SYNOPSIS OF TYPES OF
LOW-COST ROADS

Thesis for the Degree of M. S.
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Guy Jean-Pierre Plumail
1950

This is to certify that the

thesis entitled

SYNOPSIS OF TYPES OF
LOW-COST ROADS

presented by

GUY JEAN-PIERRE PLUMAIL

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of the requirements for

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SYNOPSIS OF TYPES OF LOW-COST ROADS

By

GUY JEAN-PIERRE PLUMAIL

A THESIS

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INTRODUCTION

Out of approximately 3,000,000 miles of roads in the United States about 50 per cent are not surfaced, 1,000,000 miles have low type surfacings, 305,000 miles have intermediate type surfacings and 194,000 miles have high type surfacing. The selection of the type used depends on the volume of traffic unevenly distributed throughout the country and is generally of the low type for traffic of less than 400 vehicles per day, of the intermediate type for traffic of 400 to 1,000 vehicles per day, and of the high type for traffic over 1,000 vehicles per day.

Hard surfaced pavements are expensive to build and to maintain. On the other hand, unsurfaced roads are muddy and impassable during wet periods, and although passable are dusty during dry weather and are a nuisance to both users and residents living beside the road.

Various methods have been devised to process Earth Roads and render them capable of supporting light traffic under normal weather conditions with reasonable maintenance. They all take the natural soil as basic material, stabilized with or without admixtures.

We shall first see what has to be known about soil as a material, what are the general features of the road, and then, what are the main types of soil stabilization to which these can be related. These main types of stabilization are: Mechanical, Chemical, Soil-Bitumen, Soil-Cement and Thermic. Mechanical, Chemical and Thermic Stabilization are low type surfacings. Soil-Bitumen and Soil-Cement Stabilization are classified as intermediate type.

These processes utilize the soil in place to the maximum and do not require highly skilled labor or specialized equipment (except Thermic Stabilization), but they are well established and standardized techniques which do not emanate from the trial and error method.

CHAPTER I

THE SOILS

Soils are composed of particles of varied size and origin. Their distribution gives to soils their properties.

By their origin they can be classed as organic or inorganic.

By their size they are classed:

Gravel	over 2.00 mm.	inorganic
Sand	from 2.00 to 0.05 mm.	inorganic
Silt	from 0.05 to 0.005 mm.	inorganic or organic
Clay	below 0.005 mm.	inorganic or organic
Collcids	below 0.001 mm.	inorganic or organic

They contribute differently to the behavior of soils.

Gravel and sand when confined contribute mainly to the bearing power. They are cohesionless, but can develop high internal friction (especially when of the angular type). They are pervious but show practically no capillary action.

Clay and colloids contribute to cohesion and are only little pervious, but they have slight bearing power, when wet are elastic and have low capillarity. Silt is of an intermediate type and has no cohesiveness with high capillarity.

The percentages of sand, silt and clay give to the soil its particular texture. In Chart I a textural classification of soils is shown.

The texture of soil can be determined by the physical characteristics of the textural groups when a small amount of moist soil is rubbed between the fingers.

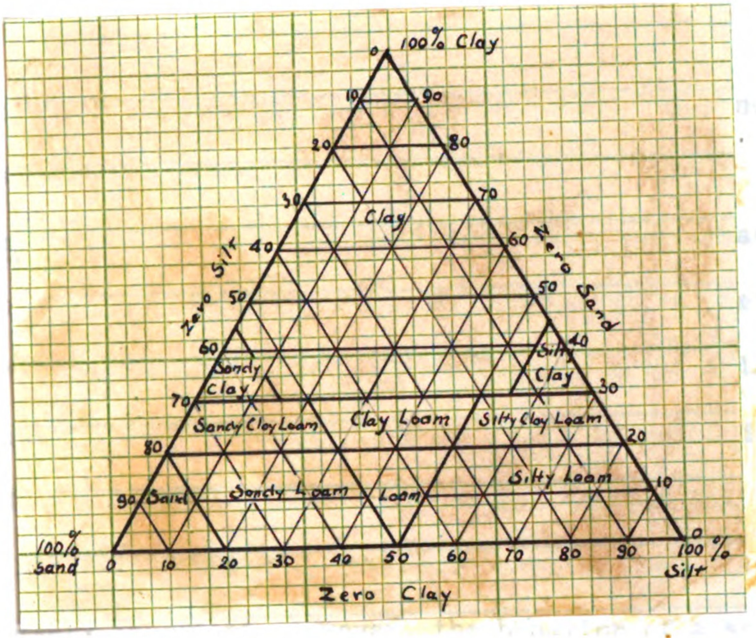


Chart I. Public Road Administration Textural Classification

<u>Sand:</u> Sand is single grained. The individual grains can readily be seen or felt. Squeezed in the hand when moist, sand will form a cast which will crumble when gently pressed or dried.

<u>Sandy Loam:</u> Soil containing mainly sand but containing sufficient silt and clay to make it somewhat coherent. The individual sand grains can readily be seen and felt. If molded when moist, it will form a cast which will bear careful handling without breaking. Sands and sandy loams can be coarse, medium or fine, depending upon the proportion of the different sizes of particles that are present.

<u>Loam:</u> Loam is a soil having a more or less balanced mixture of the different grades of sand, silt, and clay. It is mellow with a somewhat gritty feel; yet fairly smooth and slightly plastic when moist.

<u>Silt Loam:</u> A silt loam is a soil having a moderate amount of the fine grades of sand and a small amount of clay, with a large quantity of silt particles. When in dry pulverized condition, it feels soft and floury. If the

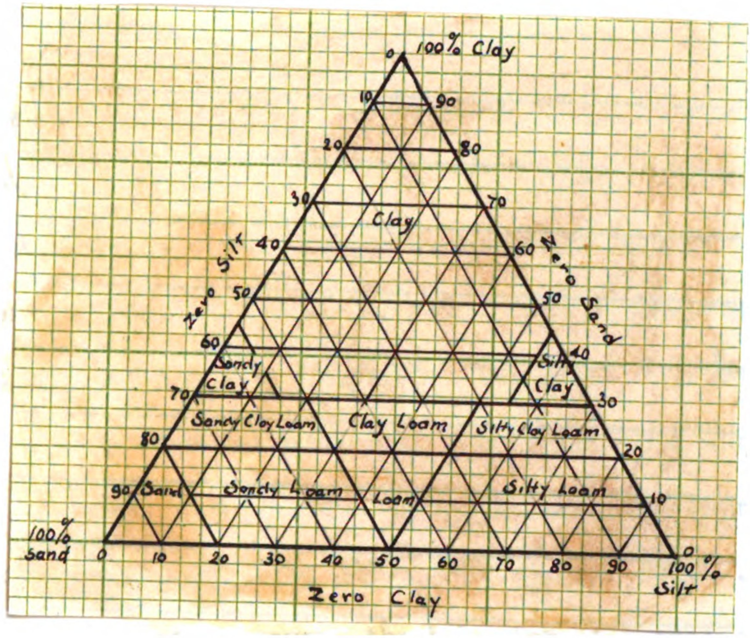
moist soil is pressed between the thumb and finger, it will not "ribbon" but will have a broken appearance.

Clay Loam: Clay loam is a fine-textured soil which breaks into clods or lumps that harden upon drying. When the moist soil is pressed between the thumb and finger, it will form a thin "ribbon". The moist soil is plastic.

Clay: Clay is a very fine-textured soil that forms hard lumps or clods upon drying. When the moist soil is pressed out between the thumb and finger, it will form a flexible "ribbon". The moist soil is very sticky.

Texture is very important; however, the behavior of a soil cannot be predicted "a priori" by merely knowing the distribution of its particles. Presence of humus, difference in origin and formation, presence of chemical compounds which tend to floculate the fine particles (like lime and magnesium) or defloculate them (like sodium or potassium) are factors of great importance. Identifying the soil to a definitely known type, classified in a logical system, is the first step to accomplish in any attempt toward stabilization of soils.

Several systems of soil classification have been proposed and are in use throughout this Country by the various agencies dealing with soils. The Public Road Administration Classification is the most widely used in the highway field but is likely to be replaced by the Highway Research Board Classification which is a revision of the original. Since data used in this thesis is not completely covered under the Highway Research Board Classification system, it was necessary to use the Public Road Administration Classification system as well. Reference will be made to these two systems as H.R.B.C. and P.R.A.C. respectively.



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U.S. Public Road Administration Classification

Soils are classified in eight groups designated as A-1 to A-8 inclusive.

Group A-I. The typical material of this group is a well-graded material (sand, silt and clay) having excellent binder. A-I soils have high internal friction, high cohesion, no detrimental shrinkage, no expansion, capillarity or elasticity. They are generally found in small deposits.

Group A-2. This group includes coarse and fine materials with improper grading or inferior binder. They have high internal friction and high cohesion only under certain conditions, may have detrimental shrinkage, expansion, capillarity, or elasticity.

Group A-3. The typical material of this group is a sand without binder, with high internal friction, and without detrimental capillarity or elasticity.

Group A-4. This group includes cohesionless silts and friable clays having no appreciable amount of sticky colloidal clay. They have variable internal friction, no appreciable cohesion, no elasticity and important capillarity.

Group A-5. This group includes micaceous and diatomaceous silts and sands. They are similar to A-4 group but in addition possess elasticity in an appreciable amount.

Group A-6. The typical material of this group is cohesive clay in a dispersed state with low internal friction, high cohesion under low moisture content, without elasticity, but likely to expand and shrink in detrimental amount.

Group A-7. This group includes micaceous, diatomaceous and flocculated clays. May contain lime or associated chemicals productive of flocculation in the soils. They are similar to A-6 group but in addition possess elasticity.

Group A-8. Typical materials of this group are peats and mucks with low internal friction, low cohesion, apt to possess capillarity and elasticity

PUBLIC ROADS ADMINISTRATION TABLE 1. - SOIL CLASSIFICATION

Group	A-1	A-2		A-3	A-4	A-5	A-6	A-7	A-8
		Friable	Plastic						
General Stability Properties	Highly Stable at all Times	Stable When Dry; May Ravel	Good Stable Material	Ideal Support When Confined	Satisfactory when dry; Loss of Stability when Wet or by Frost Action	Difficult to Compact; Stability Doubtful	Good Stability When Properly Compacted	Good Stability When Properly Compacted	Incapable of Support
Physical Constants:									
Internal Friction	High	High	High	High	Variable	Variable	Low	Low	Low
Cohesion	High	Low	High	None	Variable	Low	High	High	Low
Shrinkage	Not detrimental	Not significant	Detrimental when poorly graded	Not significant	Variable	Variable	Detrimental	Detrimental	Detrimental
Expansion	None	None	Some	Slight	Variable	High	High	Detrimental	Detrimental
Capillarity	None	None	Some	Slight	Detrimental	High	High	High	Detrimental
Elasticity	None	None	Some	None	Variable	Detrimental	None	High	Detrimental
Textural Classification:									
General Grading	Uniformly graded; coarse-fine, excellent binder	Poor grading; poor binder	Poor grading; inferior binder	Coarse material only; no binder	Fine sand cohesionless silt and friable clay	Micaceous and diatomaceous	Deflocculated cohesive clays	Drainable flocculated clays	Peat and muck
Approximate Limits:									
Sand-Percent	70-85	55-80	55-80	75-100	55 (max.)	55 (max.)	55 (max.)	55 (max.)	55 (max.)
Silt-Percent	10-20	0-45	0-45	(1)	High	Medium	Medium	Medium	Not significant
Clay-Percent	5-10	0.45	0.45	(1)	Low	Low	30 (min.)	30 (min.)	Not significant
Physical Characteristics:									
Liquid Limit	14-35	35 (max.)	35 (max.)	NP (2)	20-40	35 (min.)	35 (min.)	35 (min.)	35-400
Plasticity Index	4-9	NP-3(2)	3-15	NP (2)	0-15	0-60	18 (min.)	12 (min.)	0-60
Field Moisture Equivalent	Not Essential	Not Essential	Not Essential	Not Essential	30 (max.)	30-120	50 (max.)	30-100	30-400
Centrifuge Moisture Equivalent	15 (max.)	12-25	25 (max.)	12 (max.)	Not Essential	Not Essential	Not Essential	Not Essential	Not Essential

PUBLIC ROADS ADMINISTRATION TABLE 1. - SOIL CLASSIFICATION (Cont'd.)

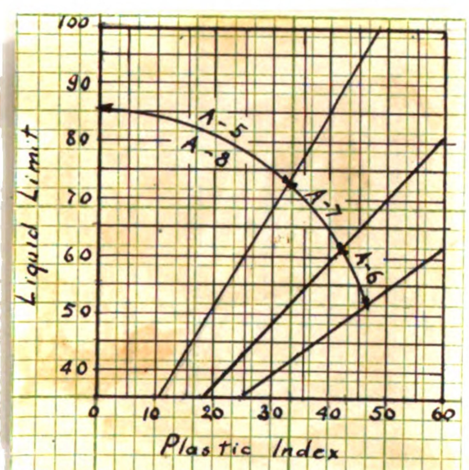
Group	A-1	A-2		A-3	A-4	A-5	A-6	A-7	A-8
		Friable	Plastic						
General Stability Properties	Highly Stable at all Times	Stable When Dry; May Ravel	Good Stable Material	Ideal Support When Confined	Satisfactory when dry; Loss of Stability when Wet or by Frost Action	Difficult to Compact; Stability Doubtful	Good Stability When Properly Compacted	Good Stability When Properly Compacted	Incapable of Support
Centrifuge Moisture (Cont'd.)									
Shrinkage Limit	14-20	15-25	25 (max.)	Not Essential	20-30	30-120	6-14	10-30	30-120
Shrinkage Ratio	1.7-1.9	1.7-1.9	1.7-1.9	Not Essential	1.5-1.7	0.7-1.5	1.7-2.0	1.7-2.0	0.3-1.4
Volume Change	0-10	0-6	0-16	None	0-16	0-16	17 (min.)	17 (min.)	4-200
Lineal Shrinkage	0-3	0-2	0-4	None	0-4	0-4	5 (min.)	5 (min.)	1-30
Compaction Characteristics:									
Maximum Dry Weight, pounds per cubic foot	130 (min.)	120-130	120-130	120-130	110-120	80-100	80-110	80-110	90 (max.)
Optimum Moisture, percentage of dry weight (approximate)	9	9-12	9-12	9-12	12-17	22-30	17-28	17-28	
Max. field compaction required, % of max. dry weight, pounds per c.f.	90	90	90	90	95	100	100	100	Waste
Rating for Fills 50 ft. or less in height	Excellent	Good	Good	Good	Good to poor	Poor to very poor	Fair to poor	Fair to poor	Unsatisfactory
Rating for Fills more than 50 ft. in height	Good	Good to Fair	Good to Fair	Good to fair	Good to fair	Very poor	Very poor	Very poor	Unsatisfactory
Required Total Thickness for sub-base, base and surfacing, inches	0-6	0-6	2-8	0-6	9-18	9-24	12-24	12-24	

(1) Percentage passing No. 200 Sieve, 0 to 10.

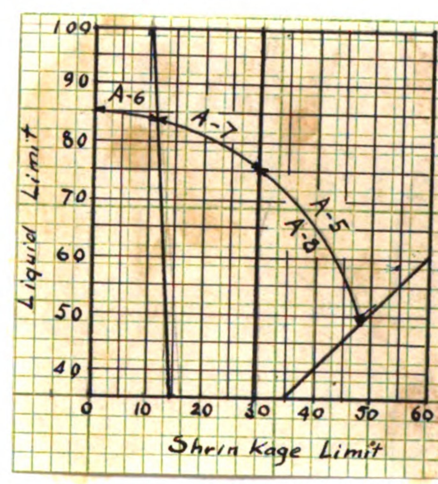
(2) NP - Non-Plastic.

		GROUP	A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8
Gradation		Coarse material, % (Plus No. 10 sieve)	0.65	0	0	0	0		0	
	Soil Mortar	Total sand, %	70-85	55 min.	0			55 maximum		
		Coarse sand, %	45-60	0	0	0	0		0	
		Silt, %	10-20	0	0	0	0		0	
		Clay, %	5-10	0	0	0	0		0	
		Passing No. 200 sieve, %	0	0	0-10	0	0		0	
Soil constants		Liquid limit, %	14-35	35 max.	NP	20-40		35 minimum		
		Plasticity index %	4-9	NP-15	NP	0-15		See chart		
		Shrinkage limit, %	14-20	0	0	20-30		See chart		
		Field moisture equivalent %	0	0	0	30 max.		See chart		
		Centrifuge moisture equivalent, %	15 max.	25 max.	12 max.	0		0		

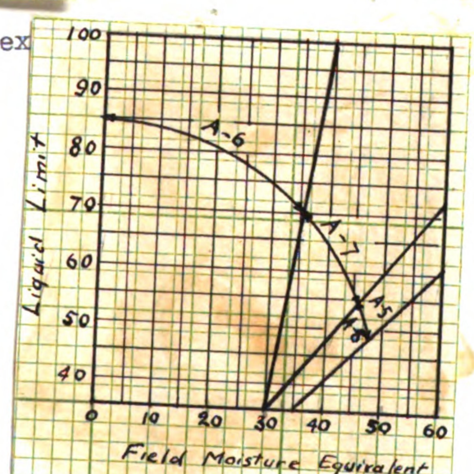
0 Not essential NP - Non plastic



Plasticity index



Shrinkage limit



Field moisture equivalent

Chart 2. U.S. Public Roads Administration soil grouping in detrimental amounts.

Table 1 gives a summary of the U.S.P.R.A. Classification.

Highway Research Board Classification

Soils are classified in seven groups designated as A-1 to A-7 inclusive. When the main groups are not enough detailed to differentiate between soils belonging to the same group, use is made of subgroups and group index.

Granular Materials (containing 35 per cent or less passing No. 200 sieve)

Group A-1. The typical material of this group is a well-graded mixture of stone fragments or gravel, coarse sand, fine sand and a non-plastic or feebly plastic soil binder. However, this group includes also stone fragments, gravel, coarse sand, volcanic cinders, etc., without soil binder.

> Subgroup A-1-a includes those materials consisting predominantly of stone fragments or gravel, either with or without a well-graded binder of fine material.
>
> Subgroup A-1-b includes those materials consisting predominantly of coarse sand either with or without a well-graded soil binder.

Group A-2. This group includes a wide variety of "granular" material which are borderline between the materials falling in Groups A-1 and A-3 and the silt-clay materials of Groups A-4, A-5, A-6 and A-7. It includes all materials containing 35 per cent or less passing the No. 200 sieve which cannot be classified as A-1 or A-3 due to fines content or plasticity or both, in excess of the limitations for those groups.

> Subgroup A-2-4 and A-2-5 include various granular materials containing 35 per cent or less passing No. 200 sieve and with a minus No. 40 portion having the characteristics of the A-4 and A-5 groups. These groups include such materials as gravel and coarse sand with silt contents or plasticity indexes in excess of the limitations of Group A-1, and fine sand with nonplastic silt content in excess of the limitations of Group A-3.

Subgroups A-2-6 and A-2-7 include materials similar to those described under Subgroups A-2-4 and A-2-5 except that the fine portion contains plastic clay having the characteristics of the A-6 and A-7 group. The approximate combined effects of plasticity indexes in excess of 10 and percentage passing No. 200 sieve in excess of 15 is reflected by group index values of 0 to 4.

Group A-3. The typical material of this group is fine beach sand or fine desert-blow sand without silty or clay fines or with a very small amount of nonplastic silt. The group includes also stream-deposited mixtures of poorly graded fine sand and limited amounts of coarse sand and gravel.

Silt-Clay Materials (containing more than 35 per cent passing the No. 200 sieve).

Group A-4. The typical material of this group is a nonplastic or moderately plastic silty soil usually having 75 per cent more passing the No. 200 sieve. The group includes also mixtures of fine silty soil. The group index values range from 1 to 8, with increasing percentages of coarse material being reflected by decreasing group index values.

Group A-5. The typical material of this group is similar to that described under Group A-4, except that it is usually of diatomaceous or micaceous character and maybe highly elastic as indicated by the high liquid limit. The group index values range from 1 to 12, with increasing values indicating the combined effect of increasing liquid limits and decreasing percentages of coarse material.

Group A-6. The typical material of this group is a plastic clay soil usually having 75 per cent or more passing the No. 200 sieve. The group also includes mixtures of fine clayey soil and up to 64 per cent of sand and gravel retained on the No. 200 sieve. Materials of this group usually have high volume change between wet and dry states. The group index values range from 1 to 15, with increasing values indicating the combined effect of increasing plasticity indexes and decreasing percentages of coarse material.

Group A-7. The typical material of this group is similar to that described under Group A-6, except that it has the high liquid limits characteristic of the A-5 group and may be elastic as well as subject to high volume change. The range of group index values is 1 to 20, with increasing values indicating the combined effect of increasing liquid limits and plasticity indexes and decreasing percentages of coarse material.

> Subgroup A-7-5 includes those materials with moderate plasticity indexes in relation to liquid limit and which may be highly elastic as well as subject to considerable volume change.
>
> Subgroup A-7-6 includes those materials with high plasticity indexes in relation to liquid limit and which are subject to extremely high volume changes.

Group Index is given by the empirical formula

$$\text{Group index} = 0.2a + 0.005ac + 0.01\ bd$$

in which

a = that portion of percentage passing No. 200 sieve greater than 35 and not exceeding 75, expressed as a positive whole number (1 to 40)

b = that portion of percentage passing No. 200 sieve greater than 15 and not exceeding 55, expressed as a positive whole number (1 to 40)

c = that portion of the numerical liquid limit greater than 40 and not exceeding 60, expressed as a positive whole number (1 to 20)

d = that portion of the numerical plasticity index greater than 10 and not exceeding 30, expressed as a positive whole number (1 to 20)

Table 2 gives a summary of the H. R. B. Classification.

TABLE 2. - HIGHWAY RESEARCH BOARD CLASSIFICATION OF HIGHWAY SUBGRADE MATERIALS
(With Suggested Subgroups)

General Classification	Granular Materials (35% or less passing No. 200)							Silt-Clay Materials (More than 35% passing No. 200)			
Group Classification	A-1			A-2							A-7
	A-1-a	A-1-b	A-3	A-2-4	A-2-5	A-2-6	A-2-7	A-4	A-5	A-6	A-7-5 A-7-6
Sieve Analysis, Percent											
No. 10	50 max.										
No. 40	30 max.	50 max.	51 min.								
No. 200	15 max.	25 max.	10 max.	35 max.	35 max.	35 max.	35 max.	36 min.	36 min.	36 min.	36 min.
Characteristics of fraction passing No. 40:											
Liquid Limit				40 max.	41 min.	40 max.	41 min.	40 max.	41 min.	40 max.	41 min.
Plasticity Index	6 max.		N.P.	10 max.	10 max.	11 min.	11 min.	10 max.	10 max.	11 min.	11 min.[a]
Group index[b]	0		0	0		4 max.		8 max.	12 max.	16 max.	20 max.
Usual Types of significant Constituent Materials	Stone Fragments, Gravel and Sand		Fine Sand	Silty or Clayey Gravel and Sand				Silty Soils		Clayey Soils	
General Rating as Subgrade	Excellent to Good							Fair to poor			

Classification Procedure: With required test data available, proceed from left to right on above chart and correct group will be found by process of elimination. The first group from the left into which the test data will fit is the correct classification.

[a]Plasticity index of A-7-5 subgroup is equal to or less than LL minus 30. Plasticity index of A-7-6 subgroup is greater than LL minus 30.

[b]See group index formula for method of calculation. Group index should be shown in parenthesis after group symbol. as: A-2-6(3), A-4(5), A-6(12), A-7-5(17), etc.

Chart B

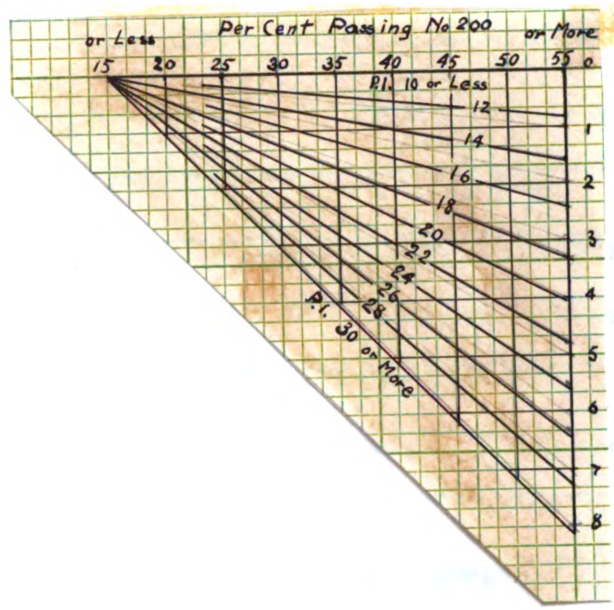


Chart A

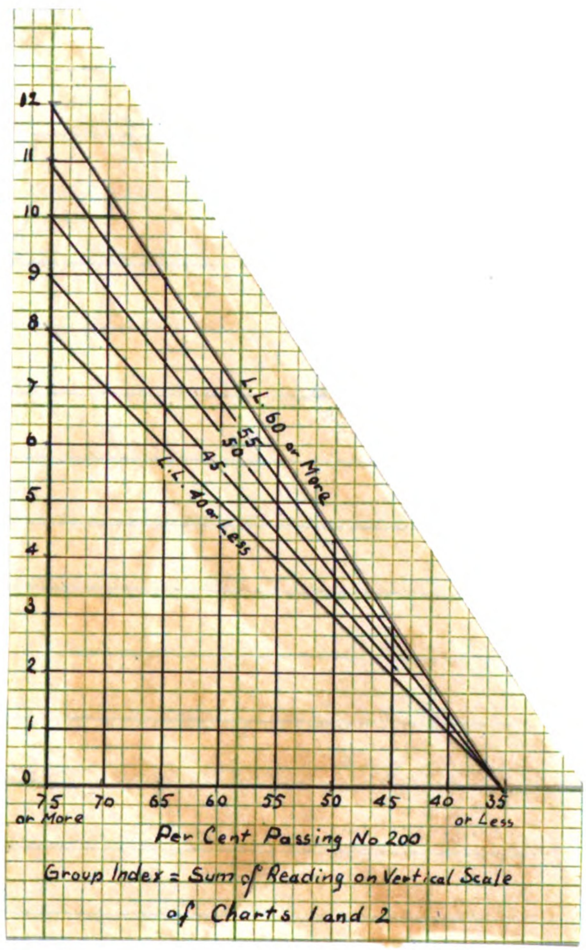


Chart 3. Highway Research Board Group Index

CHAPTER II

THE ROAD

The road structure can be divided in two parts: The road surface and the foundation. The road surface consists essentially of a base course whose structure must be such that it can support without failure the combined detrimental action of weather and traffic. The road surfaces we are concerned with in this study are of the flexible type, i.e. they are not designed to support the pressure of the applied traffic load, but to transmit it to the foundation.

The road surface is subject to complex efforts: vertical pressure of the vehicles load, horizontal shears in all directions, impact due to accelerating, decelerating, braking, or skidding. Rain by splash and runoff action tends to wash away the fine soil fraction, dryness with wind blow causes dust and granular fractions to loosen. By the impact, stamping, suction, tangential efforts, friction, vibration of the wheels, the surface fails in several spots, grains are projected and pot holes are formed. As the surface becomes rough vibrations of the vehicles' springs assembly loosen material in longitudinal stripes like waves whose distance is regular and corresponds to the period of the spring vibration for the average speed of the bulk of the vehicles.

In order to prevent this deterioration a "wearing course" is usually placed which provides a surface to resist abrasion of tires and water.

The foundation or subgrade must carry without failure the stresses transmitted through the base course. Therefore it is necessary to have definite information regarding its bearing capacity. Methods used for that purpose are the California Bearing Ratio Test, the triaxial compression test, the plate bearing test and the cone bearing test.(1)*

The foundation must be uniform. Weak spots are likely to settle irregularly with traffic, deflection and cracks may appear to the surface allowing water to enter the structure. It must be stable. Volume changes due to climatic variation and moisture fluctuation must be eliminated. By shrinkage or swelling they provoke breakdown of the soil structure and the lowering of the bearing capacity.

(1)The values given by these different tests are only comparative and have not yet been related one to another.

* See Appendix I

CHAPTER III

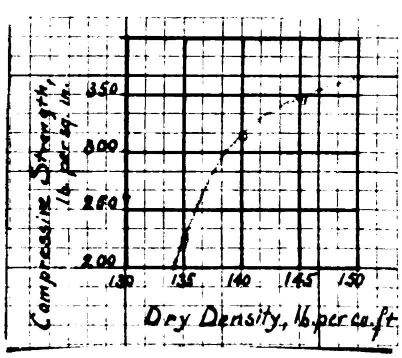
MECHANICAL STABILIZATION

Mechanical stabilization is the title given to those methods of construction in which soils or soil-aggregate materials, are mechanically manipulated to provide foundation, base or surface courses, able to carry with only slight degradation traffic loads under all normal moisture and traffic conditions.

The purpose of this manipulation is either to increase the density of, to produce a greater uniformity in, or to reduce the moisture content of the soil.

This is to be obtained because of the following facts:

Effect of Density on Compressive Strength



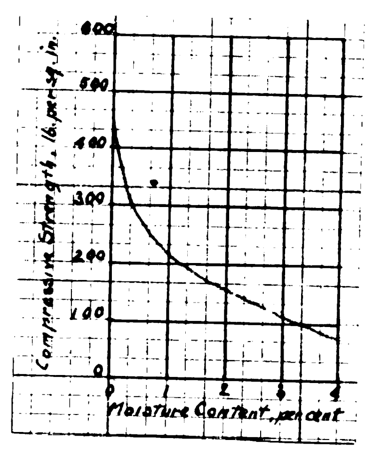
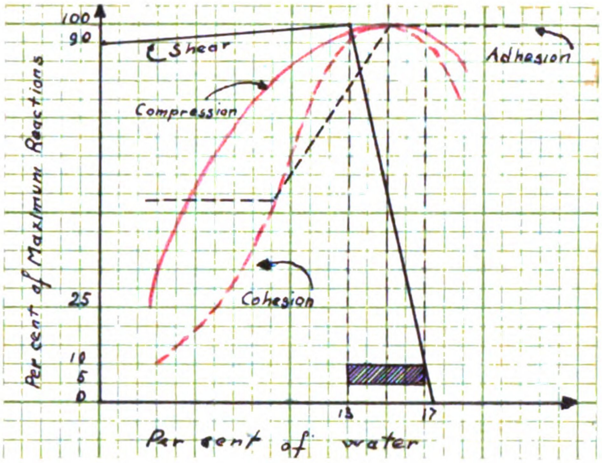


Figure 1 emphasizes the following relation: as density is lowered, bearing capacity falls off rapidly.

Effect of Moisture Content on Bearing Capacity

Figure 2 shows that as the moisture content of a mechanically stabilized mixture is increased, its compressive strength decreases rapidly.

In effect the values corresponding to cohesion, adhesion, compression, shearing resistance are plotted on the same graph. As the moisture content is increased it is readily seen that maximum reactions occur in the plastic range.

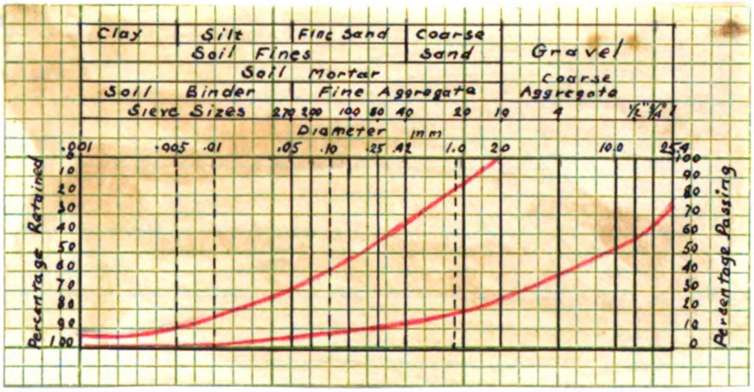


These facts stress the importance of P.I. and L.L. in the selection of materials. In mechanical stabilization soils having P.I. of less than 6 are generally specified.

Once the proper material is selected moisture control is of utmost importance. It is accomplished by good drainage, proper gradation and adequate compaction.

Drainage is obtained by shoulders and gutters for surface water and by sub-drains and eventually subbases for ground water.

Gradation generally adopted falls in the grading band shown in Fig. 4



Compaction is made at 95%-100% of optimum moisture content given by the Moisture Density Test*.

Mechanical stabilization is obtained by the utilization of the natural properties of the soil components:

Gravel and sand make the skeleton.

Clay acts as a binder.

Silt is a filler.

Materials

Gravel and sand must be sound and durable. The angular shaped grains are most desirable for they give better interlocking action.

Clay must be free from organic or deleterous material.

Two types of mixtures are considered:*

Type A Sand clay mortar

Type B Coarse graded aggregate (gravel, crushed stone, slag)

Surface Material

(1) Gradation

Type A Sand Clay Mortar

Passing	Percentage by Weight
1 inch sieve	100
No. 10 sieve	65 - 100
Material passing No. 10 sieve	
No. 10 sieve	100
No. 20 sieve	55 - 90
No. 40 sieve	35 - 70
No. 200 sieve	8 - 25

*See Appendix
*Ref. 44

Type B Coarse Graded Aggregate

Passing	Percentage by Weight
1 inch sieve	100
3/4 inch sieve	85 - 100
3/8 inch sieve	65 - 100
No. 4 sieve	55 - 85
No. 10 sieve	40 - 70
No. 40 sieve	25 - 45
No. 200 sieve	10 - 25

(2) Characteristics of material passing the No. 40 sieve for surface courses

$$4 < \text{P.I.} < 9$$

$$\text{L.L.} < 35$$

fraction passing No. 200 sieve   2/3 of fraction passing No. 40 sieve

Base Course Material

(1) Gradation

Type A. Sand Clay Mortar
same as for type A surface course

Type B. Coarse Graded Aggregate

Passing	1 - inch Maximum	2 - inch Maximum	3 - inch Maximum
	Percentage by Weight		
3 inch sieve			100
2 inch sieve		100	65 - 100
$1\frac{1}{2}$ inch sieve		70 - 100	
1 inch sieve	100	55 - 85	45 - 75
3/4 inch sieve	70 - 100	50 - 80	
3/8 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

(2) Characteristics of material passing the No. 40 sieve for base course

P.I. $\leqslant$ 6

L.L. $\leqslant$ 25

fraction passing No. 200 sieve   1/2 of fraction passing No. 40 sieve

<u>Subbases</u>

Type A. - Drainage layers to the depth affected by frost for naturally silty soils which become unstable due to frost or subsequent thaw characteristics: Non-plastic materials -8 per cent maximum passing No. 200 sieve.

Type B. - Subbase on soils of low support and treatment on plastic soils (P.I.   15) which are subject to detrimental volume change.

Characteristics same as for type A and also materials having:

L.L. $<$ 35

P.I. $<$ 15

65 per cent maximum passing No. 200 sieve.

In location not subject to detrimental frost any material having:

L.L. $<$ 40

P.I. $<$ 1/4 of L.L.

These are satisfactory materials; however, materials falling outside the preceding specifications can be suitable under particular local conditions.

Unless the subgrade was or has been compacted to 95 per cent or more of the Proctor density, the upper part of the subgrade must be scarified to a sufficient depth to provide after compaction a layer at least 12 inches thick. Materials scarified are windrowed and then spread, disced or harrowed in order to break all clods, adjusted to correct moisture content, then compacted in layers 6 inches thick or less by means of sheepsfoot rollers. The surface layer must be mulched by discing or harrowing and moisture content adjusted. Then it is compacted with pneumatic or steel wheeled rollers.

In this operation any soft spots must be excavated and replaced with sound material.

Moisture content, as already pointed out, is of utmost importance.

As in any compaction by sheepsfoot rollers all stones exceeding 3 inches in greatest dimension must be removed.

Proportioning the Mixture

The problem is to obtain an adequate mixture with generally two materials whose physical constants prove to be satisfactory. There are several approaches to the problem. One is to combine material for desired Atterberg limits and then see if grading is satisfactory. Another is to combine for grading within limits of specifications then test for Atterberg limits. Finally the trial and error method can be used.

Combining for Atterberg Limits

Generally P.I. is considered as representative enough and is the only Atterberg test used. The Michigan State Highway Department[1] has devised a formula solving the problem. The mechanical analysis and P.I. are determined for soil in place and binder sod. The P.I. is chosen near the lower limit allowed by the specifications. The percentage of binder soil to add is:

$$P = K \times R \times \text{percentage of road material passing the No. 40 sieve}$$

in which K is a constant given by a table

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

Samples of the mixture are tested for sieve analysis L.L. and P.I. and if the results are within the specifications limit it is adopted. Otherwise new assumptions are made according to experience, and new mixtures are tried until one complies with the specifications.

(1) Ref. 21

Combining for Sieve Analysis

The P.R.A. has devised a graphical method solving the problem as follows:[2]

On a chart the percentage of fractions passing the different sieves is indicated on one side for the gravel and on the other for the binder soil. The corresponding percentages for each sieve are connected by means of pins and fine threads. A movable scale corresponding to the desired grading is moved from the first scale toward the second until distribution corresponds to specification. The relative distance moved gives the percentage of binder soil to add to the granular material.

With the Michigan State Highway Department, the method consists of calculating the difference between the desired grading and the gradings of the two materials to be combined if one is finer and the other is coarser than the desired grading. The difference is calculated between the percentage passing each sieve for the desired grading and each of the two materials, then added without respect to sign. The ratio of the two summations is the desired ratio. In both methods the mixtures are tried for L.L. and P.I. for compliance with the specification.

The Trial and Error Method is used in mixing the two materials until mixture proves satisfactory.

Finally the Service des Travaux Publics de Tunisie* has adopted a method which consists of plotting the Atterberg limits for various mixtures of aggregate and soil binder and, by the shape of the curves, decide which is the most suitable without respect of grading.

Construction Procedure

Subgrade. In setting the subgrade the following fundamental principles

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(2) Ref. 18

* Ref. 19

must be observed:

Adequate drainage must be provided, keeping in mind that capillary moisture cannot be drained.

Materials must be thoroughly compacted in layers not over 6 inches for all soil fills and for the upper 12 inches of all soil cuts.

Grade line must be maintained at least 4 feet above the level of the soil water table.

All pockets of soil of frost heave texture must be removed to the depth of frost penetration, where frost heaving and frost boils have or may develop and backfilled with soil of non-frost heaving texture.

All deposits of heat and muck must be removed from beneath the subgrade by excavation, displacement, dynamiting or jetting with water.

Procedure adopted is similar to the one used for base course as explained later.

Subbase - Over objectionable soils a sand subbase is used as capillary cutoff. The top 3 inches of this layer must be treated by the addition of a soil binder in order to insure a stabilized layer of uniform compaction and thickness. This treatment gives to the subbase a surface able to support the construction equipment and operations without objectionable deterioration.

Base Course

As already pointed out, good stabilization depends on two factors: (a) gradation and (b) compaction. Procedure according to methods is set as follows:

Road mixing method - The binder is obtained by blading it off the shoulders, the road bed or shallow pits, in thin cuttings easy to pulverize when dry. It is hauled onto the road, dumped and spread out to dry. It is worked by discing and rolling until:

100 per cent pass the 1 inch sieve

and at least 80 per cent pass the No. 4 sieve

The material is then windrowed in proper amount by means of windrow eveners on one side of the road. Drying can be facilitated by spreading a small amount of the aggregate over the binder soil. With heavy clay addition of water facilitates pulverization by shaking the dry lumps. The aggregate is mixed according to the proportions adopted by means of road mixing equipment, i.e. multiple blade drags, motor grader, harrows or plows. The moisture content is gradually brought slightly above optimum moisture content.

The mixture is shaped and then compacted with sheepsfoot rollers in layers of uniform thickness, (4 inches or less). If the final thickness is to be greater than 8 inches, the mixture is placed in several layers. Thickness varies in the States but 6 inches seems to be recommended. During operations moisture content and crown are frequently checked, and the road surface is sprinkled and shaped so that at the end of the operation the materials will be compacted at least to 95 per cent of the Proctor density and the road will have the desired crown and cross section.

Plant mixing method

Mixing in central or portable plants is a little more expensive than road mixing, but it has some advantages:

a. The mixture obtained is more uniform.

b. Weather conditions are of less importance.

c. Less traffic interruption occurs.

d. There is a greater ease in supplying the water.

e. Less equipment is required on the road.

f. Laboratory control of the mixture is easier.

Tests to be carried out:

a. Before Construction

1. Mechanical Analysis
2. Liquid Limit
3. Plastic Limit
4. Plasticity Index
5. Centrifuge Moisture Equivalent
6. Field Moisture Equivalent
7. Shrinkage Limit
8. Permeability
9. Capillarity
10. Shear and Bearing Test
11. Proctor Density

b. During and After Construction

1. Moisture Density
2. Proctor Density
3. Gradation

Limitations

As base course, mechanically stabilized soils can be satisfactory when used on sound and properly drained foundations.

As surface course in temperated climates, under alternate rainy and sunny periods, evaporation compensates water percolation and only little maintenance is required although it has a tendency to become dusty when dry and somewhat muddy and slippery when wet. A partial palliative resides in the use of chemicals as will be seen in the next chapter.

Under adverse conditions continuous rain saturates the surface and base course, weakening their bearing capacity. Frost will also achieve the destruction of the structure.

So mechanical stabilization is a first step in stage construction and provides the necessary stability to permit light traffic on roads otherwise impassable, when other means would be too expensive. However, a surface treatment with bituminous material will, at low cost, provide the road with a sufficient protective cover. Generally the bituminous treatment of waterproofing the road surface will prevent evaporation and it will be necessary to reduce the percentage of the binder soil which is more affected by moisture. By revamping the surface, i.e. adding aggregate to the surface material after scarification, a gradation falling in the range of the base course material recommendation is obtained. After compaction the road surface will be ready for the treatment.

Construction Equipment

The main pieces of equipment used in mechanical stabilization are the:

Power Shovels - as excavating or loading devise:can be steam, diesel or diesel electric powered, have generally from 3/8 to 2 1/2 cu. yd. capacity, and can excavate from 25 to 250 cu. yd. per hour, and are generally crawler driven.

Drag-Line Excavator - for the same purpose is usually used in the handling of wet material; capacity depends on the size of equipment used and on the distance to which the material is to be removed. Up to 200 cu. yd. per hour can be handled on short angle swings.

Rooters - are used to tear up stiff material (hardpan, gravel, and macadam).

Bulldozers - are used for excavating or placing fill when short hauls (not over 200 feet) are required and quantity of material to move is not sufficient to warrant more important equipment.

Scrapers - tractor propelled, are very efficient for hauls of 1,000 to 3,000 feet, have great mobility, are self-loading units, can lay down their load in a layer of even depth. Capacity up to 26 cu. yd. Production can reach 140 cu. yd. per hour for normal digging with 1,000 ft. hauls.

Blade Graders - generally self-propelled, are perhaps the most important piece of equipment in soil stabilization. They are equipped with an adjustable steel moldboard or blade and sometimes with leaning wheels to balance the lateral thrust on the moldboard. Can be provided with scarifier attachment.

Elevating Graders - are heavy pieces of equipment. The grader plows up the earth, lifts it from the ground and dumps it on a moving belt which carries the material to a chute through which it is guided into wagons or trucks. Can load a 13 cu. yd. wagon in 30 to 40 seconds. Generally excavate from 400 to 750 cu. yd. per hour.

Truck and Tractor Wagons - are attached to a loading unit. Trucks have lower capacity, higher speed, and need a runway. They are preferred for long hauls. Tractor Wagons have higher capacity, lower speed, but can turn and dump their load faster than do trucks. They have a capacity up to 20 cu. yd.

Windrow Eveners - consist of forms through which materials are shaped in regular windrows.

Spreaders - are open boxes hauled by trucks, open in front to permit the dumping of the mixed materials, and having an adjustable opening at the rear in order to leave a layer of uniform thickness.

Equipment used in mixing operations consists of cultivating tools which are somewhat heavier than those used in the fields.

Three or Four-Bottom Gang Plows, Offset Discs, Harrows, Spring-Tooth Field Cultivator and Specialized Equipment: Multiple blade drags which mix the materials in place.

Single Pass Stabilizers - are traveling pug mill plants which take the soil from the road bed, pulverize it and mix its various fractions with water, and leave the materials in a uniform layer ready to be compacted. Such traveling plants have been adapted to other types of soil stabilization as will be seen later.

Water Tanks - equipped with pressure distributor have usually 1,000 gal. capacity and can be emptied in 5 minutes.

Finishing Tools - Rollers are of three types: The Tamping roller generally called Sheepsfoot Roller, consists of a steel cylinder roll equipped with tamping feet, can be weighted with water and is usually pulled by a tractor. The Pneumatic Tire Roller, a loaded multiple rubber tire platform giving a smooth rolling is hauled by a tractor. The Three-Wheel Roller gives a smooth, dense surface and can be steam, diesel, or gasoline powered.

Spike Tooth Harrows - nail drags and broom drags are used as finishing tools to clean or remove the prints from the surface.

Mixing plants - consist of: screening and crushing equipment to produce the aggregate, desintegrator units to pulverize the binder soil and mixing units to obtain the mixture at the right moisture content ready to be compacted.

In order to prevent any deterioration of the treated surfaces: Equipment having crawler treads must be equipped with wood-block treads or steel street plates. All wheels except flat wheel roller must be equipped with rubber tires.

CHAPTER IV

CHEMICAL STABILIZATION

Chemical Stabilization is the name given to those methods of Mechanical Stabilization utilizing a chemical product as an admixture, thus improving the performance of the soil-aggregate material.

Chemicals used extensively so far are: Calcium chloride, magnesium chloride and sodium chloride to a lesser extent. All three are hygroscopic, i.e., they have the property of attracting water and holding it. Calcium and magnesium chloride are also deliquescents thereby dissolving themselves into the air moisture.

Many studies have been carried out on calcium chloride and an outline of its characteristics follows:

Calcium chloride ($CaCl_2$) added to the soil material greatly improves the soil performance by regulating its behavior in the presence of water.

Moisture attraction. $CaCl_2$ attracts moisture from the air. Table I shows to what extent, according to Relative Humidity and Temperature.

TABLE I

Deliquescence

(Lowest Relative Humidity and Temperature at Which Calcium Chloride Will Dissolve)

Relative Humidity	Temp., Deg. F.
20	100
30	74
40	44
43	32

TABLE I (Cont'd.)

Hygroscopicity

(Pounds of Water Taken Up by One Pound of Flake Calcium Chloride at Different Humidities)

Relative Humidity	Temp., Deg. F.	Lbs. of Water Taken Up by 1 lb. $CaCl_2$
36	77	1.0
60	77	1.6
70	77	2.0
80	77	2.8
85	77	3.5
90	77	5.0
95	77	8.4

As is readily seen in Table 2, water containing $CaCl_2$ shows a lowering of the Vapor Pressure and an increase of the Surface Tension over plain water. Figure 5 also shows this reaction.

TABLE 2

Temperature, Deg. F.	Vapor Pressure	
	Plain Water	Concentrated Calcium Chloride
41	6.54	2.74
50	9.21	3.71
59	12.79	4.76
68	17.54	6.06
77	23.76	6.97
84	30.04	7.30
104	54.32	10.53

Fig. 5 Surface Tension of $CaCl_2$ Solutions at 77°F.

As a consequence Evaporation Losses are greatly reduced. (See Fig. 6)

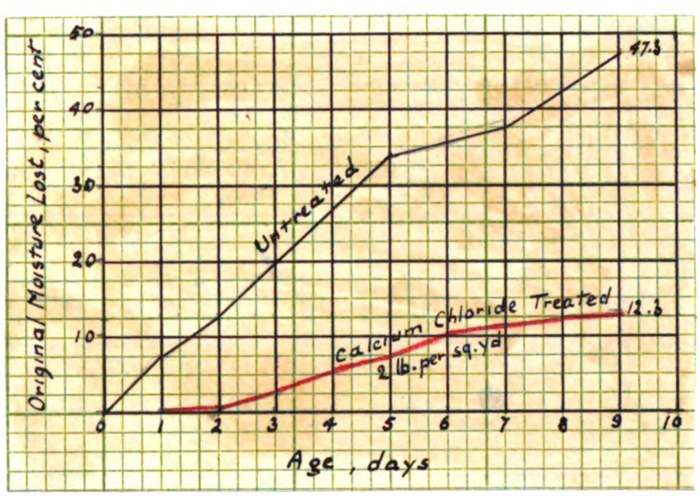

Fig. 6 Relation of Evaporation Losses from Treated and Untreated Soil-aggregate Road Mixtures.

<u>Density</u>. A very interesting characteristic of CaCl treated soils is that under the same compactive effort, they show an increase of 11%, approximately, in weight over plain soils.

Compaction. As a consequence $CaCl_2$ treated soils require less compactive effort in order to attain a given density as is shown in Fig. 7.

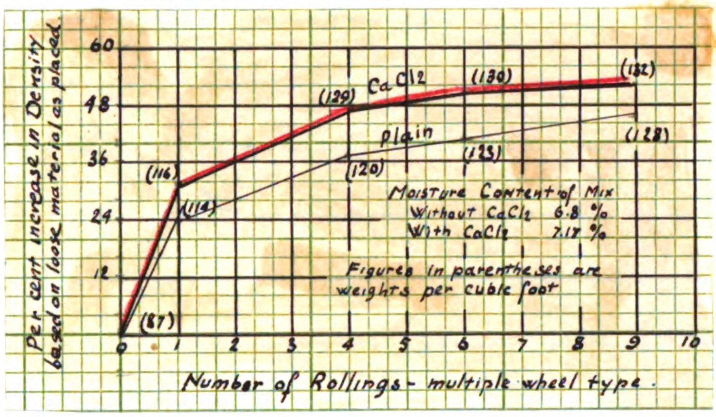

Fig. 7 Relationship of Density and Number of Rollings on Stabilized Road Mixes With and Without $CaCl_2$

It has also been observed (see fig. 8), that the resultant density is obtained for 85 per cent by the roller compaction and for 15 per cent by the shrinkage compaction or the seasoning of the road; but also only 10 per cent of the structural stability is obtained during the rôller compaction, 90 per cent being obtained during the shrinkage compaction or seasoning of the road. These results, based on a series of tests, show the importance of allowing the road to season properly, and the importance of CaCl in controlling the rate of drying during both the compactions and seasoning period.

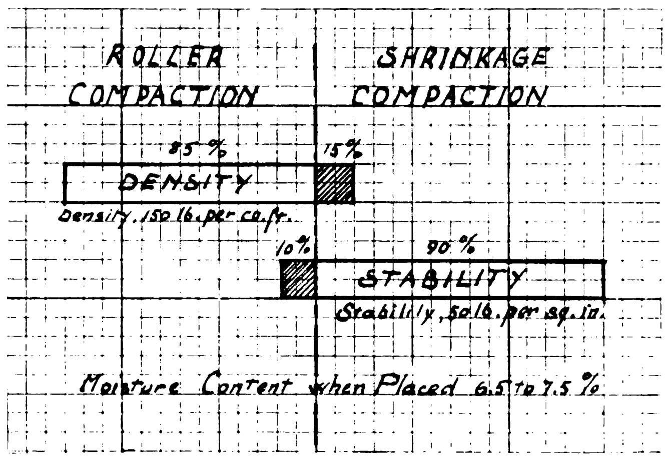

Fig. 8 Average Relative Effects of Roller and Shrinkage Compaction on the Density and Structural Stability of Calcium Chloride Stabilized Roads

In a comparative compactive test carried out on circular experimental tracks, $CaCl_2$ treated soils required 18,200 trip against 60,000 for plain soil to attain a similar density.

Evaporation is responsible for the decrease of compaction efficiency as moisture content falls under the optimum value. As shown in Fig. 9, $CaCl_2$ slows down the rate of evaporation.

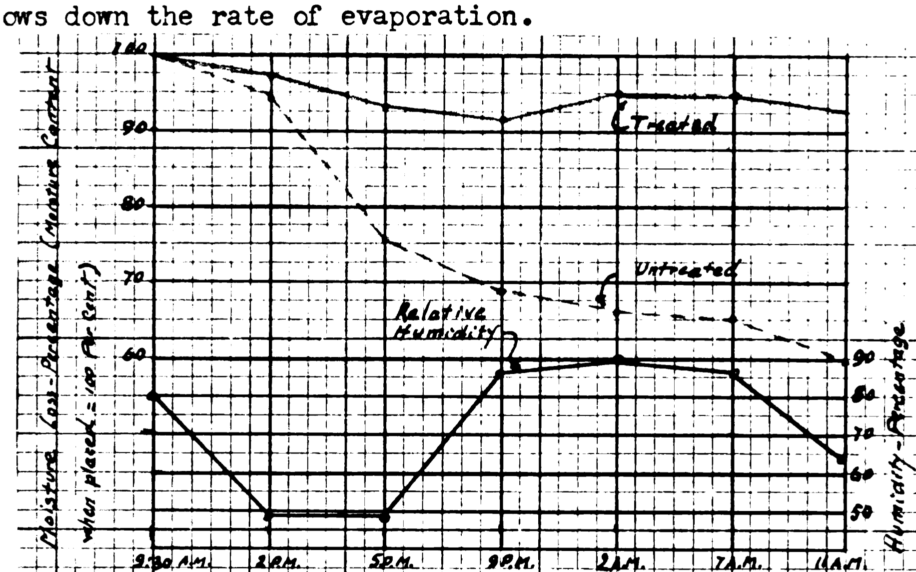

Fig. 9 Relationship Between the Rates of Evaporation of Moisture from Treated and Untreated Soils and the Effect of the Relative Humidity on the Hygroscopic Property of the $CaCl_2$ Treated Soils

Uses:

$CaCl_2$ is employed for both surfaces and base courses. The benefits derived from its use are:

Surface course

1. Abatement of the dust.
2. Increase of the binding power.
3. Conservation of the surface material.

In a study carried out it was found that the loss of material for $CaCl_2$ stabilized roads was only 37 per cent of the loss of material for ordinary untreated roads.

Base course

1. Cuts in water costs.
2. Cuts in compaction costs.
3. Extention of compaction period.
4. Greater Density.
5. Reduction of Frost Damages.

Quantity: Varies with soils

Surface course: $\frac{1}{2}$ to 2 lbs. per sq. yd. usually consists of an initial treatment of from 3/4 to $1\frac{1}{2}$ lb. and of lighter treatments of generally $\frac{1}{2}$ lb. per sq. yd. at intervals during the season.

Base course: Recommendations are 0.5 lb. per sq. yd. per inch of thickness with a maximum of 2 lbs. per layer (i.e. 4" maximum thickness). For plant mixing the finished material must contain 5 to 8 per cent by weight of moisture and at least 10 lbs. of $CaCl_2$ per ton of mixture.

Procedure

$CaCl_2$ is used in the form of flakes or in concentrated solution. In road mixed materials $CaCl_2$ is spread uniformly over the materials by means of mechanical spreaders or sprinkling systems.

For both surface and base course application must be done during a period of high humidity, i.e. during the night or early in the morning, or when the soil is dampened by rain or by artificial sprinkling. In plant mixed materials $CaCl_2$ is incorporated during the mixing period.

Limitations

In soils having high capillarity, $CaCl_2$ concentrates near the surface and can be washed away by rain.

In soils having high permeability, $CaCl_2$ percolates through the road material to the subgrade. In both cases, the structure looses the additional binding power provided by $CaCl_2$ and maintenance of the correct amount is very costly. However, with most of the soil-aggregate mixtures, the cost of initial and periodical application of $CaCl_2$ is approximately equal to the cost of replacement of the loosened material resulting from surface wear which is estimated to be approximately $\frac{1}{2}$ to 1 inch per year.

Moreover, elimination of dust hazard and smoother surface results in saving for the public.

$CaCl_2$ stabilized roads furnish a good base for higher type surfacing. $CaCl_2$ seems to aid the absorption of bituminous priming materials.

CHAPTER V

SOIL-BITUMEN STABILIZATION

Soil-Bitumen Stabilization is the name given to those methods of construction in which a bituminous material is incorporated in a soil or soil-aggregate mixture in order to stabilize it and render it capable of carrying the applied traffic loads under all normal conditions of moisture and traffic.

In cohesive soils the bituminous material acts as a waterproofing agent in order to maintain a low moisture content.

In non-cohesive soils it acts also as a binding agent by binding the soil particles together. In no case must the bituminous content be in excess of the volume of voids from the Proctor density in order to prevent excess lubrication of the particles giving instability. There are several types of bituminous stabilization. The principal ones are:

Natural Soil-bitumen mixture generally refers to a waterproofed system of a naturally cohesive soil without respect of gradation of soil material.

Dense Graded-Soil-bitumen mixture is a system of well graded soil material from fine to coarse having high potential density (could be mechanically stabilized) and waterproofed by a uniform distribution of a small amount of bituminous material.

Open Graded-Soil-bitumen mixture, also called Sand-bitumen, is a system in which loose beach, dune, pit or river sand is cemented together by bituminous material.

Dense Graded-Soil-bitumen Stabilization

Dense Graded-Soil-bitumen Stabilization is used as a base course of 4 to 8 in. thickness. It consists of a mixture of sand or stone screenings, gravel or crushed stone, a clay binder, and waterproofed by the incorporation of from 1 to 2 or more per cent of bituminous waterproofing material.

Materials

Aggregates must be free from injurious quantities of flaky materials, soft shale, organic matter or other deleterious material.

Soil Binder must be free from injurious amounts of organic matter and all passing a 1 inch sieve.

Water must be clean, free from any injurious substances as salt, oil, acid, alkaly organic matter, etc.

Bituminous waterproofing material* can be:

Tar	grade	RT - 4
Emulsified Asphalt	grade	1 and 2
Cut-Back Asphalt	grade	RC - 1

Bituminous Primer

Tar	grade	RT_2 to RT_4
Emulsified Asphalt	grade	1 and 2
Asphalt	grade	MC - 0

Gradation

Gradation is of utmost importance. The gradings used are similar to those used for Mechanical Stabilization. However, since the fine fraction requires more bituminous material than the coarse one, it is advantageous to

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* See Table

use gravel and/or crushed stone. Three possible gradations are given below. They have given good results, however they are not the only ones and others may prove satisfactory.

Grading Passing:	Type A %	Type B %	Type C %
$1\frac{1}{2}$ in. square screen	100	-----	-----
1 in. square screen	80 - 100	100	-----
3/4 in. square screen	65 - 85	80 - 100	100
No. 4 sieve	40 - 65	50 - 75	80 - 100
No. 10 sieve	25 - 50	40 - 60	60 - 80
No. 40 sieve	15 - 30	20 - 35	30 - 50
No. 100 sieve	10 - 20	13 - 23	20 - 35
No. 200 sieve	8 - 15	10 - 16	13 - 30

Recommendations: colloidal clay fraction $\leqslant$ 8 per cent (for type C only)

fraction passing No. 40 sieve $>$ 40 per cent of fraction passing No. 10 sieve

fraction passing No. 200 sieve $<$ 60 or preferably 50 per cent of fraction passing No. 40 sieve

a tolerance of 15 per cent at every point of the grading curve is generally adopted (see Fig. 4).

Bitumen Content, in percentage of the dry weight of soil:

For type A or B: in dry climates — a minimum of 1 per cent

in climates having moderate to heavy rainfalls — a minimum of 2 per cent

For type C: in dry climates — a minimum of 2 per cent

in climates having moderate to heavy rainfalls — a minimum of 3 per cent

Moisture content

Must be in a range of plus or minus 0.5 per cent from the optimum moisture content.

Optimum moisture content is for types A and B about 6 per cent.

" " " " for type C about 8 per cent.

Construction Equipment

In order to give reliable service all pieces of equipment must be in first-class condition. Equipment having crawler treads must be equipped with wood-block treads or steel street plates. All wheels except a flat wheel roller must be equipped with rubber tires. All equipment must be such as not to disrupt the treated surfaces.

Equipment consists of the standard equipment used for Mechanical Stabilization:

Trucks or Wagons
Tractors
Three-Bottom Gang Plows
Heavy-Duty Orchard Type Cultivators
Disc Harrows
Windrow Eveners
Spreader Boxes
Blade Grader
Multiple Blade Drags (blade depth 20 in. minimum)
Sheepsfoot Rollers (optional)
Spring Tooth Harrows
Multiple-Wheel Pneumatic-Tired Rollers (3 to 7 tons, 200 lbs. per in. of tread width)
Tandem Rollers (rolls of at least 42 in. diameter, 48 in. width and 200 to 300 lbs. per linear inch)
Nail Drags
Broom Drags

and of specialized pieces of equipment including:

Heating equipment (when necessary). Bituminous material can be heated directly inside the tanks by means of coils- steam, oil or electrically heated (and plunged into the material. An outside system is used when the material is in a pumpable state. It is then circulated through a heating system called booster and dumped again in the tank where temperature raises quickly. For small amounts portable kettles are used. No water or injurious materials must be allowed to enter the system. Thermometers must indicate temperature of the material near the source of heat or in the heating system.

Bituminous Distributors. Normal capacity from 600 to 1,500 gal. They are equipped with an independent heating device and a pump distributing system having a capacity of at least 200 gal. per min. Distribution is made by means of nozzles mounted on spray bars on various widths (6 to 24 feet). Distributors must be equipped with a tachometer and distribution tables, thermometers, adequate pressure and volume gages in order to control the temperature and the quantity of spread material.

Traveling Mixing Plants can be used. They are single-pass stabilizers which can incorporate the desired amount of bituminous material to the soil aggregate and leave it ready to be compacted.

Central or Portable Plants can be used when the mixing plant is preferred to the mixed in place method. They can be provided with bituminous material storage, heating, feeding and dosing system to get the material ready to be spread and compacted.

With the two last auxillary loading devices, supplying tanks and pumping systems are required (varying with the make).

Construction Procedure

Base Course:

Base courses are usually laid 4 to 8 in. thick.

Preparation of Aggregate Materials

Plant Mixing. Selected materials are loaded and moved from the pit to the plant in the proportion required to meet the specifications for type A, B or C.

Road Mixing. When part or all of the materials are furnished by the road bed, this one is scarified or plowed to a depth sufficient to furnish enough loosened material which is put in windrows of proper size on one side of the roadway. When part or all of the materials are taken from other sources, they are hauled and placed in windrows as specified before. The soil binder material must be pulverized so that 85 per cent passes the No. 4 sieve.

Subgrade must meet the general requirements of foundations as explained in Chapter 3.

Temporary drainage must be provided in order to prevent water from accumulating in the subgrade or on the material in the process of mixing.

Priming:a prime coat of bituminous material is generally placed on the subgrade to prevent capillary rises from the subgrade through the base. Prime coat is applied on the free part of the roadway in a wet state, to facilitate absorption. When this is completed (generally in 24 hours), the windrows of soil and aggregates are moved from one side of the road to the other and priming is completed on the untreated part and allowed to be absorbed by the subgrade.

Mixing

Plant mixing. Aggregate and soil binder material are fed in adequate proportions into mixing units and thoroughly mixed with proper amounts of water and bituminous material.

Blade Mixing - Windrow of aggregate and soil binder is spread. Materials are pulverized by harrowing, discing, and blading and are uniformly moist. Bituminous material is spread by means of distributors and thoroughly mixed with the moist aggregate by harrowing, discing, blading and with additional sprinkling of water to keep the mixture moist. Then the mixture is bladed into windrows.

Traveling Mixing Plant - Materials in one or more windrows are picked up by the traveling unit which mixes them while moving with proper amounts of water and bituminous material supplied by portable supply tanks.

Spreading

Spreading is accomplished before the moisture content of the mixture falls below the optimum moisture content* by means of spreading boxes, blade graders, rubber tired motor patrols with a wheel base of at least 15 feet or traveling plants (certain types). The layers are of a uniform thickness of not more than 2 inches.

Compaction

Rolling of each layer is accomplished immediately after spreading. First with a steel wheeled roller and then with pneumatic tired rollers. The mixture must not be allowed to dry at any time during the operation and water must be sprinkled when necessary. If too wet, the mixture must not be applied but kept until it can be worked satisfactorily.

Each layer is rolled until 95 per cent of the Proctor density is obtained. If depressions occur, additional mixture must be provided, bladed and rolled until proper grade is obtained. Each layer is allowed to dry when compaction is finished, until moisture content is inferior at 4 per cent.

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* Determined by the Standard Compaction Test

When emulsions are used the remaining water content must not exceed 25 per cent of the optimum. When rain is not anticipated during construction, layers of up to 6 inches in thickness can be compacted with Sheepsfoot rollers.

The construction of bituminous stabilized bases must not be attempted when the temperature is 35 degrees F. or less and is falling.

Wearing Surface

Soil-bituminous mixtures are generally too friable and wear rapidly under traffic. They must be protected by a wearing surface very soon after construction. The thickness of the surfacing varies with the anticipated volume of traffic.

Usually for light traffic a penetrating prime and an application of high viscosity emulsified asphalt, R.C.-cut-back, hot penetration asphalt or tar of 0.4 to 1/2 gal. per sq. yd. is satisfactory. It is spread by means of distributors and covered by means of mechanical spreaders with clean stone chips up to 1/2 inch in size.

The surfacing must be well sealed against entrance of surface water.

Natural Soil-Bitumen Stabilization

Natural soil-bitumen stabilization is used as a base course of 4 to 8 inches in thickness. It consists of a mixture of natural cohesive soil to which bituminous materials are incorporated in the proportion of from 4 to 7 per cent of the dry weight of the soil, in order to waterproof it.

It is a variation of the method previously described, in which greater tolerance in gradation results in higher bitumen requirements.

Materials

Soil must be free from injurious amounts of flaky materials, organic matters or other deleterious materials. Presence of large quantities of sand, gravel or crushed stone is desirable as it increases the stability and decreases the amount of bitumen required.

General recommendations are:

Gradation, Maximum size: Must not be greater than 1/3 of the compacted thickness, or if the base is made up of several layers can be of the same size as the compacted thickness of one lift.

Passing No. 4 sieve $>$ 50 per cent

Passing No. 40 sieve from 35 to 100 per cent

Passing No. 200 sieve from 10 to 50 per cent

Characteristics of fraction passing No. 40 sieve

L. L. $<$ 40

P. I. $<$ 18

Water must be clean, free from any injurious matters as salt, acid, alkaly organic matter, etc.

Bituminous materials. Although rapid, medium, or slow-curing liquid have been successfully used, medium-curing cut-back are recommended. Preferred tars are RT3 to RT 6 grades. Emulsions must be tested for several viscosities, and their use involves features differing from that of liquid asphalts and tars.

In fact many types of bituminous materials have been used and there is a need for materials specifications and tests standardization.

Construction equipment is the same as listed on page 42. Moreover a minimum of 20 in. for the discs of disc harrows and 14 in. for plows in gang is recommended.

Construction procedure is the same as described on page 43.

Open-graded Soil-bitumen Mixture (Sand-bitumen)

Sand-bitumen stabilization is used as a base course 3 to 10 inches in thickness. It consists of a mixture of sand, with or without mineral admixture, and a bituminous binder.

Materials

Sand must be free from organic matter and of lumps, balls or adherent films of clay.

Gradation	passing No. 200 sieve	12 per cent
for wind blown or dune sand	passing No. 200 sieve	25 per cent
providing that fraction passing No. 40 sieve have	Field Moisture Equivalent	20 "
	Linear Shrinkage	5 per cent

Stability

Stability for cut-back asphalts

Modified Hubbard-Field Stability test value[1] $\geqslant$ 1200 lbs.

Stability for tars

Florida Bearing Value[1] $\geqslant$ 25 lb. per sq. in.

Stability for Emulsified asphalts

Florida Bearing Value[1] $\geqslant$ 30 lb. per sq. in.

Mineral admixture (optional) can consist of: crushed stone, crushed slag, crushed or round gravel, stone or slag screenings, rock dust, loess, other sand or non-cohesive mineral matters which give to the mix the desired stability and density.

Bituminous Binder

Tar[2] RT - 6, RT - 7, RT - 8, RT - 9, RT - 10.

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[1] See Appendix II
[2] See Table

Bituminous Binder (Continued)

Cut-back Asphalt RC - 1, RC - 2, RC - 3.

Emulsified Asphalt Grade 1 and 2

Recommendation

Tar:

Mixing Methods	Sand Passing No. 200 Sieve %	Recommended Grade of Tar
Blade	12 - 25	RT - 6,7
Blade	0 - 12	RT - 7,8,9
Plant	12 - 25	RT - 7,8
Plant	0 - 12	RT - 8,9,10

Cut-back Asphalt:

Mixing Methods	Sand Passing No. 200 sieve %	Recommended Grade of Asphalt
Blade	15 - 25	RC - 1
Blade	0 - 15	RC - 2
Plant	15 - 25	RC - 2
Plant	0 - 15	RC - 3

Emulsified Asphalt - Grade 1 when to be spread with a distributor truck

Grade 2 may be diluted prior to application to reduce viscosity.

Construction Equipment

Same as described on page 42. In addition:

When the depth of pavement is more than 5 in. Three-Bottom Gang Plows with 14 in. bottoms, capable of plowing to a depth of 10 in. are used.

When the depth of pavement is less than 5 in. Heavy Duty Orchard Type Cultivators are used.

Disc Harrows must be equipped with 22 in.

Windrow Eveners must be equipped with an adjustable gate not over 4 ft. wide and not less than 2 ft. high. It must be large enough to carry at least 2 cu. yd. of material in addition to the volume occupied by the windrow itself in the evener. The height of the windrow must be not less than 25 per cent of the width.

Construction Procedure

Same as described on page 43. In addition, aeration or curing operations must be carried out with blade drags, until the bituminous mixtures meet the following requirements:

Cut-back Asphalt - Average minimum Hubbard Field Stability value of 1200 lb.

Tar - Average minimum modified Florida Bearing Value of 150 lb. per sq. in.

Emulsified Asphalt - Average modified Florida Bearing Value of 150 lb. per sq. in.

The bituminous binder must not be applied when the air temperature is less than 50 deg. F.

Surface requirements. The surface must not show any depression greater than 1/4 inch when a 10 ft. straight edge having a standard template, cut to the true cross section, is laid parallel to the center line of the completed base. Any definiency must be corrected.

Seal Coat. The mixture being of the open type, generally three weeks after completion a seal coat is applied in order to prevent entrance of water. It consists of a uniformly applied coat of the bituminous material used in the base course construction, spread by means of a pressure distributor, then covered with coarse sand, or fine, clean stone or slag chips, and broom dragged until the binder has been blotted up or blended with the underlying surface.

Limitation

Dense graded soil-bitumen is a very suitable stabilizing method requiring only a small amount of bituminous material. The maintenance is easy and consists of patching and eventually re-shaping. The material so stabilized can be re-worked without any trouble.

Natural soil-bitumen requires a little higher percentage of material but is somewhat less troublesome as for tests and gradation.

Sand-bitumen is limited to areas where sand is predominant.

Dense graded soil-bitumen base and sand-bitumen base are very satisfactory as an intermediate type pavement. The latter two bitumen bases plus the natural soil-bitumen base can be used as foundation for a higher type pavement.

Other types of Soil-bitumen Stabilization are:

Oiled Earth Roads

Oiled Earth Roads are properly graded, compacted and drained earth roads, waterproofed by application of oil or other low viscosity bituminous material.

In this process, the bituminous material is not mixed with the soil but allowed to penetrate 3/4 to 1 inch deep.

Requirements

Surface. The surface must be sufficiently moist so the pore spaces are open. If too dry, dust film will prevent penetration or cracks will result in non-uniform penetration.

Material. Uniform products containing all intermediate fractions are preferred to heavy material, cut-backs with light volatile material. A variety of products have been used.

Slow-curing cut-backs, especially SC-2, are particularly well adapted but Medium-curing material, MC-1 and MC-2, are preferred in some areas.

Tars used are RT-1 and RT-2, or when the soil to be treated contains substantial amounts of aggregate admixture, RT-2 and RT-3 are used.

Construction Equipment

Consists of standard grader and bituminous pressure distributor.

Construction Procedure

Just before treatment the road surface is bladed in order to eliminate dust, crust and depression, thus leaving a surface clean and containing sufficient moisture to facilitate penetration.

The oil is applied by means of a distributor in one or three coats, three coats being more desirable, allowing the bituminous material to be

Asphalt Membranes Stabilization

This method is an improvement of Mechanical Stabilization. As shown in fig. 10, it consists of two waterproofing coats one under, the other above a mechanically stabilized base course which is confined and kept at a chosen moisture content so that weather fluctuations have no influence on its behavior. During construction precautions must be taken so that the under coat is not damaged. It is better ro protect the shoulders from mutilation.

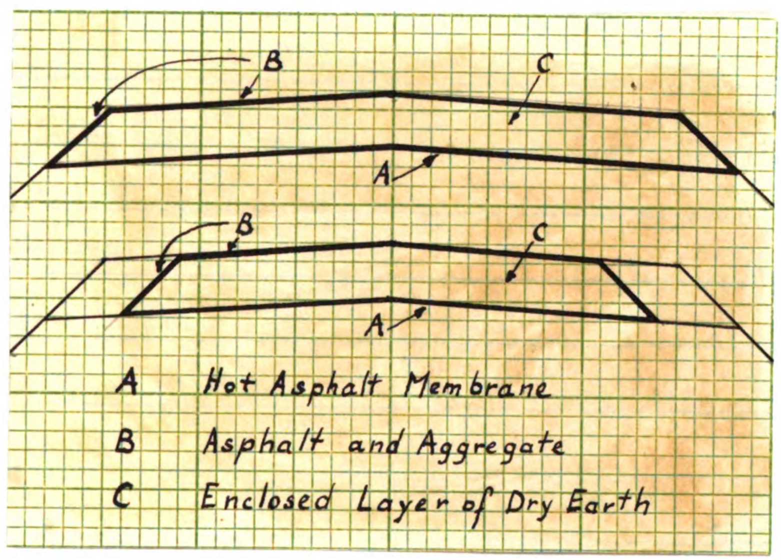

Fig. 10 Stabilization with Membrane

Subgrade Oiling

It is a treatment which consists of insulating the soil which will serve as a foundation from the base to be constructed. Comparing with sand subbase, oiling prevents water from percolating as well as rising by capillarity. In fact it is similar to an Oiled Earth Road taken as a foundation for a base course for new construction.

completely absorbed before another coat is applied, which can require from several hours to one or more days depending on weather conditions. Light application of clean sand or fine granules may be scattered on the surface but excess must be avoided.

When applications are completed, the surface is allowed to cure for 24 hours and then open to traffic.

Maintenance of Oiled Earth Roads usually takes place after each season's use. This consists of patching and of surface treatments after irregularities have been shaved.

Oil Quantity. The three applications of the initial treatment total 1 gallon per sq. yd. The first season's treatments 1/2 gal. per sq. yd. The second and following treatments 1/4 gal. per sq. yd.

Limitation. This method is not used where granular type soils are encountered but with silts, clays and silt-clay soils where local aggregates are not available. It is a low cost, semi-permanent improvement of earth roads.

Suboiling Method

This method is a variation of the Natural Soil-bitumen and Oiled Earth methods of construction in which a liquid bituminous material (oil or tar) is introduced into the soil by means of a special form of scarifier, called suboiler, having a small pipe attached to the back of each tooth. The treatment is applied when the soil is damp and the oil is diffused upward by capillary pressure. When the entire mass is permeated and bound together, the surface is leveled and compacted.

The quantity of bituminous material varies from 2 to 4 gal. per sq. yd. for a treatment of 4 to 6 in. depth.

SPECIFICATIONS OF BITUMINOUS MATERIALS USED IN CHAPTER 5

Tar

Grade Destination	RT-1	RT-2	RT-3	RT-4	RT-5	RT-6	RT-7	RT-8	RT-9	RT-10
Typical Uses*	Prime coat		Prime coat, carpet coat		Carpet coat, road-mix		Carpet coat, road-mix, plant mix, seal coat			Carpet coat, plant mix, seal coat, bituminous macadam, crack filler
CHARACTERISTICS										
Specific gravity, 25°/25° C	1.08+	1.08+	1.09+	1.09+	1.10+	1.10+	1.12+	1.14+	1.14+	1.15+
Specific viscosity, Engler										
At 40°C	5-8	8-13	13-22	22-35						
At 50°C	....	....	.....	.....	17-26	26-40	....	....	....	....
Float test, seconds										
At 32°C	....	....	.....	.....	.....	.....	50-80	80-120	120-200	
At 50°C	....	....	.....	.....	.....	.....	.....	......	....	75-100
Water, per cent, by volume	2.0-	2.0-	2.0-	2.0-	1.5-	1.5-	1.0-	0	0	0
Solubility in carbon disulfide, per cent	88+	88+	88+	88+	83+	83+	78+	78+	78+	75+
Total distillate, per cent, by weight										
To 170°C	7-	7-	7-	5-	5-	5-	3-	1-	1-	1-
To 200°C	....	....	.....	.....	.....	.....	.....	.....	.....	.....
To 235°C	....	....	.....	.....	.....	,,,..	.....	.....	.....	.....
To 270°C	35-	35-	30-	30-	25-	25-	20-	15-	15-	10-
To 300°C	45-	45-	40-	40-	35-	35-	30-	25-	25-	20-
Softening point of distillation residue, Ring and Ball, °C	35-60	35-60	35-60	35-60	35-65	35-65	35-65	35-65	35-65	40-70
Application temperatures*	60° - 125°F		80° - 150° F				150° - 225°F			175°-250°F

*For guidance of user; not a part of the specification.

SPECIFICATIONS OF BITUMINOUS MATERIALS USED IN CHAPTER 5

Cut-back Asphalt

Type of Product	Medium-Curing Products	Rapid-Curing Products		
Grade Designation	MC-0	RC-1	RC-2	RC-3
CHARACTERISTICS				
Water, per cent	None	None	None	None
Flash point, Cleveland open cup, °F	100+	....	80+	80+
Furol viscosity				
At 77°F	75-150	....	....	....
At 122°F	......	75-150	....	....
At 140°F	......	......	100-200	250-500
At 180°F	......	......	....	....
Per cent of total distillate to 680°F by volume				
To 374°F	......	10+	....	....
To 437°F	25-	50+	40+	25+
To 500°F	40-70	70+	65+	55+
To 600°F	75-93	88+	87+	83+
Residue from distillation to 680°F				
Per cent, by volume, by difference	50+	60+	67+	73+
Penetration at 77°F, 100 g., 5 sec	120-300	80-120	80-120	80-120
Ductility at 77°F	100+	100+	100+	100+
Solubility in carbon tetrachloride, per cent	99.5+	99.5+	99.5+	99.5+
Application temperature, °F	50-120	80-125	100-175	150-200

Note. If the penetration of the residue from distillation is more than 200 and its ductility at 77°F is less than 100, the material will be acceptable if its ductility at 60°F. is 100+.

SPECIFICATIONS OF BITUMINOUS MATERIALS USED IN CHAPTER 5

Emulsified Asphalt

Grade	1		2
Tests on Emulsion			
Furol Viscosity at 77 F	20/100		700 -
Residue by Distillation, %	55/60		60/65
Settlement, 5 days, %		3 -	
Demulsibility, 50 cc N/10 $CaCl_2$, %		1 -	
Sieve Test, Ret'd. on 20 Mesh, %		0.1 -	
Miscibility, 2 hr., %		Pass	
Cement Mixing, max. %		2 -	
Tests on Residue			
Penetration at 77 F., 100 g., 5 secs		100/200	
Soluble in CS_2 (Pet. Asp.) %		97.5 +	
Soluble in CS_2 (Nat. Asp.) %		95.0 +	
Ash		2 -	
Ductility at 77 F		40 +	
Temperature of Application, deg. F		60/140	

Note: Grade 1 is preferred when emulsified asphalt is to be spread with a distributor truck. Grade 2 may be diluted with water prior to application to reduce viscosity as required.

CHAPTER VI

SOIL-CEMENT STABILIZATION

Soil-Cement Road Stabilization is the name given to the method of road construction utilizing Portland cement to harden permanently the natural soil, and render it capable of developing sufficient resistance from the subgrade, to support the traffic load under all normal conditions of moisture and traffic.

Soil-cement must be considered as distinct from concrete. In concrete it appears that the aggregate is coated by the cement. In soil-cement, the cement is coated by the soil.

Soil-Cement Performance

In soil-cement stabilization cohesion is obtained by the binding power of cement only, and if the bounds are broken, it is definitive, cement cannot hydrate again. Soil-cement is porous and water can enter it. In soil-cement the particles are connected to one another by sorts of threads which are cement crystals.

If the voids are important the threads are thin and easily broken by the water allowed to enter. If the particles are close to one another, the threads are thicker, the amount of water entering is less, the mass being more cohesive resists better the detrimental action of water.

This demonstrates the utmost importance, greater than in any other stabilization method, of the pulverization of soil, compaction of the mixture and proper hydration of the cement. All three depend upon moisture content.

Easy pulverization is obtained at a moisture content between the Plastic Limit and the Shrinkage Limit.

Maximum compaction is obtained at optimum moisture content for the mixture.

Proper hydration requires special care after completion, to prevent evaporation of water.

Materials

Soils: The recommended grain size limits are

maximum size	3 inches
passing No. 4 sieve	$\geqslant$ 50 per cent
passing No. 40 sieve	15 to 100 per cent
passing No. 200 sieve	$\leqslant$ 50 per cent

The recommended limits of physical constants are

$$L. L. \leqslant 40$$

$$P. I. \leqslant 18$$

Soil material must be economically pulverized and free from injurious amount of organic matter.

Water: Must be clean, free from any injurious substances as salt, oil, acid, alkaly, organic matter, etc.

Cement: Is Portland cement Type I* sometimes Type II or Type III.

Material Requirements

The amount of water depends upon the moisture content required for easy pulverization, and upon the optimum moisture content necessary in order to obtain maximum effectiveness from the cement, and maximum compaction of the mixture.

The cement requirement varies, according to the soil used, from 6 to 20 per cent of the dry weight of soil.

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* See Table

Generally: A_2 soils[1] require 6 to 10 per cent

A_3, A_4, A_5 soils require 8 to 12 per cent

A_6, A_7 soils require 10 to 14 per cent

(A_1 and A_8 soils are not mentioned, A_1 being very rarely found in substantial amounts and A_8 being definitely unsuitable)

Practically: No cement contents less than 7 or more than 14 per cent are recommended. As an indication:

85 per cent of all soils require less than 14 per cent

50 per cent of all soils require less than 10 per cent

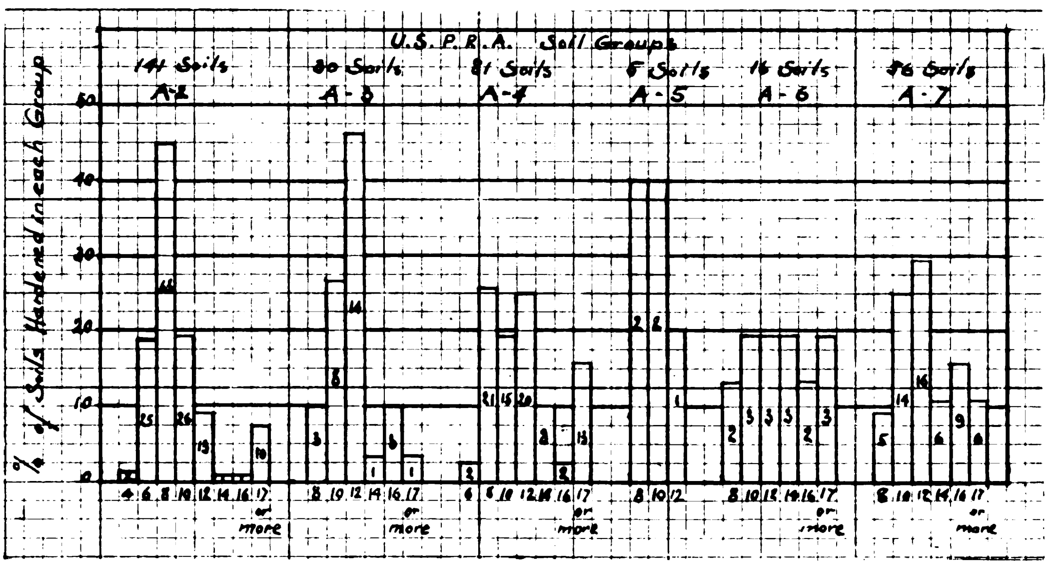

Chart 4. U.S.P.R.A. Soil Groups and Cement Contents for Adequate Hardening (Data from Portland Cement Association Soil-Cement Laboratory)

The extent to which the soil has been hardened by the action of cement is checked by means of two closely related tests: the Wet-Dry Cycle Test, and the Freeze-Thaw Cycle Test. For the Wet-Dry Cycle Test specimens are, according to standard procedure, wetted and dryed. Then the exfoliated

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(1) P.R.A.C.

materials are brushed with a wire brush, the whole operation constituting one cycle. The test is carried out for 12 cycles. For the Freeze-Thaw Cycle specimens are, according to standard procedure, frozen, then allowed to thaw and brushed at the end of the cycle. The test is also carried out for 12 cycles.

During the Tests:

1. In no case must the sample absorb a volume of water greater than the pore spaces.

2. The maximum volume must not be greater than 2 per cent over the volume at time of molding.

3. Total material losses are calculated and must not exceed the following maximum for either of the two tests:

A_2 and A_3 soils	not over	14 per cent
A_4 and A_5 soils	not over	10 per cent
A_6 and A_7 soils	not over	7 per cent

4. Strengths of soil-cement specimens tested in compression at various ages after 1 to 4 hours soaking in water must increase with age and with increases in cement in the range of cement content complying with the preceding requirements.

Construction Equipment

Equipment is the same as described in Chapter III. Additional Equipment: Rotary Tillers or Rotary Speed Mixers are used for pulverizing and mixing. Cement Hauling Trucks and Cement Spreaders take care of the handling of cement. Single-Pass Stabilizers specially adapted to soil cement perform mixing operation and leave the materials in windrows or in a uniform layer ready to be compacted.

Construction Procedure

Soil-cement bases are built with a 6 inch maximum depth. When greater thickness is needed, multi layers must be used.

Grade Preparation and Pulverization

The roadway must first be bladed and shaped to the desired final crown. Then the soil is loosened to 5.5 inches in depth (for a 6 inch base thickness). The remaining half inch being loosened during the pulverization and mixing operations.

It is pulverized until at least 80 per cent, exclusive of stone and gravel, pass a No. 4 sieve. Control of moisture content and careful checks of the depth are very important.

Spreading Cement. Cement can be spotted by hand or by mechanical spreaders. In the first case spreading is accomplished by repeated trips of a spike tooth harrow.

Mixing Operations. Can be accomplished by mixed in place or plant mix (traveling or stationary) methods.

Mixed in place - The most efficient procedure is to use a train processing system, as illustrated in figure 11.

Dry mix - This is accomplished by cultivators and rotary tillers.

Moist mix - This is accomplished by means of all the mixing tools. The moisture content is gradually brought a little above the optimum, by sprinkling water with distributor tanks. Uniformity and depth of the moisture must be carefully checked.

Plant mix - Stationary or traveling plants can perform mixing operations including dosage of cement and water. Pulverization and compaction are performed in the same manner and with the same equipment as in the mixed in place method.

SOIL-CEMENT "TRAIN" PROCESSING

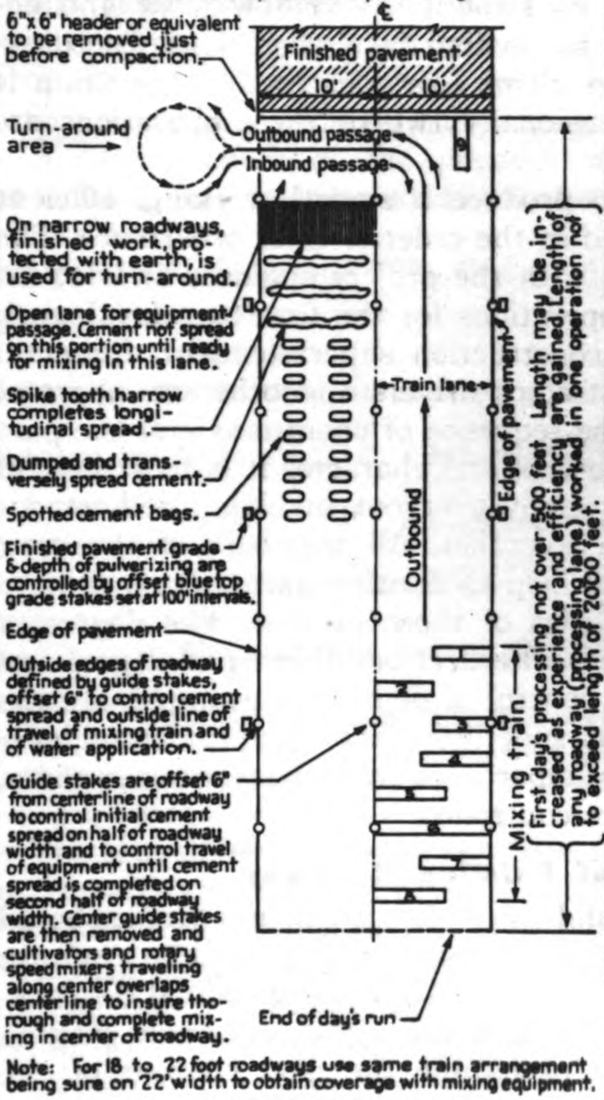
For 20' Roadway
Two train lanes, each 10' wide

Preparation of Roadway for Processing

First, the roadway section is graded to line and grade required in completed section. All such grading must be completed before pulverizing and processing operations start.

Outside edges of roadway to be pulverized are defined with guide stakes in the same manner as for processing. A short section is then loosened and pulverized to 5½" depth with road rooter, scarifier on motor grader, disc harrows, rotary speed mixers, springtooth cultivators, gang plows, etc., as needed. Should soil be dry and hard, it may be made mellow for rapid pulverizing by repeated water applications which are permitted to soak into the soil. After soil characteristics are learned pulverizing may be completed on some soils as part of mixing operations after cement is added.

Usually on the day before cement is spread, sufficient water is applied on section to be processed and partially mixed in so that 3 to 6 water applications per 10' width during processing operations will fulfill water requirements. The section is then leveled for cement spread and processing.



Note: For 18 to 22 foot roadways use same train arrangement being sure on 22' width to obtain coverage with mixing equipment.

Mixing Train Units

Unit No.	No. Req'd	Width	Description of Unit	Motive Power
1	1	4'-8"	Gang plow, Heavy duty, 4-14 inch bottoms (Omit coulters)	Tractor, Crawler type, Min. 35 D.B.H.P.
2	1	4'-8"	Gang plow, Heavy duty, 4-14 inch bottoms (Omit coulters)	Tractor, Crawler type, Min. 35 D.B.H.P.
3	1	12'	Motor grader 12' moldboard	Self-powered
4(1)	1	8'	Cultivator, Heavy duty, springtooth, 12" spacing. Fitted with 4" double pointed chisels.	Tractor, Crawler type, Min. 35 D.B.H.P.
5	1	8'	Cultivator, Heavy duty, springtooth, 12" spacing. Fitted with 4" double pointed chisels.	Tractor, Crawler type, Min. 35 D.B.H.P.
6(2)	2	10'	Pressure distributor, 1000 gallons capacity	Self-powered
7(1)	1	6'	Rotary speed mixer, Self-powered, trailer mounted	Tractor, Crawler type, Min. 35 D.B.H.P.
8	1	6'	Rotary speed mixer, Self-powered, trailer mounted	Tractor, Crawler type, Min. 35 D.B.H.P.
9(1)			Cultivator-Unit No. 4 or Rotary speed mixer-Unit No. 7	

Routing of Mixing Trains

First round trip (See sketch) - Use Cultivators (Units 4 and 5) and Rotary Speed Mixers (Units 7 and 8) only. These machines, otherwise, to maintain same relative position each passage.

Second round trip. Add Plows (Units 1 and 2) and distributor (Unit 6). Use entire train as shown. All machines to maintain same relative positions. Generally desirable to add about ⅛ of required water on outbound and ¼ on inbound passages. On outbound passage, Motor Grader (Unit 3) will define pavement edge line by cutting V-shaped trench to depth of subgrade; and on inbound passage to blade in any loose cement wasted outside the edge line. This unit to be used on outer edges only -- Not along center line.

Intermediate round trip or trips - If, at this stage it is determined that remaining water requirements cannot be supplied in one final round trip, remove Plows (Units 1 and 2) and Rotary Speed Mixers (Units 7 and 8) and make intermediate round trip or trips with Distributor (Unit 6) followed immediately by Cultivators only (Units 4 and 5) until deficiency is supplied.

Final round trip - Use entire train as shown. Add remaining water requirements. On outbound passage, Motor Grader (Unit 3) will blade in any loose soil-cement wasted outside the edge line and on inbound passage will define edge by cutting V-shaped trench to depth of subgrade. Mixing train then moves to next train lane. Sheepsfoot Roller compaction train and finishing operations follow. There should be no traffic intervening.

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(1) Unit 9 - Cultivator (Unit 4) or Rotary Speed Mixer (Unit 7) concentrate for short periods on cross mixing adjacent to previous day's run. Hand shovelers supplement mixing adjacent to headers to keep ends even, to remove any raw soil and return mixed soil-cement to section.

(2) When necessary, second distributor (Filled) should be available to replace (Unit 6) on inbound passage. Spray bars should be of the full width of train lane. On long water hauls additional distributor or water supply trucks may be needed.

Substitutions

It is inevitable that units of equipment available will vary with different jobs. However, it is recommended that even though substitutions or omissions are necessary, the pattern of the train and order of its movements be followed as closely as possible.

Portland Cement Association, Chicago 10, Illinois, February 1946 - SCX-12

Figure II

Compaction and Finishing Operations. The mixture is compacted by Sheepsfoot rollers until the feet of the roller penetrate about one inch. The surface is then leveled by the spike tooth harrow, and, constantly shaped to the grade and kept to adequate moisture content. Finally the spike tooth harrow is replaced by nail drags and broom drags, and Sheepsfoot rollers by pneumatic or smooth wheel rollers. Compaction is continued until density is at least 95 per cent of the Proctor density.

Soil cement surfaces are friable and after curing a wearing course is provided to protect the base.

Curing. Although a bituminous prime can be applied immediately after final rolling, the soil-cement is allowed to cure for seven days with a protective cover of hay, straw, moist earth or waterproofed paper to prevent evaporation.

Prime. The surface is cleaned with rotary broom and blower, and a bituminous prime is applied. Materials used are:*

Tars	RT - 2, 3
Cutbacks	RC - 1, 2

The quantity varies from 0.15 to 0.25 gal. per sq. yd.

After a minimum of 24 hours, the excess prime is blotted up with sand.

Bituminous Surface. Then a 1/2 inch to 2 inch bituminous pavement is generally applied on the completed base.

Limitations

Besides the usual soil investigation tests, determination of the proportions of the soil-cement mixture requires tests which last at least one month (likely longer). During the construction itself the weather must be such that operations can be carried out without too many interruptions.

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* See Table of Chapter V

Once constructed, soil-cement bases are very satisfactory on sound subgrades for light traffic under all normal weather conditions and have occasionally been submitted to heavier traffic. However, this implies the risk of the permanent destruction of the structure.

TABLE OF PHYSICAL REQUIREMENTS OF CEMENTS

	Type I	Type II	Type III
Fineness, specific surface, sq. cm. per g.:			
Average value, min.	1600	1700	....
Minimum value, any one sample	1500	1600	....
Soundness:			
Autoclave expansion, max., per cent	0.50	0.50	0.50
Time of setting (alternate methods):			
Gillmore test:			
Initial set, min., not less than	60	60	60
Final set, hr., not more than	10	10	10
Vicat test:			
Initial set, min., not less than	45	45	45
Final set, hr., not more than	10	10	10
Tensile strength, psi.:			
The average tensile strength of not less than three standard mortar briquets, prepared in accordance with Method T 1, shall be equal to or higher than the values specified for the ages indicated below:			
1 day in moist air	....	....	275
1 day in moist air, 2 days in water	150	125	375
1 day in moist air, 6 days in water	275	250	...
1 day in moist air, 27 days in water	350	325	...
Compressive strength, psi.:			
The average compressive strength of not less than three mortar cubes, prepared in accordance with Method T 106, shall be equal to or higher than the values specified for the ages indicated below:			
1 day in moist air	....	....	1300
1 day in moist air, 2 days in water	1000	750	3000
1 day in moist air, 6 days in water	2000	1500	....
1 day in moist air, 27 days in water	3000	3000	....

CHAPTER VII

THERMIC STABILIZATION

Thermic Stabilization is the title given to the method of road construction in which a soil, which in its natural state cannot be utilized as road material without admixture, is transformed by a heat treatment, to provide an all weathered base course.

Material

This process may utilize soils deficient in coarse elements. Soils having high clay content are particularly suitable.(1) The intense heat partially fuses the soil which agglomerates in coarse fractions, looses all its plastic properties and derives an aggregate already in place to which fractions of the original soil are added to provide a good gradation.

Construction Equipment

Consists of the standard equipment performing the operation of mixing, shaping and compaction and of a highly specialized piece of equipment. Although other systems could be devised, reference will be made to the type of machine having been used so far.(2) It is a traveling brick-kiln. It consists of a furnace sending burning gases under pressure into the soil and thus producing its fusion, and in front a scarifying attachment. Its progress under operating conditions is from 30 to 80 ft. per hour.

Construction Procedure

The treatment is generally applied to earth roads proving unsatisfactory under wet weather conditions. The traveling machine scarifies the road surface and melts the soil to a depth varying from 2 to 4 inches with the nature of the soil, the heat produced and the duration of exposition (controlled by the speed of travel). It has been found economical to treat the soil in one

(1) No data are thought to be available in either P.R.A. or H.R.R. Classifications.
(2) Irvine Road Machine

or two layers 3 inches thick according to subgrade condition and anticipated traffic. The treated width is 6 ft.

After treatment, the loose brick like material is composed of coarse particles of various sizes, which will constitute the aggregate of the final mixture. The fine fraction is provided by the natural soil which, consists principally of clay acting as a binder. The soil is spread from the shoulders on the roadway and thoroughly mixed with aggregate, then shaped and compacted as in other methods.

Seal Coat

Since the finished surface is somewhat porous due to the composition of the aggregate, a light bituminous treatment can be applied in penetration, in order to waterproof the road structure.

Limitation

The heat treatment is very successful in areas where the soil consists primarily of clay, without nearby sources of aggregate and where cement and bituminous materials are too expensive to be used for secondary roads. (These conditions occur in Australia, Indo-China and Africa).

In comparison to other methods Thermic Stabilization requires a highly specialized equipment, but with a construction program large enough, the process is advantageous in the long run, the initial cost being compensated by the low exploitation cost.

Although the penetration of gases is rather limited, the effect of the heat tends to improve in depth the subgrade properties. It is probable that the treatment lowers capillarity and increases porosity of the material. Subgrade characteristics must be known before any attempt is made to superficially stabilize the soil.

Heat treated surfaces have withstood heavy traffic under all weather conditions and have been subjected to flood condition with only slight damage.

CONCLUSION

In establishing a network of low and/or intermediate type roads, decisions of methods to be adopted are based on data concerning two aspects of the problem: the economical one and the technical one; these are so closely related that they cannot normally be segregated.

These data are: condition of the subgrade, climate, material locally available (soil, aggregate and other admixtures), currently practiced techniques, relative costs (initial and maintenance), and life expectancy with respect to climate and anticipated traffic, in the scope of long range planning studies. It may be necessary to treat the subgrade or insulate it. Many times it is feasible and more economical to increase the base course thickness. The base course thickness is dependent on the method adopted and materials utilized which can be the most efficiently placed with an optimum thickness. The following table presents an indication of the thickness for various layers composing the road structure based on the soils encountered.

Soil Group Classification	A-1-b	A-1-a	A-2-a	A-2-b	A-3	A-4 A-4-7	A-5 A-5-7	A-6	A-7
Depth of:									
Wearing Course -in.	2	2	2	2	2	2	2	2	2
Base Course - in.	0	5	5	6	5	8	8	8	8
Subbase Course -in.	0	0-12	0	0-12	0	2-14	4-14	0-14	0-14
Total Thickness - in.	2	7-19	7	8-20	7	12-24	14-24	10-24	10-24

Recommended Thickness of Pavement Courses for
10,000-Lb. Wheel Loads (Ref. 63 p.9)

Climate has a direct influence on the road features and fixes the extent to which surface and ground drainage and waterproofing should be emphasized.

The methods to be employed depend also on the duration of the construction period.

Aside from the texture and physical properties, the chemical composition of the soil, and more particularly of clays and colloids, is very important. This is responsible for the floculated or defloculated state of the fine material, the efficiency of Portland cement, the water and bitumen affinity, and directly influences the proportion of admixture. Bacterial activity also may modify the soil behavior.

Where several methods of soil stabilization may be suitable, the economical factor will decide which one to adopt. Soil-bitumen stabilization is indicated in certain countries producing and refining oil, but having no native cement. Soil-cement will be preferred in others which are producing cement but would have to import bituminous products. Others lacking both cement and bituminous materials may employ thermic stabilization and find it to be more economical where extensive projects are involved.

This brings up the question of skill of local contractors, highway engineers, and the availability of equipment. In effect, engineering personnel can be trained and new equipment procured only if projects to be carried out are on a large enough scale to warrent the efforts and money invested.

Such techniques have been developed in order to utilize local material or by products whose physical or chemical properties improve the natural soil. Examples of these materials are:

(a) Gravel found in natural deposits and used in surfacing earth roads constitute the gravel roads.

(b) Crushed stones, especially limestone, trap, chert. Soft lime in particular has been used extensively.

(c) Iron ore and blast furnace slag

(d) Shell and coral

(e) Scoria

(f) Sugar-cane molasses (India)

(g) Euphorbia latex (A.O.F.)

All of the above materials have been used, modifying chemical exchanges in the soil and/or giving an additional binding power. Other materials may be tried and new techniques developed in the future.

Finally such decision should be taken in the scope of long-range planning, including studies on: probable development, anticipated traffic, and more generally future transportation problems of the particular location. Therefore it is seen that the life expectancy of the road is another important factor. One road will have to be relocated and hard surfaced because of the large volume of induced traffic, and the new pavement will be placed on practically a new structure. Another will only need a higher type surfacing as a wearing course and will utilize entirely the existing structure.

Since these are the first steps in a stage construction which, after having induced a traffic volume parallely follows its development, low intermediate types of roads built by the soil-stabilization methods are well adapted to actual needs and are, as railroads have been in the last century, of an utmost importance in agricultural promotion as well as in industrial development of a country.

APPENDIX I

Tests and Test Methods with References, for Mechanical and Chemical Stabilization

Test	Reference
1. Method of surveying and sampling soils	A.S.T.M. Standard D 420-45
2. Preparation of samples for Mechanical Analysis and Determination of Subgrade Soil Constant	A.S.T.M. Standard D 421-39
3. Sieve Analysis	A.S.T.M. Standard C 136-46
4. Mechanical Analysis (hydrometer and sieve)	A.S.T.M. Standard D 422-39
5. Liquid Limit	A.S.T.M. Standard D 423-39
6. Plastic Limit and Plasticity Index	A.S.T.M. Standard D 424-39
7. Specific Gravity	A.S.T.M. Standard D 854-45T
8. Centrifuge Moisture Equivalent	A.S.T.M. Standard D 425-39
9. Field Moisture Equivalent	A.S.T.M. Standard D 426-39
10. Shrinkage Limit	A.S.T.M. Standard D 427-39
11. Capillarity	H.R.B. Current Road Problem No. 8 Appendix 2
12. Permeability	H.R.B. Current Road Problem No. 8 Appendix 3
13. Moisture Density	A.S.T.M. Standard: D 698-42T
14. California Bearing Ratio	A.S.T.M. Technical Publications June 1947
15. Plate Bearing	A.S.T.M. Technical Publications June 1947
16. Cone Bearing	A.S.T.M. Technical Publications June 1947

APPENDIX I (Cont'd.)

Test	Reference
17. Triaxial Compression	A.S.T.M. Technical Publications June 1947
18. Volume Changes	A.S.T.M. Standard C 157-43
19. Consolidation	H.R.B. Proceeding, Volume 18 (1938) p. 371

APPENDIX II

Tests and Test Methods with References, for Soil-Bitumen Stabilization

Test	Reference
1. Same as those used for Mechanical and Chemical Stabilization in addition:	Appendix I
2. Method of Test for the Determination of Suitable Proportion of Soil Asphalts or Soil-Aggregate Asphalt Mixtures	A.S.T.M. Technical Publication Sept. 1944
3. Field Procedure for the Design of Cut-back Asphalt-Soil Mixtures	A.S.T.M. Technical Publication Sept. 1944
4. Method of Test for Asphalt Soil Stabilization Design	A.S.T.M. Technical Publication Sept. 1944
5. Method of Test for the Determination of Suitable Proportions of Soil-Asphalt or Soil-Aggregate-Asphalt Mixtures	A.S.T.M. Technical Publication Sept. 1944
6. Method of Test for Stabilization of Soils with Bituminous Materials	A.S.T.M. Technical Publication Sept. 1944
7. A Combined Test for Determining the Volume Change and Loss of Stability in Bituminous-Soil Mixtures in the Presence of Water	A.S.T.M. Technical Publication Sept. 1944
8. Method of Test for Stability of Mixtures of Soils and Liquid Asphaltic Products	A.S.T.M. Technical Publication Sept. 1944
9. Method of Test for Determining the Modified Bearing Value of Soil-Bituminous Mixtures	A.S.T.M. Technical Publication Sept. 1944

APPENDIX II (Cont'd.)

Test	Reference
10. Method of Test for the Determination of the Quantity of Cut-back Asphalt for Stabilizing Sandy Soils	A.S.T.M. Technical Publication Sept. 1944
11. Method of Making Bearing Value Tests on Soils for use in Sand-Bituminous Road Mix	A.S.T.M. Technical Publication Sept. 1944
12. Method of Test for Water Absorption, Volume Change and Stability of Mixtures of Soil and Tar	A.S.T.M. Technical Publication Sept. 1944
13. Procedures for Evaluating Tar-Soil Mixtures	A.S.T.M. Technical Publication Sept. 1944
14. Method of Test for Soil-Bitumen Mixtures by Means of the Free Rubber Closed System Stabilometer	A.S.T.M. Technical Publication Sept. 1944
15. Method for Testing Soil-Bituminous Mixtures by Means of the Hveem Stabilometer	A.S.T.M. Technical Publication Sept. 1944
16. Water Absorption and Resistance to Plastic Flow of Soil and Emulsified Asphalt Mixtures	A.S.T.M. Technical Publication Sept. 1944
17. Modification of the Florida Bearing Value Test	A.S.T.M. Technical Publication Sept. 1944

A tentative test is proposed by the Bituminous Producers Cooperative Research Committee, to Standardize the various procedures actually in use.

18. Proposed Method of Test for the Determination of Absorption, Expansion and Strength Characteristics of Soil-Bituminous Mixtures	H.R.B. Current Road Problems No. 12 Appendix B

APPENDIX III

Tests and Test Methods with References, for Soil-Cement Stabilization

Test	Reference
1. Same as those used for Mechanical and Chemical Stabilization in addition:	Appendix I
2. Moisture Density Relations of Soil-Cement Mixtures	A.S.T.M. Standard D 558-48
3. Wetting and Drying	A.S.T.M. Standard D 559-48
4. Freezing and Thawing	A.S.T.M. Standard D 560-48
5. Cement Content of Soil-Cement Mixtures	A.S.T.M. Standard D 806-44T

BIBLIOGRAPHY

Chapter I Soils

1. Dent, George H., "Maryland's Mobile Soils Laboratory", Highway Research Board Proceedings, Volume 19 (1939)

2. Feld, Jacob, "General Engineering Approach to the Classification and Identification of Soils", Highway Research Board Proceedings, Volume 28 (1948)

3. Highway Research Board, "The Formation, Distribution and Engineering Characteristics of Soil", Research Series No. 87 (1943)

4. Hogentogler, C. A. and Others, "Subgrade Soil Constants, Their Significance and Their Application in Practice", Public Roads, Volume 12 (1931)

5. Housel, W. S., "Laboratory Manual of Soil Testing Procedures", University of Michigan (1946)

6. Taylor, D. W., "Fundamentals of Soil Mechanics", John Wiley and Son, Inc. 1948.

7. Terzaghi, Karl and Peck, Ralph, "Soil Mechanics in Engineering Practice", John Wiley and Son, Inc.(1948)

8. Woods, K. B., "Soil Mechanics in Highway Construction", Civil Engineering, Volume 7, No. 1 (1937)

Chapter II Road

9. American Society of Civil Engineers, "Principles Applying to Highway Roadbeds", Transaction, Volume 104 (1930)

10. Baker, R. F., "Investigation of Field and Laboratory Methods for Evaluating Subgrade Support in the Design of Highway Flexible Pavements", Highway Research Board Proceedings, Volume 28 (1948)

11. Casagrande, A. and Stanton, T. E., "Road Foundation Practice", Engineering News-Record, Volume 118, No. 1 (1937)

12. Harold, Allen, "Compaction of Embankments, Subgrade Treatments and Soil Stabilization", Highway Research Board Proceedings, Volume 18, Part I (1938)

13. Irzard, Carl, F., "Report of Committee on Surface Drainage", Highway Research Abstracts, Volume 19, No. 3 (1949 March)

14. Muri, Levi, "Present Practice in Drainage on Highways," Highway Research Board Proceedings, Volume 22 (1942)

15. Spangler, M. G., "Some Problems in Subgrade Moisture Control", Highway Research Board Proceedings, Volume 25 (1945)

16. Steele, D. J., "Application of the Classifications and Group Index in Estimating Desirable Subbase and Total Pavement Thickness", Highway Research Board Proceeding, Volume 25 (1945)

17. Woods, K. B., "Report of Committee on Frost Heave and Frost Action in Soil", Highway Research Board, Bulletin, No. 14 (Oct. 1948)

Chapter III Mechanical Stabilization

18. Aaron, Henry, "Stabilization Control on the Washington Airport", Highway Research Board Proceeding, Volume 21, (1941)

19. Bonnenfant, "Les Sols Stabilizes an Beton d'Argile", Revue Generale des Routes, No. 197 (June 1948)

20. Caupen, W. H. and Smith, J. R., "The Behavior of Densified Soil Water Mixtures Under very Adverse Water Conditions", Highway Research Board Proceedings, Volume 23 (1943)

21. Downey, B. R., "Soil Control in Consolidated Maintenance", Highway Research Board Proceedings, Volume 21 (1941)

22. Highway Research Board, "Compaction of Subgrades and Embankments", Bulletin No. 11 (1945)

23. Highway Research Board, "Granular Stabilized Roads," Bulletin No. 5

24. Nikirk, F. A., "Report of Subcommittee No. 2 on Soil Compaction", American Road Builders' Association Proceedings (1941)

25. Stanton, T. E., "Report of Subcommittee No. 1 on Soil Compaction", American Road Builders' Association Proceedings (1941)

26. Willis, G. A., "Report of Subcommittee on Design of Natural Soil Mixtures and Effect of Admixtures of Commercial Products Such as Crushed Stones, Gravel and Slag", Highway Research Board Proceedings, Volume 21 (1941)

27. Winterkorn, H. F., "Fundamental Approach to the Stabilization of Cohesive Soil", Highway Research Board Proceedings, Volume 28 (1948)

28. Wooltorton, F. L. D., "Relation Between the Plastic Index and the Percentage of Fines in Granular Soils Stabilization", Highway Research Board Proceedings, Volume 27 (1947)

29. Zeigler, E. J., "Effect of Material retained on the No. 4 Sieve on the Compaction Test of Soil", Highway Research Board Proceedings, Volume 28 (1948)

30. "Regles d'emploi des Betons d'Argile, Travaux"(June 1945)

Chapter IV Chemical Stabilization

31. American Road Builders' Association, "Report of Committee on $CaCl_2$ Soil Stabilization", Technical Bulletin No. 127 (1948)

32. American Road Builders' Association, "Report of Committee on $CaCl_2$ Soil Stabilization", Technical Bulletin No. 154 (1949)

33. Calcium Chloride Association, "Soil-Aggregate Stabilization and the Use of $CaCl_2$ ", Bulletin No. 26 (1942)

34. Calcium Chloride Association, "Surface Consolidation and Maintenance with $CaCl_2$", Bulletin No. 29 (1946)

35. Highway Research Board, "Economics of Stabilization with $CaCl_2$", Proceedings Volume 19 (1939)

36. Highway Research Board, "Measurement of Wear on Gravel Roads", Proceedings Volume 18, Part I (1938)

37. Highway Research Board, "Use of $CaCl_2$ in Soil Stabilization", Proceedings Volume 18, Part II (1938)

Chapter V Bituminous Stabilization

38. Asphalt Institute, "Asphalt Handbook"

39. Asphalt Institute, "Flexible Pavements", Information Series No. 36 (April 1940)

40. Asphalt Institute, "Required Thickness of Asphalt Pavement", Research Series No. 8 (May 1941)

41. Asphalt Institute, "Soil Stabilization with Asphalt", Construction Series No. 40 (Aug. 1938)

42. Griffith, J. M., "Selection of Test Equipment Synopsium on Asphalt Paving Mixtures, " Highway Research Board Report No. 7B (June 1949)

43. Highway Research Board, "Factors Involved in Stabilizing Soils with Asphaltic Materials", Proceedings, Volume 23 (1943)

44. Highway Research Board, "Soil-Bituminous Roads", Current Road Problems No. 12 (Sept. 1946)

Chapter VI Soil-Cement Stabilization

45. American Road Builders' Association, "Committee Report on Soil-Cement Stabilization", Technical Bulletin No. 137 (1948)

46. Highway Research Board, "Prevention of Moisture Loss in Soil-Cement with Bituminous Material", Research Report No. 8-F (Sept. 1949)

47. Highway Research Board, "The Unconfined Compressive Strength of Soil-Cement Mixtures", Proceeding Volume 21 (1941)

48. Portland Cement Association, "Soil-Cement Mixtures", Laboratory Handbook

49. Portland Cement Association, "Soil-Cement Roads", Construction Handbook

Chapter VII Thermic Stabilization

50. Commissioner of Main Roads, "Fifteenth Annual Report", Queensland, Australia, June 1936

51. Commissioner of Main Roads, "Sixteenth Annual Report", Queensland, Australia, June 1937

52. St. Clements Press, Ltd., "The Irvine Road Machine", London, England

Recommended Bibliography

53. American Association of State Highway Officials, "Manual of Highway Construction Practices and Methods" (1950)

54. Other Publications of the American Association of State Highway Officials.

55. American Road Builders' Association, "Developments in Soil Stabilization" Proceedings (1938)

56. Publications of the American Society of Civil Engineers.

57. Other Publications of the American Road Builders' Association

58. American Society for Testing Materials, Standards

59. Bateman, "Highway Engineering", John Wiley and Sons

60. Bruce and Clarkeson, "Highway Design and Construction", International Textbook Company (1950)

61. Crawford, C. J., "Highway Planning in a Rural State", Highway Research Board, Bulletin No. 17 (Dec. 1948)

62. Farrell, Fred, B. and Paterick, Henry R., "Life Characteristics of Highway Surfaces", Highway Research Board Proceedings, Volume 28 (1948)

63. Highway Research Board, "Thickness of Flexible Pavements for Highway Loads", Bulletin No. 8 (1945)

64. Other Publications, Proceedings and Bulletins of the Highway Research Board

65. Hogentogler, C. A. and Willis, E. A., "Essential Considerations in the Stabilization of Soils", Transactions, American Society of Civil Engineers, Volume 103 (1938)

66. "International Conference of Soil Mechanics", Proceedings, 1947

67. Johnson, A. Morgan, "Laboratory Experiments with Lime-Soil Mixtures", Highway Research Board Proceedings, Volume 28 (1948)

68. Kennedy, G. Donald, "Current Long Range Studies of Highway Modernization Program", Highway Research Board, Bulletin No. 12 (Aug. 1948)

69. Shaw, H. B., "The Economy of Highway Improvements", Highway Research Board Proceedings, Volume 13 (1933)