MICHIGAN
STATE HIGHWAY DEPARTMENT
G. Donald Kennedy
State Highway Commissioner

GRAYLING CEMENT AND BITUMINOUS SOIL STABILIZATION PROJECTS

By

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Research Project 36 E-5 (1)

Research Laboratory
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CONTENTS

PREFACE

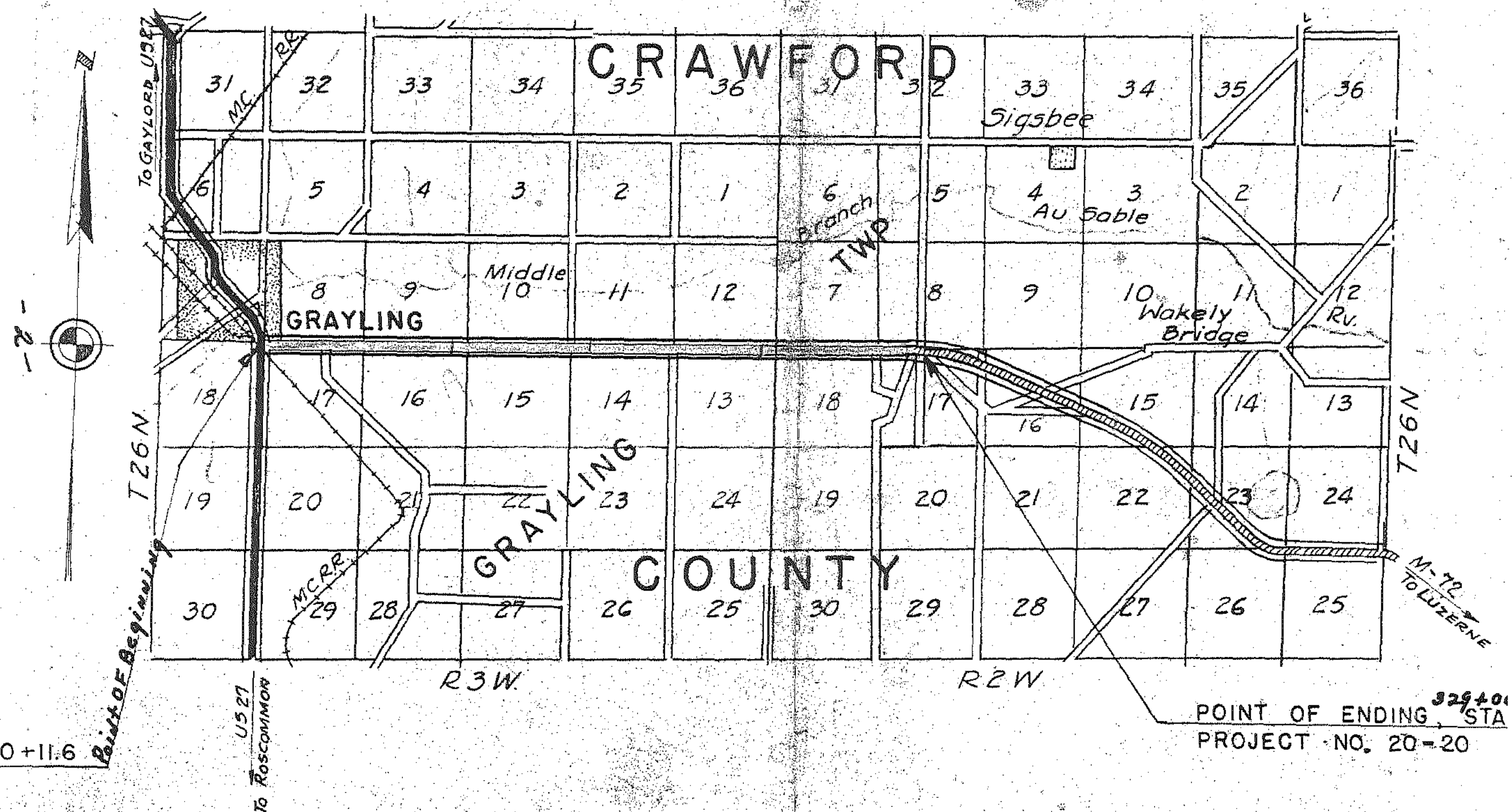
This report presents a complete account of the design and construction of an experimental soil stabilized project using the existing road way material, suitable fines, Portland cement and bituminous materials to produce a low-cost, light traffic road surface.

The report includes the important factual data relevant to the project, such as description, purpose and scope of the project, cost, preliminary laboratory studies, construction procedure, condition survey and conclusions.

The project is 6.229 miles in length, located on M-72, from US-27 Grayling east and designated as state project M 20-20, C2. The project consists of 1.572 miles of soil-cement construction and 4.657 miles of sand-bituminous stabilization.

The project was constructed under regular contract and construction procedure using the Michigan State Highway Department's 1940 specifications with necessary supplementals. The contract was awarded to A. W. Hodgkiss, of Petoskey, Michigan. The processing work started August 29, 1941 and was completed October 15, 1941.

The Grayling project was constructed concurrently with the Stockbridge soil-cement stabilization project which has been discussed separately in another report entitled "Construction of Experimental Soil-Cement Stabilization Road Surface", Stockbridge, Michigan, dated April 1942.



CRAWFORD COUNTY
GRAYLING TWP
GRAYLING
Sigsbee
Au Sable
Middle Branch
Wakely Bridge
Rv.
MC RR
M.C.R.R.
To GAYLORD US27
US27 To ROSCOMMON
M-72 To LUZERNE
T26N
T26N
R3W.
R2W
0+11.6 Point of Beginning
POINT OF ENDING, STA 329+0
PROJECT NO. 20-20

PROJECT STATISTICS

Construction Project No. - M 20-20, C2

Location - On M-72 from Grayling east

Length - 6.229 miles

Width - 22 feet

Surface - Soil-cement and bituminous stabilization

Bids opened - June 18, 1941

Contract awarded - July 7, 1941

Contractor - A. W. Hodgkiss, Petoskey, Michigan

Started grading - July 4, 1941

Started soil-cement processing - August 1, 1941

Started bituminous processing - August 25, 1941

Completed processing - October 15, 1941

Total cost of processing surface -	$49,132.66
Cost of surface treatment -	5,974.02
Cost of grading and other operations	36,181.56
Total cost of project -	$91,288.24
Engineers Estimate	68,299.87
Amount over and above estimate	$22,988.37

COST DATA SUMMARY

Type Stabilization	Sta. to Sta.	Stations	Total Sq. Yds.	Total Cost	COST per sq.yd. cents	Surface Treatment per sq.yd. cents	Total Cost per sq.yd. cents
AE-7	-1.88 to 80+00	81.88	20,015	$13,258.91	.6624	.1474	.8098
T-3	80+00 to 86+00	6.00	1,467	957.75	.6528	---	- -
RC-2	86+00 to 163+00	77.00	18,822	11,677.78	.6204	- -	- -
MC-2	163+00 to 246+00	83.00	20,289	10,818.23	.5332	- -	- -
Soil-Cement	246+00 to 329+00	83.90	20,509	12,419.99	.6056	.1474	.7530

INTRODUCTION

Road stabilization is the process of giving natural soils enough abrasive resistance and shear strength to accomodate traffic or loads under prevalent weather conditions, without detrimental deformation. The methods employed include the use of admixtures, compaction and densification by specific technical theory and laboratory control. Optimum water content is fundamental with gradation. Admixtures may be soil materials, deliquescent chemicals, solutions of electrolytes, soluble cementitious chemicals, primes and neutralizers, and insoluble binders.

In the north central part of the lower peninsula, of the state of Michigan, there are approximately three million acres of a type of soil which has been classified by soil engineers as Grayling sand. In addition to this type of soil, there are many other related types of soil which are so closely similar that they also present a vast field for stabilization incidental to sub-base and surface construction on the secondary road system. Therefore, it is important for the Michigan State Highway Department to know how to stabilize these sand soils and what admixtures to employ.

The Grayling experimental project was constructed to determine the feasibility of stabilizing the existing sand road surface with different types of stabilizing admixtures and to develop specifications for the use of the Michigan State Highway Department in constructing such types of roads.

The soil material throughout the project was quite uniform and consisted of practically all new material obtained from grading operations adjacent to the roadway or from local borrow pits. The soil was not mechanically stable in itself, therefore, quantities of silt and mineral filler were added in predetermined amounts to give the desired stability before incorporating the binders.

Four different types of binders were specified and used for comparative study. They are as follows: Portland cement; medium curing road oil, MC-2; Rapid curing cut back material, RC-2; road tar, T-3 and bituminous emulsion, AE-7.

The Portland cement section and the bituminous emulsion section were surface treated, shortly after completion of the project, with a double seal surface treatment to preserve the surface. The other sections were left unsealed in order that continued curing of the bituminous binder could take place.

Limestone dust mineral filler was originally specified throughout the project to provide for deficiency in fines. A deposit of silt was found locally during the construction of the project and this material was eventually substituted for the limestone dust.

Some difficulty was experienced by the contractor on the bituminous section because of adverse weather conditions. This was to be expected because weather conditions in late September and October are not ideal for this type of construction. In general, the entire project has turned out quite satisfactorily. Upon examination, the following year, the surface with the exception of two local areas seems to be developing into a sound substantial base course suitable for the conditions to which it will be subjected.

The report will be presented in three main parts, consisting of a separate and complete discussion of the soil-cement stabilized section, the sand-bituminous section and a general summary of the project as a whole.

PART I

SOIL-CEMENT SECTION

Part I contains a description of the preliminary studies prior to construction of the soil-cement stabilized surface, as well as the various operations incidental to the processing of the surface.

The laboratory and field operations were under the supervision of S.M. Cardone, and T.H. Thornburn. Part I is essentially a report on the work which they submitted upon completion of the project.

SOIL-CEMENT STABILIZATION SECTION

The soil-cement section of the Grayling soil stabilization project is 1.572 miles in length, located between stations 246+00 to 329+00, at the east end of the stabilization project.

The stabilized surface is 22 feet wide and 5 inches deep surface treated with a bituminous chip double seal wearing course.

The soil type throughout the soil-cement section is a poorly graded incoherent material known as Grayling sand. The fines in the sand were augmented by limestone mineral filler from Petoskey and silt obtained locally. The addition of fines was necessary in order to facilitate construction operations and to obtain a durable surface.

The report will discuss, in detail, first the preliminary laboratory studies prior to construction operations then the construction operations performed during the consolidation process.

Laboratory Studies

The laboratory study incidental to any soil stabilization project consists essentially of four parts, the soil survey, sampling of the project, laboratory analysis for soil constants and special control tests for determining quantity of binder to use for each soil type.

At times, other special studies are deemed necessary to insure a satisfactory surface. For example, in this case it was necessary to add fines to existent soil type to obtain mechanical stability. Therefore, it was necessary to conduct comparative studies on several types of fillers in order to determine the best material to use with due consideration to its cost.

Soil Survey

In 1939, the Grayling project was recommended for soil stabilization study, but for various reasons the project was dropped. However, not before considerable laboratory work was done under the supervision of W.S. Housel, at Ann Arbor. At that time a comprehensive soil survey was made of the project by A.R. Lundahl, Assistant Engineer of Soils. The results of the original soil survey were taken into account when the project was revived in 1941.

The preliminary grading plans contemplated the use of the existing road surface material at some points, and preliminary soil samples were obtained at numerous points on the road as well as from cuts and borrow pits. From the preliminary samples three representative soils were selected for molding durability specimens.

The laboratory analysis consisted of the usual gradation, P.I., S.L., L.L., p^h organic content and specific gravity. These factors and other information are summarized in forms 849-1,2,3 and 4.

Optimum Moisture, Maximum Density

The optimum moisture and maximum density of each raw soil was run in accordance with A.A.S.H.O. Method T 99-38. From this test a curve was obtained for each soil showing the moisture-density relation. The moisture density tests for soil-cement mixtures at 6 and 10 percent cement content were run in accordance with A.S.T.M. Designation D 558-40 T, and curves were plotted for each soil. From these curves data were later obtained from which, by interpolation, the quantities for molding durability and compressive strength specimens were obtained.

Molding Specimens

For each soil sample, compressive strength specimens were molded with 6 percent and 10 percent cement content by volume, one for each of 2, 7 and 28 day tests, making a total of 6 specimens for each soil. The standard Proctor mold making 4" x 4.6" cylinders of 1/30 cubic foot was used. The specimens were cured in a moist atmosphere up to the time of breaking and soaked in water for one hour before testing.

This test, although intended primarily as a qualitative test of the hardening properties of the soil-cement mixture, will also reveal the relative strengths between different soil-cement mixtures.

Standard Proctor cylinders for durability studies were molded for each soil. This consisted of one specimen for each of 6, 8 and 10 percent cement content by volume of the minus No. 4 soil for the soils having small amounts of plus No. 4 and 9, 11.5 and 14 percent cement for soil No. 6-8 which contained a large amount of plus No. 4. A control specimen containing the middle cement content was molded for each of the wet-dry and the freeze-thaw tests. A total of 8 specimens were molded for each soil.

Durability Tests

All specimens were cured for 7 days in a moist atmosphere before starting them on their durability cycles. Freeze-thaw specimens were cured in the same manner as the wet-dry cylinders and run through 12 cycles in accordance with A.S.T.M. Designation D 560-40 T. Results of this test are also summarized in form No. 849 (1-2-3-4), as well as in table 2. Curves bases on results in table 2 have been plotted as illustrated in figures 1 to 4 inclusive.

The four wet-dry specimens were run through 12 cycles in accordance with the A.S.T.M. Designation D 559-40 T. The maximum soil losses and volume changes are summarized in form No. 849 (1-2-3-4), table 2 and figures 5 and 6.

Laboratory Studies in Admixtures

In order to improve the gradation or stability of the poorly graded Grayling sand a number of fillers were molded in durability specimens. A stack dust by the commercial name of Agri-fil was used in the laboratory and found to be entirely unsatisfactory. The volume change of this material is so great that some of the specimens cracked and disintegrated during the curing period. See figure 7, sample 9B. The amount of this material added was sufficient to raise the soil fraction passing the 200 sieve from approximately 2 percent to 10 percent.

The same amount of limestone dust was used in a separate series of specimens with the natural Grayling sand. This material proved to be decidedly beneficial. Referring to form No. 849, a comparison in durability may be seen between soil No. 9 which is the natural Grayling sand and soil No. 9-A which contains approximately 8 percent of limestone dust. See figure 7. The significant point to note is that in the soil-cement mixture containing 10 percent cement by volume the natural soil suffered

23.2 percent soil loss while the same mixture with an additional 8 percent limestone dust showed only 12.6 percent soil loss, practically only one-half as much. The volume changes which were within safe limits remained approximately the same in either case. The maximum allowable soil losses for A-2 and A-3 soils according to A.S.T.M. Designations D 559-4T and D 560-40T are set at 14 percent. The Grayling sand falls in the A-3 soil classification.

Field Control Factors

On the basis of the laboratory studies, the most economical cement content which gave the allowable soil losses and volume changes was found to be 10 percent for the mixture of Grayling sand and limestone dust. Since the final grading plans called for the regrading of the entire roadway consisting of cuts and fills of Grayling sand, the cement content was set at 10 percent except for the first 1200 feet. At the beginning of the soil-cement section, between stations 329 and 317 it was noted that the roadway material contained a considerable amount of the B horizon and some of the original, weathered road surface material which was similar to soil No. 7 reported herewith. The soil losses in this soil were 13.2 percent in the 8 percent cement content, and the cement content was set at 8 percent for the first 1200 feet.

The plus No. 4 material in the Grayling sand was negligible, being only about 1 percent and all calculations were based on the minus No. 4 soil fraction. The optimum moisture and maximum density found in the laboratory were specified as a guide in field work, but the actual moisture-density relations found from daily tests of the actual mixture on the roadway were used for job control.

Upon completion of the laboratory studies, specifications were developed for use in construction of the stabilized surface. The construction phase of the soil cement section is discussed in detail under "Construction Procedure".

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State Highway Commissioner

RESEARCH DIVISION

Form No. 849 - 1
Soil Series **Grayling**
Date Tests Completed **July 15, 1941**
Project No. **M 20-20, C2**

SUMMARY OF TESTS ON SOIL AND SOIL-CEMENT MIXTURES

STATE SOIL NO.	GRADATION - Per Cent of Total: Gravel; Retained on No. 4 Sieve	Gravel; No. 4 To No. 10 (2.0 mm)	Sand; 2.0 To 0.25 mm	Sand; 0.25 To 0.05 mm	Silt; 0.05 To 0.005 mm.	Clay; 0.005 To 0.000 mm.	Colloids; 0.001 To 0.000 mm.	PHYSICAL TEST CONSTANTS L. L.	P. I.	S. L.	pH	ORGANIC CONTENT, p.p.m.	TEXTURAL CLASS	Sp. Gr.	U.S. P.R.A. Soil Group (Soil Mortar)
	21.5	4	43.2	21.3	4.5	5	--	10	0	20	7.4	10,000	sand	2.67	A-3
Soil Mortar Only			58	29	6	7									

Also included in clay. Fraction passing #10 Sieve.

Absorption of plus #4 material, 1.16% by dry weight. Color of moist soil **Dk.Brown**. Sp. Gr. of plus #4 material **2.63**.

TESTS ON MINUS No. 4 MATERIAL

MOISTURE-DENSITY RELATIONS: Opt. Moisture Content, %			Opt. Density, lb. per c.f.			COMPRESSIVE STRENGTHS - lb. per sq.in. (1) Age When Tested - Days: Two			Seven			Twenty-eight		
Cement Content by Volume - %						Cement Content by Volume - %								
0	6.0	10.1	0	6.0	10.1	6	10		6	10		6	10	
8.2	7.8	8.2	119.2	121.6	123.8	38	54		56	318		211	790	

(1) Submerged in water for 1 hr. before testing.

FIELD CONTROL FACTORS

Cement Content:	TOTAL	%
	Minus#4	%
Optimum Moisture Content:	Total	%
	Minus#4	%
Density, lb./cu.ft. dry wt.:	Total	
	Minus#4	

Not encountered in the field

DATA FROM SPECIMENS USED FOR TWELVE CYCLES OF DURABILITY TESTS

	CEMENT CONTENT; % BY Volume. Theoretical	Obtained Ave.	DENSITY; lb. per c.f. oven dry wt. Theoretical	Obtained, Ave.	MOISTURE CONTENT; % by oven dry wt. Theoretical	Obtained, Ave.	SOLIDS % by Volume Ave.	TOTAL SOIL LOSS; % of original dry weight. WET* DRY	FREEZE-THAW	MAXIMUM VOLUME CHANGE; % of molded volume. WET - DRY Plus	WET - DRY Minus	FREEZE-THAW Plus	FREEZE-THAW Minus	MOISTURE CONTENT FOR SATURATION; % by oven dry wt. WET-DRY	FREEZE-THAW	MAX. MOISTURE; percentage above or below Saturation. WET-DRY	FREEZE-THAW
Total	7.1	7.1	131.5	131.7	6.3	6.5											
Minus #4	9.0	9.0	122.9	123.4	8.1	8.3		2.7	3.2								
Total	9.1	9.0	132.2	132.5	6.5	6.6											
Minus #4	11.5	11.5	124.0	124.7	8.4	8.4	79.22	0.7	2.5	2.2	0.0	1.5	0.0	10.0	10.2	-3.7	-2.3
Tatal	11.1	11.2	133.2	133.1	6.7	6.7											
Minus #4	14.0	14.0	125.0	125.1	8.5	8.3		0.7	1.1								
Total																	
Minus #4																	

U.S.D.A., B. of C. & S., Soil Series ---

Soil Horizon ----   Soil No. 6 - 8

Original Roadway Material

8968

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RESEARCH DIVISION

Form No. 849 - 2
Soil Series Grayling
Date Tests Completed July 15, 1941
Project No. M 20-20, C2

SUMMARY OF TESTS ON SOIL AND SOIL-CEMENT MIXTURES

STATE SOIL NO.	GRADATION - Per Cent of Total: Gravel; Retained on No. 4 Sieve	Gravel; No. 4 To No. 10 (2.0 mm)	Sand; 2.0 To 0.25 mm	Sand; 0.25 To 0.05 mm	Silt; 0.05 To 0.005 mm.	Clay; 0.005 To 0.000 mm.	Colloids; 0.001 To 0.000 mm.	PHYSICAL TEST CONSTANTS L. L.	P. I.	S. L.	pH	ORGANIC CONTENT, p.p.m.	TEXTURAL CLASS	Sp. Gr.	U.S. P.R.A. Soil Group (Soil Mortar)
	1	.8	58.9	26.8	5.3	6.7	--	0	0	18	8.1	14,000	sand	2.67	A-3
Soil Mortar Only			60	27	6	7	--								

Also included in clay. Fraction passing #10 Sieve.

Absorption of plus #4 material, 2.12% by dry weight. Color of moist soil Dk.Brown. Sp. Gr. of plus #4 material 2.67.

TESTS ON MINUS No. 4 MATERIAL

MOISTURE-DENSITY RELATIONS: Opt. Moisture Content, %			Opt. Density, lb. per c.f.			COMPRESSIVE STRENGTHS - lb. per sq.in. (1), Age When Tested - Days: Two			Seven			Twenty-eight		
Cement Content by Volume - %						Cement Content by Volume - %								
0	6.0	10.3	0	6.0	10.3	6	10		6	10		6	10	
8.3	8.4	8.3	117.6	120.4	122.8	32	—		55	260		242	613	

(1) Submerged in water for 1 hr. before testing.

FIELD CONTROL FACTORS

Cement Content:	TOTAL	7.9 %
	Minus #4	8.0 %
Optimum Moisture Content:	Total	8.3 %
	Minus #4	8.4 %
Density, lb./cu.ft. dry wt.:	Total	122.1
	Minus #4	121.7

Not encountered in the field.

DATA FROM SPECIMENS USED FOR TWELVE CYCLES OF DURABILITY TESTS

	CEMENT CONTENT; % BY Volume. Theoretical	Obtained Ave.	DENSITY; lb. per c.f. oven dry wt. Theoretical	Obtained, Ave.	MOISTURE CONTENT; % by oven dry wt. Theoretical	Obtained, Ave.	SOLIDS % by Volume Ave.	TOTAL SOIL LOSS; % of original dry weight. WET* DRY	FREEZE-THAW	MAXIMUM VOLUME CHANGE; % of molded volume. WET - DRY Plus	WET - DRY Minus	FREEZE-THAW Plus	FREEZE-THAW Minus	MOISTURE CONTENT FOR SATURATION; % by oven dry wt. WET-DRY	FREEZE-THAW	MAX. MOISTURE; percentage above or below Saturation. WET-DRY	FREEZE-THAW
Total	5.9	6.0	121.9	120.4	8.3	7.5											
Minus #4	6.0	6.0	120.4	120.9	8.4	7.6		17.1	75.2								
Total	7.9	7.9	122.0	122.1	8.3	8.3											
Minus #4	8.0	8.0	121.5	121.7	8.4	8.3	72.25	4.3	13.2	1.7	0.0	2.7	0.0	14.4	14.3	-3.0	-1.7
Tatal	9.9	9.9	122.3	122.4	8.2	8.4											
Minus #4	10.0	10.0	122.6	122.6	8.3	8.3		1.7	5.6								
Total																	
Minus #4																	

U.S.D.A., B. of C. & S., Soil Series --- Soil Horizon --- Soil No. 7

Original Roadway Material

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RESEARCH DIVISION

Form No. 849 -3
Soil Series Grayling
Date Tests Completed July 15, 1941
Project No. M 20-20, C2

SUMMARY OF TESTS ON SOIL AND SOIL-CEMENT MIXTURES

STATE SOIL NO.	GRADATION - Per Cent of Total: Gravel; Retained on No. 4 Sieve	Gravel; No. 4 To No. 10 (2.0 mm)	Sand; 2.0 To 0.25 mm	Sand; 0.25 To 0.05 mm	Silt; 0.05 To 0.005 mm.	Clay; 0.005 To 0.000 mm.	Colloids; 0.001 To 0.000 mm.	PHYSICAL TEST CONSTANTS L. L.	P. I.	S. L.	pH	ORGANIC CONTENT, p.p.m.	TEXTURAL CLASS	Sp. Gr.	U.S. P.R.A. Soil Group (Soil Mortar)
	.4	.5	55.5	41.6	2	0	--	0	0	21	6.3	7,000	sand	2.63	A-3
Soil Mortar Only			56.	42	2	0	--								

Also included in clay. Fraction passing #10 Sieve.

Absorption of plus #4 material, -- % by dry weight. Color of moist soil Tan . Sp. Gr. of plus #4 material --- .

TESTS ON MINUS No. 4 MATERIAL

MOISTURE-DENSITY RELATIONS: Opt. Moisture Content, %			Opt. Density, lb. per c.f.			COMPRESSIVE STRENGTHS - lb. per sq.in. (1): Age When Tested - Days: Two			Seven			Twenty-eight		
Cement Content by Volume - %						Cement Content by Volume - %								
0	6.2	10.6	0	6.2	10.6	6	10		6	10		6	10	
12.5	10.0	10.5	109.7	113.0	115.2									

(1) Submerged in water for 1 hr. before testing.

FIELD CONTROL FACTORS

Cement Content:	TOTAL	10.0 %
	Minus#4	10.0 %
Optimum Moisture Content:	Total	10.0 %
	Minus#4	10.0 %
Density, lb./cu.ft. dry wt.:	Total	115.2
	Minus#4	115.2

DATA FROM SPECIMENS USED FOR TWELVE CYCLES OF DURABILITY TESTS

	CEMENT CONTENT; % BY Volume. Theoretical	Obtained Ave.	DENSITY; lb. per c.f. oven dry wt. Theoretical	Obtained, Ave.	MOISTURE CONTENT; % by oven dry wt. Theoretical	Obtained, Ave.	SOLIDS % by Volume Ave.	TOTAL SOIL LOSS; % of original dry weight. WET* DRY	FREEZE-THAW	MAXIMUM VOLUME CHANGE; % of molded volume. WET - DRY Plus	WET - DRY Minus	FREEZE-THAW Plus	FREEZE-THAW Minus	MOISTURE CONTENT FOR SATURATION; % by oven dry wt. WET-DRY	FREEZE-THAW	MAX. MOISTURE; percentage above or below Saturation. WET-DRY	FREEZE-THAW
Total	6.0	6.0	113.1	112.8	10.0	10.3											
Minus #4	Same as total							46.5	67.2								
Total	8.0	8.0	113.9	114.2	10.2	10.5											
Minus #4	Same as total						68.84	24.9	39.0	1.7	0.0	1.5	0.0	17.3	16.8	-5.4	-4.2
Tatal	10.0	10.0	114.9	115.7	10.4	10.9											
Minus #4	Same as total							13.7	23.2								
Total																	
Minus #4																	

U.S.D.A., B. of C. & S., Soil Series ---   Soil Horizon C   Soil No. 9

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Form No. 849 - 4
Soil Series Grayling
Date Tests Completed July 15, 1941
Project No. M 20-20, C2

RESEARCH DIVISION

SUMMARY OF TESTS ON SOIL AND SOIL-CEMENT MIXTURES

STATE SOIL NO.	GRADATION - Per Cent of Total: Gravel; Retained on No. 4 Sieve	Gravel; No. 4 To No. 10 (2.0 mm)	Sand; 2.0 To 0.25 mm	Sand; 0.25 To 0.05 mm	Silt; 0.05 To 0.005 mm.	Clay; 0.005 To 0.000 mm.	Colloids; 0.001 To 0.000 mm.	PHYSICAL TEST CONSTANTS L. L.	P. I.	S. L.	pH	ORGANIC CONTENT, p.p.m.	TEXTURAL CLASS	Sp. Gr.	U.S. P.R.A. Soil Group (Soil Mortar)
	0	.5	47.0	43.5	9.0	0	0					7,000	sand	2.62	A-3
Soil Mortar Only			47.5	43.5	9.0	0	0	Also included in clay.	Fraction passing #10 Sieve.						

Absorption of plus #4 material, ___% by dry weight. Color of moist soil ________. Sp. Gr. of plus #4 material ________.

TESTS ON MINUS No. 4 MATERIAL

MOISTURE-DENSITY RELATIONS: Opt. Moisture Content, %			Opt. Density, lb. per c.f.			COMPRESSIVE STRENGTHS - lb. per sq.in. (1): Age When Tested - Days: Two			Seven			Twenty-eight		
Cement Content by Volume - %						Cement Content by Volume - %								
0	5.4	8.9	0	5.4	8.9	6	10		6	10		6	10	
10.7	9.9	9.6	116.3	118.3	118.9									

(1) Submerged in water for 1 hr. before testing.

FIELD CONTROL FACTORS

Cement Content:	TOTAL	10.0 %
	Minus#4	10.0 %
Optimum Moisture Content:	Total	%
	Minus#4	%
Density, lb./cu.ft. dry wt.:	Total	
	Minus#4	

DATA FROM SPECIMENS USED FOR TWELVE CYCLES OF DURABILITY TESTS

	CEMENT CONTENT; % BY Volume. Theoretical	Obtained Ave.	DENSITY; lb. per c.f. oven dry wt. Theoretical	Obtained, Ave.	MOISTURE CONTENT; % by oven dry wt. Theoretical	Obtained, Ave.	SOLIDS % by Volume Ave.	TOTAL SOIL LOSS; % of original dry weight. WET* DRY	FREEZE-THAW	MAXIMUM VOLUME CHANGE; % of molded volume. WET - DRY Plus	WET - DRY Minus	FREEZE-THAW Plus	FREEZE-THAW Minus	MOISTURE CONTENT FOR SATURATION; % by oven dry wt. WET-DRY	FREEZE-THAW	MAX. MOISTURE; percentage above or below Saturation. WET-DRY	FREEZE-THAW
Total	6.0	6.0	118.5	117.8	9.9	10.4											
Minus #4	Same as total							29.1	52.0								
Total	8.0	8.0	118.7	118.1	9.7	10.7											
Minus #4	Same as total						71.36	16.2	30.0	1.5	0.0	1.5	0.0	15.2	15.2	-5.0	-3.5
Tatal	10.0	10.0	118.9	119.2	9.5	10.1											
Minus #4	Same as total							8.3	12.6								
Total																	
Minus #4																	

U.S.D.A., B. of C. & S., Soil Series ______ Soil Horizon C Soil No. 9 - A

TABLE I

WETTING-DRYING DURABILITY TEST OF SOIL-CEMENT MIXTURES

Progressive Soil Loss - Percent of Original Oven-Dry Weight

Soil No.	Percent Cement by volume	WETTING-DRYING CYCLES											
		1	2	3	4	5	6	7	8	9	10	11	12
6-8	7.1	1.1	1.4	1.6	1.6	1.6	1.6	1.8	2.1	2.3	2.5	2.5	2.7
	9.0	0.2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.7	0.7
	11.2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.7	0.7
7	6.0	2.0	2.7	4.0	5.2	6.2	7.2	8.7	10.2	10.9	12.6	14.9	17.1
	7.9	1.0	1.2	1.7	2.0	2.2	2.4	2.7	2.9	3.2	3.7	4.1	4.9
	9.9	0.5	0.5	0.7	0.7	0.7	0.7	0.7	1.0	1.2	1.5	1.7	1.7
9	5.96	11.1	16.1	19.3	24.4	29.1	33.6	36.8	40.0	41.8	- -	44.2	46.5
	7.98	7.1	9.7	11.3	13.9	16.3	18.4	19.9	21.5	22.8	- -	24.2	24.9
	10.0	3.4	5.9	6.7	7.8	9.0	10.1	11.1	11.6	12.4	- -	12.9	13.7
9-A	5.96	3.6	9.9	13.3	16.3	18.6	21.2	23.0	- -	24.8	26.0	27.0	29.1
	7.98	2.0	4.8	7.1	8.9	10.2	11.7	12.7	- -	13.5	14.5	15.0	16.2
	10.0	1.0	2.5	3.8	4.8	5.5	6.3	6.8	- -	7.3	7.6	7.6	8.3

TABLE II

FREEZING-THAWING DURABILITY TEST OF SOIL-CEMENT MIXTURES

Progressive Soil Loss - Percent of Original Oven-Dry Weight

Soil No.	Percent Cement by volume	FREEZING-THAWING CYCLES											
		1	2	3	4	5	6	7	8	9	10	11	12
6-8	7.1	0.2	0.5	0.7	1.1	1.4	1.6	1.8	2.3	2.3	2.5	3.0	3.2
	9.0	0.9	1.4	1.6	1.8	2.0	2.0	2.0	2.3	2.3	2.3	2.5	2.5
	11.2	0.2	0.2	0.5	0.5	0.7	0.7	0.7	0.9	0.9	0.9	1.1	1.1
7	6.0	2.5	4.4	6.9	11.3	15.0	22.9	34.0	47.6	50.3	58.7	68.3	75.2
	7.9	1.0	1.7	2.7	3.7	4.7	5.1	6.6	7.8	8.1	9.8	11.5	13.2
	9.9	0.7	1.0	1.5	1.7	2.2	2.7	3.2	3.7	3.9	4.4	4.9	5.6
9	5.96	7.7	12.3	17.1	27.0	36.8	46.6	54.7	59.8	63.0	- -	64.8	67.2
	7.98	4.2	6.6	7.9	11.6	16.3	22.1	27.1	30.8	33.2	- -	36.0	39.0
	10.0	2.6	3.4	4.9	6.8	8.9	11.7	14.3	16.7	18.2	- -	21.1	23.2
9-A	5.96	3.1	11.0	16.6	27.3	33.9	38.0	40.3	- -	44.1	48.8	- -	52.0
	7.98	2.0	6.6	10.4	15.0	18.5	21.0	22.8	- -	26.6	27.6	- -	30.0
	10.0	0.8	2.0	3.5	5.0	6.8	8.3	8.8	- -	10.1	11.1	12.6	- -

SOIL-CEMENT LOSSES RESULTING FROM 12 CYCLES OF FREEZING-THAWING DURABILITY TEST

GRAYLING PROJECT
Soil No. 6-8

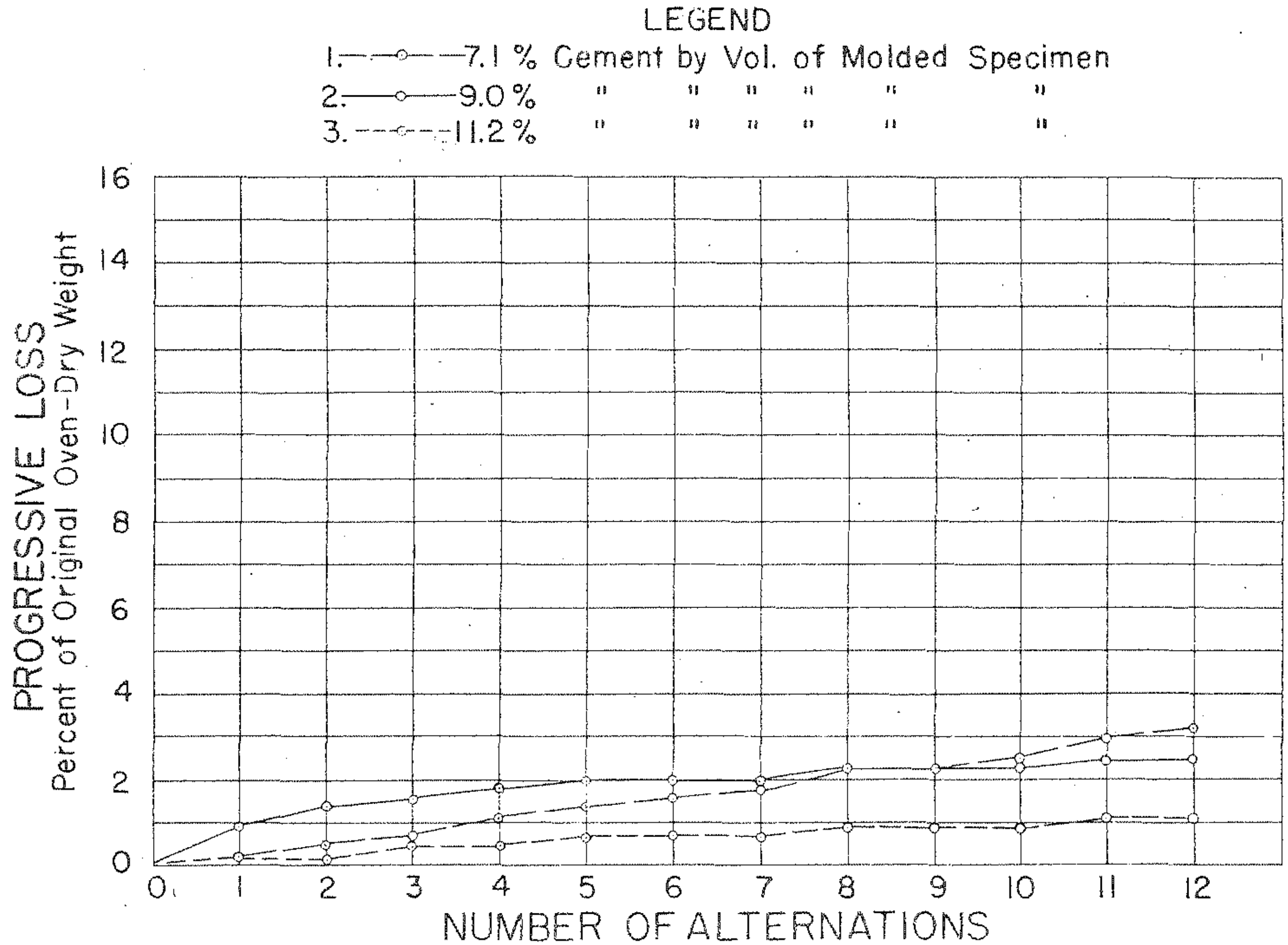


Fig. 1

SOIL-CEMENT LOSSES RESULTING FROM 12 CYCLES OF FREEZING-THAWING DURABILITY TEST

GRAYLING PROJECT
Soil No. 7

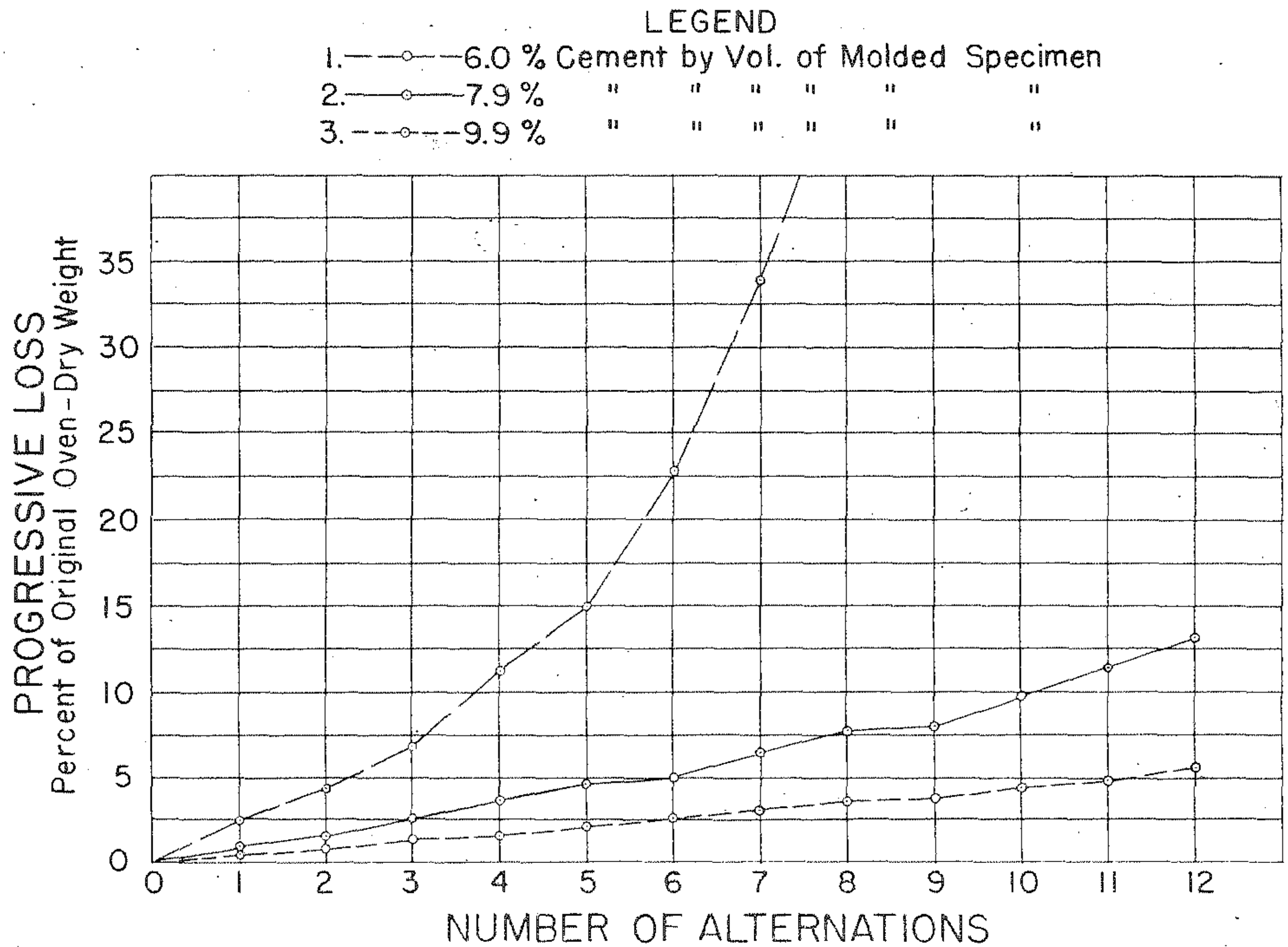


Fig. 2.

SOIL-CEMENT LOSSES RESULTING FROM 12 CYCLES OF FREEZING-THAWING DURABILITY TEST

GRAYLING PROJECT
Soil No. 9

LEGEND
1. ---o--- 5.96% Cement by Vol. of Molded Specimen
2. ——o—— 7.98% " " " " " "
3. --o-- 10.00% " " " " " "

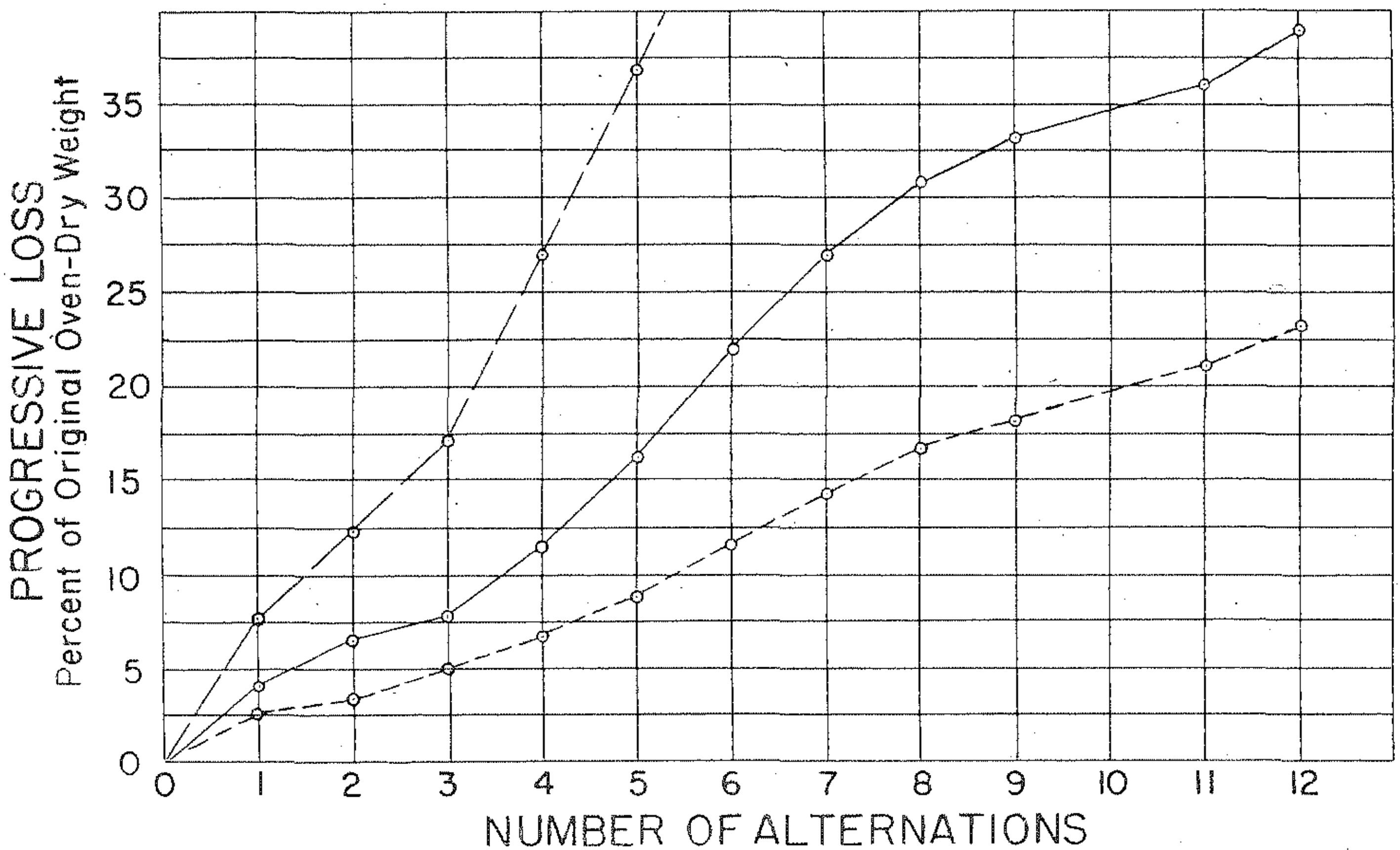


Fig. 3

SOIL-CEMENT LOSSES RESULTING FROM 12 CYCLES OF FREEZING-THAWING DURABILITY TEST

GRAYLING PROJECT
Soil No. 9-A
(Containing 8% Limestone Dust)

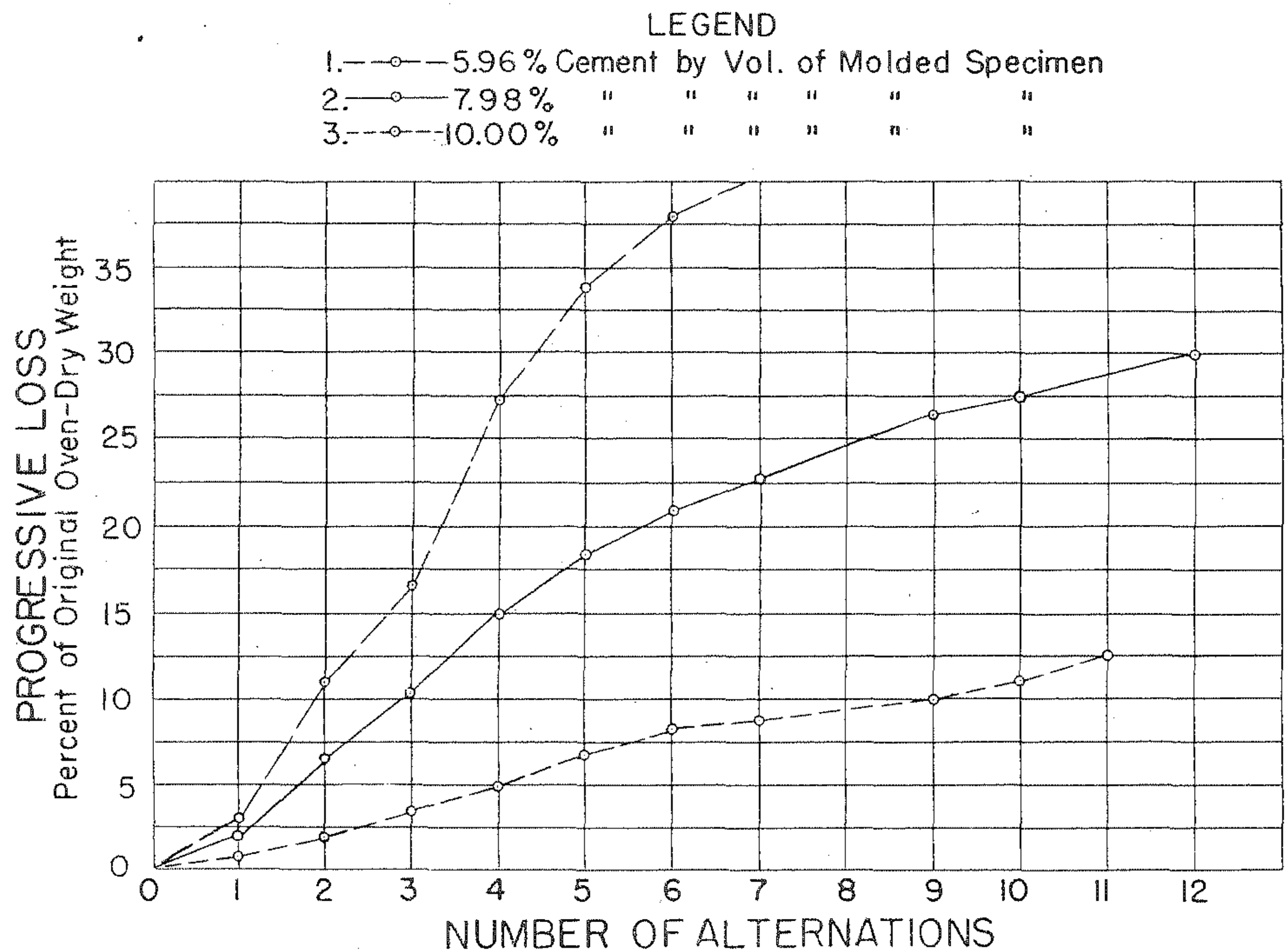


Fig. 4

SOIL-CEMENT LOSSES RESULTING FROM 12 CYCLES OF WETTING-DRYING DURABILITY TEST

GRAYLING PROJECT
Soil No. 9-A
(Containing 8% Limestone Dust)

LEGEND
1.——o——5.96 % Cement by Vol. of Molded Specimen
2.——o——7.98 % " " " " " "
3.——o——10.00 % " " " " " "

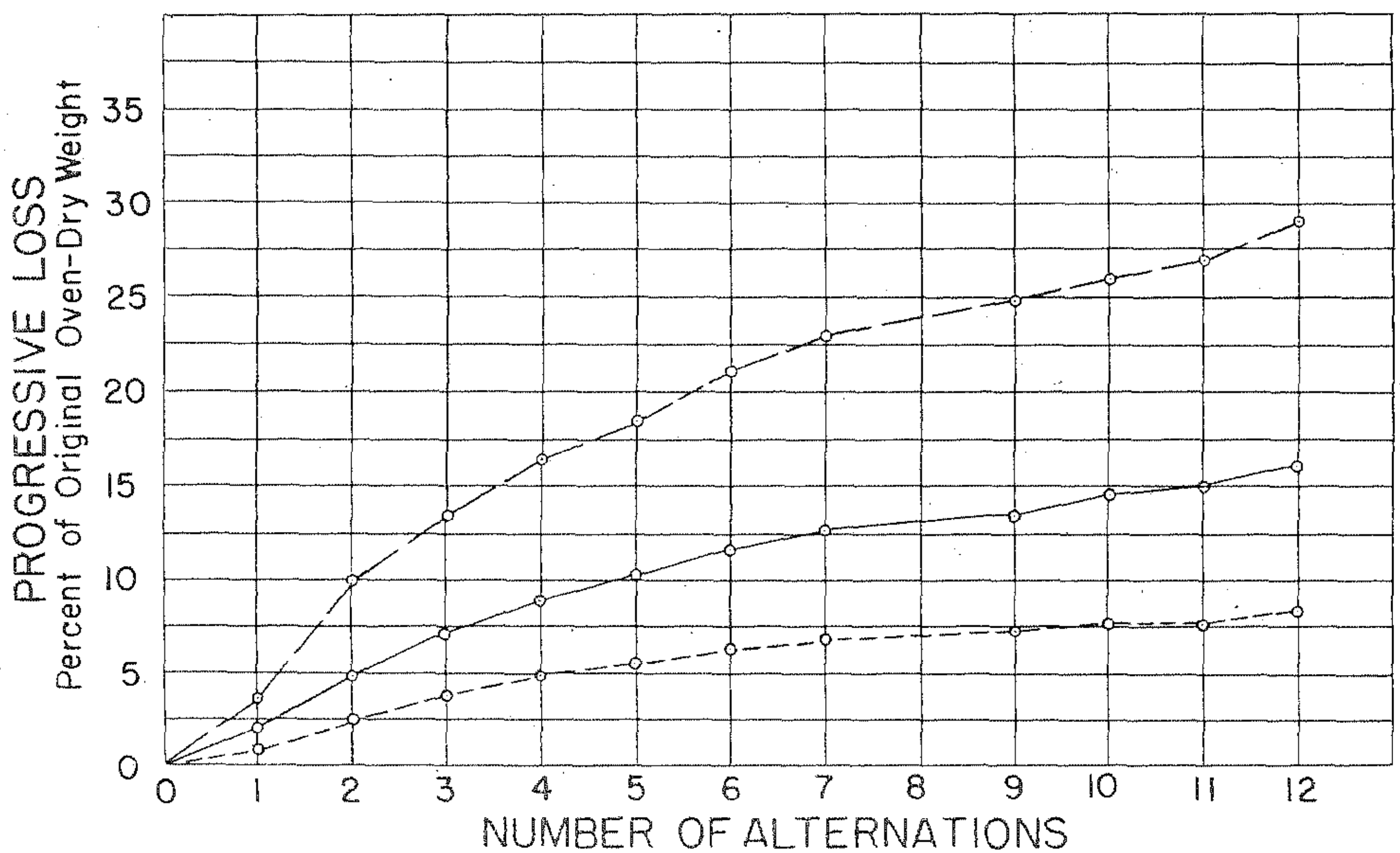


Fig. 5

SOIL-CEMENT LOSSES RESULTING FROM 12 CYCLES OF WETTING-DRYING DURABILITY TEST

GRAYLING PROJECT
Soil No. 9

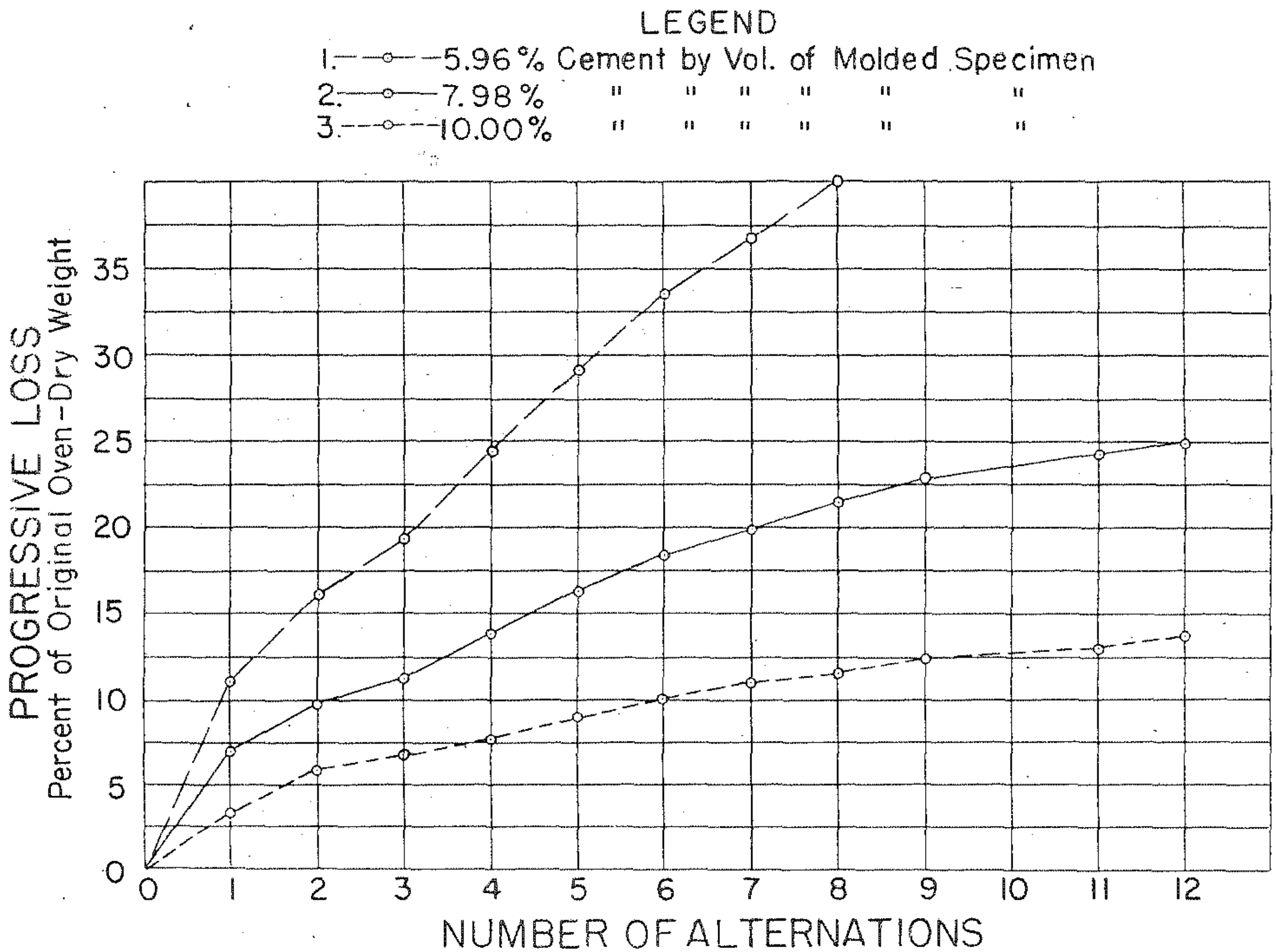
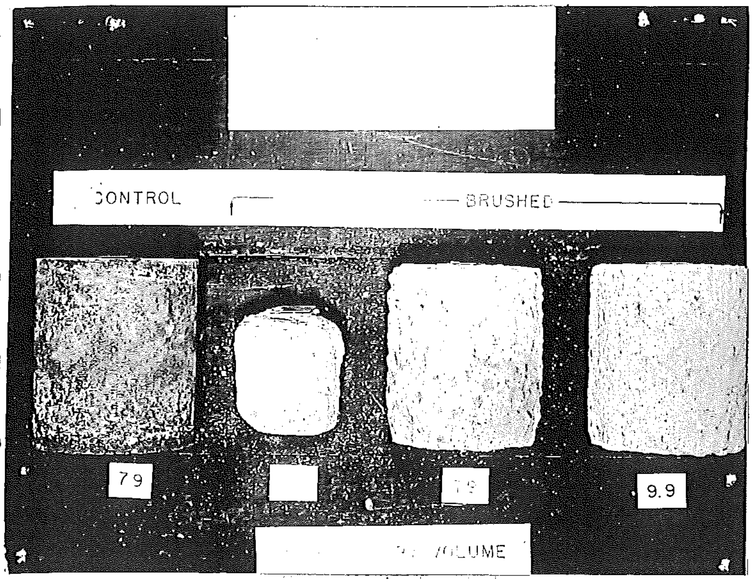
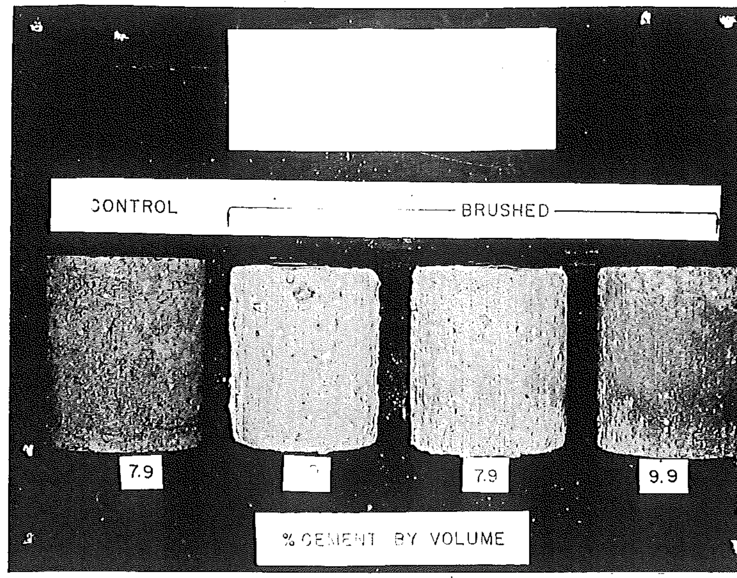


Fig. 6.

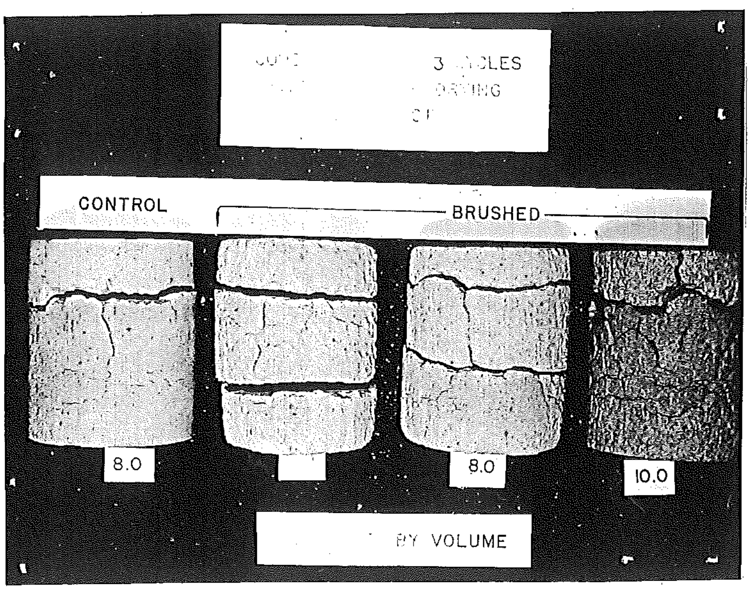
DURABILITY STUDIES



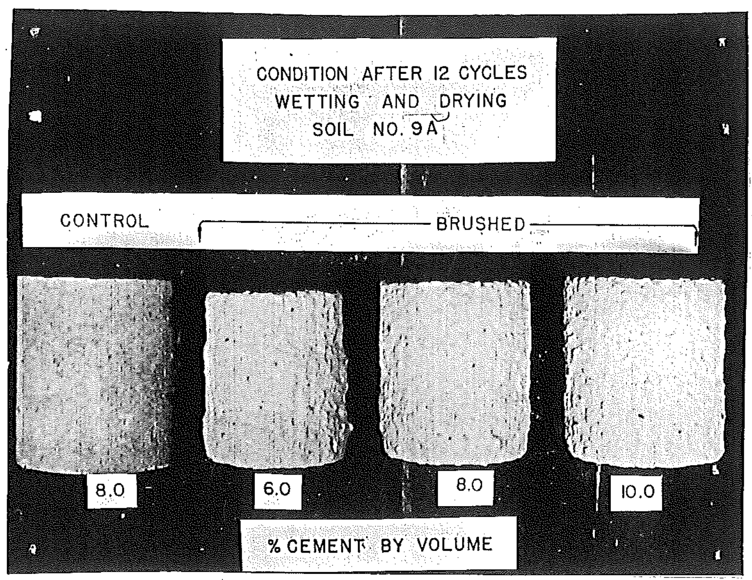
Sample No. 7 Condition after 12 cycles freezing and thawing



Sample No. 7 Condition after 12 cycles wetting and drying



Sample No. 9B Grayling sand containing 8% "Agri-fil". Disintegration due to excessive volume change after 3 cycles.



Sample 9A Grayling sand containing 8% limestone dust

Figure 7

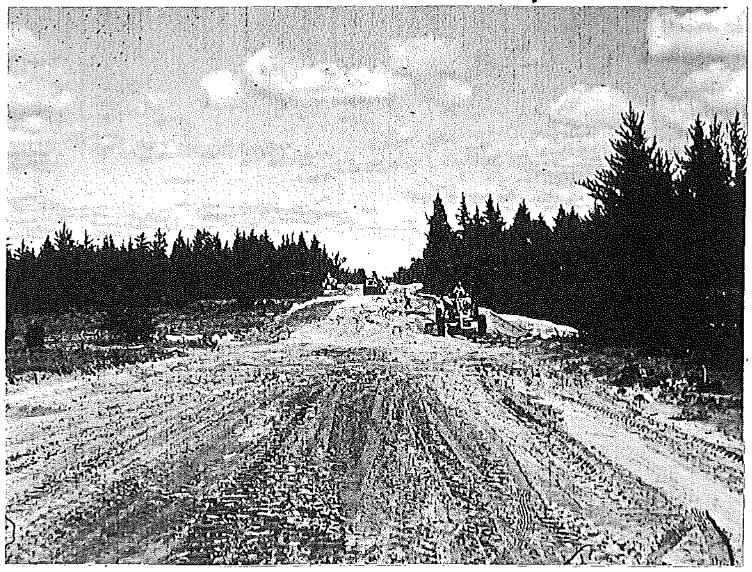
CONSTRUCTION PROCEDURE

The construction procedure which was used in processing the soil cement stabilized surface consisted of the following operations; preparation of the fine grade and adding necessary fines, application of the Portland cement, dry mixing, application of water and wet mixing, consolidation, curing and final surface treatment. These operations as they were applied to the Grayling project are discussed in the above order.

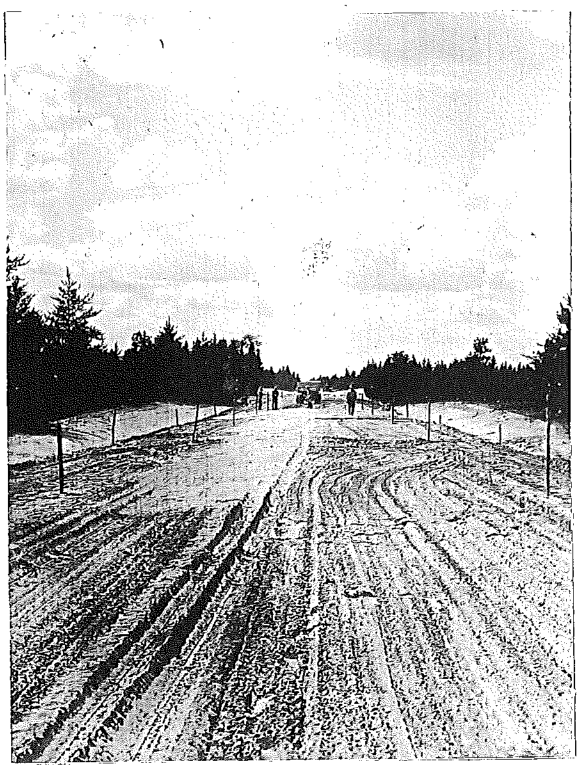
Added Fines

As explained under laboratory studies, the Grayling sand contained a very low percentage of natural fines and, therefore, in order to obtain stability and durability, it was necessary to add a certain percentage of filler to the mixture. The filler materials used on the project were limestone dust, clay and silt.

Limestone dust: The addition of the limestone dust on the grade presented some difficulties. The material could not be spread uniformly by means of a spreader box due to the difficulty of pulling the box through the loose sand and the uneven flow of the limestone dust out of the box. An attempt was made at shoveling the material out of the trucks and onto the grade, but this also proved to be unsatisfactory. Finally, a fairly satisfactory application was accomplished by spreading directly from the trucks with spreader chains properly adjusted. Limestone dust was added from station 329 to station 255+50 at the rate of 8 percent by weight. See figure 8. The limestone dust improved the stability of the sand to a considerable extent.



(A) - Grading Operations



(B) - Spreading Limestone Dust

(C) - Mixing Limestone Dust with Surface Material

Figure 8

<u>Clay:</u> It was realized that in order to give the sand sufficient bearing capacity to support the construction equipment some material must be added which would improve the stability either by mechanical arrangement of particles or by cohesion. A clay deposit within an average haul of one mile was investigated. The contractor added and manipulated approximately 8 cubic yards of this clay at his own expense over a distance of 75 feet. Since the clay has a P.I. of about 30 it was impossible to pulverize it sufficiently on the grade to render it effective as a binder. The stability was improved slightly over the 75 feet, but it is believed that this was due, not to any cohesive action, but rather to an arching action similar to the behavior of graded aggregates. The remaining balls of clay may have a detrimental effect in the weathering action of the finished road.

<u>Silt:</u> From station 255+50 to 246+00, which constituted the balance of the soil-cement project, 8 percent silt was added. The silt was found in a deposit approximately 3-1/2 miles from the job. The same method was used for spreading as was finally adopted for the limestone dust. The silt behaved very similar to the limestone dust. No difference was apparent in the stability, workability, optimum moisture and maximum density, as compared with the limestone dust section.

<u>Preparation of Grade, Stakes, etc.</u>

Prior to the day of processing the grade was checked and given a preliminary shaping. Grade stakes were set on each side of the road at each station on a 4 foot offset from the edge of treatment and 12 inches above the bottom of the finished roadway at the centerline. By this method the control for depth was accomplished by measuring down from a string line stretched across the grade stakes, to the bottom of treatment, 12 inches at the centerline and 13-1/2 inches to 14 inches at the edges for a 1-1/2 inch to 2 inch crown. This proved very successful except that where the stakes were put in too far in advance of processing in the relatively loose sand they may have settled, thus probably causing excessive depth of treatment. In a situation of this kind, the grade stakes should be set not more than one or two days in advance of processing in order to reduce errors in depth of treatment to a minimum.

In order to reduce the quantity of water to be added during processing operations, the soil was wetted at first to within 2 percent of optimum of the raw soil on the day before processing, usually in the evening to reduce evaporation losses. During the latter part of the project the pre-wetting was increased to the optimum moisture of the raw soil to further reduce the water to be added during processing.

Prior to the addition of cement, guide laths were placed at 100 foot intervals, 6 inches outside of the edge of treatment on each side of the road. Towards the end, the project guide stakes were placed at every 50 feet in order to aid further the inexperienced equipment operators in maintaining a straight edge.

Addition of Cement

Immediately proceding the spreading of cement, the grade was given a preliminary shaping to remove all ruts and wheel marks. The cement trucks were taken down the center of the road and cement sacks were unloaded and spaced by the aid of a 100 foot chain with metal tags attached at the proper intervals. A 6 by 6 inch beam was dragged behind the truck to eliminate the wheel marks and this was supplemented by shovels to insure an even surface before the sacks were opened. For the 8 percent cement spread, the sacks were spotted in 4 longitudinal rows of 18 sacks each and for the 10 percent cement spread, 5 rows of 18 sacks were used. See figure 9. This proved to be a convenient arrangement as it was necessary to merely increase the number of rows from 4 to 5 to go from the 8 percent to the 10 percent cement spreads and still keep the same interval on the chain. It is believed that small pieces of red cloth tied on the chain would have been more satisfactory than the sheet metal tags which were rather difficult to see.

The sacks were opened and each transverse row of sacks was shaped into a windrow of cement running across the road and within 1 foot from each edge. Care had to be exercised to keep the men from spreading the cement too close to the edge of the treatment. After the cement was shaped into windrows the latter were spread by dragging the spike tooth harrow with spikes set at about 45°. This spread the cement evenly from one windrow to the next except for one weakness. The tracks, made by tractor pulling the dray, filled up with cement and caused a number of streaks of rich mix, which required excessive manipulation to eliminate them. When this-was discovered, the method of spreading was changed. The sacks were opened, dumped in a pile and then spread evenly with square point shovels. After this operation it was discovered that running the spike tooth harrow as before aided in accomplishing a very uniform spread.

Dry Mixing

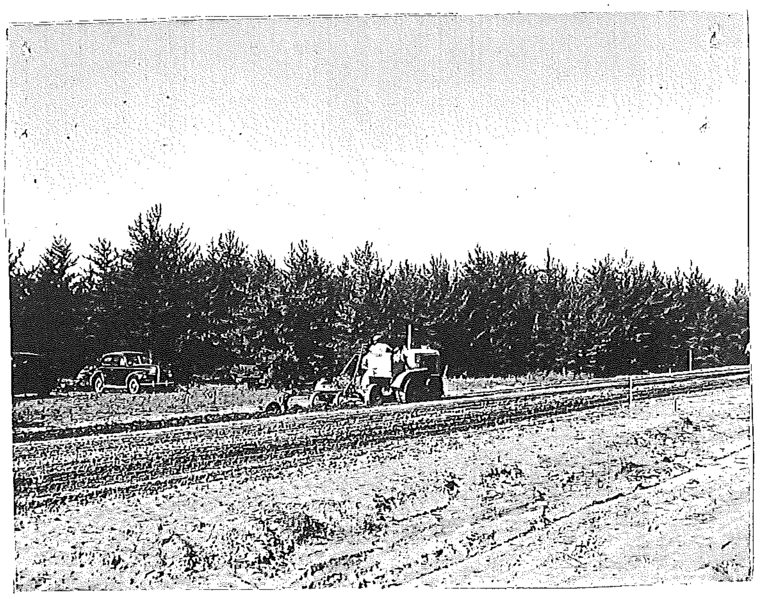
Dry mixing started immediately after the cement spread with one pass of the field cultivator. This was followed by two passes of the rotary tiller which thoroughly mixed the top 3 or 4 inches. See figure 9. This was about as deep as the tiller would penetrate with the power available. Following the tiller the 3 gang plow was used to bring the unmixed material up from the bottom. The plowing was started at the center (up one side of the center line and down on the other) and carried to the edge. At first the plowing was followed by numerous passes of the field cultivator and the rotary tiller to thoroughly mix the material throughout the depth of treatment. Later the plowing was followed by a disc harrow and then by the rotary tiller. This completed the dry mixing.

Final Application of Water

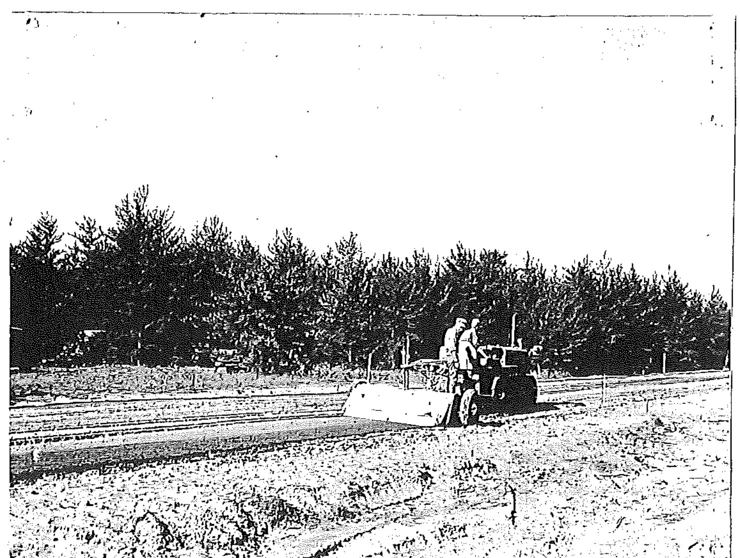
As stated above, the pre-wetting was accomplished the evening before processing. When the pre-wetting was carried to about 8 percent of raw soil the dry mix checked about 5 to 6 percent and when carried to optimum the dry mix contained 6.5 percent to 7.5 percent, with an optimum of approximately 10.3 percent. There is an indication that in pre-wetting too high in this type of soil there is a correspondingly greater moisture loss. When water has to be paid for at a rate of better than $8.00 per 1000 gallons it may be more economical to specify greater water spreading capacity.

Final water application toward the end of the job required approximately 4 applications which consumed on the average about 2 hours. The rate of spreading for each truck load was adjusted so that one round trip

(A) Spotting Cement Sacks



(B) Turning in cement with 3-bottom gang plow



(C) Mixing and pulverizing with rotary tiller emptied the full load. The water truck was filled from a 1500 gallon storage tank at the forward end of the days processing. The spray bar was 11 feet long and equipped at first with 1/16 inch and later with 1/8 inch nozzles. The capacity of the tank was 1100 gallons. See figure 10.

Difficulty was experienced throughout the project in spreading the water uniformly. The truck had to be pulled by a tractor and at times the sand was so unstable that the tank truck could not keep in a straight line as the front wheels would slide laterally. The water spreading may be improved somewhat by the use of a 22 foot spray bar. During the water application the field cultivator followed close behind the water tank to fold the water in.

Wet Mixing

Following the water spread, at first, the wet mixing was accomplished by numerous passes of the field cultivator and the rotary tiller until the moisture was uniform throughout the full depth. However, at times it was difficult to obtain the water penetration to the bottom of treatment. Later the sequence of operations was changed to include, except for the plowing, the same order of equipment application in the wet mix as used in the dry mix. This proved to be very satisfactory and no difficulty was experienced in obtaining uniform water mixing with much less work. The indispensable piece of equipment which mixed the material from top to bottom was the disc harrow. The wet mixing operations required on the average 1-1/2 hours.

Compaction

Following the wet mixing, the grade was given a preliminary shaping and the sheepsfoot roller was introduced. See figure 10. It was found that a unit weight of 80 p.s.i. worked about the best. The average time required for this operation was approximately 1-1/2 hours. Difficulty was experienced in packing the edges as the feet would punch through the relatively unstable sand on the outside of the processed section.

Shaping

When the sheepsfoot roller had compacted all but 1 to 1-1/2 inches, the spike tooth harrow was used to scratch the top compaction planes. Then the road was given a final shaping. This is the operation which was the most tedious.

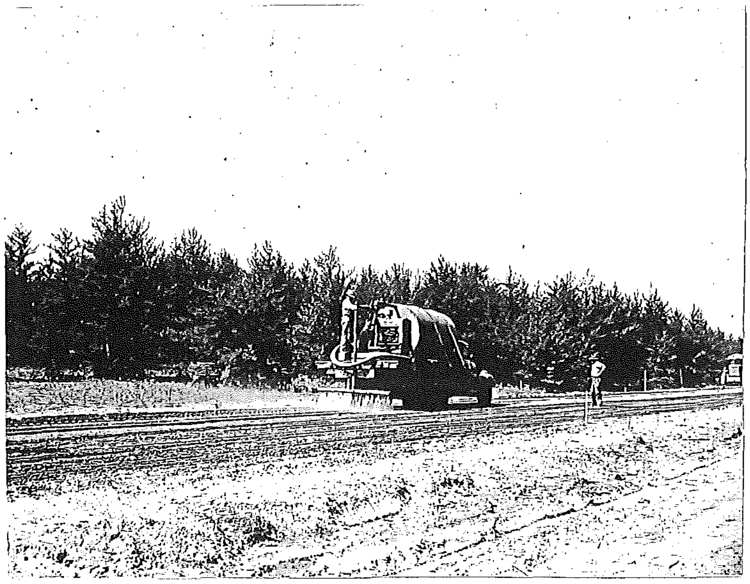
The unskilled grader operators consumed entirely too much time and accomplished only a mediocre job. This operation required approximately 1-1/2 hours.

Shaping was also done before cement spreading and following the wet mixing operations.

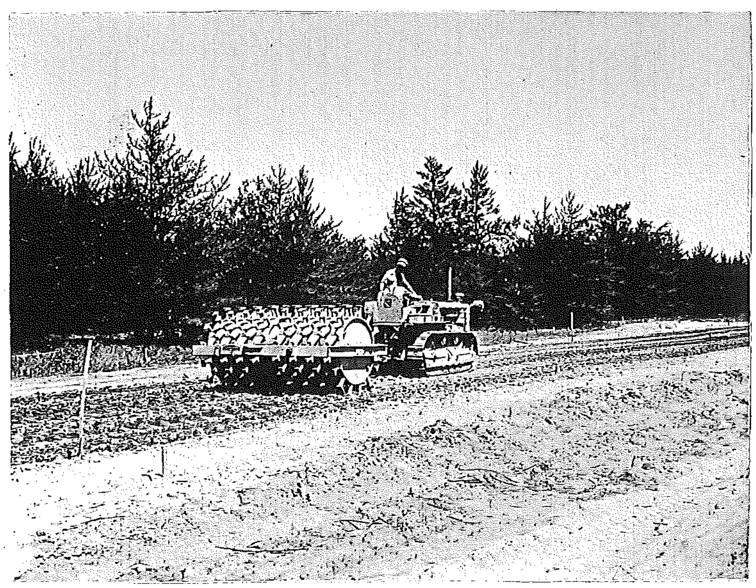
Pneumatic Rolling

At first the pneumatic tire roller was not used as it was thought that the smooth roller following the sheepsfoot roller would suffice to give the desired compaction. After the first two days processing when it was discovered that the 5 ton smooth roller could not be used due to the unstable nature of the soil, the pneumatic roller was introduced and the smooth roller omitted. The pneumatic roller operated satisfac-

FIGURE 10



(A) Application of Water



(B) Consolidation by Sheepsfoot Roller

torily with 2 or 3 passes being sufficient to compact the surface. During the latter part of the project a road drag, made up of two pieces of angle iron with mechanism for varying the angle of the blades, was used to obliterate some of the tire marks left by the rubber tired roller. Also, before and during the rubber tired rolling a spike tooth harrow with teeth set almost flat was applied to scratch overlapping tire compaction places and maintain as even a surface as possible.

Checks of the densities obtained indicate that the rubber tired roller as well as the sheepsfoot roller gave good densities.

Smooth Roller

It is recommended that in the future no processing be permitted unless the contractor has a smooth roller of the proper proportions. It is believed that in material similar to that encountered on this project a smooth pull roller of 2 to 3 tons with a 3 to 4 foot diameter should give satisfactory results. Such a roller, if not made commercially, could be made up at relatively small cost from a seamless water tank, with provision for filling with water.

Curing

Wet earth curing was used throughout the project. The cover was usually applied on the morning following the processing. At first the cover was applied with a heavy patrol grader. This proved to be quite unsatisfactory as the wheels cut into the fresh roadway. The method was then changed and the cover applied by hand. When there was an impending rain in the evening the treated roadway was covered with waterproof paper immediately after the end of processing operations. It is suggested that covering the treated roadway with water-proof paper immediately after completion be specified as standard procedure.

Control of Moisture, Density, etc.

During the afternoon preceding the days processing the raw soil was sampled and moisture content determined. Sufficient water was added to bring the soil to its optimum. During dry mixing, the soil-cement mixture was sampled and its moisture content determined. At the same time, the optimum moisture and maximum density test was run to determine the exact maximum density and optimum moisture under actual field conditions. From the moisture check and the optimum obtained the final water application was specified.

At the conclusion of wet mixing another moisture check was made and if the water content was found to be below optimum additional water was added. It is important at this point to estimate the evaporation losses so that it will not be necessary to add water after wet mixing is completed, as this will delay construction operations for as much as one hour.

At the start of packing operations large soil-cement samples were taken for the molding of laboratory specimens. During the first part of the project, the grade was sampled at 3 or 4 stations and a composite sample made up for the laboratory specimens. Later the material was sampled every 200 feet and specimens molded from each station. This was done in order to attempt to evaluate the difference in soil, water and cement content at different points in the days run.

Another moisture check was made of the material remaining unpacked after the sheepsfoot roller completed its work. The final moisture check wa s made by visual inspection during the rubber tired rolling and, when needed, a very light spray was applied.

In places where it is not convenient to move the field laboratory along with the processing such as was the case on this project, a convenient method of making the numerous moisture checks, which must be done rapidly, is to provide a box in which is carried a scale for weighing and a gasoline stove for drying the moisture samples. In this manner, all moisture checks are made very conveniently adjacent to the days processing.

Density tests of the completed roadway were usually made on the day following the processing. To simplify the field work a 2 quart jar was filled with a definite amount of previously calibrated sand, and one jar was provided for each test to be run. The excavated material was carefully placed in a moisture proof can and labeled to correspond to the particular jar used. In this manner no weighing was done in the field.

Checks on depth of completed roadway were made at the same time as the density tests. All density tests showed densities well within the minus 5 pounds per cubic foot usually allowed. The depths were practically all more than 5 inches. This was due to the difficulty in controlling the equipment in the loose sand.

<u>Field Specimens</u>

A large number of Proctor cylinders were molded from roadway material taken at the time of final mixing. It is contemplated to use these specimens for future laboratory study to attempt to evaluate field factors such as mixing, control of admixes and moisture and thus obtain a correlation between the durability of laboratory and that of field specimens. The study in the laboratory of actual cores taken from the processed roadway as to the voids characteristics, durability, density and compressive strength would also afford a comparison between laboratory specimens and the product to be obtained in the field.

CONCLUSIONS

The following conclusions are based on observations made during the various stages of construction.

1. The point of primary importance which this project has demonstrated so far is that soils with poor gradations present construction difficulties. The soil on this project is so poorly graded that it lacks sufficient stability to support the equipment during construction. This caused poor control of depth and water spreading and made construction operations generally difficult.

2. The rotary tiller is a very efficient piece of equipment, if properly powered. The power supplied by a 40 h.p. tractor is quite deficient.

3. In the absence of sufficient power for the rotary tiller, a disc harrow is an invaluable asset. A disc harrow should be on hand at every job where there is lack of power for the rotary tiller and for emergency use.

4. In loose soils plowing should be held to a minimum. One pass of the plow is usually sufficient to bring material up from the bottom.

5. A spray bar on the water distributor, of sufficient length to cover the full width of roadway in one pass should be specified.

6. After completion of smooth rolling, absolutely no equipment should be allowed on the treated roadway, and even walking should be restricted to a minimum, until covered with at least 2 inches of soil.

7. Curimg material should be wetted by hand.

8. The length of roadway which may be treated successfully in one day depends entirely on the condition and amount of equipment available and on the skill and organization of the contractor's personnel. During the latter part of this project, with unskilled equipment operators, mediocre organization, not the best of equipment and difficult working conditions, 800 feet of 22 foot roadway were processed in a 12 hour day.

TABLE III

SUMMARY OF CONSTRUCTION IRREGULARITIES

Date	Station	Weather	Temp.	Hours	Soil Condition	CONSTRUCTION IRREGULARITIES	Test Hole Densities	
							Station	Total
8-1-41	329 to 323	Clear- a.m. Clear- p.m.	82° 88°	10-1/2	Cement - 8% Limestone dust added 329-328 - 3.3% 328-323 - 7.1%	Spray nozzles too small, removed. Water accumulated in wheel tracks. Rotary tiller cultivator and plow were used. Cultivator followed water distributor. After every trip final mixing done with tiller. Smooth roller did a poor job because moisture content was too high. Overestimated moisture losses		
8-2-41	323 to 318	Clear- a.m. Clear- p.m.	76° 90°	13-1/4	Cement 8% Limestone dust-5.6%	Applied water without spray nozzles, smooth roller bogged down in very sandy spot.	321+50 319+00	122.7 130.0
8-7-41	318 to 312	Clear- a.m. Clear- p.m.	80° 92°	11	Cement 10% limestone dust-8.1%	Difficulty in spreading cement and applying water. Poor operator on patrol grader	317+00 314+50	117.0 118.0
8-8-41	312 to 302	Fair- a.m. Cloudy- p.m.	86° 92°	21-3/4	Cement 10% Limestone dust 8.1%	Application of water slow	310+00 306+00	119.0 118.0
8-12-41	302 to 294	Cloudy- a.m. Cloudy- p.m.	69° 62°	15-1/4	Cement 10% Limestone dust 8%	Method of spreading cement changed. Sacks spotted and cement spread by hand. Difficulty in controlling depth of plowing. Disc mixed uniform full depth	301+00 299+50 297+50	115.1 115.3 121.0

Date	Station	Weather	Temp.	Hours	Soil Condition	Construction Irregularities	Test Hole Densities	
							Station	Total
8-13-41	294 to 286	Cloudy-a.m. Clear-p.m.	65° 68°	15	Cement 10% Limestone dust 8%	Unit pressure 100#/sq.in.too heavy for compaction. Unit with sheepsfoot roller to 80#/sq.in.gave satisfactory compaction. Difficulty in spreading water. Contractor attempted to spread cover material by grader. This operation was stopped because grader marked surface.	293+00 291+00 289+00 287+00	120.9 116.1 115.9 119.9
8-14-41	286 to 278+25	Cloudy-a.m. Cloudy-p.m.	66° 73°	18-1/4	Cement 10% Limestone dust 8%	Difficulty encountered in obtaining proper compaction at edge of treatment in cut section. Water distribution not uniform. Rain at 10:30. Surface covered with paper.	285+00 283+00 281+00 279+00	125.6 118.8 112.1 131.0
8-16-41	278+25 to 270+34	Cloudy-a.m. Fair-p.m.	68° 72°	17-3/4	Cement 10% Limestone dust 8% Silt 8%	Silt spread rate 5yds/sta. After compaction with sheepsfoot surface rolled once with roller then rolled with steel float Obtained best surface with this method. Contractor short-handed thus operation dragged out.	277 275 273 271	109.4 115.2 122.4 121.0
8-18-41	270+34 262+46	P.Cloudy-am P.Cloudy-pm	74° 76°	12	Cement 10% Limestone dust 8% to sta. 267 Silt 8%	Operations normal. Difficulty in compacting edges.	270 268 266 264	118.9 114.0 105.9 109.0
8-19-41	262+46 to 254+60	Cloudy-a.m. Fiar - p.m.	63° -	17-3/4	Cement 10% Silt 8%	Operations normal. Difficulty in compacting edges		no data
8-20-41	254+60 to 246	P.Cloudy-am Cloudy-p.m.	76° 71°	17-1/4	Cement 10% Silt 8%	Operations normal. Poor compaction between sta. 249+50 to 248+50 in a cut section.		no data

PART II

SAND-BITUMINOUS STABILIZATION

Part II contains a description of the various activities incidental to the construction of the sand-bituminous section of the Grayling project.

The laboratory studies and observations on field operation were under the supervision of T. Wolczynski. Part II is essentially his report which was submitted upon completion of the project.

This report represents the experience and knowledge obtained from actual trial in the field to produce satisfactory base course by the stabilization of sand with several totally different types of bituminous substances. The bituminous materials utilized include, medium curing asphaltic oil (MC-2), rapid curing asphaltic oil (RC-2), slow breaking asphaltic emulsion (AE-7), and a cut-back road tar (T-3).

The sand-bituminous stabilization section is approximately 4-1/2 miles in length, located on the west end of the Grayling project. This is the first project of its type and scope to be attempted by the Michigan State Highway Department.

The construction of the bituminous section will be discussed under laboratory studies and field operations. The laboratory studies will include methods of determining the filler and binder content and the establishment of specification requirements. Field operations involve all operations incidental to producing a satisfactory surface.

Laboratory Studies

Several of the southern coastal states have been stabilizing local sands for road purposes with considerable success. Their problem is somewhat analogic to the situation at Grayling and consequently we have profited a great deal by their experiences in sand-bituminous mixtures. In addition the various manufacturers furnishing bituminous materials for this particular project were very cooperative and helpful by submitting specifications and recommendations for sand-bituminous mixtures.

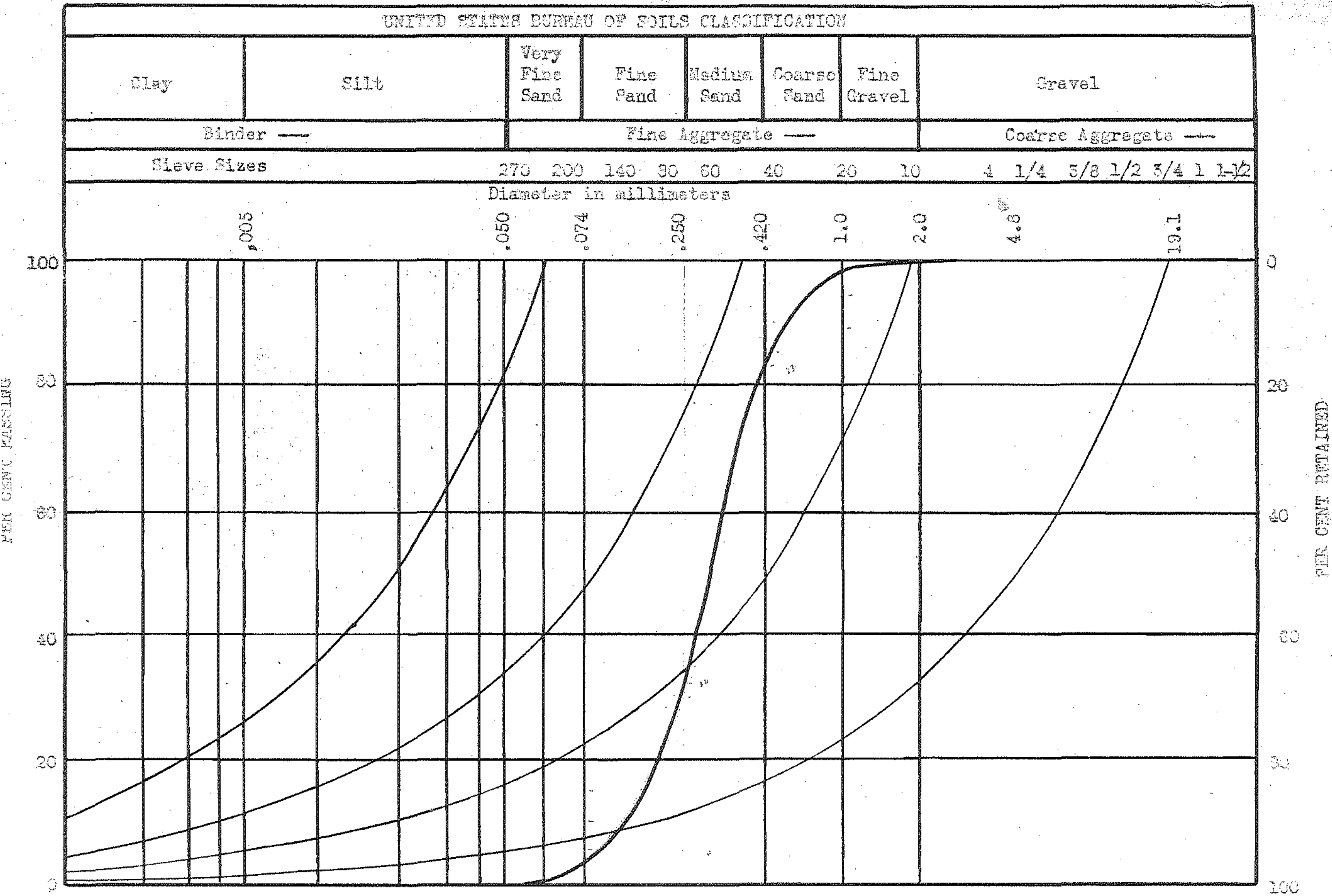
The laboratory phase of the work consisted of a careful study and analyses of the soils on the project; the determination of the optimum bitumen content and preparation of specifications.

The Soil

Grayling sand exhibits very poor bearing capacity, lacks sufficient fines, and, in general, is a poorly graded mixture comparable to dune sand, as can be seen by observing the typical grading curve presented in Figure 11. The usual methods of stabilization of such a soil would involve the use of considerable quantities of clay and gravel. As clay and gravel are not always available locally, and as gravel type bases require oil aggregate mats to produce satisfactory all-weather surfacing, it becomes apparent that there is a need for other means of producing all-weather stabilized bases which when sealed or armor coated will produce comparable results to those obtained by means of gravel base and oil aggregate surfacing.

Addition of Filler for Stability

The first step in the stabilization of this soil with bituminous materials required that sufficient fines be added to bring up the bearing strength of the sand, which in many cases was below 20 pounds per square inch. As silt is the most economical source of filler and is always available locally, it was thought advantageous to use it in preference to more expensive types of filler. The effect of filler on bearing strength of Grayling sand is well substantiated by the laboratory data plotted on Figure 12. It may be stated that the bearing test is an excellent method for predicting both in the field and the laboratory the suitability of a



TYPICAL ANALYSIS OF GRAYLING SAND

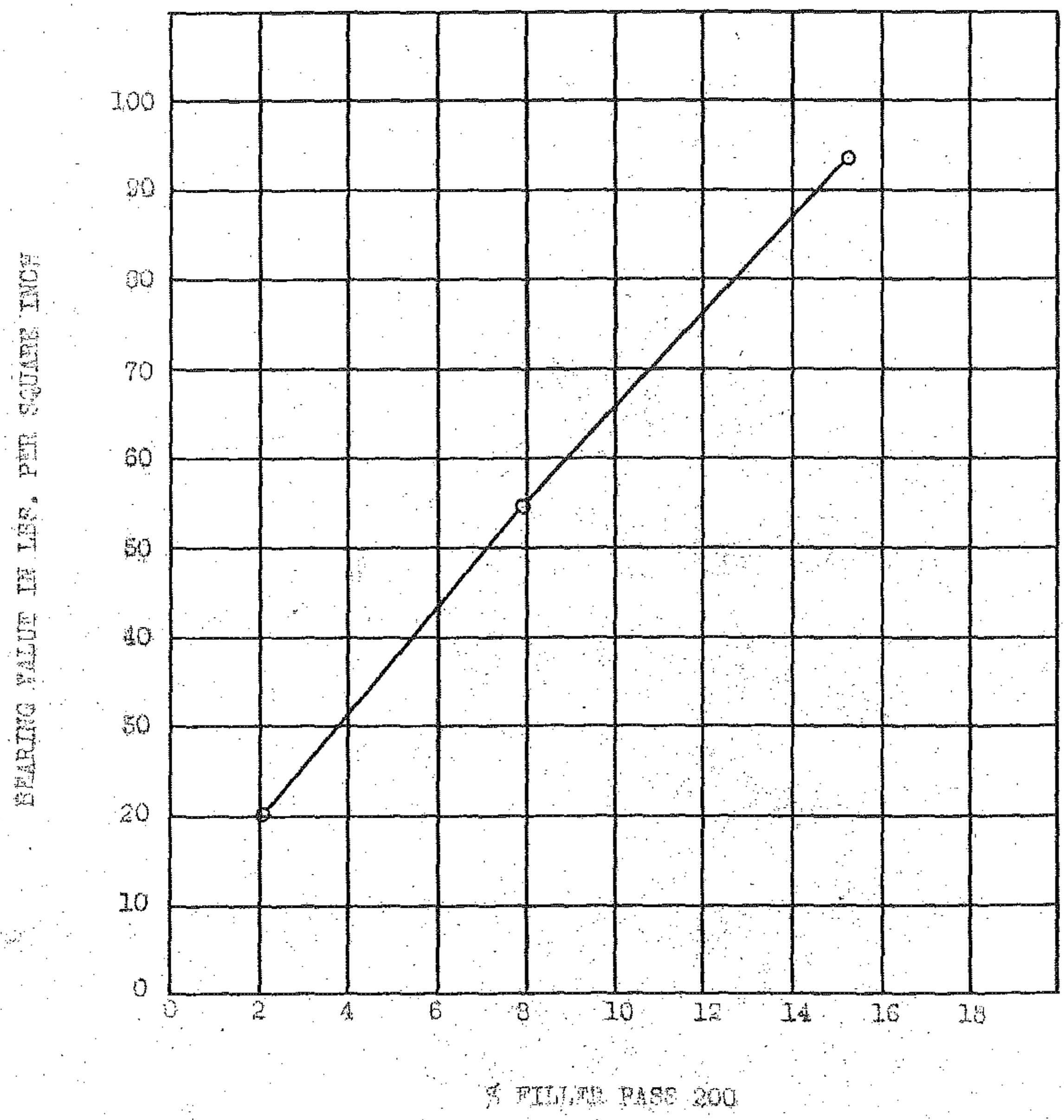
(Figure 11)

THE EFFECT OF FILLER ON THE

BEARING CAPACITY OF

GRAYLING SAND

Florida Bearing Test



(Figure 12)

sand or soil for bituminous stabilization. Experience in the field indicates that when the bearing strength is below 25 pounds per square inch, it becomes very difficult to support construction equipment and to obtain mixes having satisfactory stability; this was found to be definitely true by actually omitting the addition of filler on several sections.

From what was mentioned in the above paragraph it does not follow that excess filler is advantageous, even though bearing strength will be higher with excess filler. The economics of bituminous stabilization demands that a minimum of bituminous material be used. High filler contents require more binder to produce mixes which will not be friable and which will resist the effects of abrasion from exposure to traffic prior to armor coating.

Thus, it is of the utmost importance that the minimum of filler be established for the soil as well as the optimum amount of bitumen which will be required for this amount of filler. This, of course points out the importance of having close control of the amount of filler added in the field if best results are to be secured, and if the filler content is found to be low on checking the subgrade then more should be added; if too high, then the subgrade which is to be treated should be incorporated to a sufficient depth so as to decrease the concentration of the portion to be stabilized. Therefore, once the minimum filler content is established, it is possible to determine in the laboratory the optimum bitumen needed for stabilization. Physical characteristics of the subgrade prior to application of bituminous material are shown in Tables No. 4, 5, 6 and 7. Information as to bearing capacity, gradation and moisture in subgrade, and also fines added to the various sections are given, and bear out facts expressed in previous paragraphs. The stability of the sand-filler mixture was determined by the Florida sand stability test.

TABLE 4

MC-2 Stabilizer Data Prior to Application

Condition of Sand Soil

Sta. to Sta. Total Section	Moisture Percent	GRADATION Passing 10 Retained 50	Passing 50 Retained 100	Passing 100 Retained 200	Passing 200	Bearing Test Lbs.	Silt Applied yds/sta	Remarks
246-242	4.0	42.1	45.0	6.2	6.7	39	5	Normal filler content
242-230	3.0	38.6	50.2	5.1	6.1	33	5	Normal filler content
230-217+50	4.0	39.3	43.5	6.2	11.0	45	10	→ Sta.221-219 extra filler
		45.4	45.4	4.2	5.0	37	5	→ sta.230-221 normal filler
		49.7	45.5	2.4	2.4	19	None	→ Sta.219-217 no filler added
217+50 205+25	2.8	38.5	50.5	4.8	7.2	42	None	Normal filler content
205+25 187+50	2.2	47.2	40.0	5.2	7.6	39	None	Normal filler content
187+50 → 176	7.8	40.4	46.5	6.4	6.7	42	None	Normal filler content
176-163	4.2	51.4	36.5	6.6	5.5	45	None	Normal filler content

TABLE 5

RC-2 STABILIZER DATA PRIOR TO APPLICATION

Sta. to Sta. Total Section	Moisture Percent	GRADATION				Bearing Test lbs.	Silt Applied yds/sta	Remarks
		Pass. 10 Ret. 50	Pass 50 Ret. 100	Pass 100 Ret. 200	Pass. 200			
163-152	4.5	41.9	48.6	6.1	3.4	19	5	Normal filler content
152-141	7.2	31.3	49.2	8.4	10.6	40	5	Normal filler content
130-132	5.3	39.5	39.5	6.6	14.3	66	10	Double amount filler
132-134		47.4	43.2	6.6	2.8	22	None	No filler applied
141-134		37.1	45.7	7.4	9.8	43	5	Normal filler content
130-119	5.0	43.5	41.2	7.3	8.0	62	5	Normal filler content
119-113+50	4.0	43.1	36.8	8.5	11.6	72	5	Normal filler content
113+50-108	4.0	43.1	36.8	8.5	11.6	72	5	Normal filler content
108-97	5.0	40.5	38.4	8.3	12.8	35	5	Normal filler content
97-86	3.0	43.6	38.8	7.2	10.4	64	5	Normal filler content

TABLE 6

AE-7 Stabilizer Data Obtained Prior to Application

Sta. to Sta. Total Section	Moisture Percent	GRADATION				Lbs. Bearing Test	Silt Applied yds/sta	Remarks
		Pass. 10 Ret. 50	Pass. 50 Ret. 100	Pass. 100 Ret. 200	Pass. 200			
3-8	8.2	61.7	18.4	3.3	7.6	54	5	Filler content normal
8-19+50	7.7	38.1	32.8	6.3	13.8	70	5	Filler content too high
19+50-32	7.6	37.6	37.6	6.0	12.9	76	5	Filler content too high
32-44	7.0	33.3	37.3	8.2	12.9	62	5	Filler content too high
44-56	6.9	38.0	38.5	11.3	12.0	65	5	Filler content too high
56-68	7.5	32.5	45.5	9.0	13.0	64	5	Filler content too high
68-80	7.7	36.0	47.0	6.3	10.3	62	5	Filler content too high

TABLE 7

T-3 Stabilizer Data Prior to Application

Sta. to Sta. Total Section	Moisture Percent	GRADATION				Bearing Test lbs.	Silt Applied yds/sta	Remarks
		Pass.10 Ret. 50	Pass.50 Ret.100	Pass.100 Ret. 200	Pass. 200			
80-83	10.7	33.2	44.4	7.7	14.7	65	5	Abnormally high filler content
83-86	8.6	34.6	46.9	8.1	10.4	55	5	Abnormally high filler content

33.9 46.7 7.9 11.5
34.2 46.1 8.0 11.7

Florida Sand Stability Test

The sand is oven-dried to constant weight. Six hundred grams of the dried sand are slightly dampened with 10.5 cc of water and mixed to uniformity. The sand is placed in a cylindrical cup 3 inches in diameter by 3 inches in height and given an initial pressure by hand and then subjected to a pressure of 1200 pounds for compaction. The bearing plate is removed and a small bearing plate of exactly one square inch area is placed in the center of the cup on the surface of the sand. A load is applied to the bearing plate in a lever arm machine by allowing lead shot to flow into a bucket on the end of the lever arm. Shot is applied until the bearing plate upsets the stability of the sand. The load in pounds per square inch is recorded. (The weight of shot is multiplied by 4 to determine the pressure per square inch on the sample as the lever arm has a 4 to 1 ratio.) The Florida SRD has adopted the requirement that the sand must have an untreated stability of 25 pounds to be satisfactory for bituminous mix.

Optimum Bituminous Content

The principle involved in stabilizing sandy soils is based upon the fact that the bearing capacity of a granular material like sand can be greatly increased by simply increasing the internal friction of the surfaces of the soil particles with films of bitumen. The factor of cohesiveness produced by the bitumen enters the picture only from the standpoint whether or not our design calls for a traffic resistant base. Thus, a base which lacks sufficient cohesion might have excellent stability yet would abrade excessively if not sealed early enough with an armor coat. Where sufficient cohesion is obtained in addition to stability, then it is possible to withold a seal-coating until maximum curing of the mat is obtained.

In order to obtain the optimum bitumen content, mixes were prepared and specimens of varying bitumen and filler contents were made and were tested both in an uncured and cured condition by means of a modified Hubbard and Field Stability Test. Specimens were also tested under the effects of both capillary moisture and total immersion in water. Results were plotted for each bituminous material as to stability and absorption. From this data the optimum bitumen content was ascertained. Typical results are shown graphically in figure 13. Maxima on curves indicate proper amount of bituminous material, that is, when bituminous material is plotted against stability in pounds.

It was found from the above laboratory work that the optimum bitumen content for the following materials, T-3; MC-2; and AE-7 were 6 percent, 6 percent and 8 percent respectively. At the time of performing the laboratory work we anticipated using T-3 for an entire section. However, it developed later that we could not obtain sufficient T-3 material to do the work, consequently, RC-2 asphaltic material was substituted. The percentage of RC-2 used was approximately 4 to 5 percent.

Upon the basis of the laboratory work it was possible to prepare specifications and instructions incidental to construction procedure. The specifications are included in the Appendix.

CONSTRUCTION PROCEDURE

The construction procedure for building a sand-bituminous stabilized surface consists essentially of three major operations; mixing operations, aerating or curing and consolidation and finishing. The three operations will be discussed in the order mentioned.

DESIGN
SAND-BITUMINOUS MIXTURE
MC-2 ASPHALT
10% MINERAL FILLER

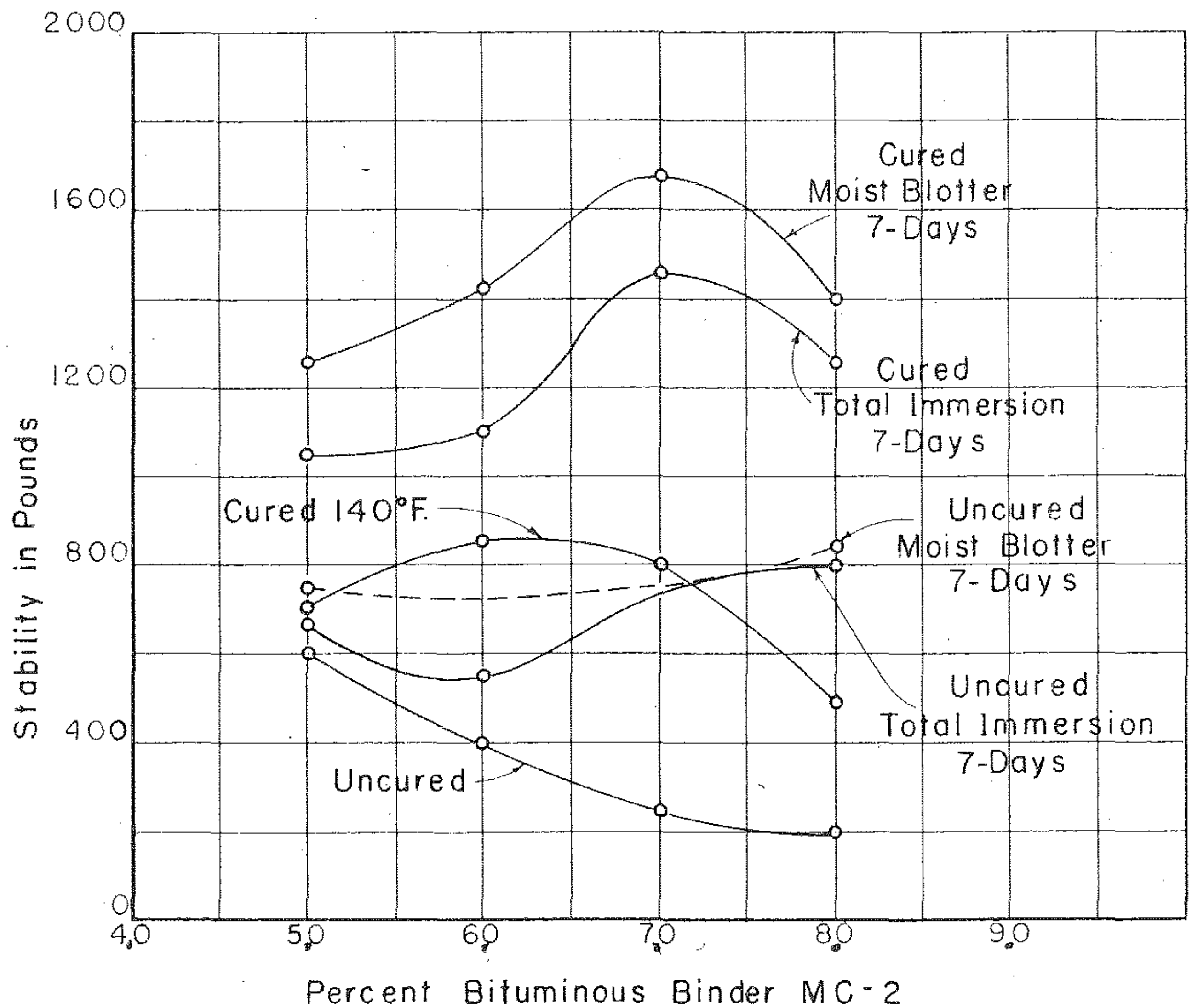


Figure 13

Mixing Operations

Mixing operations include the incorporation of fines into the natural soil to produce mechanical stability, the addition of necessary moisture to insure proper distribution of the bituminous materials, and the application of bituminous binder and subsequent mixing operations.

Incorporation of Fines

After the proper amount of silt had been spread upon the sand subgrade, it was intimately mixed with the sand. The mixing was accomplished most effectively by several passes of the Seaman Rotary Tiller which, when set to proper depth, produced a mix of silt and sand of a surprising degree of uniformity. See Figure 14.

Addition of Water

A comprehensive study was made on the effect of water upon the mixing operation. This study revealed that a certain amount of water aids greatly the mixing process. However, successful results were obtained over quite a great range of moisture contents, which seems to indicate that final conclusions must be based upon durability of the various sections treated. Excess water is less objectionable with bituminous materials which are less prone to stripping action of water, this indicates that some consideration should be given to this phase of the problem of stabilization with bituminous materials. With asphaltic emulsion of the slow breaking type, some of the bituminous material may be washed out of the mix due to rainfall, actual extractions on mixes indicated that the losses are very low even under the severest rainfalls; hence, with emulsions as well as with other bituminous materials, excess moisture is not objectionable if it can be evaporated by

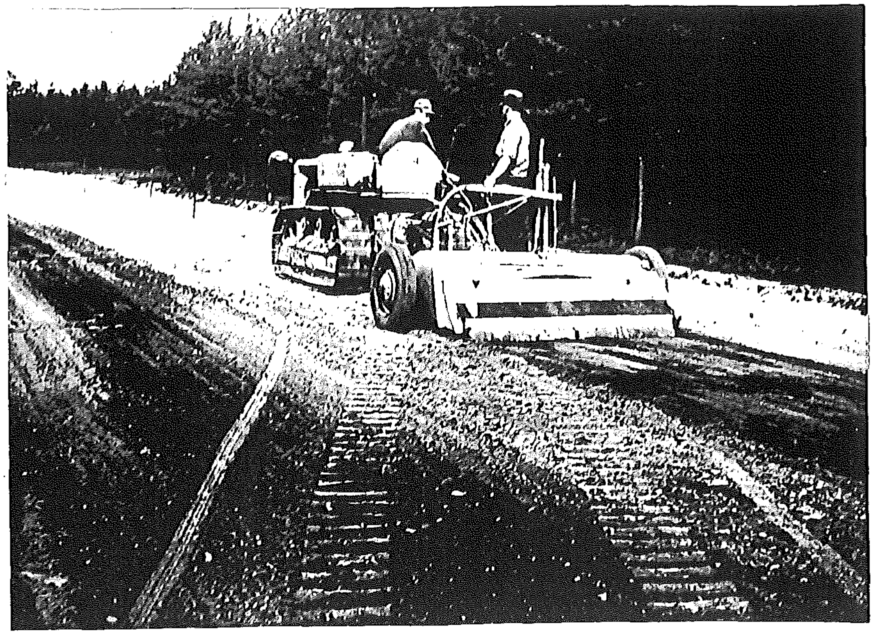


Figure 14. Mixing silt into sand subgrade by means of the Seaman Rotary Tiller

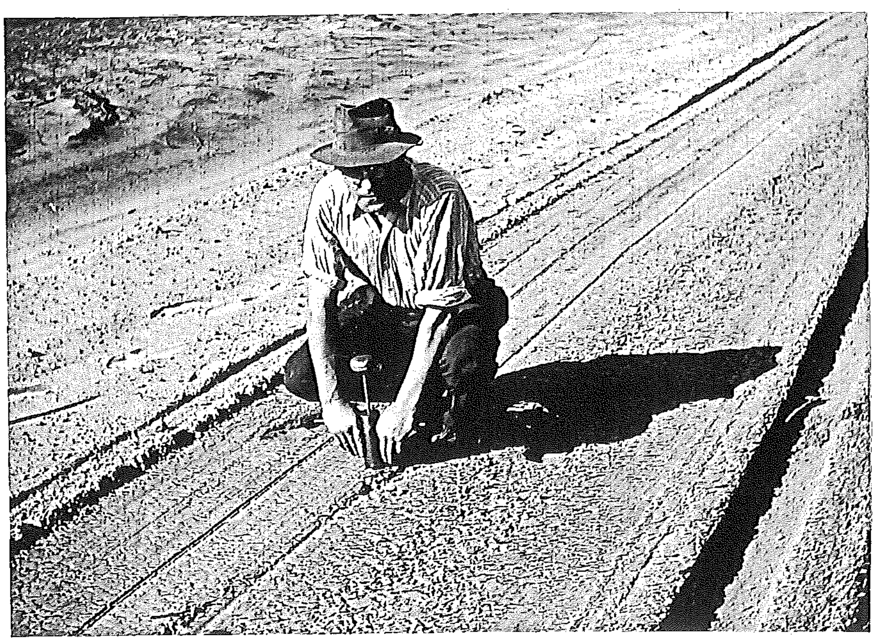


Figure 15. Sampling the subgrade prior to application of bituminous material.

aeration to give a mix capable of being compacted.

An application rate of 0.5 to 0.6 gallons per square yard per inch depth from a 1000 gallon distributor was found to be satisfactory for most of the bituminous materials, as the emulsion must be added in larger quantities, the application rate was raised slightly to between 0.6 to 0.7 gallons per square yard per inch depth. See figures 15 and 16.

Application of Bituminous Material

The data obtained concerning application of the bituminous materials in the field are shown in tables 8, 9, 10 and 11. One factor which must be given consideration in the problem of application of the bituminous materials is that a system of distribution be used which will not delay the continuous addition of the bituminous material to the subgrade within a practical length of time. The hauling of the bituminous materials from a remote loading location would require auxiliary distributors. Also, it is of prime importance that too large a capacity of distributor not be used unless sufficiently powered tractors are available to help pull the distributor through difficult subgrades.

The 22 foot width base required that an 11 foot spray bar be used on the distributor. After each application of the bituminous material, a spring tooth harrow or spike tooth drag was used for initial mixing. Then final mixing was accomplished by use of a disc harrow followed by a patrol grader or bull dozer, and lastly followed by a rotary tiller, until uniformly mixed. See figures 17, 18, 19, 20 and 21. Condition of the sand base and shoulders limited mixing procedure, a 6 inch uncompacted or a 5 inch compacted depth was mixed full depth. Although this contradicts methods used elsewhere, our

Figure 16. Sand subgrade prior to application of bituminous binder.

Figure 17. Application of bituminous material

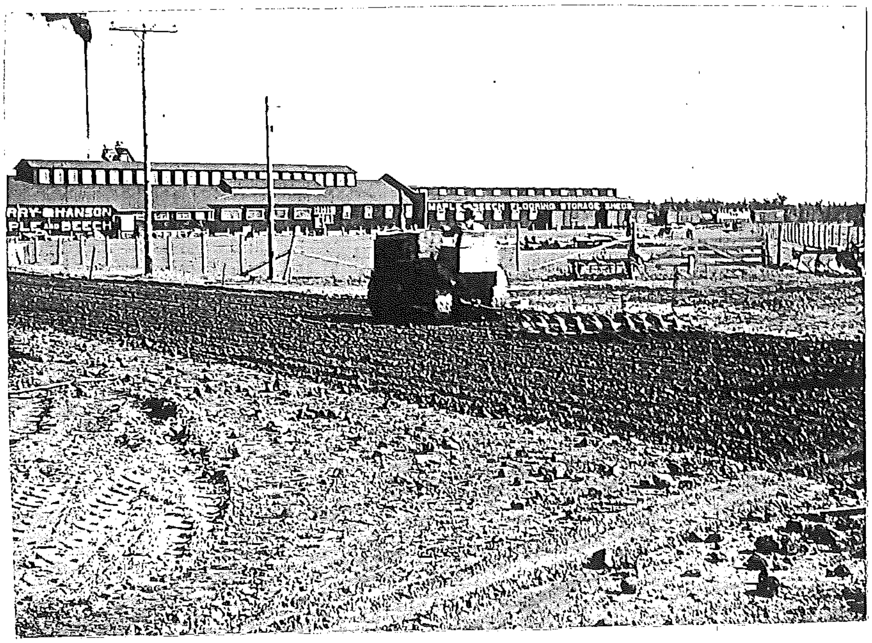


Figure 18. Initial mixing by means of a spring tooth type of harrow.

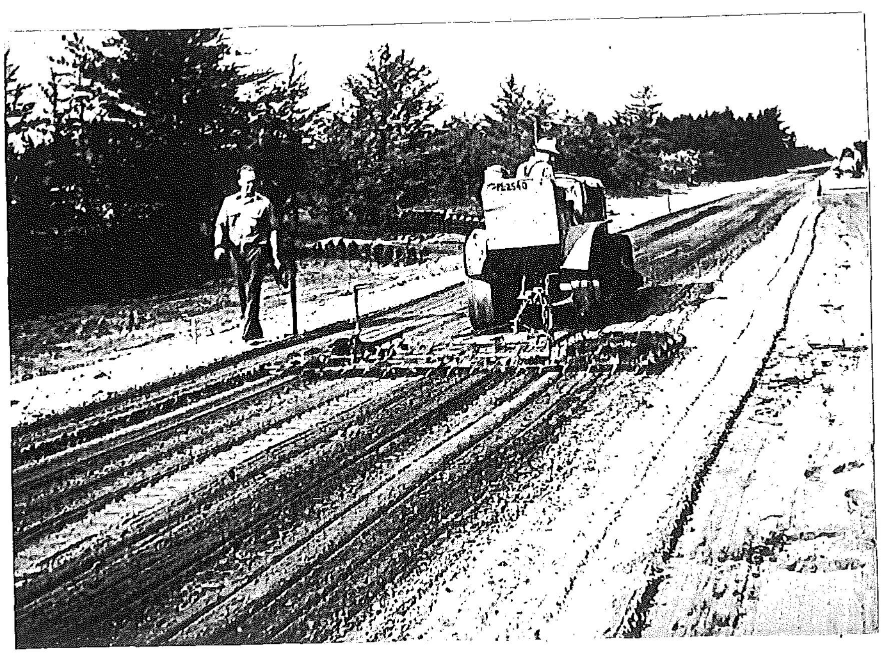


Figure 19. Initial mixing with the spike tooth type of harrow.

TABLE 8

MC-2 Stabilizer, Data Concerning Application

Total Sect. sta. to sta.	Moisture Prior to Application Percent	Actual Gals. 60°F per syd./in.	No. of Appli- cations	No. of Feet	Total Gals. 140°F	Total Gals. 60°F	MC-2 per 100 lbs. dry sand, (lbs.)	MC-2 per cent	Remarks
246-242	4.0	0.52	5	400	2600	2510	4.9	4.67	75% full depth, 25% used to enrich top 2". Top - 5.7% MC-2 Bottom - 3.46% MC-2
242-230	3.0	0.52	5	1200	7825	7560	4.9	4.37	1200 gal. top 3-1/2" 4.77% 6625gal. mixed full depth 3.65%
230-217+50	4.0	0.50	5	1350	8500	8200	4.70	4.50	Full depth
217+50 - 203+25	2.8	0.51	5	1425	9200	8900	4.83	4.60	Full depth
203+25 - 187+50	2.2	0.55	6	1575	11000	10,600	5.2	4.84	Full depth
187+50-176	7.8	0.57	5	1150	8200	7900	5.3	5.03	Full depth
176+163	4.2	0.57	5	1300	9150	8850	5.3	5.03	Full depth

TABLE 9

RC-2 Stabilizer, Data Concerning Application

Total Sect. sta. to sta.	Moisture in sand percent	Actual Gals. 60°F per syd./in.	No. of Applications	No. of feet	Total Gals.	RC-2 per 100 lbs. dry sand, (lbs.)	RC-2 percent		Remarks
163-152	4.5	0.53	4	1100	7100	4.70	4.50		Full depth *
152-141	7.2	0.55	4	1100	7350	4.88	4.66		Full depth *. Sta. 144 to 141 additional 400 gal. enriched full depth 5.85#/100# 5.5% RC-2
141-130	5.3	0.55	4	1100	7350	4.88	4.66		Sta. 132-134 had no silt. Sta. 130-132 had 10 yds/sta. additional 950 gal. used to enrich top
130-119	5.0	0.55	4	1100	7350	3.66	3.53	Bot.	75% RC-2 full depth
						6.11	5.75	Top	25% RC-2 top 2-1/2 inches
119-113+50	4.0	0.55	4	550	3675	3.66	3.53	Bot.	75% RC-2 full depth
						6.11	5.75	Top	25% RC-2 top 2-1/2 inches
113+50-108	4.0	0.55	4	550	3675	3.66	3.53	Bot.	75% RC-2 full depth
						6.11	5.75	Top	25% RC-2 top 2-1/2 inches
108-97	3.75	0.55	4	1100	7350	3.66	3.53	Bot.	75% RC-2 full depth
						6.11	5.75	Top	25% RC-2 top 2-1/2 inches
97-86	3.0	0.55	4	1100	7350	3.66	3.53	Bot.	75% RC-2 full depth
						6.11	5.75	Top	25% RC-2 top 2-1/2 inches

*1800 gallons used to enrich rescarified brittle surface stations 163-144

TABLE 10

T-3 Stabilizer, Data Concerning Application

Total Sect. sta.to sta.	Moisture in sand percent	Actual Gals. 60°F per syd/in.	No. of feet	Number of Applications	Total Gallons 60°F	T-3 per 100 lbs. dry sand, (lbs.)	T-3 per cent	Remarks
80-83	10.7	0.59	300	5	2.50	6.25	5.9	Too much moisture
83-86	8.6	0.59	300	5	2.50	6.25	5.9	Too much moisture

TABLE 11

AE-7 Stabilizer

Data Concerning Application

Total Sect. sta.to sta.	Moisture in sand percent	Actual Gals. 60°F per syd./in.	No. of Appli-cations	No. of Feet	Total Gals. 60°F.	* AE-7 per 110 lbs. dry sand, (lbs.)	AE-7 per cent	Bit. per cent	Remarks
3-8	8.2	.658	6	500	4350	6.6	6.2	3.72	2850 full depth 1500 enrich top 1-1/2"
8-19+50	7.7	.692	5	1150	9680	6.4	6.0	3.60	7600 full depth 900 enrich top 1-1/2"
19+50-32	7.6	.678	5	1150	10,150	6.7	6.3	3.78	7600 full depth 1900 enrich top 1-1/2" 250 gal. used to sweeten sandy spots.
32-44	7.0	.650	5	1200	9500	5.7	5.4	3.24	7600 gallons full depth 1900 gallons top
44-56	6.9	.650	5	1200	9500	5.7	5.4	3.24	7600 gallons full depth 1900 gallons top
56-68	7.5	.650	6	1200	11,400	7.2	6.7	4.02	Full depth
68-80	7.7	.650	6	1200	10,400	6.6	6.2	3.72	Full depth

* Intersection to station 3
6400 gallons

experiment shows that mixing full depth will produce satisfactory mixes of a very uniform character. The disc harrow aids greatly in getting the mix down to full depth, while the patrol grader or bull dozer aids in applying pressure on the mix so that the "oil balls" are broken up. The rotary tiller is especially adapted to the elimination of sand streaks sometimes formed when discing and other operations are being carried on to obtain the proper depth. The rotary tiller also acts as an excellent mixing tool, as it kicks up masses of bituminous material and sand to the surface where they can be further disintegrated by the use of equipment which will impart pressure to the mix. However, it was found that the rotary tiller was the most effective as a mixing tool when used with asphaltic emulsion.

Enriched Top Course

On some of the sections the top course was purposely enriched. This varied the mixing procedure somewhat only insofar as some of the bituminous material was held back and was applied later and then mixed in the top portion of the base only. This was found to be poor practice where the binder gives sufficient cohesiveness and the asphalt residue is soft, as rutting may occur, as in the case of the medium curing asphaltic oil. With rapid curing oil, for the amount used and the rapid aeration undergone, it was found necessary to enrich the top of the base to get a top surface which would have proper cohesive properties. In the case of the asphaltic emulsion, it was found that even with enrichment, lack of cohesiveness could not be entirely eliminated; this was partially due to excessive rains encountered and bad weather for drying. In all cases sufficient stability of base was obtained with all bituminous materials used.

CURING OF BITUMINOUS MIXTURES

The most difficult problem confronting the engineer in the field in using cutback oils is to ascertain when the bituminous mix is sufficiently cured or aerated for compaction. Proper curing is very critical, because if the mix is over cured, then it will be dry and dead and the particles of sand or soil will not bind properly. On the other hand, if the mix is insufficiently cured, the base will become unstable, thus resulting in displacement and rutting of the road surface.

Determination of Proper Curing

In order to remove the hazard of guessing as to the degree of curing, a method used in Nebraska was adopted and used in the field to determine the loss of volatiles from the bituminous mixes which contained cutback asphaltic oils. A simple description of the test is given as follows; 500 grams of the mix are weighed and transferred into a thousand cubic centimeter round bottom, short neck pyrex flask, then approximately 350 cubic centimeters of water and 3 grams of sodium carbonate are added to the flask; next a stopper is inserted into the neck of the flask and the contents of the flask are shaken thoroughly for 5 minutes, an A.S.T.M. crank case dilution trap containing water is placed through a cork in the neck of the flask and a reflux condenser is attached to the top of the trap. The tip of the condenser is placed at the indentation in the trap. After the assembly of the apparatus, (see sketch figure 22) heat is applied so that a reflux rate from 85 to 95 drops per minute is maintained.

At the end of a 3 hour period, the heat is removed, and after 15 minutes the volume of distillate floating on top of the water in the graduated column of the trap is read. Loss is calculated as percent of aeration.

$$\text{cms. oil in mix} = \frac{\text{wt. of oil}}{\text{sp. gr. of oil}}$$

$$\% \text{ distillate recovered} = \frac{\text{c.c. dist. in trap}}{\text{c.c. of oil in mix}} \times 100$$

$$\% \text{ aeration} = \frac{A - B}{C} \times 100 \quad \text{where}$$

A = percent distillate in unaerated sample

B = percent distillate in areated sample

C = percent distillate in unaerated mix

With the other bituminous materials where the above test could not be utilized, stability tests were used as a criteria for proper curing. The data obtained in the field on mixes prior to their compaction, includes moisture by the A.S.T.M. method, stability and percent aeration where possible to apply, and also bitumen content by rotarex extraction. The data obtained from the various sections of the Grayling project are presented in Tables 12, 13, 14 and 15.

In a separate study, investigation was carried on in the laboratory to ascertain the effect of curing upon the stability of mixes. Controlled specimens containing no moisture were made from mixes which were allowed to cure to various degrees. These specimens were tested for stability, typical data is shown in Figure 23 for MC-2. The effect of moisture upon the stability of cured mixes was also studied. Here it was found that when the proper amount of water was in the specimens and the specimens were compacted, maximum stability resulted upon curing to constant weight. See Figure 24).

TABLE 12

MC-2 Stabilizer

Data Obtained on Mix Prior to Compaction

Total Section sta. to sta.	Bitumen by Extraction percent	Stability in pounds	Water in mix percent	Distillate Recovered c.c.	Aeration percent	Remarks
246-242	4.8	500	0.0	2.5	62.7	—— Top proper aeration
	3.8	200	0.8	2.5	39.6	—— Bottom insufficient aeration
242-230	4.4	600	1.0	3.1	45.7	—— Top proper aeration
	3.6	200	1.6	2.6	38.7	—— Bottom insufficient aeration
230-217+50	4.8	450	1.3	3.4	36.0	Insufficient aeration
217+50 - 203+25	3.9	500	0.8	2.8	51.8	Proper aeration
203+25 - 187+50	4.8	600	3.8	2.8	51.0	Proper aeration
187+50 - 176	4.4	350	2.2	3.8	39.7	Insufficient aeration
176-163	4.5	400	1.12	3.1	47.8	Proper aeration

TABLE 13

RC-2 Stabilizer

Data Obtained Prior to Compaction

Total Section Sta. to Sta.	Bitumen by Extraction percent	Stability in pounds	Water in Mix percent	Distillate Recovered c.c.	Aeration percent	Remarks
163-152	3.4	400	4.2	1.9	65.5	
152-141	3.2	500	4.0	1.4	75.9	
	4.6	450	4.8	2.3	66.4	Station 144-141 enriched
141-130	3.2	400	3.2	2.2	49.6	Bottom
	5.9	500	2.1	3.7		Top enriched 1 to 1-1/2 inches
130-119	4.9	450	3.1	2.7	61.0	Top, 25% RC-2 saved to enrich top half of mat.
119-113+50	4.4	450	2.5	2.9	58.4	Top, 25% RC-2 saved to enrich top half of mat.
113+50-108	4.6	400	2.8	2.9	58.4	Top, 25% RC-2 saved to enrich top half of mat.
108-97	4.8	450	1.2	2.6	66.7	Top, 25% RC-2 saved to enrich top half of mat.
97-86	4.7	500	1.4	2.4	65.5	Top, 25% RC-2 saved to enrich top half of mat.

TABLE 14

AE-7 Stabilizer

Data Obtained Prior to Compaction of Mix

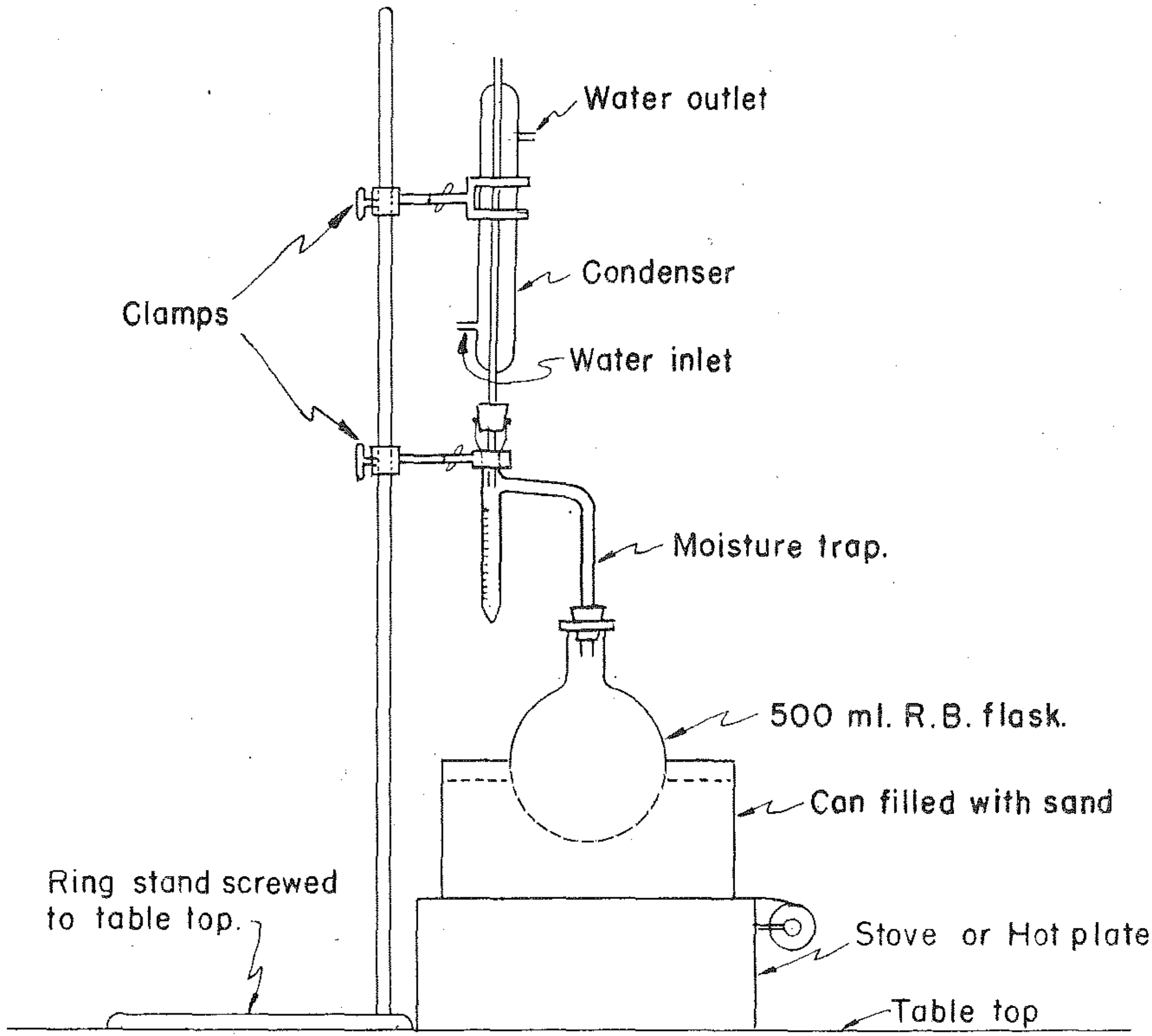
Total Section Sta. to Sta.	Bitumen by Extraction percent	Water in Sand percent	Water in Mix when Compacted percent	Stability pounds	Remarks
3-8	3.9	8.2	6.6	600	Friable mix
8-19+50	3.7	7.7	7.5	400	Friable mix
19+50-32	3.8	7.6	7.0	400	Friable mix
32-44	3.1	7.0	8.7	300	Friable mix
44-56	3.2	6.9	8.0	1100	Friable mix
56-68	3.8	7.5	9.4	300	Friable mix
68-80	3.4	7.7	7.6	800	Friable mix

TABLE 15

T-3 Stabilizer

Data Prior to Compaction

Sta. to Sta. Total Section	Moisture Percent	T-3 by Extraction percent	Bitumen Percent	Stability Pounds	Remarks
80-83	5.3	5.6	3.92	900	Mix unsatisfactory, too soft
83-86	5.6	5.7	3.99	850	Mix unsatisfactory, too soft



Sketch showing apparatus set-up for moisture determination on bituminous aggregate.

(A.S.T.M. D 95-30)

Figure 22

THE EFFECT OF LOSS OF VOLATILES UPON STABILITY

MC-2

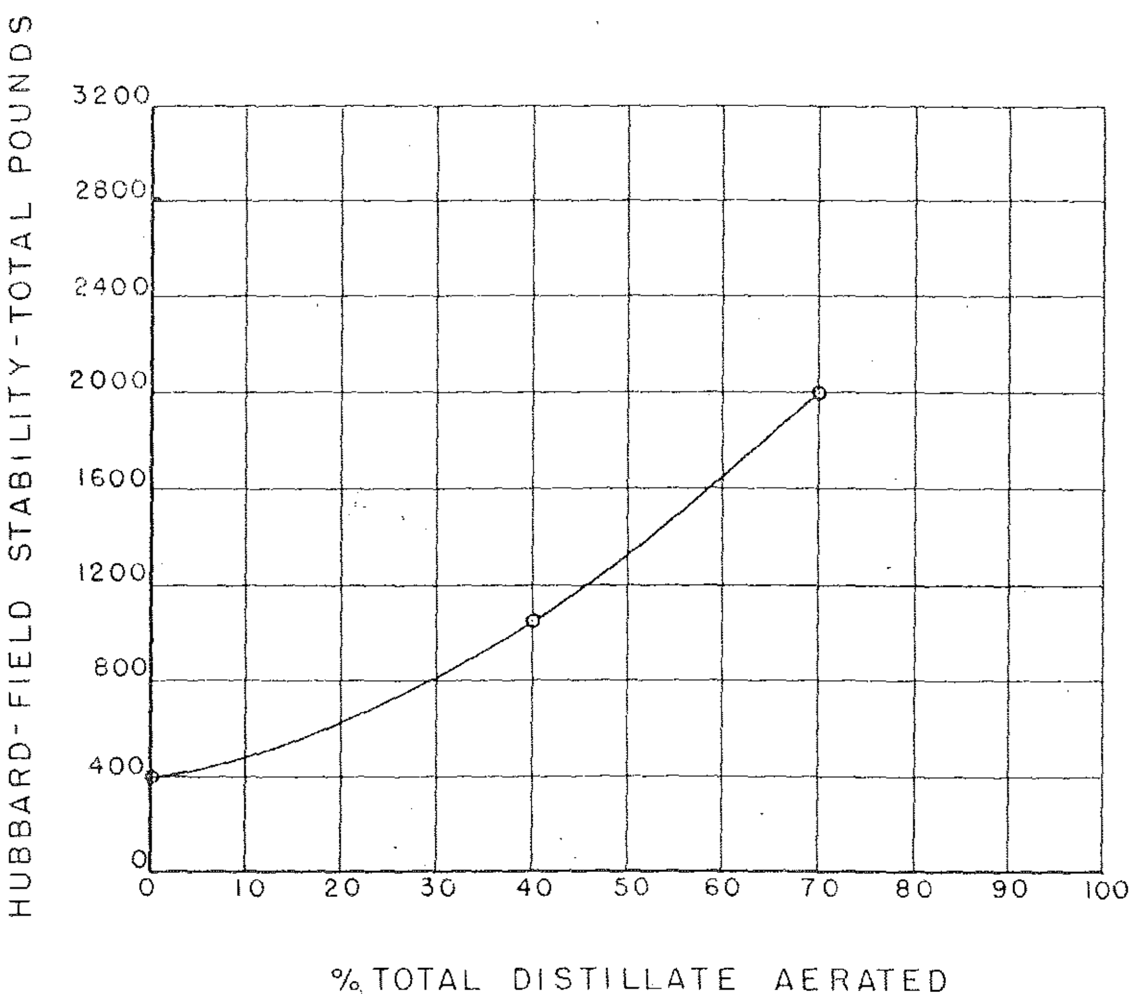


FIGURE 23

THE EFECT OF AMOUNT OF WATER PRESENT ON MIXING

6.5% TAR T-6
10% MINERAL FILLER

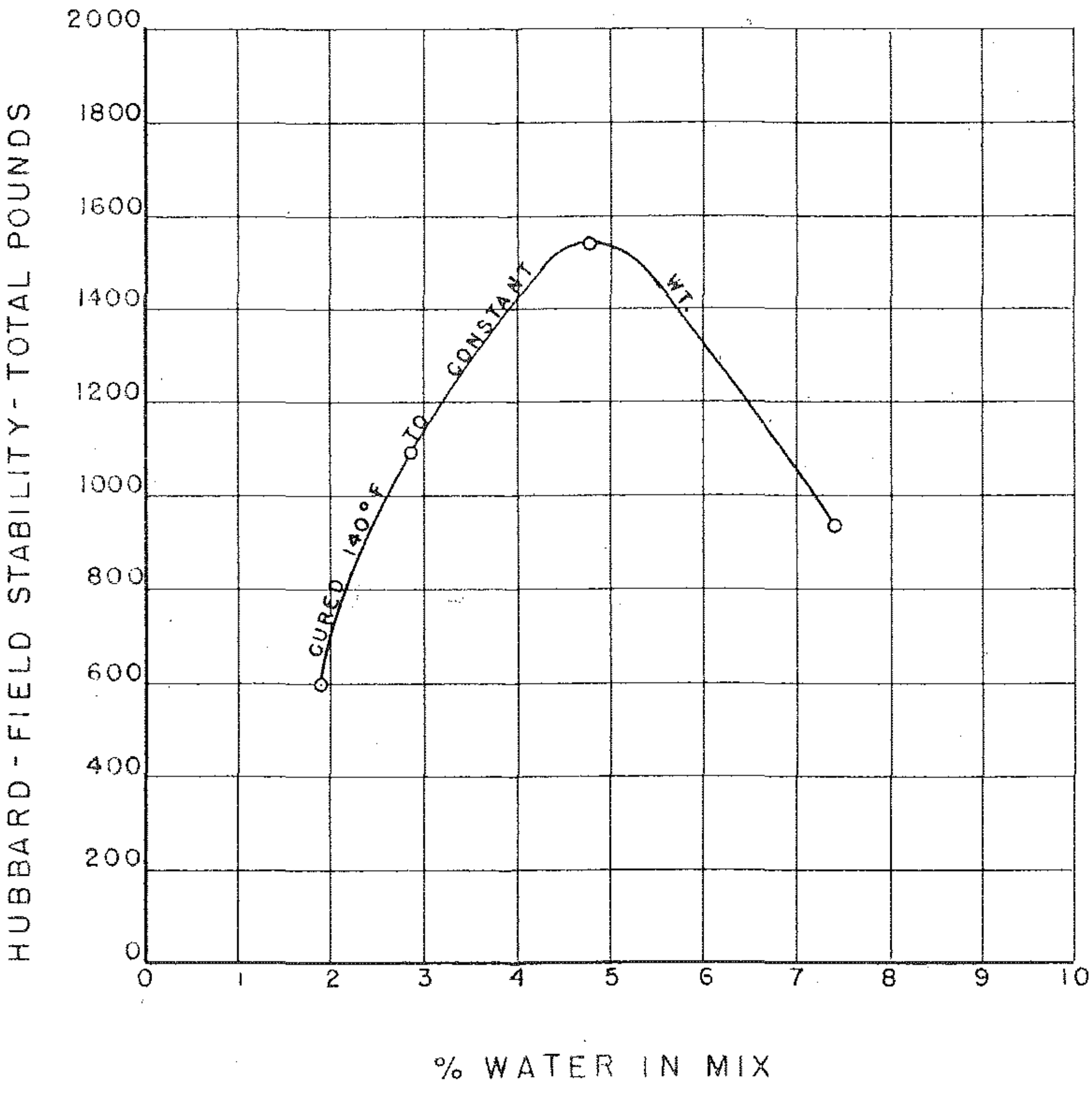


FIGURE 24

This data indicates that for an optimum bitumen content there must be a critical moisture content so that maximum stability be obtained after compaction.

In the field, aeration or curing is obtained by the use of the rotary tiller or disc harrows. Thus, weather conditions and temperature effect the economics or cost of this phase of the work. When weather conditions are proper, then the mixing process alone may be sufficient to produce proper aeration. However, curing is primarily a function of the type of bituminous material used.

COMPACTION AND FINISHING

After a satisfactory uniform mix has been obtained and the mix is sufficiently cured, the next step in building the stabilized base involves compaction and finishing. This involves initial compaction which is obtained with a rubber tired roller, and final compaction which is obtained with a 5 ton tandem roller. The sheepsfoot roller did not prove satisfactory for compacting the sand-bituminous mixture, therefore, it was discarded after a few trials.

Initial compaction

Two different methods of compaction were used successfully. The first method involved the following procedure; a patrol grader was used to straight edge the completed mixture to true grade and proper crown; then this operation was followed by rolling with a rubber tire roller at edges, working toward the middle to maintain crown of base; then any further defects caused by difference in packing by compaction are corrected by patrol grader equipment. Finally, this is rolled with a rubber tire roller once again. See Figure 25. The second method used was developed for the finishing of mixes which ordinarily would set up too rapidly and hence require that less time be spent in the finishing operation, as in the case of the rapid curing asphaltic oil. Three-fourths of the total bituminous material to be added is thoroughly mixed in and the base undergoes an initial shaping and patrol grader operation. Then the remainder of the bituminous material is added and mixed thoroughly; rubber tire roller followed by final shaping with patrol grader and float maintenance followed by the rubber tire roller.

Final Compaction and Finishing

Regardless which of the two methods mentioned above are used, the final compaction and finishing can be secured by use of a 5 ton steel tandem roller. See figure 26. However, the use of the roller must be judicious, as in the case of medium curing asphaltic oil MC-2, it is necessary to wait until temperatures are down early in the morning, while in the case of other bituminous materials which set up very hard it is better to roll when it is warmer. In still other cases, it might pay to forego final rolling until base has stood and cured for 4 or 5 days. However, in any case, the final rolling with a steel roller will be governed by the factors of temperature, stability of mixture, climatic conditions, and moisture in the base.

Figure 25. Compaction with rubber tired roller

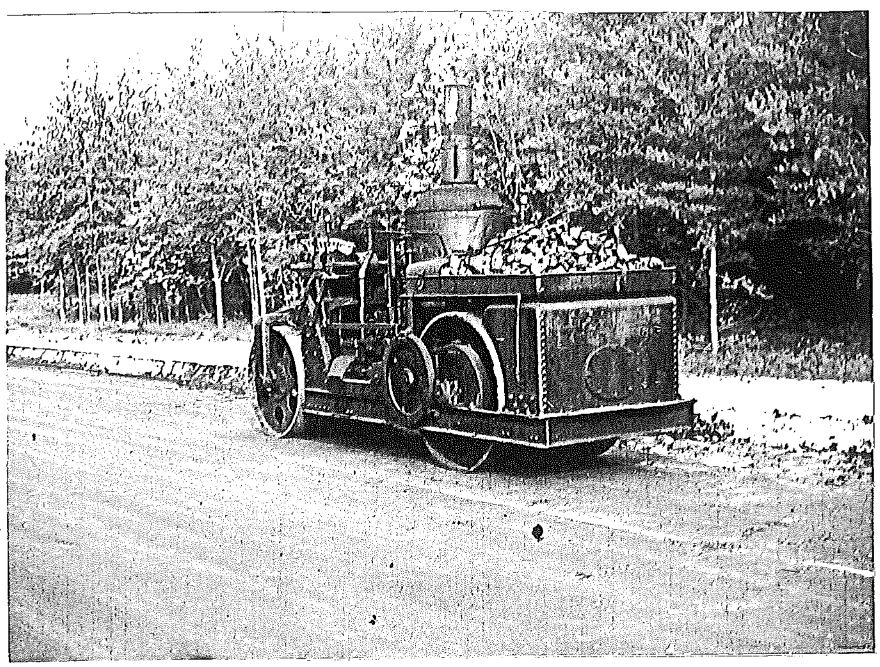


Figure 26. Final compaction by 5-ton steel roller

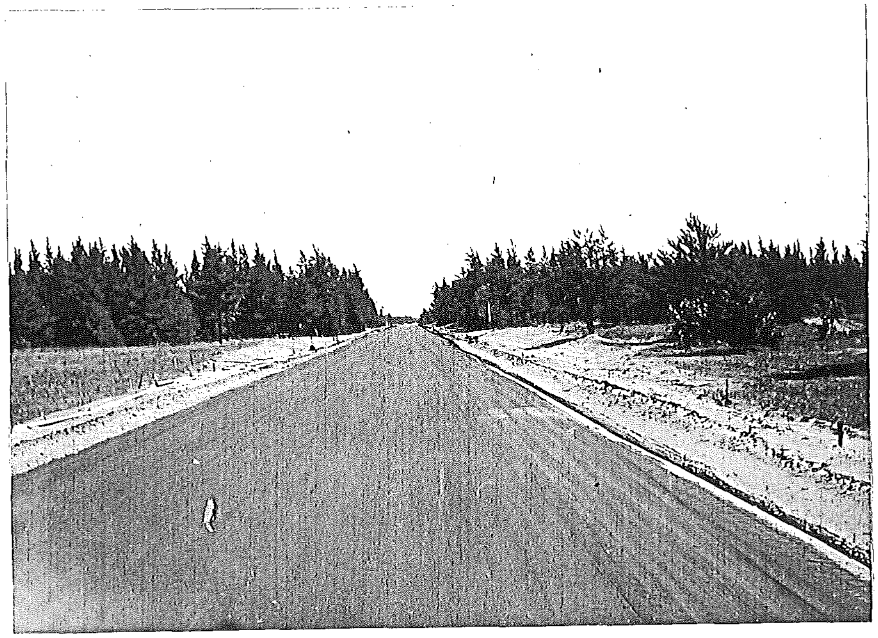


Figure 27. Typical base after bituminous stabilization.

TABLE 16

Typical Analysis of Tar, T-3

General Characteristics	Liquid
Water	1.0
Specific Gravity, 25°/25° C	1.154
Specific Gravity, 15.5°/15.5° C	1.157
Specific Viscosity, 40°C	18.8
Total distillate by weight	
to 170°C	0.5
to 270°C	21.2
to 300°C	28.7
Softening point R + B°C	57°C
Total between CS_2	95.12%

TABLE 17

Typical Analysis of Asphaltic Materials

CHARACTERISTICS	ANALYSIS	
Material	MC-2	RC-2
Specific Gravity, 25°/25°C	.973	.966
Flash Point	75°C	34°C
Viscosity Furol, 60°C	199	——
" " 50°C	——	325
Distillation - 225°C	1.0	16.0
315.5°C	18.0	23.0
360°C	23.0	24.0
Oliensis Test	Negative	Negative
Test on Distillation Residue		
Penetration	178	110
Ductility	110+	110+
Solubility in CCl_4	99.9	99.96
Source	Texas,Lockport	Lion, Eldorado Ark.

RECOMMENDATIONS FOR BITUMINOUS STABILIZATION

From observations in the field, it becomes evident that plant mix would give better results than those obtained by road mix. Control of mixing operation is difficult and the climatic conditions are such that some form of plant mix would be preferable, if consistent results in a whole construction season are to be obtained. When we consider that our gravel stabilized bases were road mixed and then later were as economically produced by plant methods, it becomes apparent that the more consistent results obtained by plant mixing should be applicable to bituminous stabilization with the same effectiveness as now obtained with gravel base stabilization. As the bituminous stabilized base is much superior to the gravel stabilized base from the standpoint of all weather effectiveness and maintenance, it is recommended that plant mix methods be utilized on future projects rather than road mix where bituminous stabilization is to be carried out.

If road mix methods are to be always successful over the greatest variation in climatic conditions, then the proper type of bituminous material will have to be devised. Thus, each bituminous material has some merit yet no single material has the combination of qualities which would give the most ideal results. To elucidate further, the above stated fact, it is but necessary to compare the properties of medium curing MC-2 and rapid curing RC-2 asphaltic oils as used in road mix stabilization. The MC-2 bituminous material requires considerable aeration to make a suitable base, as this aeration only proceeds at an economical rate when the weather is hot. It is evident that in cool weather manipulation costs become excessive and aeration may not be adequate. The RC-2 bituminous material revealed that aeration proceeds too rapidly for the speed of mixing obtainable with the equipment used, hence mix is too viscous and cannot be finished properly due to lack of workability. From this it can be seen that neither MC-2 nor RC-2 have the ideal properties and each has at least one bad shortcoming that is detrimental in its use as a stabilizing agent. In the case of AE-7 asphaltic emulsion, although this material mixes with ease, it requires that a great deal of water must be evaporated in order to obtain the best result, this becomes impractical in rainy weather or cool weather. It is, therefore, recommended that a more suitable bituminous material for this type of bituminous road mix stabilization be devised. This might be done in one of two ways, that is, one by the cutting back a heavier MC asphaltic oil with light volatiles, or by blending an RC asphaltic oil with MC type of asphaltic oils, or possibly blending an SC oil with an RC oil.

Another factor which will improve the present results obtained with the bituminous material as used at Grayling is to improve the application methods. The best application is not to spread the bituminous material evenly over the subgrade, as this often results in a deficiency of bituminous material at the edges which are inherently weak. Perhaps it would be better practice to spray a little heavier concentrated spray toward the edges and a lighter spray toward the center of the road where there is a tendency for over-lapping. The rate of application is affected greatly by the distance of the tank car to the point of application on the subgrade, hence it is advisable to have sufficient number of auxiliary tanks to insure rapid application. When it is impossible to get the bituminous material to the point of application fast enough, then the contractor should hold to a shorter working stretch, so that too much time is not lost in applying the stabilizer.

It is recommended that a close check be made upon the materials used by the contractor to build up the grade to meet the requirements shown in the plans. If convenient the contractor will use top soil or any sandy material obtainable from a bank or field, as at Grayling where this work was carried on most economically with Le Tourneau turmiples. Therefore, if the material should be full of frost heave or is very irregular in character there may be considerable trouble involved in mixing and stabilizing the built up subgrade, and too high an amount of stabilizer may be required to obtain economical stabilization.

It is advisable to keep close check on depth of subgrade stabilized, otherwise there may be considerable difficulty in getting the maximum value obtainable from the amount of bituminous material. This can best be done during the various stages of the mixing by the inspector or engineer, as once the pavement is compacted it is too late to correct the lack of depth required without undue expense to the contractor. It is also recommended that some data be obtained in the future so as to predict what depth of subgrade has to be stabilized in order to get a prescribed compacted depth of finished mat.

From time to time, field inspection should be made to ascertain from the data obtained at the time of construction as to durability of the various sections. In this way, through field observations, it will be possible to make conclusions regarding the effect of different amounts of moisture and filler and other such variables in the field.

Results of laboratory tests using the Hubbard Field Method indicate that further improvement in designing mixes might be obtained if triaxial cell or stabilometer method could be applied. From a scientific point of view, the Hubbard Field method does not give all of the information, whereby the stabilometer gives a more complete record as to design of mixes.

Another important consideration in the bituminous stabilization problem, is the idea of producing more economic stabilization by enriching the top enough so that no armor coat will be required. This would be desirable if costs are to be cut down to a minimum. It is recommended that sections, where MC-2 and RC-2 were used, be left open and not sealed, in order to ascertain feasibility.

It is further recommended that stripping tests be developed to ascertain suitability of bitumen used in stabilization, as it is certain that a bituminous material which will adhere to sand in the presence of moisture is to be preferred in road mix stabilization.

Experiments should be carried on to ascertain the effect of freezing and thawing along with the absorption to ascertain percentage of water which can damage stabilized base in conjunction with various bituminous substances.

PART III

CONDITION SURVEY

AND

SUMMARY

Part III presents a compilation of cost data for the various types of stabilized surfaces on the Grayling project, as well as the results of a condition survey before and after one winter in service and a general summary of the whole project.

COMPILATION OF COST DATA

In the introduction of this report, the cost per square yard of each type of stabilized surface was mentioned. For the purpose of comparative study a more complete summary of the various cost items will be presented as follows.

Soil-Cement Stabilization

1898 barrels of cement	at $2.20	$ 4175.60
250,025 tons limestone dust	at 5.35	1337.64
105 tons silt	at 2.75	288.75
198/1000 gallons water	at 8.00	1584.00
83.9 station manipulation	at 60.00	5034.00
Cost of processing surface		$ 12419.99

Cost per square yard = $12,419.99 ÷ 20,509 = 60-1/2¢ per square yard

Surface treatment cost –	
20,509 x 14.74 =	3023.02
Total cost of soil cement section	$ 15,443.01

Total cost per square yard for completed surface equal to 60.56 + 14.74 = 75¢.

MC-2 Bituminous Stabilized Section

54,393 gallons MC-2	at $0.11	$ 5,983.23
400 tons silt	at 2.75	1,100.00
83.0 station manipulation	at 45.00	3,735.00
Total cost of section		$ 10,818.23

Cost per square yard = $10,818.23 - 20,289 = 53-1/3¢

No surface treatment.

RC-2 Bituminous Stabilized Section

55,031 gallons RC-2	at $ 0.13	$ 7,154.03
385 tons silt	at 2.75	1,058.75
77.0 station manipulation	at $45.00	3,465.00
Total cost of section		$ 11,677.78

Cost per square yard = $11,677.78 - 18,822 = 62¢

No surface treatment

T-3 Bituminous Stabilized Section

2800 gallons T-3	at $ 0.16	$ 608.00
29 tons silt	at 2.75	79.75
6 stations manipulation	at 45.00	270.00
Total cost of section		$ 957.75

Cost per square yard = $957.75 - 1467 = 65-1/4¢

No surface treatment

AE-7 Bituminous Stabilized Section

71,238 gallons AE-7	at $ 0.12	$ 8,548.56
373 tons silt	at 2.75	1,025.75
81.88 station manipulation	at 45.00	3,684.60
Total cost of processing surface		$ 13,258.91

Cost per square yard = $13,258.91 - 20,015 = 66-1/4¢

Surface treatment cost 20,015 x 14.74 =		3,961.22
Total cost of section		$ 17,220.13

Total per square yard = 66.24 = 14.74 = 81¢

Surface Treatment

6,437 gallons T-3	at $ 0.16	$ 1,029.92
14,302 gallons T-8	at 0.15	2,145.30
459.1 tons 26A	at 4.00	1,836.40
228.6 tons 32A	at 4.00	914.40
400 gallons AE-2	at 0.12	48.00
Total cost resurfacing		$ 5,974.02

Cost per square yard $5,974.02 - 40,524 = 14-3/4¢

It is interesting to note from the study of the cost data above that the total cost per square yard of any of the four types of stabilized surface including surface treatment would approximate the cost of oil aggregate construction.

Condition Survey
December 5, 1941

On December 5th, the stabilized sand project at Grayling was inspected as to its service behavior. The entire cement and asphalt sections have been seal coated with the former showing a good surface with few irregularities. The emulsion section shows up the traffic ruts wherever they were located originally in the surface of the base course. Had it been sealed prior to the development of these ruts, the riding qualities would have been satisfactory.

The tar stabilization was a complete failure and is being reworked and patched by the Maintenance Division.

The stabilized area using RC-2 is too rough for a satisfactory method of low cost stabilization and there are indications that failures may develop. It seems that this section will require reworking of the surface when weather permits with a slower breaking asphalt to permit a satisfactory surface finish.

The MC-2 stabilized sand has all the indications of being an acceptable base treatment or seal coating.

Summarizing the entire project the inspection shows that cement, MC-2 or asphalt emulsion to be adequate for stabilizing sand from a service behavior at this early date.

Condition Survey
April 28, 1942

A visual examination was made of the Grayling project in April 1942,, six months after completion of the project. The survey was made by F.R. Olmstead and E. A. Finney. The results of the examination are as follows:

Asphalt Emulsion Section, AE-7, station 0+00 to 80+00

In spite of adverse weather conditions during construction, the base seemed to be in very good condition with the exception of a few rough spots in definite areas. The most serious condition at the present time is the progressive stripping of the surface treatment from the base course. It is apparent that the first stripping started where the surface material was picked up in spots by the tires of passing trucks. This is clearly illustrated in figure 28. A close examination reveals a definite lack of bond between the surface treatment and the base. It seems that the surface treatment was applied to the base when the base was wet. Such a condition is not conducive to good bonding characteristics between surface and base course.

Further maintenance on this section will be required this summer to recondition the surface.

Tar Section, T-3, station 80+00 to 86+00

The tar section is the poorest surface of the entire project. The base in general is soft, lacking stability and consequently has rutted badly. Extensive patching operations have been necessary to preserve the existing surface and insure safe travel. See figure 30. The surface has started to oxidize badly. A physical examination of the material in the surface is necessary to disclose reasons for existent conditions.

Cut Back Asphalt Section, RC-2, station 86+00 to 163+00

Extensive roughness and patching was observed in two locations of this section. The mixture itself appeared to be very hard. Rutting and patching

Figure 28. General view AE-7 section with surface treatment. Note stripping of surface from base.

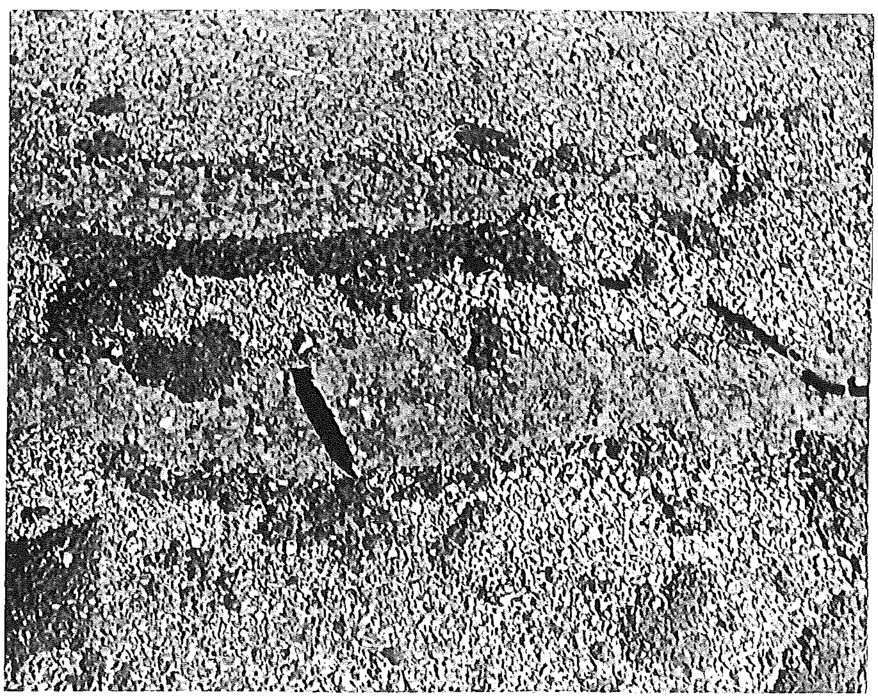


Figure 29. Close view of AE-7 surface and stripped area.

Figure 30. General view of tar section patched throughout length.

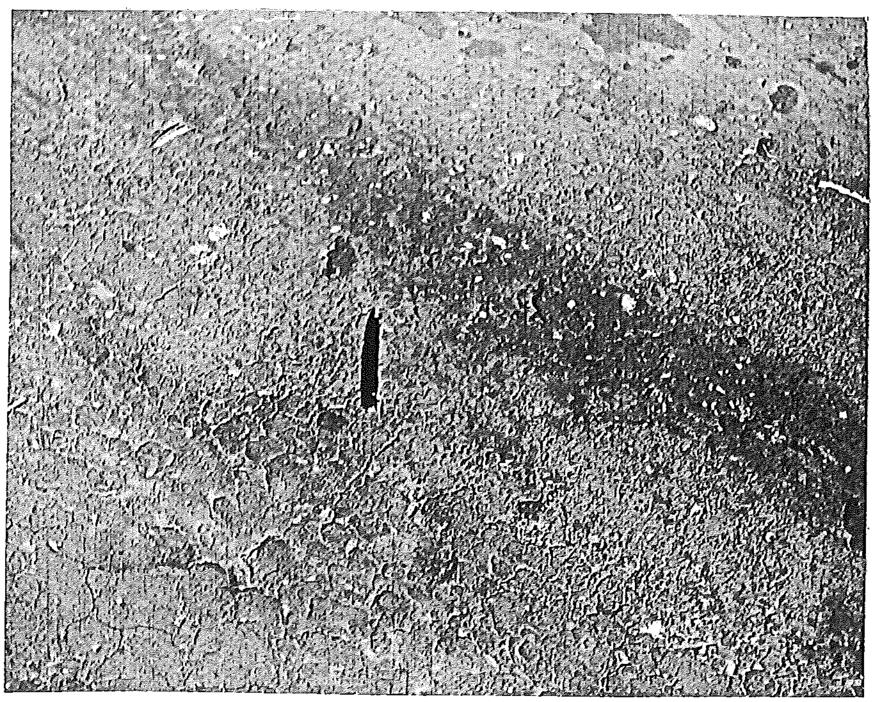


Figure 31. Close view of tar surface.

was noted between stations 86+00 and 97+00. The area between 97+00 and 141+00 appeared to be in good condition with but slight rutting in spots. The condition of the surface is illustrated in figures 32 and 33.

From station 141+00 to 163 the surface was very rough and was apparently patched by the contractor last fall. Patching by the contractor would indicate an attempt to rectify the results of poor workmanship during this part of the section. Such operations should not have been permitted. This particular section has been repatched by the Maintenance Division. Surface illustrated in figures 34 and 35.

<u>Medium Curing Asphalt Section, MC-2,</u> station 163 to 246.

In general, the section constructed with MC-2 asphaltic material varies considerably in its condition and appearance. The surface between station 163 to 187+50 seemed to be in very good condition with slight rutting in spots.

The area between station 187+50 to 203 +25 was rutted to the extent that patching was necessary. See figures 36 and 37.

The area between station 203+25 to 217+50 appeared to be in good condition with the exception of one spot between station 207-203. This area contained longitudinal cracking as illustrated in figure 38, an evidence of mat displacement under loads.

The area between station 217+50 and 242 was in fair condition, smooth and had good riding qualities. The surface is illustrated in figures 39 and 40.

The section between station 242 and 246 constitutes the first area of sand-bituminous stabilization performed by the contractor. Naturally, since this type of work was new to everyone, a certain amount of trouble should be expected from the first days run. The surface is, in general, fairly smooth

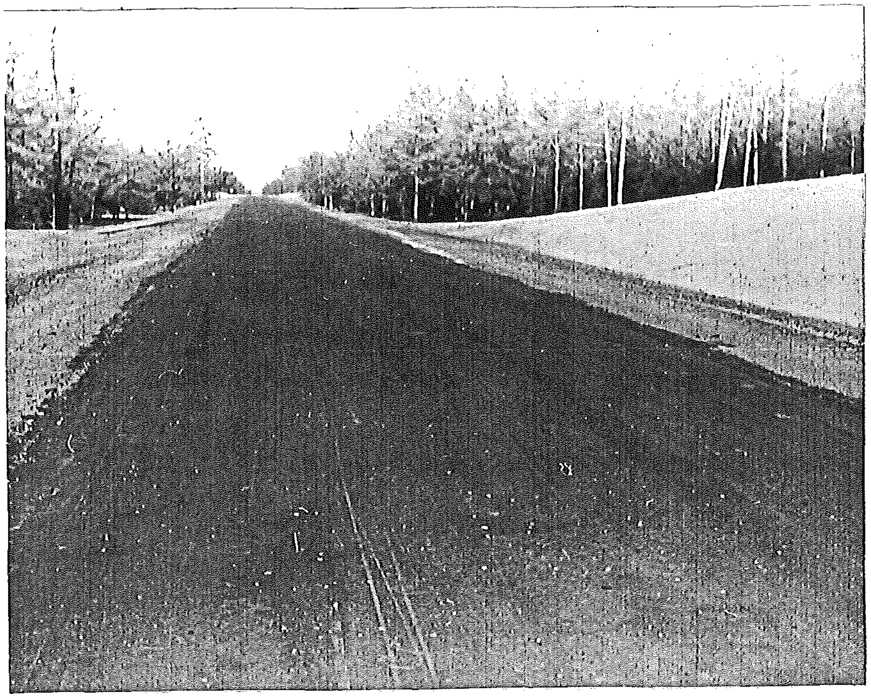


Figure 32. General view of RC-2 section, station 119+00.

Figure 33. Close view of RC-2 surface

Figure 34. General view RC-2 section, station 144-163. Light area at right is old patch by contractor.

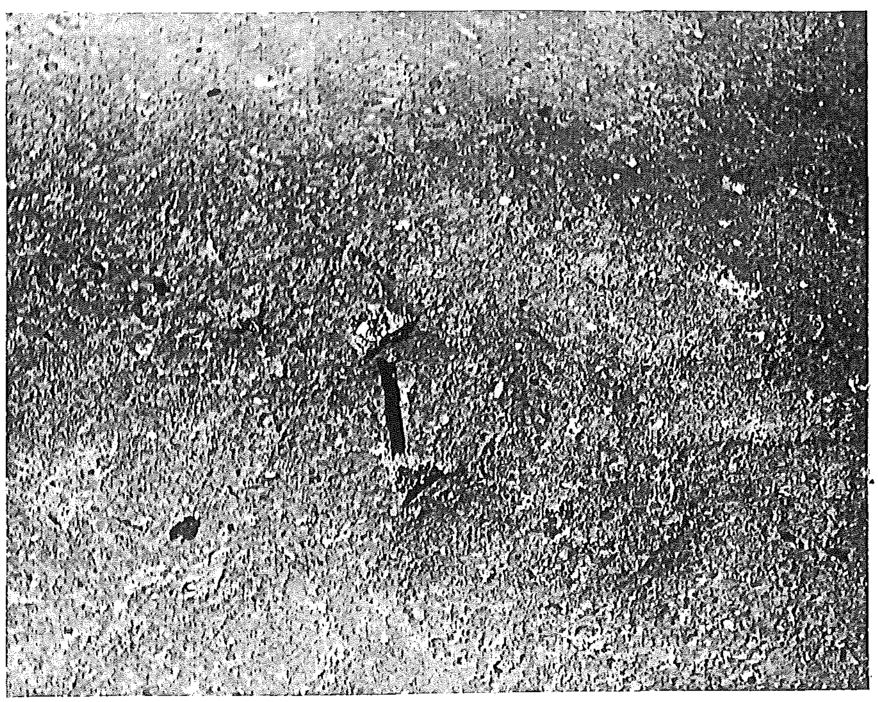


Figure 35. Close view of surface.

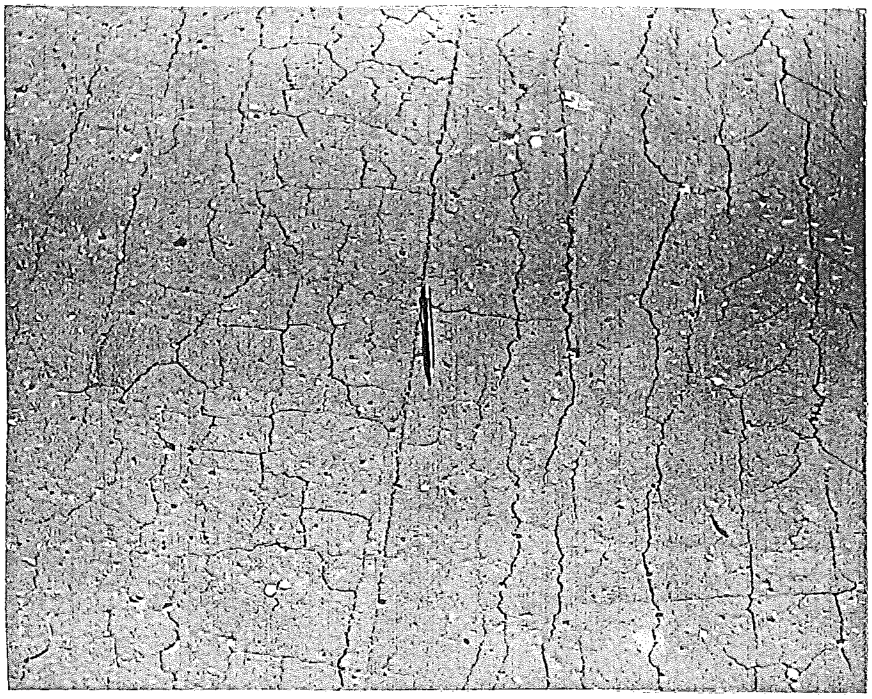


Figure 38. MC-2 section, station 205. Note longitudinal cracking.

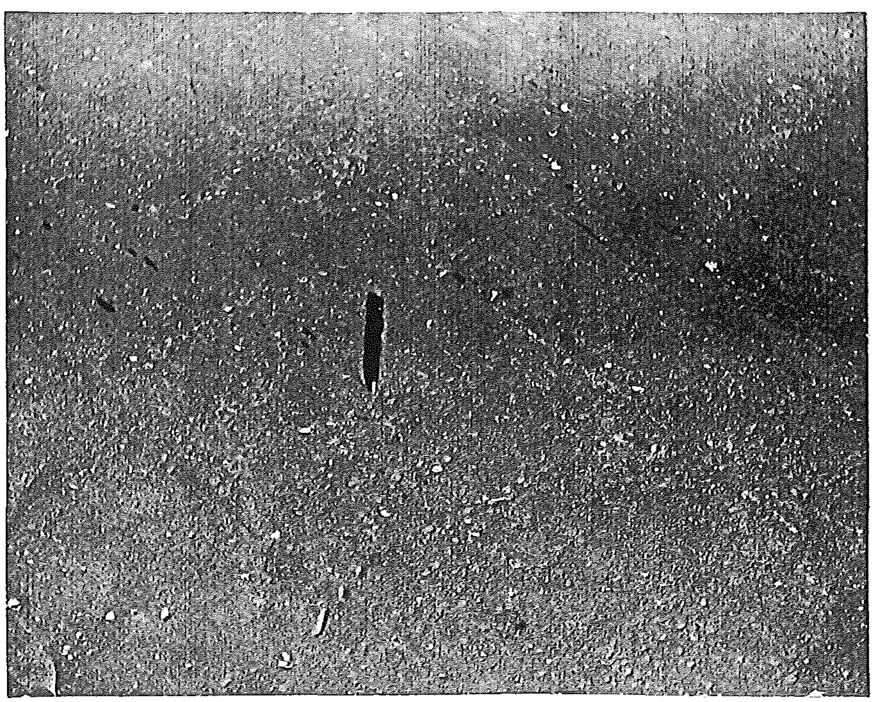


Figure 39. MC-2 section, station 227. Note smooth dense surface.

however it is weak structurally because longitudinal cracking is in evidence and rutting has started. See figures 41, 42 and 43.

<u>Soil-Cement Section,</u> station 246 to 329

The soil-cement section was surface treated soon after construction, consequently the whole section appeared to have weathered the first winter in excellent shape. The riding qualities of the surface are good and the surface treatment seems to have bonded perfectly with the soil-cement base. See figures 44 and 45.

<u>General Remarks</u>

When the project was set up it was understood that the Maintenance Division would assume the responsibility of stabilizing the shoulders after completion of the stabilized surface by the contractor. At the time of the condition survey, this operation had not been done and consequently a very potential traffic hazard exists on the project. The line of demarcation between surface and shoulder is not clearly defined. The shoulder material is so unstable that two wheels of a car onto the shoulder is sufficient cause to produce stalling of the vehicle or even more serious consequences under proper circumstances.

Figure 42. General view MC-2 section, station 246. Surface poor, rutting.

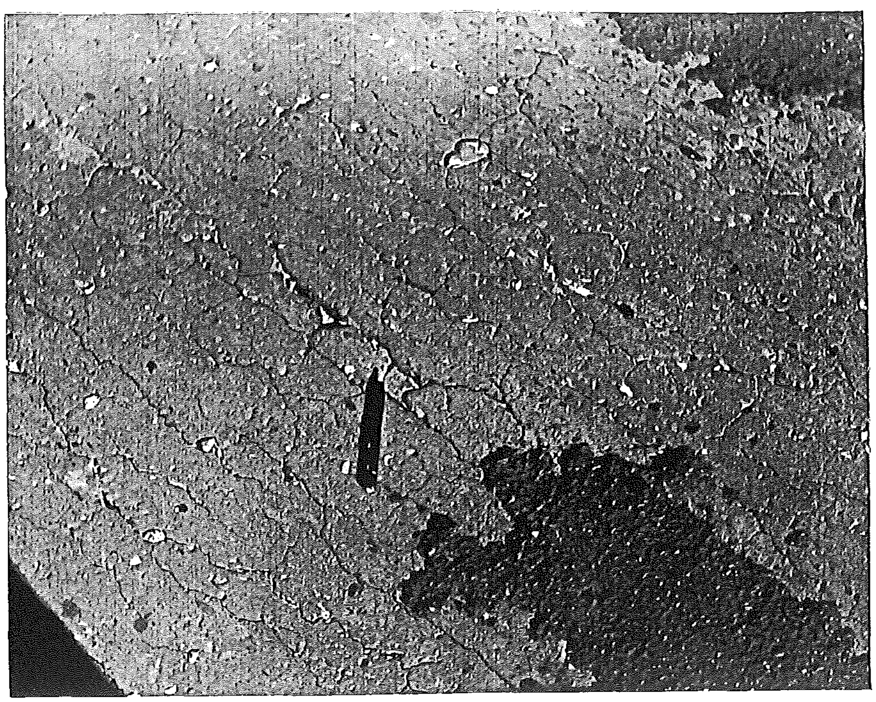


Figure 43. MC-2 section, station 246. Note longitudinal cracking.

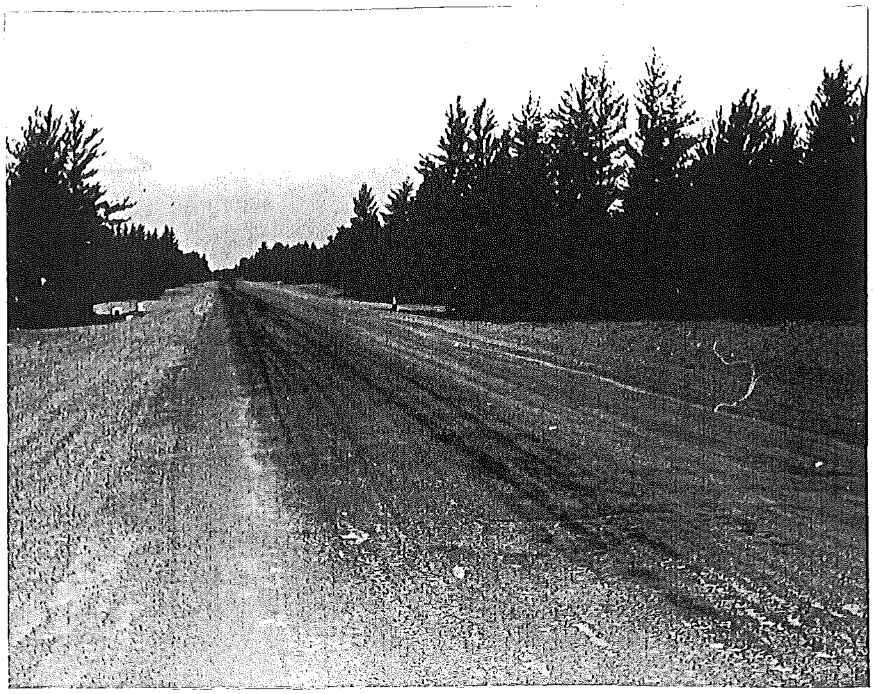


Figure 44. General view, soil cement section surface treated limestone chips.

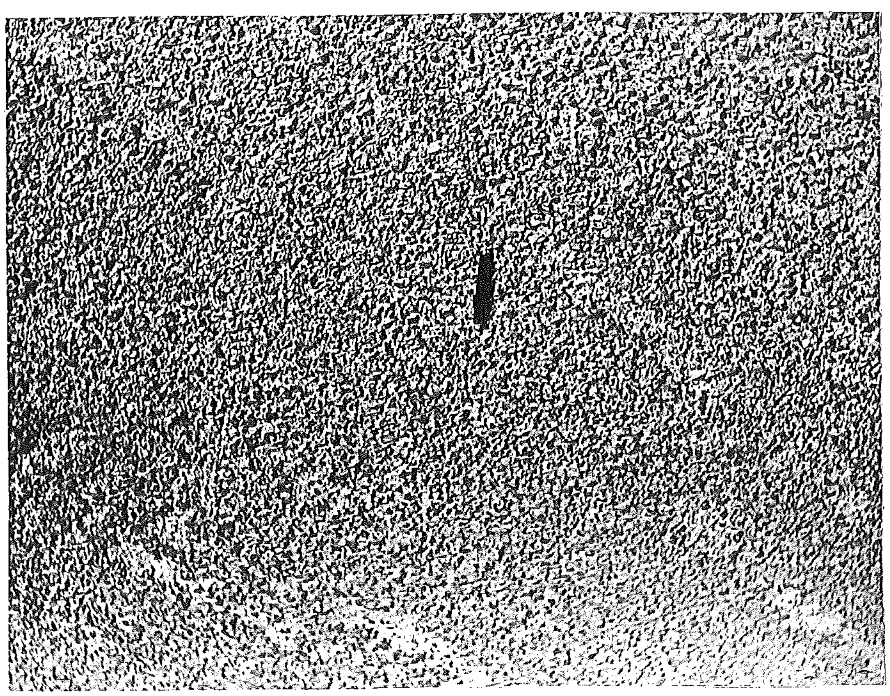


Figure 45. Close view of soil-cement surface.

General Summary and Conclusions

The purpose of the Grayling project was to study the feasibility of stabilizing a natural sand soil with different types of binders. From the standpoint of soil-stabilization practice, it has been definitely proven that sand soils are adaptable to stabilization provided adequate fines are added to produce a mechanically stable material prior to adding the binder.

From the results of the study so far it is apparent that Portland cement is a very satisfactory binder for sand soils. Of the bituminous sections, the one containing MC-2 is apparently the best. The asphalt emulsion section was in poor shape before application of surface treatment. The RC-2 material is too rapid a curing material for road mix work. Under plant mix operations it may be ideal. Although the tar section turned out to be the poorest surface of the entire project, tar as a binder should not be condemned as a material for stabilization work. It is believed that very good results can be obtained from any one of the following types of binders, asphalt emulsion, liquid asphalts and tars, provided that the proper grade and quantity of binder is used, that sufficient and proper construction operations are performed and that the climatic conditions are suitable to the particular type of bituminous binder used. Further laboratory studies are necessary to substantiate these facts.

The possibility of using oil-aggregate plant equipment should be considered for producing a bituminous stabilized base course. Plant mix methods for this type of work should be as economical as gravel base stabilization.

The cost per square yard of processed surface for each of the four sections is within the range of oil aggregate construction costs.

There is a tendency on the part of the contractor to attempt to process more road area per day than his organization and equipment are capable of doing efficiently. Consequently, the work drags on into the night and the various processing operations are usually not carried out to completion. This practice is responsible to a great degree for the present condition of the various soil-cement surfaces. This practice should be definitely controlled by some proper method.

It was noted that the contractor on the Stockbridge project, as well as on the Grayling project drove heavy equipment on the soil-cement surface the day after construction. On the Grayling project, the contractor drove his water truck and power grader over the surface and the weight of the equipment caused slight rutting of the surface. When the rutting of the surface was noted, the contractor was notified to remove his equipment from the uncured surface. It is recommended that no traffic be permitted on a soil cement surface prior to completion of the curing period.

Throughout the project, the edge of the processed surface was persistently soft and difficult to compact. This was attributed to the lack of support to the processed sand by the unstabilized shoulder material. To overcome this situation, it is suggested that the entire roadway from the outside shoulder edge to the outside shoulder edge be mechanically stabilized with fines before processing the traveled roadway.

It was observed that the use of a steel float immediately behind and attached to the pneumatic roller produced the best surface.

The quantity of fines in the mixture were kept to a minimum consistent with adequate stability of the surface and for workmanship. However, the mechanical stability of the unprocessed material was not sufficient to support the construction equipment to the point where maximum efficiency in operation could be obtained. Therefore considerable delay and trouble was encountered in applying the water and bituminous binders. It is believed that sufficient fines should be incorporated into the sand to provide mechanical stability capable of supporting the processing equipment at least during the early stages of the work.

It was planned to make a physical survey of the various stabilized areas to obtain samples for laboratory analysis for the purpose of correlating design and construction practices with the present condition of the road surface. This survey and laboratory work should be done this summer before the surface is sealed.

The unsealed portion of the bituminous section should not be surfaced treated until late this summer. This elapse of time should allow the base to become thoroughly cured with the possibility that by proper manipulation the surface may be restored to somewhat its original condition without excess maintenance. Thereupon it will be in better condition to receive the surface treatment.

It was suggested to the Construction Division in September 1941 that the sand shoulders should be stabilized as soon as possible with clay or other suitable material in order to eliminate a potential traffic hazard. At the time of the spring inspection in April 1942, the work had not been done.

PART IV

APPENDIX

The appendix contains copies of the specifications which were used on the Grayling project, special correspondence concerning the surface treatment for the soil-cement and asphalt emulsion surfaces and the bibliography.

SUPPLEMENTAL SPECIFICATION
FOR
SAND-BITUMINOUS SURFACE ROAD MIX

1.00 General:

This work shall consist of a surface course composed of bituminous binder and sand, mixed in place on the proposed grade in accordance with these specifications and in conformity with the lines, grade, compacted thickness and typical cross-section and location of each type of bituminous material shown on the plans, or as directed by the Engineer.

1.01 Composition of Mixture: The constituents of the surface course shall be combined in such proportions that, after complete mixing, the resultant mixture shall be homogeneous and all particles coated with bituminous material. The exact quantity of bituminous material shall be determined by the Engineer during the operations of applying and mixing and will depend on the character and grading of the aggregate material. The quantity of bituminous material shall be approximately three-tenths (0.3) to four-tenths (0.4) gallon per square yard per inch of compacted depth for tar; sixty-five hundredths (0.65) to seventy-five hundredths (0.75) gallon per square yard per inch of compacted depth for cut-back asphalt; and six-tenths (0.6) to seven-tenths (0.7) gallon per square yard per inch of compacted depth for emulsified asphalt. The proportions shall be varied, as directed by the Engineer.

II MATERIALS

The materials to be furnished and used, excepting those specified herein shall be those prescribed under the several items involved.

2.00 Bituminous Materials:

(a) Tar used for the mixing course shall conform to Michigan State Highway Department 1940 specification, T-6.

(b) Cut-back asphalt for the mixing course shall conform to the Michigan State Highway Department 1940 Specification, Asphaltic Oil, MC-2.

(c) Emulsified Asphalt AE-7. This material shall meet the requirements of 1940 Michigan State Highway Specification with the residue from evaporation or distillation test penetration (25 degrees, 100 g., 5 sec) between 100-200.

In the preliminary laboratory tests and in the construction of the sand-bituminous surface road mix where Emulsified Asphalt is specified, the Emulsified Asphalt shall mix readily with the sand without separation, coagulation, breaking down or forming lumps of asphalt. After mixing with sand it shall dry uniformly and rapidly without showing any tendency toward forming a skin on the surface and the asphalt shall remain uniformly dispersed throughout the sand. The Emulsified Asphalt shall be homogeneous emulsion of asphalt and alkaline water, manufactured and stabilized with a total of not more than 1-1/2% of emulsifying and stabilizing agents. It shall be miscible with pure water in all proportions and shall show no separation of asphalt after thorough mixing, within thirty (30) days after delivery, provided separation has not been caused by freezing.

2.01 Mineral Filler: Mineral Filler shall meet the Michigan State Highway Department 1940 Specification for Mineral Fillers 3-MF.

2.02 Water: Water shall meet Michigan State Highway Department 1940 Specification as described under 4.14.02 (b).

2.03 Aggregate: The proposed surface material shall be sand, or a mixture of sand, gravel and mineral filler, in the proper proportions to form a dense mixture.

III CONSTRUCTION METHODS

3.00 Equipment:

All equipment necessary for the proper construction of this work shall be on the project, in first-class condition, and shall have been approved by the Engineer before construction will be permitted to begin.

3.01 Equipment Requirements: The following equipment shall be required for the construction of a Sand Bituminous Road Mix:

- One bituminous pressure distributor - equipped with heating device
- One water pressure distributor.
- Not less than one rubber tired patrol with a twelve (12) foot blade and one rubber tired patrol grader with a ten (10) foot blade. The number of graders shall be governed by the number of units of other equipment in use.
- Three disc harrows - twenty-two (22) inch disc of an approved type for proper mixing.
- One 3-furrow gang plow - fourteen (14) inch bottoms, capable of plowing to a depth of ten (10) inches.
- One 3-section spring tooth harrow with alfalfa teeth.
- Sufficient rubber tired tractors of the proper size and horse power to handle the equipment used.
- One sheep's-foot roller with ground pressure 50 to 100 pounds per square inch of tamper area, having tamping feet of 10 to 12 square inch area.
- One pneumatic tire roller.
- One five (5) ton tandem roller with provisions to ballast to eight (8) tons.
- An approved heater for heating the blade of the grader.
- One retread mixing machine of an approved type (optional).

<u>3.02 Trimming and Finishing Earth Grade:</u> This work shall be done according to standard specification 2.13. Any additional soil or mineral filler needed shall be placed as the Engineer may direct and any unsuitable soil or material, including material retained on a 2-1/2" screen shall be removed by raking and replaced with material acceptable to the Engineer.

<u>Pulverizing:</u> The subgrade shall be scarified and pulverized until 80% of the soil passes a No. 4 sieve. The materials shall be mixed at the moisture content specified by the Engineer for a sufficient depth and width to give the compacted cross section as shown on the plans. After completion of the mixing operation, the subgrade shall be dragged with a spring tooth harrow, and all roots and foreign matter shall be removed. The subgrade material shall be shaped with a patrol grader having a twelve (12) foot blade until a uniformity of line and grade has been obtained to the satisfaction of the Engineer.

<u>3.03 Application of Water:</u> When required, in order to assist in the mixing of the bituminous material and soil, the soil shall contain not less than approximately the optimum moisture content at the time of mixing. If sufficient moisture is not present in the soil, water shall be added by means of an approved pressure distributor and applied in such quantities and at such a rate as directed by the Engineer. The approximate moisture content, based on the oven-dry weight of the compacted mixture, required in the bituminous sand-mixture at the time of compaction are given below.

Station From	To	Approx.dry wt. of compacted mix wt./cubic foot	Approx.moisture content req'd in compacted mix,%	Estimated moisture of air dry mix, %	Approximate water per syd. gals.
0	117	117	9.0	0.4	5.2
117	122	125	9.0	0.3	5.4
122	164	117	9.0	0.4	5.2
164	246	117	9.0	0.4	5.2

<u>3.04 Applying Bituminous Material:</u> After the subgrade has been shaped to the satisfaction of the Engineer, bituminous material shall be applied uniformly over the road material by means of an approved mechanical pressure distributor equipped with spray bars capable of spraying the bituminous material uniformly over the entire width of the proposed surface. When applying tar, the temperature shall be not less than 90°F and should heating be necessary for proper distribution, the material shall be heated to not more than 150°F.

No bituminous material shall be applied when the air temperature is less than 60°F in the shade or when, in the opinion of the Engineer, the weather condition or the condition of the subgrade is unsuitable. Each application shall consist of thirty-five hundredths (0.35) gallon per square yard, or as directed by the Engineer.

3.05 Manipulation: Mixing shall be done with an approved type disc harrow with a twenty-two (22) inch disc, 3-furrow gang plow and grader with twelve (12) foot blade. After each application of bituminous material, continuous mixing with harrow shall follow. After approximately the specified amount of bituminous material per square yard has been applied it shall be continuously mixed with harrows for a depth of approximately two (2) inches, mixing with harrows over the entire width of the pavement shall be continued until a uniform distribution of bituminous material is obtained through the two (2) inch treated depth. The two (2) inch treated depth then shall be windrowed with a twelve (12) foot blade, from center to outside of edges of road surface. After windrowing application of bituminous material to the untreated subgrade shall be continued in the same manner until the full depth required for the compacted surface shown on the plans with the required optimum moisture content and richness has been obtained. This procedure shall be followed for mixing unless otherwise directed by the Engineer.

Material that has been windrowed outside of edges shall then be pulled in and spread with the twelve (12) foot blade to a uniform surface. After material has been spread the entire surface shall be plowed to its full depth.

After plowing, application of bituminous material shall continue as specified in paragraphs 3.04 and 3.05, until the proper bitumen content has been obtained or as directed by the Engineer.

After a sufficient quantity of bituminous material has been applied, the mixing for the entire width and depth shall be continued to the satisfaction of the Engineer.

3.06 Provision for Drainage of Base and Subgrade: During construction adequate provision shall be taken to drain all surface water from the base and subgrade. This shall be accomplished by lateral ditches through the shoulders of the road, or by other equally satisfactory methods. The drains shall be located as directed by the Engineer at all points necessary to provide proper drainage. During final compaction of the stabilized base course, the drains shall be filled and thoroughly compacted to the elevation of the shoulders.

3.07 Preparing Mixture for Compaction: Prior to compaction, the soil mixture shall be tested for moisture content and the moisture adjusted to the specified amount, as directed by the Engineer. This may be accomplished either by mixing in additional water or by manipulating the mixture until excess moisture has evaporated, whichever is required.

3.08 Compaction and Shaping: After mixing has been completed, the surface shall be leveled with the twelve (12) foot blade grader to line, grade and cross-section, as shown on the plans for finished pavement. The soil mixture shall be thoroughly compacted by means of a sheeps-foot roller, starting compaction at the bottom and working toward the top until the entire depth is uniformly compacted to the greatest density practicable. During compaction, the mixture shall be disced and bladed to insure uniform compaction. After compaction to approximately half the depth, the disc harrows shall be removed and the mixture leveled and brought to proper cross-section by means of a pneumatic-tire patrol grader. Compaction shall continue to refusal, as determined by the Engineer. When the sheeps-foot roller will not compact to the surface, the upper two (2) inches of the base course shall be loosened, shaped to the proper cross-section and compacted with an approved pneumatic-tire roller.

3.09 Finishing and Rolling: After the pavement has set to the satisfaction of the Engineer, it shall be rolled with a pneumatic tire-roller. Rolling shall be done longitudinally, beginning at the edges and proceeding toward the center. After proper setting of the mixture, final rolling shall be done with a five (5) ton tandem roller, equipped with scrapers and water pads on the wheels to prevent picking up of the material. Rolling shall be done longitudinally until a uniform compaction and smoothness has been obtained, and all tractor and other marks are eliminated.

3.10 Testing Surface with Straight Edge: The surface shall then be checked with a ten (10) foot straight edge laid parallel to the center line, and any variations greater than one-fourth (1/4) inch shall be corrected either by additional rolling, by removing material from the pavement and replacing with properly prepared mixture and compacting to a density and uniformity to conform with the surrounding area, or by the addition of a properly prepared mixture, to the scarified surface and compacting to a density and uniformity to conform with the surrounding area. Any corrective operations shall be made at the expense of the Contractor. The method to be used shall be as directed by the Engineer.

3.11 Measurement of Thickness: During various stages of construction, test holes or trenches shall be dug by the Contractor as directed by the Engineer, in the mixture to determine the thickness. After the bituminous road mix is completed, test holes or cross-sectional trenches shall be dug at intervals of not more than five hundred (500) feet, or at closer intervals if necessary. The average thickness of the surface will be determined from measurements made on these test holes or trenches and shall be within one-half (1/2) inch of the thickness shown on the plans except that the thickness at any one place may be within three-quarters (3/4) of an inch of that shown on the plans for surface constructed in one day. When the surface fails to meet the thickness limits the area to be corrected shall be corrected either by additional rolling, by removing material from the pavement and replacing with properly prepared mixture and compacting to a density and uniformity to conform to the surrounding area, or by the addition of a properly prepared mixture to the scarified surface and compacting to a density and uniformity to conform with the surrounding area. Any corrective operations shall be made at the expense of the Contractor. The method to be used shall be as directed by the Engineer. After rolling has been completed, the edges of the surface shall be cut to true line, and the shoulders and slopes dressed to the cross-sections shown on the plans, or as directed by the Engineer.

3.12 Protection of Pavement: After the pavement has been completed, traffic shall not be allowed to use same until the pavement has set hard enough to eliminate rutting and cracking.

Opening of pavement to traffic shall be as directed by the Engineer. Sufficient waterproof paper or other mats approved by the Engineer should be on hand to protect the entire surface of the mixture following the placing of the bituminous material and prior to completion of the final compaction operation against the entrance of water into the mixture due to rain.

Any finished portion of the roadway adjacent to construction which is traveled by equipment used in constructing an adjoining section shall be continuously covered with building paper or equivalent and at least six (6) inches of earth or equivalent for area necessary during successive operations to prevent equipment from marring the surface of the completed work.

3.13 Construction Limitations: Bituminous material shall be applied only to such an area that all the operations specified in paragraphs 3.04, 3.05, 3.07, 3.08 and 3.09 can be continuous and completed within the working day.

IV METHOD OF MEASUREMENT

4.00 Trimming and Finishing Earth Grade:

Trimming and finishing earth grade will be measured in stations along the centerline.

4.01 Manipulation: will be measured by stations along center line of Sand-Bituminous Surface Road Mix. No allowance will be made for any work done outside of the lines established by the Engineer. The average thickness of the surface constructed during one day shall not be less than 90% or more than 110% of the thickness shown on the plans.

4.02 Bituminous Materials: will be measured by volume in gallons at a temperature of 60°F. Volume corrections will be made as specified under Non-Skid Surface Treatment 4.06.05.

4.03 Mineral Filler: will be measured by weight in tons.

4.04 Water: will be measured in 1000 gallon units.

V BASIS OF PAYMENT

5.00 Trimming and Finishing Earth Grade:

Trimming and finishing earth grade will be paid for at the contract unit price per station within the limits as provided on the plans or by authorization.

5.01 Manipulation: will be paid for at the contract unit price per station which price will include pulverizing and mixing before and after the application of bituminous material, shaping and compacting and final finishing and rolling and all other items covered by these specifications not covered by contract unit prices. In addition, such price and payment shall be full compensation for all equipment, tools, labor and incidentals necessary to complete all work described under the specification, excluding the bituminous material and mineral filler and the application of same. The completion of shoulders to the lines and grades shown on the plans will be considered part of this item.

5.02 Bituminous Materials for Mixture: will be paid for at the contract unit price per gallon which price shall be payment in full for furnishing, heating, hauling and applying. No increase in unit payment will be made for increased or decreased quantities of bituminous materials.

5.03 Mineral Filler: will be paid for at the contract unit price per ton which price shall be payment in full for furnishing, hauling and applying the mineral filler. No increase in unit payment will be made for increased or decreased quantities of mineral filler.

5.04 Water: will be paid for at the contract unit price per 1000 gallons, which price shall be payment in full for furnishing, hauling and applying water.

No increase in unit payment will be made for increased or decreased quantities of water.

SUPPLEMENTAL SPECIFICATIONS FOR SOIL-CEMENT SURFACE

1.01 Description: This item shall consist of a surface composed of a combination of soil and Portland cement uniformly mixed, moistened and compacted in accordance with these specifications, and shaped to conform to the lines, grades, thickness and typical cross-section shown on the plans. In general, construction shall proceed as follows:

(a) The soil in the subgrade shall be pulverized for the necessary depth and the full width to be treated with cement.

(b) Portland cement shall be uniformly spread and mixed with pulverized soil.

(c) Water shall be added as needed with a pressure distributor and shall be uniformly incorporated in the mixture in the amounts required to attain the optimum moisture content specified by the Engineer for the soil-cement mixture.

(d) The mixture shall be compacted uniformly with sheeps-foot rollers in one continuous operation. The mixture shall be compacted at the optimum moisture content and to the density specified by the Engineer.

(e) After compaction is completed with the sheeps-foot rollers, the surface shall be shaped, water added as needed and further compacted and finished with a smooth-wheeled roller supplemented with a multiple wheel pneumatic-tire roller or its equivalent.

The equipment used shall be in suitable operating condition and approved by the Engineer. Equipment not satisfactory to the Engineer shall be removed and satisfactory equipment supplied.

1.02 Materials: The materials to be furnished and used, excepting those specified herein shall be those prescribed under the several items involved.

(a) Portland Cement: Portland cement shall be in accordance with 4.14.02 of the Standard Specifications.

Contractors, at their option, may use bulk cement, provided the apparatus for handling, weighing and spreading the cement is approved by the Engineer in writing.

(b) Water: The water used in the construction of this surface shall be in accordance with 4.14.02 of the Standard Specifications.

(c) Soil: The soil for this surface shall consist of the natural material in the roadway or selected soil and mineral filler which shall be approved by the Engineer.

(d) Mineral Filler shall meet the Michigan State Highway Department 1940 Specification for Mineral Filler 3-MF.

1.03 Construction Methods:

(A) Equipment

All equipment used in this work shall be of sufficient size and in such mechanical condition as to meet the requirements and to produce work of satisfactory quality. The design and construction of all equipment shall be approved by the Engineer before the work is started.

1. Road mix equipment - Blade machines shall be self-powered, shall have pneumatic tires and shall be of approved design, so constructed and maintained that they will properly spread and finish the soil cement mixture. Gang plows, multiple disc harrows and rotary tillers shall be so constructed as to prevent any cutting of the subgrade during mixing operations.

(B) Construction Procedure

(a) Provisions for Traffic - The Contractor shall perform the work covered by these specifications while the sections involved are closed to traffic, following the distribution of the cement on the soils through the seven (7) day curing period of the completed surface.

(b) Trimming and Finishing Earth Grade: This work shall be done according to Standard Specification 2.13. Any additional soil or mineral filler needed shall be placed as the Engineer may direct and any unsuitable soil or material including material retained on a 2-1/2" screen shall be removed by raking and replaced with material acceptable to the Engineer.

(c) Pulverizing - Prior to the application of cement, the soil to be treated shall be scarified and pulverized for sufficient width and depth to give the compacted cross-section shown on the plans. Pulverizing shall continue until eighty (80) percent of the soil, by dry weight (exclusive of gravel or stone retained on a No. 4 sieve) shall pass a No. 4 sieve, and the soil shall be manipulated until the percentage of moisture in the soil does not exceed by more than two (2) the percentage of moisture specified by the Engineer for the soil-cement mixture before compaction. The length of subgrade scarified and pulverized at any time shall not exceed the length which can be completed in accordance with this specification in two (2) working days except by permission of the Engineer.

(d) Application of Cement - The pulverized soil shall be shaped to the approximate cross-section shown on the plans and the specified quantity of Portland cement required for the full depth of treatment shall be uniformly spread over the surface in one operation in a manner satisfactory to the Engineer. Portland cement shall be applied at the rate of 0.09 barrels per square yard of completed surface five (5) inches thick. However, the Engineer may direct that the rate of application be decreased to not less than 0.07 barrels or increased to not more than 0.11 barrels per square yard of completed surface five (5) inches thick. No equipment except that used in spreading or mixing shall be allowed to pass over the freshly spread cement until it is mixed with the soil as specified under Manipulation.

(e) Manipulation - 1. Road Mix Method - Immediately after the cement has been distributed it shall be mixed with the loose soil for the specified full depth of treatment. Care must be exercised that no cement is mixed below the desired depth. Mixing may be accomplished with gang plows, disc harrows, rotary tillers or other implements approved by the Engineer and shall be continued for as long a period of time and repeated as often as may be necessary to insure a thorough, uniform and intimate mix of the soil and cement and until the resulting mixture is homogeneous and uniform in appearance. The mixture shall then again be shaped to the lines and grades shown on the plans. The soil-cement mixture shall not remain undisturbed between the mixing and compaction operations for more than thirty (30) minutes.

(f) Application of Water - Immediately after mixing of soil and cement is complete, the moisture content of the soil-cement mixture shall be determined by the Engineer and, if required, water shall be uniformly applied in such quantities and at such a rate as directed by the Engineer. The approximate amount of water required, based on the oven-dry weight of the compacted mixture, required to construct the surface will be approximate 7.2 gallons per syd. from station 246 to 292 and 6.8 gallons per syd. from station 292 to 329. This includes 2 gallons per square yard for protection and 10% for evaporation. No change in the contract unit price will be considered because of variation in the amount of water used. A water supply and pressure-distributing equipment shall be provided which will permit the continuous application of all water required on the section of roadway being processed within three (3) hours. Each application or increment of water shall be partially incorporated by gang plows, disc harrows, rotary tillers or other implements approved by the Engineer so as to avoid concentration of water near the surface. After the last increment of water has been added, mixing shall be continued by using gang plows, disc harrows, rotary tillers or other implements approved by the Engineer. This equipment shall be of sufficient size and capacity to distribute the moisture uniformly throughout the full depth of the mixture distribution in one (1) operation. Particular care shall be exercised to insure satisfactory moisture distribution along the edges of the section. When water spreading and mixing is completed, the percentage of moisture in the mixture, on a basis of dry weight shall not vary from the specified optimum percentage of moisture of the mixture by more than one-tenth (1/10) of the optimum percentage of mixture. This specified optimum moisture shall be that prevailing in the moist soil-cement at the time of compaction and will be determined in the field by a moisture density test (A.S.T.M. Designation D 558-40 T) on representative samples of soil-cement mixture obtained from the roadway toward the conclusion of the mixing operations.

(g) Compaction - Prior to the beginning of compaction, and as a continuation of mixing operations, the mixture shall be thoroughly loosened for its full depth and then shall be uniformly compacted with a sheeps-foot roller. Compaction shall begin at the bottom and shall continue until the entire depth of soil-cement mixture is uniformly compacted to the density specified by the Engineer. The approximate density (or densities) as based on the oven-dry weight of compacted mixture, required in the surface is from 120 to 133 pounds per cubic foot. The density, based on the oven-dry weight of the compacted mixture, specified for the completed roadway by the Engineer during construction will be determined by a moisture-density test (A.S.T.M. Designation D 558-40 T), shall be that prevailing in the moist soil-cement at the time of compaction and shall be run in the field on representative samples of soil-cement mixture obtained from the roadway toward the conclusion of the moist mixing operations.

The sheeps-foot rollers used for compaction shall have tamping feet of ten (10) to twelve (12) square inch area and capable of applying fifty (50) to one hundred (100) pounds per square inch. The unit weights shall be computed by considering the entire weight of the roller being carried by one transverse row of feet. The rate of operation and number of rollers shall be sufficient to compact uniformly the section of roadway being processed for the specified width and depth within two (2) hours.

After the mixture is compacted, the surface of the treated roadway shall be reshaped to the required lines, grades and cross-sections and then shall be lightly scarified to loosen any imprints left by the compacting or shaping equipment, until a surface mulch of not more than one (1) inch in thickness is obtained that contains the specified optimum moisture. The resulting surface then shall be thoroughly rolled with pneumatic-tire rollers of the size specified by the Engineer and smooth-wheel tandem rollers having a gross weight of five (5) tons with provision to ballast to eight (8) tons. When directed by the Engineer, surface finishing methods may be varied from this procedure provided a dense uniform surface, free of surface compaction planes, is produced. The moisture content of the surface material must be maintained at its specified optimum during all finishing operations. The surface compaction and finishing shall be done in such a manner as to produce in not over two (2) hours a smooth closely knit surface free of cracks, ridges or loose material conforming to the crown grade and line shown on the plans. A bulkhead shall be placed at the end of each day's work.

(h) Protection and Cover - Sufficient waterproof paper or other mats approved by the Engineer shall be on hand to protect the entire surface of the mixture following the placing of the cement and prior to completion of the final compaction operation against the entrance of water into the mixture due to rain.

At any time when there is freezing temperature and in all cases after October 1, there shall be available a sufficient amount of clean, dry straw or hay to cover at least 2500 lineal feet of pavement and as much more as may be necessary for protection according to these specifications.

When the temperature falls below 40°F at any time during the first five (5) days of the curing period the pavement shall be covered with six (6) inches of loose dry straw which shall remain in place ten (10) days.

After the roadway has been finished as specified herein it shall be protected against rapid drying for a period of seven (7) days by applying a two (2) inch covering of earth or other materials approved by the Engineer, which will be moistened initially and subsequently as may be necessary as specified under 4.14.03 (t) of the Standard Specifications.

Any finished portion of the surface adjacent to construction which is traveled by equipment used in constructing an adjoining section shall be continuously covered with building paper or equivalent and at least six (6) inches of earth or equivalent for area necessary during successive operations to prevent equipment from marring the surface of the completed work.

(i) Construction Limitations - Cement shall be applied only to such an area that all the operations specified in paragraphs (d) to (g) inclusive, can be continuous and all but final surface finish completed within six (6) hours after the beginning of water application to the thoroughly mixed soil-cement. No cement shall be applied when the percentage of moisture in the soil in the subgrade immediately beneath the pulverized material exceeds the optimum moisture content specified by the Engineer for that particular soil or when the percentage of moisture in the pulverized soil exceeds the optimum moisture of the soil-cement mixture by more than two (2) percent. When any of the operations, after the application of cement, are interrupted continuously for more than thirty (30) minutes for any reason, or when the uncompacted soil-cement mixture is wetted by rain so that the average moisture content exceeds the tolerance given in paragraph (f), the entire section shall be reconstructed in accordance with this specification.

(j) Weather Limitations - During seasons of probable freezing temperatures, no cement shall be applied unless the temperature is at least forty (40) degrees Fahrenheit in the shade and rising.

(k) Opening to Traffic - The Contractor will not be permitted to drive heavy equipment over completed portions, but pneumatic-tired equipment required for constructing adjoining sections may be permitted after the surface has hardened sufficiently to prevent the equipment marring the surface, provided protection and cover specified in paragraph (h) are not impaired. Completed portions may be opened to traffic after the seven (7) day's protection specified in paragraph (h), provided the surface has hardened sufficiently to prevent marring by traffic.

(l) Tolerance in Density and Thickness - The density of the soil-cement roadway will be determined by the Engineer after each day's construction. Any portion which has a density of five (5) pounds or more below that specified by the Engineer shall be removed and replaced to meet this specification.

The thickness of the soil-cement roadway will be determined from measurements of cores drilled from the finished roadway or from thickness measurements at holes drilled in the finished roadway at intervals not to exceed 500 feet. The average thickness of roadway constructed during one (1) day shall be within one-half (1/2) inch of the thickness shown on the plans, except that the thickness at any one place may be within three-quarters (3/4) of an inch of that shown on the plans. Where the average thickness shown by the measurements made in one day's construction is not within the tolerance given above, the Contractor will be required to reconstruct this day's work at his own expense.

(m) Maintenance - The Contractor shall be required to maintain at his own expense the entire roadway within the limits of his contract in good condition satisfactory to the Engineer from the time he first starts work until such work shall have been completed and accepted. Maintenance shall include immediate repairs of any defects that may occur either before or after the cement is applied, which work shall be done by the Contractor at his own expense and repeated as often as may be necessary to keep the roadway continuously intact. Repairs are to be made in a manner to insure restoration of a uniform surface and durability of the part repaired.

<u>1.04 Method of Measurement:</u> Trimming and Finishing Earth Grade will be measured by length along the centerline of the road in stations of one hundred (100) feet, between the limits as provided on the plans or by authorization.

Cement will be measured in barrels, to be applied as provided on the plans or by authorization.

Mineral Filler will be measured by weight in tons.

Water will be measured by volume in thousand (1000) gallon units as provided on the plans or by authorization.

Manipulation will be measured by length along the centerline of the road in stations of one hundred (100) feet.

<u>1.05 Basis of Payment:</u> This work shall be paid for at the contract unit prices for the following items, which prices shall be full payment for furnishing all

materials, equipment, tools, labor and incidentals necessary to complete the work and for carrying out the maintenance provisions in this specification.

If additional gravel, sand or clay is required for preparing the foundation, it will be paid for at the contract or authorized unit price per cubic yard for Earth Excavation, with overhaul allowance.

Cement will be paid for at the contract unit price per barrel delivered on the project. Payment will be made only for cement incorporated in the work.

Water will be paid for at the contract unit price per thousand (1000) gallons and shall be full payment for providing and spreading on the roadway the water required to produce the moisture content specified for the soil-cement mixture and for wetting the protective cover on the completed surface. This price shall not include any costs incurred in the mixing the water with the soil-cement. No increase in unit payment will be made for increased or decreased quantities of water.

Manipulation will be paid for at the contract unit price per station which price shall be full payment for pulverizing the roadway, for handling, hauling and spreading cement, mixing the cement with the pulverized soil, mixing the water with the soil-cement mixture, compacting the mixture, surface finishing, placing protective cover on the roadway, including all costs of labor, equipment, supplied and all other items covered by these specifications except for these items on which separate contract unit prices are required. The completion of shoulders to the lines and grade shown in the plans will be considered part of this item.

Mineral Filler will be paid for at the contract unit price per ton which price shall be payment in full for furnishing, hauling, and applying the mineral filler. No increase in unit payment will be made for increased or decreased quantities of Mineral Filler.

SURFACE TREATMENT PROCEDURE

The following is a copy of a letter directed to Mr. H.C. Bacon, District Engineer from J.G. Schaub, Engineer of Construction and Operations, dated October 17, 1941, concerning the patching of bad areas and the application of a seal coat to the asphalt emulsion section of the project.

"This is to advise that it will not be possible to remix the top inch of the asphalt emulsion experimental section on the above noted project by the addition of more asphalt emulsion or by the use of a slow curing oil. It would be too late to get delivery on asphalt emulsion this year. We have checked with the Trumble Refining Company at West Branch and find that they are not operating and they are uncertain when they will be in production again.

"The other recourse is to patch the ruts and depressions in this particular section with some kind of a cold patch mixture and then cover it with a seal coat. This work would have to be carefully done and the holes and depressions will have to be painted with an asphalt emulsion in order that the patching material will stick to the surface.

"I have been advised by the contractor, Mr. Wm. Hodgkiss, that there is some CP-1 cold patch mixture in stockpile about five miles west of Gaylord. The emulsion required for treating the patched areas can probably be secured from the General Paving Company who are using emulsion for tack coat on the Manton resurfacing job.

"If a single seal is placed on the eighty-three stations of the emulsion section at the rate of 25/100 gallon per square yard, it would require a little over 5,000 gallons. Mr. Hodgkiss has contacted the Lewis Tar Company who are willing to release one car of T-8 tar, but they will not ship less than 6,000 gallons and that will probably have to be shipped in an 8,000 gallon car.

"Due to the porous nature of the existing emulsion surface, you may find that 3/10 gallon per square yard will not be excessive, in which case the 6,000 gallons would be about right. If you find that the surface will not carry over 1/4 gallon per square yard, the surface treatment can probably extend a little further on to the next section until the material is used up.

"We have authorized Mr. Hodgkiss to order the tar prime and to proceed with the cold patch repairs as outlined. We have estimated that the cover material should be about 25 pounds per square yard of 26-A or 26-B chips, which he states he will be able to obtain. This amount can be adjusted according to the needs after the surface treatment work gets under way.

"Will you kindly arrange with Mr. Claud Yockey for the release of the CP-1 cold patch repair material, and we will try and work out some method of paying for this material or replacing it. Also, advise the Project Engineer, James Scott, regarding this proposed work and forward the necessary authorizations covering the materials and costs to this office as soon as possible."

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