure is helpful for two reasons. In the first place the material requirements of the two parts are different. For the road surface only materials which conform to more or less rigid specification requirements are suitable. For the protection of the subgrade against detrimental climatic influences, however, by subbase and blanket layers numerous materials have been found suitable. It is also desirable to make a distinction between surface and foundation from the viewpoint of design to withstand wheel loads of different weights.

MATERIALS

Materials for use in granular stabilized roads are commonly classified as aggregate and soil.

Aggregate is that part of a natural deposit or of a granular stabilized mixture retained on a No. 200 sieve. In a mixture it is called the granular fraction.

Soil is a general term covering naturally occurring materials which contain some aggregate and a fine-soil fraction which provides the soil binder. That part passing the No. 200 sieve is the fine-soil fraction.

The significant parts of a soil-aggregate mixture for stabilized road use are the granular fraction and the fine-soil fraction consisting of silt and clay.

Granular Fraction. With the possible exception of mica flakes and peat particles, all materials retained on the No. 200 sieve can be considered suitable granular material. In selecting the source consideration should be given to the durability of the material.

Fine Soil Fraction. That portion of the material which passes the No. 200 sieve is responsible for the muddy condition of the path or road observed in wet weather. It consists principally of silt and clay.

Silt includes the coarser grains of the fine soil fraction and can be readily distinguished from clay by its grittiness if a tiny amount is placed in the mouth and bitten between the teeth. Silt alone can become very unstable when wet but does not produce a sticky mud.

Clay particles are smaller than silt particles and give no sensation of grittiness when bitten. It is the clay particles which become cohesive when wet and, therefore, produce tenacious mud.

In a stable soil mixture the granular fraction is assumed to furnish strength and hardness and otherwise to function much the same as aggregate in a cement concrete mixture. The silt functions as a filler to help seat the granular particles and the clay as a cementing medium to bind all the fractions into a strong durable mass.

In practice we are concerned with two characteristics of the total soil-aggregate mixture; (1) the grading of the particles, and (2) the binding properties of the fine soil fraction.

Tests and Their Significance

For use in granular stabilization processes, particle grading is measured by sieve analyses, and the binding properties of the fine soil fraction by the tests for liquid limit, plastic limit and plasticity index. The binding property tests are made upon that portion of a soil sample passing a No. 40 sieve.

Sieve Analysis

This test measures the relative amounts of various sizes of particles in the material. The gradation of the material controls the resistance to shear and abrasion which establishes the strength and hardness of the road surface.

Liquid Limit

In soil materials water can be present in three conditions (1) as a film adhering to the surfaces of the particles, (2) as capillary water and (3) as free water. The liquid limit is reached when the total water content becomes large enough for free water to be present. For water contents below this limit materials capable of holding capillary water are plastic down to the water content at the plastic limit. Above the liquid limit the materials are considered to be in a liquid state. Materials such as coarse sand that do not have spaces of capillary size are not plastic although they may hold water in the film phase. The liquid limit test measures the maximum amount of water that the material will hold in the film and capillary conditions. A high liquid limit therefore indicates that the material will hold large amounts of film and capillary water due to the presence of fine particles with large total surface area and capillary size voids. This condition tends to instability and sponginess.

Experience has shown that values, as determined by the standard liquid limit test, of 35 for surface courses where a reasonable degree of capillarity is desired, and 25 for base courses for which very little capillarity is wanted should not be exceeded.

Plastic Limit and Plasticity Index

The plastic limit simply indicates the other end of the range in water content from the liquid limit, within which the binder material has plastic properties. The significant figure is the plasticity index which is the difference between the liquid and plastic limits. It is an index of the cohesive power of the material and also of its flowability under pressure. A low plasticity index indicates low cohesiveness and a high index a tendency to instability when wet. It is obvious therefore that the optimum value will depend upon other properties of the mixture such as angularity of particles, grading, and upon whether the stabilized material is to be used in surface or base courses.

Test Procedure

A certain amount of testing is necessary for design of mixes and control of operations. Fortunately, for this work, the test procedure is simple and elaborate laboratory equipment is not required. Descriptions of the required tests with references to standardized methods are as follows:

Sieve Analysis

The size and grading of the particles are determined by sieve analysis. A weighed sample is first washed over a No. 200 sieve and the amount passing that sieve determined. The portion retained on the No. 200 sieve is then dried and separated into the sizes required by the specifications.

The methods for the common sieve

analysis are well known and need not be repeated here. Appropriate standard methods of test are:

"Sieve Analysis of Fine and Coarse Aggregates," American Association of State Highway Officials, T 27–42 and American Society for Testing Materials, C 136 – 39.

If a No. 200 sieve is not available an approximate determination of the fine-soil fraction may be made by a simple decantation test as follows:

1. The pan or vessel to be used in the determination shall be approximately 9 in. in diameter and not less than 4 in. deep.

Percentage of fine soil fraction

$$= \frac{\text{Original dry weight} - \text{weight after washing}}{\text{Original dry weight}} \times 100$$

5. If check determinations are desired, the wash water may be evaporated to dryness, the residue weighed, and the percentage calculated from the formula:

Percentage of fine soil fraction

$$= \frac{\text{Weight of residue}}{\text{Original dry weight}} \times 100$$

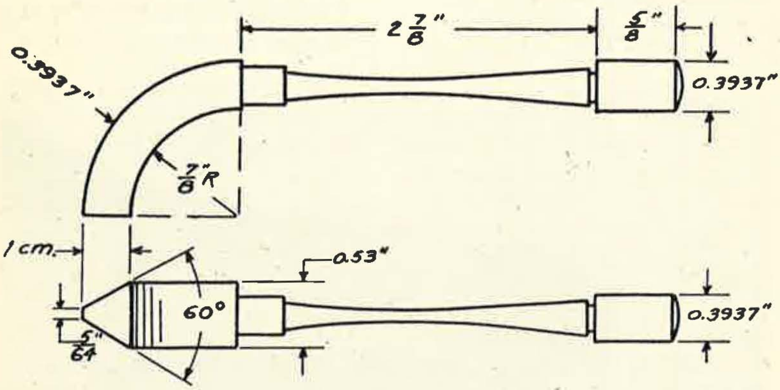


FIGURE 1—Grooving Tool

2. The sample must contain sufficient moisture to prevent segregation and shall be thoroughly mixed. A representative portion of the sample sufficient to yield approximately 500 g. of dried material, shall be dried to a constant weight at a temperature not exceeding 100°C.

3. The dried material shall be placed in the pan and sufficient water added to cover the sample. The contents of the pan shall be agitated vigorously for 15 sec. and then be allowed to settle for 15 sec., after which the water shall be poured off, care being taken not to pour off any sand. This operation shall be repeated until the wash water is clear. The washed sand shall be dried to a constant weight at a temperature not exceeding 110°C. and weighed.

4. The results shall be calculated from the formula:

Liquid Limit

The test for liquid limit is made upon the portion of air-dried soil passing the No. 40 sieve.

The liquid limit is defined as that water content, expressed as a percentage by weight of the oven-dry soil, at which the soil will just begin to flow when jarred slightly. According to this definition, soils at the liquid limit have a very small but definite shear resistance which may be overcome by the application of little force. At the liquid limit cohesion in the soil is practically zero.

The moist soil sample is placed in a porcelain evaporating dish about 4½ in. in diameter, shaped into a smooth layer about ⅜ in. thick at the center and divided into two portions by means of a grooving tool of standard dimensions (Figs. 1 and

2). The dish is held firmly in one hand with the groove parallel to the line of sight and tapped lightly 10 times against the heel of the other hand. If the lower edges

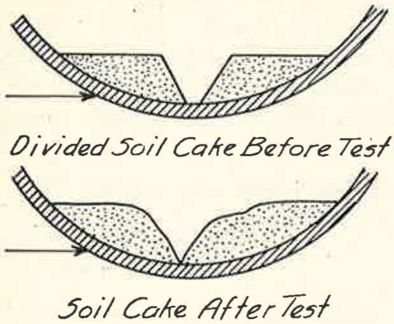


FIGURE 2—Diagram Illustrating Liquid Limit Test

more or less water, as the case may be, until the two edges meet for a length of one-half inch after 10 blows have been struck. The water content is then determined. This is the liquid limit.

A mechanical device which is calibrated against the hand method just described is used in most laboratories.

The standard methods of test are:

"Standard Methods of Determining the Liquid Limit of Soils," American Association of State Highway Officials, T 89 - 42,

"Standard Method of Test for Liquid Limit of Soils," American Society of Testing Materials D 423 - 39.

The liquid limits obtained by an operator of average experience and skill, using both

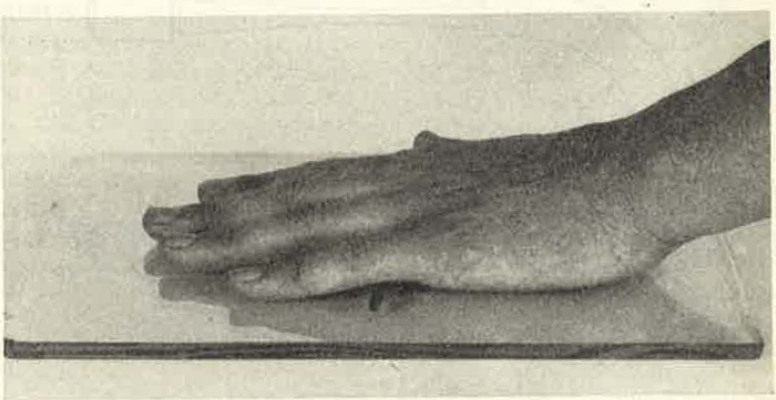


FIGURE 3—Rolling of Soil Threads in Plastic Limit Test

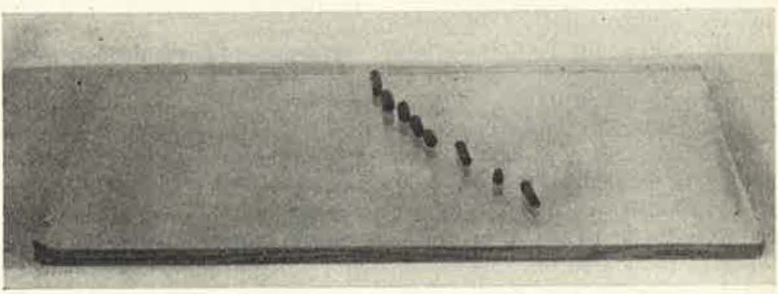


FIGURE 4—Crumbled Soil Threads Resulting from Plastic Limit Test

of the two soil portions do not flow together, the water content is below the liquid limit. If they flow together before 10 blows have been struck, the water content is above the liquid limit. The test is repeated with

hand and mechanical methods, should check closely for identical soil samples.

Plastic Limit

The plastic limit test is also made upon the portion of the air-dried soil passing

TABLE 1. STATE HIGHWAY SPECIFICATIONS FOR PLASTICITY INDEX (PI) AND LIQUID LIMIT (LL) FOR HIGHWAY CONSTRUCTION

Region and State	Base Course			Surface Course			Year
	Type and Treatment	Max. PI or Range	Max. LL	Type and Treatment	Max. PI or Range	Max. LL	
NORTH-EAST							
Vermont				Gravel	6-14		1936
Connecticut	Rolled gravel	8	25	Rolled gravel	8	25	
Connecticut				Traffic bound gravel	6	25	1940
New York				Calcium chloride or sodium chloride	6-14	35	1939
Michigan	Stabilized gravel	1-6	25	Bituminous stab.	1-6	35	
Michigan				Chemical stab.	5-9	35	1942
Michigan				Chemical stab.	8-12	35	
Wisconsin	Stabilized gravel	0-5	25	Stabilized gravel	0-5	25	1941
MIDDLE-EAST							
Illinois				Crushed rock or gravel	6-14	35	1936
Indiana	Crushed rock or gravel	6	25				1939
Ohio	Crushed rock or gravel	0-6	35	Chemical stab.	4-10	35	1939
Kentucky	Gravel	1-3	PI + 14	Gravel	1-6	PI + 14	1938
Tennessee	Gravel	2-12	45				1938
West Virginia				Crushed rock or gravel	6-14	35	1935
Virginia	Gravel	6	25	Gravel	4-9	35	1938
Maryland	Gravel	6					1939
SOUTH-EAST							
Mississippi	Sand-clay, clay-gravel.	8	25	Clay-gravel	15	30	1940
Mississippi	semi-gravel	8	25	Semi-gravel	12	28	1940
Alabama	Stab. clay calcium chloride[a]	6	25				1939
North Carolina	Fine graded	6	25	Fine graded	6	35	1939
North Carolina	Coarse graded	6	25	Coarse graded	3-10	35	1939
South Carolina	Fine graded	10	25	Fine graded	10	25	1939
South Carolina	Coarse graded	8	20	Coarse graded	8	20	1939
Georgia	Sand-clay, clay-gravel	10	25	Sand-clay. clay-gravel	10	25	1942
Georgia	Chert	6	25	Chert	6	25	1942
Florida		10	30				1941
NORTH-CENTRAL							
Minnesota	Crushed rock	8	30	Crushed rock	8	30	1938
Minnesota	Sand or gravel	14	35	Sand or gravel	12	35	1938
Iowa	Rolled stone, soil agg.	6	25	Gravel, stone	4-9	35	1941
North Dakota	Fine graded	5-15	35				1939
North Dakota	Coarse graded	5-10	35				1939
South Dakota	Sand-clay, gravel	4-9		Clay binder added to gravel	15-35		1938
Nebraska	Sand-clay	10					1937
Kansas	Sand-clay, crushed rock or gravel	2-7					1937
SOUTH-CENTRAL							
Louisiana	Sand-gravel-clay	6	25	Sand-gravel-clay	4-10	35	1940
Oklahoma	Crushed rock, gravel,	4-12	30				1937
Oklahoma	sand clay	4-12	30				1937
Texas	Caliche,[b] shell,[b] cr. stone[b]	15[d]	45				1938
Texas	Gravel[c]	12[d]					
MOUNTAIN							
Montana	Crushed rock or gravel	9	30	Crushed rock or gravel	9	30	1940
Idaho	Crushed rock or gravel[e]	9	35				
Idaho	Crushed rock or gravel[e]	0	40	Crushed rock or gravel[e]	9	35	1941
Idaho	Crushed rock or gravel[e]	6	25	Crushed rock or gravel[e]	6	25	
Idaho	Crushed rock or gravel[e]	0	30				1938
Wyoming	Crushed rock or gravel	6	25				1938
Wyoming	Stabilized clay	0	30				1938
Utah	Crushed rock or gravel	6	25	Crushed rock or gravel	6	30	1939
Colorado				Crushed rock or gravel	0-8	30	1942
Colorado				Sand-clay	0-8	30	1942
Nevada	Gravel	0-6	25-30	Gravel	0	25	1940
New Mexico	Crushed rock or gravel (3 in. max.)	6		Crushed rock or gravel (1 in. max.)	6		1941
Arizona	Crushed rock or gravel	0-6		Crushed rock or gravel	6		1942
PACIFIC							
Oregon	Crushed rock or gravel	0	35	Crushed rock or gravel	0	35	1942

[a] Expediting consolidation and preventing ravelling.
[b] The mixture shall not exceed 50 percent soil binder (wet method).
[c] The mixture shall not exceed 40 per cent soil binder (wet method).
[d] These values are still being used; however recent observations indicate that they are 2 or 3 points high.
[e] 20 per cent passing the No. 40 sieve.

the No. 40 sieve. The plastic limit is defined as the water content, expressed as a percentage by weight of the oven dry soil, at which the soil just begins to break into pieces when rolled into threads ⅛ in. in diameter (Figs. 3 and 4). Soil which cannot be rolled into threads at any water content is considered nonplastic.

The standard methods of test are:

"Standard Methods of Determining the Plastic Limit of Soils," American Association of State Highway Officials, T 90 - 42,

"Standard Method of Test for Plastic Limit and Plasticity Index of Soils," American Society for Testing Materials, D 424 - 39.

Plasticity Index. The plasticity index is defined as the difference between the liquid limit and the plastic limit. It is the range of water content through which the soil is plastic. When the plastic limit is equal to or greater than the liquid limit, the plasticity index is reported as zero. When the plastic limit cannot be determined, the plasticity index may be designated by the letters NP (nonplastic) to indicate that the soil is entirely lacking in plasticity.

Mixtures for Different Purposes

Both from the requirements in the section on Recommended Practice for Materials and Mixtures and the data in Table 1 it will be noted that many materials with characteristics suitable for surface courses are not suitable when covered or sealed with bituminous surfaces, or when used as base courses. Both surface courses and bases must have the inherent stability requisite to support the superimposed loads without detrimental deformation. Surface courses must withstand the abrasive action of traffic, should shed a large proportion of the rain which falls upon the surface and should have sufficient capillarity to replace moisture lost by surface evaporation. Base courses in contrast are protected by a cover which takes the abrasion, sheds rain and prevents evaporation.

It has been observed repeatedly that granular mixtures which served excellently as surfaces, have failed when covered by an impervious layer. Also mixtures too porous to give the best service as surfaces have been excellent when given a bituminous wearing course.

The reason for this is that the presence of clay is required in surface courses for the retention against evaporation of the amount of water necessary for stability. This same amount of clay, however, if present in base courses where evaporation from the surface is prevented by bituminous tops may swell and soften with resultant total failure of the road. Therefore, less clay, as a rule, should be used in bases than is needed in surface courses. The amount of clay in the mixture will be controlled by the character and quantity of the binder soil used.

Desirable characteristics of mixtures are indicated by plasticity indexes as follows:—For base courses not more than 6; for surface courses—4 to 9; for sub-bases not more than 15. Materials with plasticity indexes from 4 to 6 are suitable for all of these purposes.

RECOMMENDED PRACTICE FOR MATERIALS AND MIXTURES FOR GRANULAR STABILIZED ROADS

Scope

1. This recommended practice covers the materials and mixtures for granular stabilized road surfaces and base courses. The recommendations are based upon the standard specifications of the American Association of State Highway Officials[1] and the American Society for Testing Materials.[2]

Surface Course Materials

2. Sieve Analysis

Type A—Sand Clay Mortar

Passing	*Percentage by Weight*
1-inch sieve	100
No. 10 sieve	65–100

The following grading is suitable for material passing the No. 10 sieve.

Passing	*Percentage by Weight*
No. 10 sieve	100
No. 20 sieve	55–90
No. 40 sieve	35–70
No. 200 sieve	8–25

Type B—Coarse Graded Aggregate (Gravel, Crushed Stone, Slag)

Passing	*Percentage by Weight*
1-inch sieve	100
¾-inch sieve	85–100
⅜-inch sieve	65–100
No. 4 sieve	55–85
No. 10 sieve	40–70
No. 40 sieve	25–45
No. 200 sieve	10–25

NOTE: With mixtures composed predominately of angular particles a higher percentage passing the No. 10 sieve is desirable than when the material is composed of rounded particles.

3. *Characteristics of Material Passing the No. 40 Sieve for Surface Courses.* The plasticity index should be not less than 4 nor more than 9, the liquid limit should not exceed 35; and the fraction passing the No. 200 sieve should be less than two-thirds of the fraction passing the No. 40 sieve.

[1] A.A.S.H.O., Standard Specifications for Materials for Stabilized Base Course, M 56 - 42. A.A.S.H.O. Standard Specifications for Materials for Stabilized Surface Course, M 61 - 42.

[2] A.S.T.M. Tentative Specifications for Materials for Stabilized Base Course, D 556 - 40 T. A.S.T.M. Tentative Specifications for Materials for Stabilized Surface Course, D 557 - 40 T.

Base Course Materials

4. *Sieve Analysis*

Type A—Sand-Clay Mortar
Same as for Type A Road Surface
Type B—Coarse Graded Aggregate (Gravel, Crushed Stone, Slag)

Passing	1-inch Max.	2-inch Max.	3-inch Max.
	Percentage by Weight		
3-inch sieve			100
2-inch sieve		100	65–100
1½-inch sieve		70–100	
1-inch sieve	100	55–85	45–75
¾-inch sieve	70–100	50–80	
⅜-inch sieve	50–80	40–70	30–60
No. 4 sieve	35–65	30–60	25–50
No. 10 sieve	25–50	20–50	20–40
No. 40 sieve	15–30	10–30	10–25
No. 200 sieve	5–15	5–15	3–10

5. *Characteristics of Material Passing the No. 40 Sieve for Base Courses.* The plasticity index should not exceed 6, the liquid limit should not exceed 25 and the fraction passing the No. 200 sieve should preferably not exceed ½ and in no case ⅔ of the fraction passing the No. 40 sieve.

Sub-Bases

6. Type A—Drainage layers or substitute blankets to the depth affected by frost for naturally silty soils which become unstable due to frost or subsequent thaw.

Characteristics: Non-plastic granular material with not more than 8 per cent passing the No. 200 sieve.

7. Type B—Subbase on soils of low support and treatments on plastic soils (plasticity index greater than 15) which are subject to detrimental volume change.

Characteristics: Same as Type A subbase and also materials which have more than 65 per cent retained on the No. 200 sieve together with a maximum liquid limit of 35 and a maximum plasticity index of 15. Also, in locations not subject to detrimental frost, any material with a maximum liquid limit of 40 and a plasticity index not greater than ¼ the liquid limit is suitable.

Tolerances

8. The purpose of the foregoing recommendations is to produce well graded dense surface courses and well graded base courses, which have stability enough to remain intact under normal service conditions and at the same time be free from the possibility of softening under extreme climatic and unfavorable moisture conditions.

However, all road locations are not subjected to unfavorable climatic, groundwater and drainage conditions. Also many local materials have superior qualities in stabilization processes and on any particular job the specifications must be based upon the characteristics of the available local materials.

Among the local materials which either meet the requirements for granular type base or surface courses, or can be made to meet them by the addition of relatively small amounts of either fine or coarse material are: topsoil (as found in certain localities in southeastern United States) sand-clay, sand-clay-gravel, sand-gravel, crusher run quarry products, blast furnace slag, limerock, caliche, chert, volcanic cinders, burnt shale, and many others of purely local occurrence.

TABLE 2. GOOD BASE MATERIAL INDICATED BY ACCELERATED TRAFFIC TESTS OF THE PUBLIC ROADS ADMINISTRATION[a]

Test section	1	2	3	4	5	6	7	8	9
	Percentage Passing								
Grading:									
Passing 1-in. sieve	100	100	100	100	100	100	100	100	100
¾-in. sieve	98	98	95	98	96	92	100	100	99
No. 4 sieve	75*	80*	66*	76*	79*	67*	98	65*	81*
No. 10 sieve	62*	69*	57*	65*	66	59	55	35	64*
No. 40 sieve	40*	46*	37*	40*	45*	41*	25	19*	37*
No. 200 sieve	23*	24*	18*	23*	25*	22*	12	5*	12
Dust ratio[b]	0.58*	0.52*	0.49	0.58*	0.56	0.54*	0.48	0.26	0.32
Tests on material passing No. 40 sieve									
Liquid limit	17	17	18	18	17	14	14	27*	28*
Plasticity index	2	0	0	3	2	0	2	0	0
Chemical admixture	$CaCl_2$	$CaCl_2$	$CaCl_2$	NaCl	None	None	None	None	Hydrated lime
Chemical surface treatment							$CaCl_2$	$CaCl_2$	
Density at end of test, lb. per cu. ft.	142.2	139.4	141.9	144.4	141.4	139.2	131.3	131.8	107.0

* Denotes percentages outside of recommended specification limits.
[a] E. A. Willis and C. A. Carpenter, "Studies of Water-Retentive Chemicals as Admixtures with Nonplastic Road Building Materials," *Public Roads* November 1939.
[b] Ratio of material passing No. 200 sieve to material passing the No. 40 sieve.

which are not reflected by the grading and plasticity tests.

It has been demonstrated by experience that materials which conform to the foregoing recommended requirements will produce the desired result, but on the other hand many which fall outside the recommended specification limits have been found suitable under particular local conditions.

Granular type stabilization practice is not a matter of writing a specification and then shipping material in conformity with that specification from whatever distance and at whatever cost is necessary. It is rather a problem in making satisfactory use of the material immediately at hand.

A great variety of materials may be used

The best guide to satisfactory practice lies in local experience with the available materials and since granular stabilization has been used in practically all regions in the United States data are available nearly everywhere upon which to base design and specifications.

In Table 1 are given the specifications for liquid limit and plasticity index for materials which have been found suitable by the various State and county highway departments. Many of these specifications depart from the plasticity requirements recommended in this report.

In Table 2 is given a tabulation of base course materials which vary from the recommended specification requirements principally with respect to grading but which gave satisfactory performance in circular track tests.

Simplified Examination

9. Samples prepared for use as guides may assist in the selection of soil-mixtures which have the desired properties. Comparison of such model samples with other materials by manual examination may be especially helpful under emergency conditions when testing facilities are not available.

If a sample of well-graded moist material, with particles coarser than about one-quarter inch excluded, is squeezed in the hand, the following characteristics will be noted: (a) The soil is extremely gritty; (b) it can be formed into definite shapes that retain their forms even when dried; (c) if the clay alone adheres to the hands, it will only be enough to discolor them slightly; (d) if more than enough soil to discolor the hands adheres to them, it will consist of both sand and clay instead of clay alone; (e) when the moist sample is patted in the palm of the hand it will compact into a dense cake that cannot be penetrated readily with a blunt stick the size of a lead pencil; (f) If the moist sample is compacted into a container and allowed to dry it will show little or no shrinkage.

The grittiness of the sample indicates sufficient granular material. Development of some strength on drying indicates sufficient binder soil. Resistance to the penetration of the pencil or stick, even when the sample is thoroughly wetted, indicates desirable interlocking of the grains and a sufficient amount of capillary force.

Too much sand would cause the sample to fall apart when dried. Too much clay would leave the hand muddy after the moist sample was squeezed, and would cause the moist sample after being patted to offer little resistance to the penetration of the stick, and would cause excessive shrinkage of the sample on drying.

* * * * * * *

COMBINING MATERIALS

Unless the native material in place on a road after grading is a naturally stable mixture it is necessary to combine two or more materials from different sources in order to secure the desired result for the purpose at hand, whether surface course, base course or sub-base. There are four conditions which will be met although the processes of designing are essentially the same. These are: adding aggregate to the native soil in place; adding soil or soil fines to native material not sufficiently cohesive; proportioning mixtures of soil and aggregate for plant mixing and adding non-cohesive material of the proper composition to a surface course to be revamped for use as a base.

The first part of the problem will consist in finding a nearby source of material which can be combined with material in place on the graded road or with another material to produce a mixture which will be within the specified limits for liquid limit and plasticity index of that portion finer than the No. 40 sieve, and in so far as practicable within the specified grading limits. If the county in which the road project is located has been mapped for soil classification by the U. S. Bureau of Soils, sources of binder soil can be quickly located by consulting the soil map.

Having selected the materials it will then be necessary to determine the relative proportions in which they are to be mixed. The solution may be approached in three ways. One is to combine the materials so that the plasticity index of the mixture may be expected to be within the allowable range. It will then be necessary to make up a combined sample and test it to determine if the PI is as expected, if the liquid limit is within the allowable limits and if the grading is reasonably close to the specified limits. Another method is to combine the materials so that the grading is within the specified limits and then test a sample of the combined mixture to see if the LL and PI are satisfactory. The third method is simply to make trial mixes until a satisfactory one is secured.

These are all really trial and error methods but the first two have the advantage of offering guidance which may shorten the work. Experts may have no difficulty in using the third method and hitting upon a satisfactory mix on the first or second try.

The first two methods may best be described by illustrative examples.

Combining for Plasticity Index

Assume that a rather coarse material in place is to be stabilized for a surface course by the addition of binder soil. The characteristics of the materials to be combined, the specification limits and the mixture arrived at by the following described procedure are shown in Table 3.

TABLE 3

Sieve Size	Percentage Passing Sieves			
	Road Material	Binder	Specification	Mixture
1 in.	100	100	100	100.0
¾ in.	90	100	85–100	91.5
⅜ in.	75	100	65–100	78.5
No. 4	60	100	55–85	65.6
No. 10	40	100	40–70	48.4
No. 40	28	99	25–45	37.9
No. 200	6	70	10–25[a]	15.0
Liquid Limit	23	38	<35	
Plasticity Index	0	14	4–9	5

[a] The fraction passing the No. 200 sieve should be less than ⅔ of the fraction passing the No. 40 sieve.

It is apparent that the more binder is added the greater will be the PI; hence in order to keep the amount of material to be hauled and added as low as possible it will be desirable to work toward a PI for the mixture near the lower limit. Assume the desired mixture PI = 5.

The Michigan State Highway Department has devised a solution for this problem[3] as follows:

Percentage of binder soil to add = K × R × percentage of road material passing the No. 40 sieve.

$$R = 1 + \frac{\%\text{ of binder soil retained on No. 40 sieve}}{\%\text{ of binder soil passing the No. 40 sieve}}$$

In this case $R = 1 + \frac{1}{99} = 1.01$.

[3] B. R. Downey, "Soil Control in Consolidated Maintenance," *Proceedings*, Highway Research Board, Vol. 21, p. 311 (1941).

K is a conversion factor depending upon the PI of the binder, the PI of the road material and the PI desired for the mixture. Values of K are given in Table 4.

From Table 4, for PI of road material 0, PI of binder 14 and PI of mixture 5, K = 0.56.

Substituting in the formula for the material in Table 3; Binder soil to add = 0.56 × 1.01 × 28 = 15.83%. Hence we find that approximately 16 per cent of binder soil based on the weight of aggregate A must be added for stabilization purposes. The blend for the stabilized mixture will therefore be in the ratio of 100 parts of A to 16 parts of B and the mix will be 86 per cent of road material A plus 14 per cent of binder soil B.

Applying these factors to the percentages of road material and binder passing each sieve and adding them we find that the sieve analysis of the mixture should be as shown in the last column of Table 3. For instance, the amount of the mixture to pass the No. 40 sieve would be 0.86 × 28 + 0.14 × 99 = 37.9%.

It is seen that the presumptive sieve analysis of the mixture falls within the specification limits. Also the fraction passing the No. 200 sieve is less than two-thirds of that passing the No. 40 sieve which complies with that requirement of the specification.

It only remains to make sieve analysis, liquid limit and plastic limit tests on a sample of the materials combined in the relative amounts thus determined. If larger variations from the specification limits than should be allowed are found and checked it will be necessary to try again with new assumptions based upon this experience, and so on until a mixture in reasonable compliance with the specifications is found. The section on Tolerances on page 12 should be studied in this connection.

Although this illustration covers a combination of a road material with a binder soil and the factors in Table 4 are so labeled, the method may be used for the combining of any two materials having plasticity characteristics covered by the table.

TABLE 4. DESIGN CHART FOR STABILIZATION OF LOOSE FLOATING COVER

Conversion Factor (K) for Various Mix and Road Material Plasticity Indexes for 10 to 40 P. I. Binder Soils

P. I. of binder soil	Desired plasticity of mix																											
	P. I. = 7							P. I. = 6						P. I. = 5					P. I. = 4				P. I. = 3			P. I. = 2		P.I.=1
	P. I., Road Material							P. I., Road Material						P. I., Road Material					P. I., Road Mat.				P. I., Road			P. I., R.		P.I., R.
	0	1	2	3	4	5	6	0	1	2	3	4	5	0	1	2	3	4	0	1	2	3	0	1	2	0	1	0
10	2.33	2.00	1.67	1.33	1.00	0.67	0.33	1.50	1.25	1.00	0.75	0.50	0.25	1.00	0.80	0.60	0.40	0.20	0.67	0.50	0.33	0.17	0.43	0.29	0.14	0.25	0.13	0.11
11	1.75	1.50	1.25	1.00	0.75	0.50	0.25	1.20	1.00	0.80	0.60	0.40	0.20	0.84	0.67	0.50	0.33	0.17	0.57	0.43	0.29	0.14	0.38	0.25	0.13	0.22	0.11	0.10
12	1.40	1.20	1.00	0.80	0.60	0.40	0.20	1.00	0.84	0.67	0.50	0.33	0.17	0.72	0.57	0.43	0.29	0.14	0.50	0.38	0.25	0.13	0.33	0.22	0.11	0.20	0.10	0.09
13	1.17	1.00	0.84	0.67	0.50	0.33	0.17	0.86	0.72	0.57	0.43	0.29	0.14	0.63	0.50	0.38	0.25	0.13	0.44	0.33	0.22	0.11	0.30	0.20	0.10	0.18	0.09	0.08
14	1.00	0.86	0.72	0.57	0.43	0.29	0.14	0.75	0.63	0.50	0.38	0.25	0.13	0.56	0.44	0.33	0.22	0.11	0.40	0 30	0.20	0 10	0.27	0.18	0.09	0.17	0.08	0.08
15	0.88	0.75	0.63	0.50	0.38	0.25	0.13	0.67	0.56	0.44	0.33	0.22	0.11	0.50	0.40	0.30	0.20	0.10	0.36	0 27	0.18	0.09	0.25	0.17	0.08	0.15	0.08	0.07
16	0.78	0.67	0.56	0.44	0 33	0.22	0.11	0.60	0.50	0.40	0.30	0.20	0.10	0.46	0.36	0.27	0.18	0.09	0.33	0.25	0.17	0.08	0.23	0.15	0.08	0.14	0.07	0.07
17	0.70	0.60	0.50	0.40	0.30	0.20	0.10	0.55	0.46	0.36	0.27	0.18	0.09	0.42	0.33	0.25	0.17	0.08	0.31	0.23	0.15	0.08	0.21	0.14	0.07	0.13	0.07	0.06
18	0.64	0.55	0.46	0.36	0.27	0.18	0.09	0.50	0.42	0.33	0 25	0.17	0.08	0.39	0.31	0.23	0.15	0.08	0.29	0.21	0.14	0.07	0.20	0.13	0.07	0.13	0.06	0.06
19	0.58	0.50	0.42	0.33	0.25	0.17	0.08	0.46	0.39	0.31	0.23	0.15	0.08	0.36	0.29	0.21	0.14	0.07	0.27	0.20	0.13	0.07	0.19	0.13	0.06	0.12	0.06	0.06
20	0.54	0.46	0.39	0.31	0.23	0.15	0.08	0.43	0.36	0.29	0.21	0.14	0.07	0.33	0.27	0.20	0.13	0.07	0.25	0.19	0.13	0.06	0.18	0.12	0.06	0.11	0.06	0.05
21	0.50	0.43	0.36	0.29	0.21	0.14	0.07	0.40	0.33	0.27	0.20	0.13	0.07	0.31	0.25	0.19	0.13	0.06	0.24	0.18	0.12	9.06	0.17	0.11	0.06	0.11	0.05	0.05
22	0.47	0.40	0.33	0.27	0.20	0.13	0.07	0.38	0.31	0.25	0.19	0.13	0.06	0.29	0.24	0.18	0.12	0.06	0.22	0.17	0.11	0.06	0.16	0.11	0.05	0.10	0.05	0.05
23	0.44	0.38	0.31	0.25	0.19	0.13	0.06	0.35	0.29	0.24	0.18	0.12	0.06	0.28	0.22	0.17	0.11	0.06	0.21	0.16	0.11	0.05	0.15	0.10	0.05	0.10	0.05	0.05
24	0.41	0.35	0.29	0.24	0.18	0.12	0.06	0.33	0.28	0.22	0.17	0.12	0.06	0.27	0.21	0.16	0.11	0.05	0.20	0.15	0.10	0.05	0.14	0.10	0.05	0.09	0.05	0.04
25	0.39	0.33	0.28	0.22	0.17	0.11	0.06	0.32	0.27	0.21	0.16	0.11	0.05	0.25	0.20	0.15	0.10	0.05	0.19	0.14	0.10	0.05	0.14	0.09	0.05	0.09	0.04	0.04
26	0.37	0.32	0.27	0.21	0.16	0.11	0.05	0.30	0.25	0.20	0.15	0.10	0.05	0.24	0.19	0.14	0.10	0.05	0.18	0.14	0.09	0.05	0.13	0.09	0.04	0.08	0.04	0.04
27	0.35	0.30	0.25	0.20	0.15	0.10	0.05	0.29	0.24	0.19	0.14	0.10	0.05	0.23	0.18	0.14	0.09	0.05	0.17	0.13	0.09	0.04	0.13	0.08	0.04	0.08	0.04	0.04
28	0.33	0.29	0.24	0.19	0.14	0.10	0.05	0.27	0.23	0.18	0.14	0.09	0.05	0.22	0.17	0.13	0.09	0.04	0.17	0.13	0.08	0.04	0.12	0.08	0.04	0.08	0.04	0.04
29	0.32	0.27	0.23	0.18	0.14	0.09	0.05	0.26	0.22	0.17	0.13	0.09	0.04	0.21	0.17	0.13	0.08	0.04	0.16	0.12	0.08	0.04	0.12	0.08	0.04	0.07	0.04	0.04
30	0.31	0.26	0.22	0.17	0.13	0.09	0.04	0.25	0.21	0.17	0.13	0.08	0.04	0.20	0.16	0.12	0.08	0.04	0.15	0.12	0 08	0.04	0.11	0.07	0.04	0.07	0.04	0.04
31	0.29	0.25	0.21	0.17	0.13	0.08	0.04	0.24	0.20	0.16	0.12	0.08	0.04	0.19	0.15	0.12	0.08	0.04	0.15	0.11	0.07	0.04	0.11	0.07	0.04	0.07	0.04	0.03
32	0.28	0.24	0.20	0.16	0.12	0.08	0.04	0.23	0.19	0.15	0.12	0.08	0.04	0.19	0.15	0.11	0.07	0.04	0.14	0.11	0.07	0.04	0.10	0.07	0.04	0.07	0.03	0.03
33	0.27	0.23	0.19	0.15	0.12	0.08	0.04	0.22	0.19	0.15	0.11	0.07	0.04	0.18	0.14	0.11	0.07	0.04	0.14	0.10	0.07	0.04	0.10	0.07	0.03	0.07	0.03	0.03
34	0.26	0.22	0.19	0.15	0.11	0.07	0.04	0.21	0.18	0.14	0.11	0.07	0.04	0.17	0.14	0.10	0.07	0.04	0.13	0.10	0.07	0.03	0.10	0.07	0.03	0.06	0.03	0.03
35	0.25	0.21	0.18	0.14	0.11	0.07	0.04	0.21	0.17	0.14	0.10	0.07	0.04	0.17	0.13	0.10	0.07	0.03	0.13	0.10	0.07	0.03	0.09	0.06	0.03	0.06	0.03	0.03
36	0.24	0.21	0.17	0.14	0.10	0.07	0.04	0.20	0.17	0.13	0.10	0.07	0.03	0.16	0.13	0.10	0.07	0.03	0.13	0.09	0.06	0.03	0.09	0.06	0.03	0.06	0.03	0.03
37	0.23	0.20	0.17	0.13	0.10	0.07	0.03	0.19	0.16	0.13	0.10	0.07	0.03	0.16	0.13	0.09	0.06	0.03	0.12	0.09	0.06	0.03	0.09	0.06	0.03	0.06	0.03	0.03
38	0.23	0.19	0.16	0.13	0.10	0.07	0.03	0.19	0.16	0.13	0.09	0.06	0.03	0.15	0.12	0.09	0.06	0.03	0.12	0.09	0.06	0.03	0.09	0.06	0.03	0.06	0.03	0.03
39	0.22	0.19	0.16	0.13	0.09	0.06	0.03	0.18	0.15	0.12	0.09	0.06	0.03	0.15	0.12	0.09	0.06	0.03	0.11	0.09	0.06	0.03	0.08	0.06	0.03	0.05	0.03	0.03
40	0.21	0.18	0.15	0.12	0.09	0.06	0.03	0.18	0.15	0.12	0.09	0.06	0.03	0.14	0.11	0.09	0.06	0.03	0.11	0.08	0.06	0.03	0.08	0.05	0.03	0.05	0.03	0.03

Binder soil to be added (%) = KR × % of material in windrow passing No. 40 sieve.

Combining Sieve Analyses

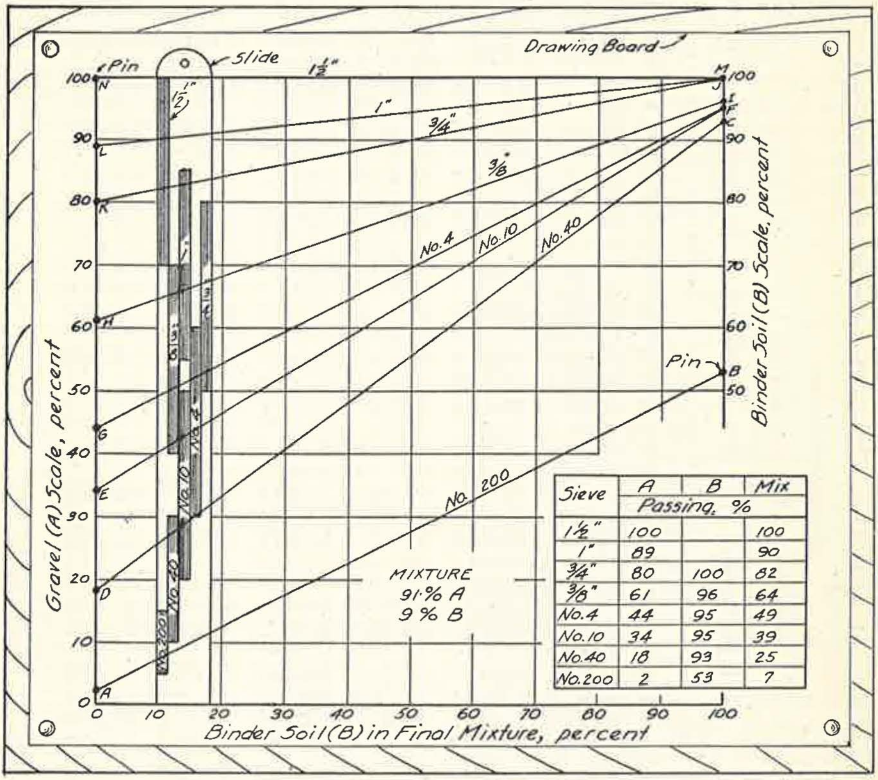
In many cases the percentages of two materials to use to give a combined sieve analysis within specified limits can be readily determined by trial computations. For more extensive use methods devised by the Public Roads Administration and the Michigan State Highway Department are described as follows:

Public Roads Administration Graphical Method[4]

The proportioning of the materials by the graphical method is performed on the mechanical device illustrated in Figure 5. This consists of a drawing board on which is mounted a piece of cross section paper at least 10 in. long by 10 in. wide and having 10 divisions to the inch in each direction, a movable paper scale, several pins represented by the black dots on the figure, and a fine thread looped around the pins. The fine thread is represented on Figure 5 by the lines connecting the pins and having sieve designations.

The movable scale is a strip of cross section paper having the same vertical scale as the fixed sheet. The limits of the specified grading are blocked off on this scale. A different movable scale has to be made for each grading band.

The operation of this device may best be illustrated by a typical example. For convenience in following the procedure, the sieve analyses of gravel sample A and binder soil sample B which are to be combined are shown on Figure 5. The first step is to place pins along the vertical scales of the fixed sheet at points corresponding to the percentages passing the various sieves, on the left for the gravel and on



Sieve	A	B	Mix
	Passing, %		
1½"	100		100
1"	89		90
¾"	80	100	82
⅜"	61	96	64
No.4	44	95	49
No.10	34	95	39
No.40	18	93	25
No.200	2	53	7

FIGURE 5—Graphical Method for Proportioning Two Soil Materials to Produce Specified Grading of Stabilized Mixture

[4] Henry Aaron, "Stabilization Control on the Washington Airport," *Proceedings*, Highway Research Board, Vol. 21, p. 515 (1941).

the right for the binder soil. Next, the end of the fine thread is tied to pin A marking the percentage of gravel passing the No. 200 sieve (2 per cent) and stretched across to pin B designating the percentage of binder soil passing the same sieve (53 per cent). The thread is then extended straight up along the binder soil scale to pin C, across to pin D, up along the gravel scale to pin E, across to pin F, and so on to pins G, H, I, J, K, L, M, and ending at pin N.

The movable scale is placed under the threads along the pins on the left side and then moved to the right until the line (indicated by the left edge of movable scale) is reached where the greatest number of threads cross within the limits specified for the corresponding sieve sizes marked on the scale. The intersection of this line with the horizontal scale at the bottom of the sheet indicates the percentage of binder soil to be added to the particular sample of gravel while the gradation of the mixture produced by this combination is read on the vertical scale at the points where this line intersects the lines formed by the different segments of the thread running across the sheet between the pins.

Michigan State Highway Department Method

The ratio of two given materials required to approximate a specified grading of the mixture of the two may be calculated from the summations of the differences between the desired grading and the gradings of materials A and B respectively, if one of the two materials is finer and one is coarser than the desired grading.[5] The differences between the percentages passing each sieve for the specified grading and each of the two materials are calculated and added without respect to sign. The ratio of the two summations is the ratio desired.

The process may be best described by means of an illustrative example as follows:

Table 5 gives the gradings of the two materials A and B, the specified grading and the desired grading of the mixture. The grading which it is desired to approach as closely as possible is one falling within the specification limits which is assumed to be satisfactory. In the case shown it is taken as the average of the specification limits except that the percentage passing the No. 200 sieve is taken as somewhat less than the average in order to hold down the amount of binder.

TABLE 5

Sieve	Specified Grading % Passing	Desired Grading of Mixture E % Passing	Material A % Passing	Difference E − A	Material B % Passing	Difference E − B
¾ in.........	100	100	98	2	100	0
⅜ in.........	60–85	73	65	8	98	−25
No. 10......	40–50	45	35	10	79	−34
No. 40......	20–35	27	25	2	15	12
No. 200.....	10–18	10	10	0	1	9
				22		80

TABLE 6

Sieve	.78 A + .22B = Final Mix % Passing	Desired Mix from Table 5 % Passing
¾ in........	.78 × 98 + .22 x 100 = 99	100
⅜ in........	.78 65 + .22 x 98 = 72	73
No. 10.....	.78 35 + .22 x 79 = 45	45
No. 40.....	.78 25 + .22 x 15 = 23	27
No. 200....	.78 10 + .22 x 1 = 8	10

From Table 5 the summation of the differences between the desired grading and Materials A and B is 22 for A and 80 for B. According to this method, as the Ratio A to B in the mix is to be as the ratio of the summations of the differences, $\frac{A}{B} = \frac{22}{80}$ or B = 3.64 A. That is, the proportions of these two materials for the final mixture will be 1 part of B to 3.64 parts of A and the mixture will contain $\frac{100}{4.66}$ = 21.6 per cent of B and $\frac{3.64 \times 100}{4.64}$ or 78.4 per cent A. Applying these per-

[5] Whenever the sieve analyses of either or both of the materials to be blended are such that both gradings in whole or in part are either finer or coarser than the desired combination grading, the ratio computed by this method may be in error. In those cases of unbalanced or non-uniform sieve analyses it may be necessary to raise or lower the ratio to secure a more satisfactory result. It is best to satisfy the grading requirements of the finer sieve fractions and neglect those of the coarser fractions whenever mixtures must be used which will not meet the desired grading requirements on all sieves.

centages to the sieve analyses of materials A and B we find the sieve analysis of the combined mixture which is shown in Table 6 to be as close to the desired mix as may be expected.

Following the determination of the presumptive grading of the mixture of the two materials a combined sample should be prepared and tested for compliance with the specifications, by tests for sieve analysis, liquid limit and plastic limit as before.

Trial and Error Method

The trial and error method consists in assuming a certain percentage of binder soil to add to the coarser material and calculating what the resulting mixture would be. If this assumed percentage does not prove satisfactory other percentages are tried until the calculations indicate a suitable mixture.

As with the other methods check tests should be made on a sample prepared by combining the two materials in the determined proportions.

REVAMPING SURFACE COURSE TO FORM BASE

It often happens that it is planned to place a bituminous cover on a stabilized road that has been in use for some time as a surface course. Unless the surface course was originally laid with this eventuality in mind and hence consists of a mix suitable for either purpose (see page 10) it will usually be found that it is not satisfactory for a base.

In some cases of this kind it may be desirable to scarify the surface course, add granular material that will bring the combined mixture into compliance with base course requirements and then reconstruct according to the proper procedure for a base course; in other cases it may be desirable to place a base course of proper thickness over the old surface.

The methods for combining materials previously discussed are applicable.

COMPACTION

Compaction of the soil aggregate mixture is a vital part of the stabilization process. To secure the desired result it is necessary that the surface, base or foundation be left in as compact a mass as possible. Compaction is measured by the density of the mass. Density as such, however, is not the controlling factor, since density is affected not only by compaction but by the amount of fine material present. What is wanted is to have the proper mixture for the purpose compacted to as great a density as possible for that mixture.

After all necessary care has been exercised to provide adequate foundations, to select and proportion suitable materials and to thoroughly mix them, granular stabilized roads must be properly compacted before it is advisable to cover them with bituminous tops. This required a judicious use of water and strict control of the rolling operations. The amount of water which will produce adequate compaction varies with the character of the soil. Adequate compaction will generally produce a weight per cubic foot equal to the maximum produced by the compaction test described hereafter.

After compaction assurance of satisfactory results will be best if a seasoning period is allowed until about 40 per cent of the moisture has disappeared.

It is high compaction that is required as distinguished from high density. Courses even with high densities might be entirely unsatisfactory when surface treated on account of too much fine material, whereas, highly compacted but more porous materials with lower densities are often entirely suitable. For densities attained in accelerated traffic tests on various base course mixtures see Table 2.

Compaction Test

This test provides a measure of the maximum density that may be secured with a given granular stabilized mixture. It is made on a series of samples containing increasing amounts of water until a condition is reached where additional water causes a decrease in the density.

Samples of the aggregate-soil mixture containing varying quantities of water shall be compacted in a cylindrical metal mold[6] by means of a metal temper having

[6] The size of the metal mold shall accommodate the maximum size aggregate used in the aggregate-soil mixtures. The standard Proctor Mold, 4 in. in diameter and 4½ in. high has been used successfully up to 1¼ in. maximum size aggregate.

a striking face 2 in. in diameter and weighing $5\frac{1}{2}$ lb. The mixture shall be compacted in the cylinder in three equal layers, each layer receiving 25 blows of the tamper dropped from 1 ft. above the surface of the layer. The density of the compacted material shall be computed in pounds of dry materials per cubic foot of compacted mixture.

This apparatus is not applicable for aggregate larger than $1\frac{1}{2}$ in.; however the principal is the same and adjustments can be made in size of mold and tamper to secure similar results.

Method of Determining Weight per Cubic Foot of Soil in Place[7]

The density of a soil layer may be determined by finding the weight of a disturbed sample and measuring the volume of the space occupied by the sample prior to removal. This volume may be measured by filling the space with a weighed quantity of a medium of predetermined weight per unit volume. Sand, heavy lubricating oil or water in a thin rubber sack may be used. Except for the determination of the weight per cubic foot of the medium, the three procedures are the same and therefore the one using sand will be described in detail. It is as follows:

1. Determine the weight per cubic foot of the dry sand by filling a measure of known volume. The height and diameter of the measure should be approximately equal and its volume should be not less than 0.1 cu. ft. The sand should be deposited in the measure by pouring through a funnel or from a measure with a funnel spout from a fixed height. The measure is filled until the sand overflows and the excess is struck off with a straightedge. The weight of the sand in the measure is determined and the weight per cubic foot computed and recorded.

2. Remove all loose soil from an area large enough to place a box similar to the one shown in Figure 6 and cut a plane surface for bedding the box firmly. A dish pan with a circular hole in the bottom may be used.

3. With a soil auger or other cutting tools bore a hole the full depth of the compacted lift.

4. Place in pans all soil removed, including any spillage caught in the box. Remove all loose particles from the hole with a small can or spoon. Extreme care should be taken not to lose any soil.

5. Weigh all soil taken from the hole and record weight.

6. Mix sample thoroughly and take sample for water determination.

7. Weigh a volume of sand in excess of that required to fill the test hole and record weight.

8. Deposit sand in test hole by means of a funnel or from a measure by exactly the same procedure as was used in determination of unit weight of sand until the hole is filled almost flush with original ground surface. Bring the sand to the ground level by adding the last increments with a small can or trowel and testing with a straightedge.

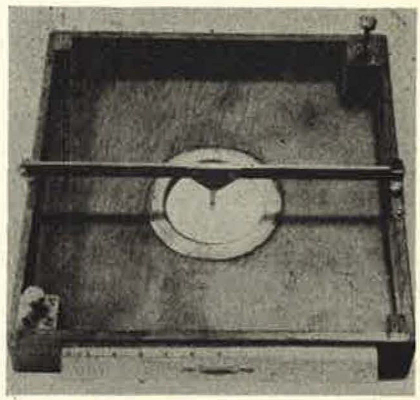


FIGURE 6—Soil Tray for Use with Post Auger in Soil Density Determination. From *Public Roads*, February, 1942

9. Weigh remaining sand and record weight.

10. Determine water content of soil samples.

11. Compute dry density from the following formulas:

Volume of soil

$$= \frac{\text{weight of sand required to replace soil}}{\text{weight per cubic foot of sand}}$$

[7] Harold Allen, *Public Roads*, February 1942, p. 278.

Wet weight per cubic foot

$$= \frac{\text{weight of soil}}{\text{volume of soil}}$$

Dry weight per cubic foot

$$= \frac{\text{wet weight per cubic foot}}{1 + \frac{\text{per cent moisture}}{100}}$$

TREATMENT WITH DELIQUESCENT MATERIALS

Some salts which have the property of dissolving themselves in water attracted from the air are useful in facilitating compaction of soil-aggregate mixtures. These salts are called deliquescent, and the chlorides of calcium and magnesium are the ones which have been extensively used in granular stabilization.

Both during construction and afterwards attainment of the high compaction essential for adequate stability cannot be secured without the presence of water. This moisture is customarily furnished by sprinkling soil-aggregate mixtures during the mixing and rolling operations. Since deliquescent salts have the property of attracting and holding water they may be used advantageously to enhance and preserve the moisture condition of the interior layers. At least 10 lb. of the deliquescent salts should be used per ton of stabilized mixture. This facilitates compaction as was shown on circular track tests performed by the Public Roads Administration.[8] For adequate compaction of base layers moistened with water, 60,000 revolutions of the pneumatic-tired wheels were required: for similar soil mixtures treated with 12 lb. of calcium chloride per cubic yard of sand-clay gravel only 18,000 revolutions were required.

Surface Courses. There is generally enough clay in a surface course mixture to hold some of the moisture applied during construction for varying lengths of time afterward. Then too, if the road surface becomes dry and dusty a deliquescent salt may be applied at the rate of approximately 1.0 lb. per sq. yd. This application should be made during periods of high humidity such as during early morning hours or after the surface has been dampened from sprinkling or from natural causes. In addition to alleviating the dust nuisance, such treatments aid in maintaining a desirable moisture content in the interior of the layer. This is due to the affinity of the chemical for water which causes it to permeate downward through the capillary passages into the mass. If water is the dust alleviating medium it will not penetrate appreciably into the dense mass and consequently will be quickly dissipated by evaporation.

Base Courses. There are two troublesome items which require special attention in the production of satisfactory base courses. In the first place, as has been pointed out previously, less clay is permitted than in surface courses. Therefore, water applied during construction evaporates leaving the layers loose and dusty soon afterward. In the second place, satisfactory compaction must be obtained as soon as possible after construction in order that the placing of the bituminous top will not be unnecessarily delayed.

A deliquescent salt applied during the mixing operations and supplemented by surface applications afterwards as needed affords three distinct benefits. (1) It will conserve enough moisture in the layer to prevent raveling, which if it occurs, will eliminate the possibility of obtaining adequate compaction, (2) it will expedite the compaction process, and (3) the use of chemical treatment during the seasoning period may caution against placing a bituminous top on a mixture, which contains enough clay to produce subsequent failure. Should excess clay be present in the mix, it may be brought to the top of the road as a slick covering if the road is kept moist enough under traffic action. In such case, the excess clay can be removed or blotted up with granular material before the bituminous top is placed. This alone might mean the difference between the future success or failure of the road.

Under present wartime conditions it is possible that in many instances bituminous materials for surface treatments may not be available and so the granular stabilized mixtures which were designed as base

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[8] E. A. Willis and C. A. Carpenter, "Studies of Water-Retentive Chemicals as Admixtures with Nonplastic Road Building Materials," *Public Roads*, November 1939.

courses must be used as surface courses for a considerable period. In such instances deliquescent chemicals applied on the surface as required will assist in preserving the base courses until such time as a protection cover may be constructed. Where bases are low in binder it may be necessary to add fines in order for the deliquescent material to be effective.

TREATMENT WITH SODIUM CHLORIDE

Common salt (sodium chloride) is also used as an admixture in granular stabilization. Although this chloride has the property of attracting and holding water, it is not deliquescent and so its principal effect is in the retention of the mixing water during the compaction period rather than in attracting additional moisture as do the deliquescent materials. It also has the property of crystallization in the pores near the surface, which may enhance stability while inhibiting further penetration of water, as well as retarding evaporation of the water already present.

Sodium chloride is used with granular stabilized mixtures at a rate of 25 lb. per cu. yd. for either surface or base courses. The salt should be thoroughly mixed with the granular material for the full depth of the treatment.

ROAD THICKNESS

The complex problem as to how thick granular stabilized roads or other flexible type pavements should be is not within the scope of this report. However, a survey was conducted by the Committee to find out what thicknesses of granular stabilized courses are now used by various State and County highway organizations.

The results of the survey are given in Tables 7 and 8. In presenting the results it was assumed, in accordance with the introduction to this report that the total road structure consists of two parts; namely, the road surface and the foundation In the surface component are included the stabilized surface course or the combination of stabilized base course and bituminous top. In the foundation component are included subbases and blanket courses.

CONSTRUCTION METHODS

The surface, base or sub-base should be constructed on a well compacted sub-grade, true to line, grade or cross section as desired. Any irregularities or non uniformities in the sub-grade will be reflected in the finished surface.

Local factors, such as availability of materials and equipment and the nature of the project will determine whether road or plant mixing methods of construction should be used in the surface, base or sub-base.

Road Mixing

This includes the mechanical mixing of the various constituents directly on the sub-grade or sub-base.

Preparation of Binder-Soil:

If the binder-soil is obtained from the roadway, shoulders, or slopes, or from a shallow pit of considerable area, it is advantageous to remove the soil by blading it off in thin cuttings, which pulverize easily when dried. The binder-soil is then hauled onto the road, dumped and spread out to dry. As the binder soil dries, it is reduced by disking and rolling until 100 per cent passes the 1-in. sieve and at least 80 per cent will pass the No. 4 sieve. It is then windrowed to one side of the roadway.

During periods of slow drying or when using wet and heavy binder-soil, the subdivision of the material may be greatly facilitated by placing a small amount of the graded aggregate over the binder-soil and disking. This operation not only reduces the size of the binder-soil, but also permits the incorporation of a considerable amount of the graded aggregate which will cause more rapid drying and less crushing effort. The addition of water will facilitate the pulverization by slaking the dry lumps.

Mixing, Watering and Compacting:

After the graded-aggregates are hauled onto the road and windrowed on the shoulder and the proper proportions have been determined, the graded aggregates and binder soil should be thoroughly mixed and combined on the road before the full

TABLE 7. CURRENT HIGHWAY PRACTICE IN ROAD SURFACE (BASE COURSE AND TOP) THICKNESS

Section: State and County	Thickness in Inches									Remarks
	Total Range	Range for Soil Type								
		A1	A2	A3	A4	A5	A6	A7	A8	
NORTH-EAST										
Maine	12–36									
New Hampshire	5									
Vermont	12–18									
Connecticut	7–9	7–9								Gravel
Rhode Island	6–24									
Michigan	5									
Huron	5									
Wisconsin	3–9	3–6	3–6	3–6	6–9	9	6–9	9		
Rock	5–14									
MIDDLE-EAST										
Illinois	7–12	7	7	7	7–12	7–12	7	7		
Cook	6–8									
Peoria	6–10									
Indiana	6, 9, 12									
DeKalb	8									
St. Joseph	6–8									
Vigo	6									
Ohio	6		6	6	6			6		
Summit	5–7									
Kentucky	3–12									
Tennessee	8									
West Virginia	5									
Virginia	8									
Maryland	4–6	4	4	4	6	6	6	6		
Delaware	6–16									
SOUTH-EAST										
Mississippi	0–8	0	0–8	0–6	4–8	0	8	8		
Alabama	8	8	8	8	8	8	8	8	[a]	
Montgomery	8 min.									
North Carolina	6–9									
South Carolina	5–8									
Georgia	6–8									
Florida	6–8	6	6–8							
NORTH-CENTRAL										
Minnesota	2–12	2–3	6	2–3	6–12		6–9	6–9		
Crow	2–9									Sand, 2–4; clay, 4–9
Iowa	6–12									
Muscatine	3–4									
Missouri	6–8									
North Dakota	7½	7½	7½	7½	7½	7½	7½	7½	7½	Extra thickness is provided by subbase
South Dakota	4 min.									
Nebraska	0–8									
SOUTH-CENTRAL										
Arkansas	6–12		6	6	6–8		8–12	8–12		
Louisiana	7									
Oklahoma	6									
Texas	3–18	3–6	3–8	3–8		6–18	6–18			Depth depends on amount and character of binder also on volume and types of traffic

[a] Use blanket course when base thickness greater than eight inches is necessary.

TABLE 7—*Concluded*

Section: State and County	Thickness in Inches									Remarks
	Total Range	Range for Soil Type								
		A1	A2	A3	A4	A5	A6	A7	A8	
MOUNTAIN										
Montana	6–18									
Cascade	6–24									
Idaho	2–12	2–4	2–4	2–4	6–12	8–12		8–12		
Wyoming	0–9	0–5	0–6	0–6	4–7	6–9	6–9	7–9	9	Edge, Center, 1½″ thinner
Nevada	6–21	6–12	6–18	6–12	12–18	15–21	15–21	15–21		
New Mexico	4–20[b]									
Arizona	0–15	0–6	0–12	0–6	6–12	0–12	12–18	9–18		
PACIFIC										
Washington	3–6	3–6	3–6	3–6	3–6	3–6	3–6	3–6		
Oregon	5–9	5	5	5	5–9	5–9	5–9	5–9		
California	3–24								12–18	Soils classified by bearing test

[b] Loose thickness based on grading, soil characteristics. California Bearing Tests used as a check. Compacted thickness averages 75% of loose thickness.

amount of water is added. Water is then evenly distributed over the dry mixed materials until the total amount present is slightly above the optimum moisture content of the mixture, and the whole is thoroughly mixed by alternately spreading and windrowing with motor graders, or by multiple blade maintainers or other suitable methods. This mixture is then spread across the roadway shaped and compacted by rolling. The method of compaction should consolidate the mixture to the full depth of the layer to which it is applied. When the mixture is spread in layers not more than 4 in. thick smooth rollers or pneumatic tired equipment may be used, but if the mixture is spread in layers of greater thickness it is advisable to use tamping rollers for the initial compaction. Courses thicker than 8 in. should be compacted in more than one layer. The water content of the mixture at the time of rolling should not be less than the optimum determined by the compaction test to obtain the required density with the least compactive effort. During the compaction operation the surface of the road should be kept smooth and shaped so that the finished roadway will have the crown and cross section desired. A modified "A" type crown of at least ½ in. per ft. of width is recommended when the stabilized course is to be used as a wearing surface.

In blade-mixing the ingredients of a stabilized wearing course, it is highly important that no appreciable amount of extra soil be picked up from the subgrade or shoulders. Carelessness in this respect may result in an excessive amount of binder soil which is especially undesirable in wet weather.

Plant Mixing

This includes either a central mixing plant or a portable plant operating along the road. The cost of plant mixing is slightly higher than that of road mixing, but the following advantages are attained: (1) A more uniform mixture is obtained; (2) Less delay on account of unfavorable weather conditions (prolonged rainy periods delay the efficient handling of clay in road-mixing); (3) Less interruption to traffic; (4) Greater convenience and less cost of supplying the necessary water for the mixture; (5) Less equipment required on the road; (6) Greater ease of laboratory control of the mixture.

The plant machinery necessary in the production of stabilized mixtures (in addition to the usual screening and crushing equipment for producing graded aggregates) varies according to the nature of the materials and the method of processing. The operation consists essentially in pulverizing the binder-soil and proportioning and feeding the graded aggregate, binder-soil, and water into a mixer, where they are combined uniformly and delivered into trucks or storage bins.

In the process most commonly used, the binder-soil is dumped into a hopper from which it feeds by gravity to a screw-conveyor which delivers it at a uniform rate to a disintegrator, either directly or by means of an intermediate belt conveyor.

The disintegrator unit consists of two pairs of rolls, the upper pair having one larger-diameter smooth-faced roll operated at slow speed and one smaller-diameter roll with longitudinal knives set in its face, operated at higher speed. The lower pair, or crusher-rolls, are both of the same diameter and are smooth-faced. This unit may be used with binder-soil containing up to about 20 per cent of water and although the most thorough pulverizing is accomplished with dry material, artificial drying has not been found necessary.

Graded aggregates are delivered from storage hoppers by controlled feeds, along

TABLE 8. CURRENT HIGHWAY PRACTICE IN FOUNDATION (SUBBASE AND BLANKET COURSE) THICKNESS

Section: State and County	Thickness in Inches										Remarks
	Total Range	Range for Soil Type									
		A1	A2	A3	A4	A5	A6	A7	A8		
NORTH-EAST											
New Hampshire	3–31		7–13	3	13–31		19				Use gravel only (abundant material)
Michigan	12–18										On poor soils
Huron	10 min.										On poor soils
Wisconsin	0–15					0–15		0–15			
MIDDLE-EAST											
Illinois	12–24						12–24	12–24			
Indiana	4–24										
Ohio	12–18				12–18	18					Remove A5 and A8
Tennessee	0–12	0	0	0	0	6–8	6–10	6–12	6–12		Treatment of unstable soils
Maryland	6–24				6–12	12–24	12–24	12–24			Remove all A8 soils
SOUTH-EAST											
Mississippi	7–12										Topping added
Mississippi	12–21		12		12–18	18	15–21	21			Topping only
Alabama	0–10	0	0	0	0–4	0–10	0–10	0–10			Topping only
North Carolina	0–24										In limited areas
South Carolina	6–12				6	6–12		6–12	12		In limited areas
Florida	0–12	0–6	0–6	0–12	0–12	12	12	12			
NORTH-CENTRAL											
Iowa	12–24				12–24		12	18–24			(In poorly drained areas)
North Dakota	0–12	0	0	0	2½–5	2½–12	2½–12	5–12			
SOUTH-CENTRAL											
Texas	0–10	0	0		0		0–10	0–10			
MOUNTAIN											
Idaho	0–18				0–8	4–12	6–12	8–18	18		
PACIFIC											
Washington	3–24	3–6	3–6	3–6	6–12	9–24	9–24	9–24			Total thickness, base & subbase
Oregon	4–12	4–8	4–8	4–8	4–12	6–12	6–12	6–12	6–12		

with the pulverized binder-soil into a mixer, usually of the pug-mill type. A pipe line provides the water necessary to bring the mixture to the desired water content.

The pug-mill contains a longitudinal shaft to which replaceable blades are attached at such an angle as to mix the materials continuously and convey them through the mill to an outlet, where the finished mixture is taken by belt or bucket conveyor to storage bins, or dropped into a pit from which it may be loaded into trucks by a clamshell dredge.

Other Equipment and Methods:

In some locations the soil overburden on pits and quarries consists of a suitable sand-clay which when passed through a vibrating screen to remove the sod and stone, becomes sufficiently pulverized.

A plate-feeder may be substituted for the screw-feeder, for use with some types of binder-soil.

In some plants the aggregate and binder-soil are proportioned and partially mixed by handling several times with a clam-shell or power-shovel.

Batching equipment designed for concrete aggregates, and a concrete mixer may be used for proportioning and mixing.

A method of processing wet binder-soil is being used successfully, which eliminates the screw-feeder. The binder-soil is passed from a hopper into an enclosed pug-mill, with sufficient water to form a thick paste. This paste is extruded, at a controlled rate, and passes, along with the flow of graded aggregate, between a pair of rollers set about one and one half inches apart. The combined binder-soil and aggregate then pass through two pug-mills, and any necessary water is added. In this process the binder-soil is thoroughly disintegrated and a uniform mix is obtained.

Portable stabilizer plant units, embodying the foregoing described features, are now being manufactured.

Mixing may also be done with a portable mixer, which moves along the roadway picking up the aggregates and binder-soil from a windrow, mixing them with water in a pug-mill and depositing the finished mixture in a windrow or spreading it into place.

This equipment requires that the binder-soil be previously pulverized (at least partially) on the roadway and is therefore more subject to wet weather delays than the stationary central plant.

Construction Factors

In many cases trouble during construction of granular stabilized roads has been blamed upon the design of the mixture, when in reality, the faults are due to the environment under which they have been placed. Some of these environmental factors are:

(a) Stabilized materials should not be placed over high capillary soils without an adequate subbase or other type of capillary cut-off.

(b) Sand subbases used for capillary cutoff over objectionable soils or sand subgrades usually require special treatment of the top three inches before placement of stabilized courses. A sandy clay or other suitable binder soil should be added and manipulated into the surface to form a firm base within the limits for Type B Subbase (page 11) which will carry construction equipment and insure uniform compaction and thickness of the stabilized layer. If the loose sand subbase or subgrade is not given this preliminary treatment, poor consolidation, non-uniform thickness of stabilized material and a distorted surface may be expected.

(c) Stabilized material should not be placed in continued wet weather in areas subject to traffic. The soil fines will be manipulated to the road surface by the action of traffic, and the surface will remain rutted and appear to contain an excess of binder soil. This also causes the compaction period to be excessive and requires considerable maintenance before compaction is complete. If the material is placed during the rainy season, traffic should be detoured and the material laid toward the plant to avoid disturbance by construction traffic. After drying, the road may be opened to traffic and continuous maintenance used until the road has been compacted satisfactorily. Additional water may be required to finish the road surface after the preliminary compaction period.

(d) Placing of stabilized materials should be restricted during the periods of spring and fall rains since the construction difficulties will more than offset the inconvenience caused by the suspension of construction. During these periods the stabilized material should be stock-piled until favorable weather permits the completion of the road construction.

MAINTENANCE OF GRANULAR STABILIZED SURFACES[9]

The basic principles governing granular stabilized road maintenance are that: (1) The surface be kept smooth, firm and free of loose material; (2) The original crown of approximately ½-inch per foot of width, be conserved; and, (3) The deterioration of the surface be minimized by the use of some dust palliative.

Blading of Granular Stabilized Roads

Granular stabilized roads, while they require much less maintenance than loosely bound surfaces, do require periodic blading.

Blading During Normal Weather: During dry weather, granular stabilized surfaces should be kept free from loose floating aggregate in order to avoid unnecessary abrasion by traffic.

Any loose material which accumulates on the road surface during dry spells should be brushed to the side of the road by light blading. If a considerable amount of such material accumulates on the side of the road, pulverized binder soil in the right amount to make a stable mixture with it should be added to the windrow. Water tank trucks should be available for preparing and compacting this material on the road surface. Before spreading and compacting the stabilized mixture, the road surface should be wetted enough to permit some cutting and bladed with an underbody blade or grader to remove all irregularities. All cutting of the surface should be from the center of the road towards the sides.

The material from this blading is added to the windrow on the roadside after which the entire windrow should be bladed on to the road surface and compacted under proper moisture conditions controlled by water tanks. Shaping and finishing operations are carried on with underbody blades and, if available, multiple blade maintainers.

Occasionally it is necessary to employ more drastic measures to improve certain sections of road to prevent development of serious ravelling, pot holes, ruts, etc. These sections should be repaired in advance of normal road blading by the use of heavy blading and scarifying equipment.

Blading During Wet Weather: When light rains occur, sufficient to moisten the road surface, fairly light blading from the center of the road toward the sides should be done with underbody units to eliminate chatter bumps, pot holes, and other minor irregularities. After the rain, while the road surface and accumulated material at the side are still moist but not wet enough to make the road muddy or slippery, the loose material should be bladed back onto the road and shaped for proper crown. Final blading and finishing should continue while the surface is compacting under traffic.

When rains occur that are heavy enough to make the road surface muddy and slippery, the unstable material on the surface should be bladed to the sides and left there. No blading from the outside toward the center of the road should be done while rain is falling or when the surface is extremely wet. As soon as this material has dried enough to recompact, it should be bladed back on to the surface and properly shaped. Final blading and finishing should be continued while the surface is compacting under traffic.

Blading Procedure to Assure Proper Crown; The granular stabilized road, like all other types, will give most satisfactory service if it is properly drained The. "Modified A" or "Straight Line" crown is most satisfactory. Parabolic type crowns are likely to develop pot holes along the center where water will stand after rains. When the center of the blade wears down first, making it difficult to shape a "Straight Line" crown, the blades should be reversed on the moldboard. Subsequent blading will then cut off the arch in the road crown and wear the blades to a straight line.

[9] Taken principally from "Soil Control in Consolidated Maintenance" by B. R. Downey, *Proceedings*, Highway Research Board, Vol. 21, p. 311 (1941).

The "Modified A" type crown with about one-half inch slope per foot of width, provides a well drained, smooth surface.

Super-elevation on curves should be maintained as originally constructed and should be bladed from the inside of the curve outward. Blading culvert and bridge approaches to prevent irregularity in the shape of the approach requires lifting and reshifting the blade while crossing the structure.

Trucks equipped with underbody blade attachments, having curved moldboards, are generally adequate for all routine blading. Multiple blade maintainers are best for final smoothing. This maintainer with its several edges and long wheel base should be used only as a finishing tool and only when the surface is moist.

Dust Palliatives

The application of deliquescent chemicals or bituminous materials serves three purposes: (1) abatement of the dust nuisance to travelers and adjacent property, (2) conservation of the surface material and (3) provision of additional binding power.

Under wartime conditions of reduced budgets economic considerations will determine how much maintenance expenditure should be made for dust palliatives. Although abatement of dust may be a comparatively minor factor under these conditions, the latter two functions have decided economic value which should be evaluated by comparison with the cost of more frequent renewals of surface material and with the cost of maintenance of binding power by addition of binder soil.

Application of Deliquescent Chemicals

The usual practice is to apply uniformly by mechanical means a light application (approximately 1½ tons per mile) in the late spring, followed by subsequent applications of two tons per mile per month during the summer season. However, precipitation and volume of traffic have a direct influence on the quantities used.

The best time to apply deliquescent chemicals is following a rain and after any necessary blading operations have been completed. If the application cannot be deferred until a rain occurs, the chemicals should be applied at night or in the morning when the higher humidity will assure more rapid solution and penetration. Some States have found it economical to pre-wet the surface by the use of water tanks before applying the chemicals. Also natural and manufactured solutions containing suitable concentrations of deliquescent chemicals have been used where transportation facilities were favorable.

Application of Bituminous Dust Palliatives

Either certain grades of tars (RT-2 and RT-3) or asphaltic oils (SC-0 and SC-1) are suitable for this purpose. However, due to wartime restrictions, the slow curing asphaltic oils are not now available. It is suggested that medium curing cutback asphalts of the lighter grades, when available, may be used for this purpose.

The rate of application depends upon the type and density of the road surface. It usually varies from 0.2 gal. per sq. yd. on dense surfaces up to 0.6 gal. on those of the most open texture. The road must be dry but not dusty when the oil is applied. To reduce inconvenience to traffic, a roadway if wide enough should be treated one half at a time or suitable material such as dry sand should be spread over the treated surface to absorb the slowly drying bitumen.