SOIL-CEMENT RUNWAYS FOR AIRPORTS

Thesis for the Degree of B. S.
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Soil-Cement Runways For Airports

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by

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SOIL-CEMENT RUNWAYS

FOR

AIRPORTS

FOREWORD

History shows us that new developments in the United States are always quickened and sharpened in times of economic stress. History has again repeated itself in the soil-cement field as well as in other fields where man's ingenuity has found opportunity for full play and development.

Back in the days of the "depression" in 1935, perhaps nowhere else in the country was there a more acute need for a light traffic, low-cost highway than in South Carolina. Instigated by South Carolina's leading engineers, a search was made for just such a highway, and it was here that soil-cement was born.

The investigation moved slowly at first for, after all, the idea of mixing soil and cement to obtain a hard, structural material was definitely contrary to all the teachings and experimental data that had heretofore existed.

Soon, however, work by the Portland Cement Association, the U. S. Public Roads Administration, and other highway departments began to develop. Gradually, scientific soil principles were uncovered which showed great promise of success with soil-cement mixtures. Field projects demonstrated that scientific control could be obtained at low cost with practical construction equipment and procedures.

The first field project using these scientific principles was built in South Carolina. Since that time, soil-cement has been successfully used not only in the construction of highways, but in low-cost houses, and especially in airports. It has spread to 40 of the United States, to many of the European countries, to China, Japan, Australia, Alaska, and

South America.

From infant to giant in eight years -- this is the progress of soil-cement!

INTRODUCTION

Soil-cement is recommended for taxiways, runways, parking and other paved areas at secondary civilian airports. It is also recommended for military airports designed for use as training and pursuit bases and for use as dive, attack, and medium bomber bases. It is also recommended for any temporary and emergency runways and for paving bordering concrete runways to permit use by the above mentioned type of plane. Soil-cement has proved by service records that it can be used a limited amount by heavy bombers in an emergency, but this definitely should not be practiced. In case there is a possibility the air field may later be devoted to use by heavy bomber planes, concrete paving should be used!

The object of this investigation is to first pick a practical site for a secondary airport, take sufficient samples of soil, and through accurate laboratory tests design soil-cement test cylinders covering a range of cement percentages.

Then, to take these cylinders and subject them to tests similiar to actual conditions that an airport runway would have to undergo. Observations drawn from these tests would then determine the practibility of using soil-cement airport runways for these soil types. Also, it is the purpose of this project to cover briefly the scope and future possibilities of airport surfaces made of soil-cement.

The site was selected from the college properties, and sufficient

borings were taken to identify the soil types. With the aid of a soils map of the vicinity, it was shown that the plot was primarily made up of Conover Loam, Brookston Loam, and Hillsdale Sandy Loam.

Five samples of soil were taken of sufficient depth and area to obtain truly representative samples. These five raw soil samples were air dried in the laboratory, and screened through a # 10 sieve.

With all samples air-dried, and passing the # 10 sieve 100%, the following tests were made on each sample.

1. The apparent specific gravity.

2. A mechanical analysis of particle sizes. By this test the grain sizes contained in each sample were determined, and with the aid of the Tri-Axial Chart, the five soils were placed in their proper groups. With these two tests completed, each soil sample was plotted on a Grading Curve, and a blend of the soils was determined. After blending, the following tests were run on the soil mix.

1. Apparent Specific Gravity Test
2. Mechanical Analysis Test
3. Liquid Limit Test
4. Shrinkage Ratio Test
5. Shrinkage Limit Test
6. Ph test (Hydrogen Ion Concentration)
7. Plastic Limit Test
8. Plasticity Index Test
9. Optimum Moisture Density Relation Test

From the results of these tests, and a selection of various cement contents, the test cylinders may be molded.

A total of twelve test cylinders shall be molded, three for each

cement percentage that was chosen. These twelve samples shall be tested in a manner that would be similiar to the actual conditions that the soil-cement would be subjected to if it were part of an airport runway.

Note: All tests run on the soil samples are standard A. S. T. M. tests. No deviation from these standard procedures has been made, except where noted.

LABORATORY INVESTIGATIONS AND RESULTS

Apparent Specific Gravity Of Soil Samples

Approximately 40 grams of oven-dried soil was placed in the mortar and ground with the pestle to a floury texture. About 30 grams was then placed in a volumetric flask of known weight and weighed on the analytical balance. A burette was filled with kerosene up to the 100 cc. mark, and approximately 40 cc. of kerosene was introduced into the flask, meanwhile twirling the flask between the hands until the powdered soil is thoroughly in suspension. The remainder of 50 cc. of kerosene was then run in, and the flask subjected to a vacuum to remove all entrained air. When bubbles of air no longer came through the kerosene, the flask was filled to the 100 cc. mark from the burette, and the volume of the remaining kerosene recorded as the volume of the contained soil.

Soil Sample	B		C		A		D		E	
Flask No.	11	10	12	11	8	9	11	10	12	8
Wt. Soil and Flask	77.38	71.95	78.30	81.75	73.00	78.22	74.50	71.82	75.70	78.00
Wt. Flask	50.25	44.25	46.70	50.25	46.60	48.60	50.25	44.25	46.70	46.60
Wt. Powdered Soil	27.13	27.70	31.60	31.70	26.40	29.62	24.25	47.57	29.00	31.40
Vol. Soil Particles	10.2	10.8	11.7	11.8	10.2	11.5	9.3	10.5	11.0	12.0
Appar. Spec. Grav.	2.66	2.67	2.69	2.69	2.59	2.60	2.61	2.63	2.64	2.62
Mean	2.665		2.69		2.595		2.62		2.63	

TABLE I

Mechanical Analysis of Soil Samples

A representative soil sample was selected from the oven-dried soil passing the # 10 sieve. 100 gram samples shall be used for sandy soils, and 50 gram samples for clay and silt soils.

The soil was placed in a glass breaker and covered with about 200 cc. of distilled water to which was added 20 cc. of sodium silicate solution. (Sodium silicate solution is to act as a deflocculating agent). The soil solution was then allowed to stand for 18 hours to assure that the clay will have softened so that it can be easily broken down, and also so that each particle is loosened from the next.

After tempering, the soil was poured into the dispersion cup, washing all material from the beaker with distilled water from a wash bottle. The dispersion cup was then filled within two inches of the top with distilled water and placed on the milk shaker which was used as a mixer. The sample was subjected to this mixing for 5 minutes or 9 minutes, depending upon whether the soil is predominantly sand or clay.

At the conclusion of the mixing time, the contents of the dispersion cup were poured into a 1000 cc. glass graduate, washing all particles from cup with distilled water. Additional distilled water was added to bring the level of the liquid up to the 1000 cc. mark. Covering the open end of the graduate with the palm of one hand, the graduate was shaken for one minute, then quickly setting it in a position where it would not be disturbed for the remainder of the test.

The hydrometer and thermometer were placed in the solution and readings taken at the end of 1, 2, 5, 10, 15, 30, 60 and 120 minutes. The hydrometer should be removed each time and inserted about 20 seconds before the next reading is taken.

Upon completion of all the readings, the contents of the graduate were washed through a #200 sieve. The sieve was then placed in the oven and allowed to dry. When the material was completely dried, it was placed upon a nest of sieves arranged in the following order. Numbers 10, 20, 40, 60, 140, 200 and the pan. The set of sieves was placed in the Ro-Tap machine, and shaken for 20 minutes. The material retained on each sieve was weighed and recorded.

Corrections must be applied in the hydrometer analysis for temperature of solution and specific gravity of the soil, since the hydrometers have been calibrated for standard conditions. These standard conditions are:

1. That the apparent specific gravity of the soil is 2.65.
2. That the specific gravity of the suspending medium is constant and equal to .9984 at 19.4° C.
3. That the coefficient of viscosity, n, is equal to that of water at the same temperature.
4. That the distance, L, through which the particles fall in a given time period is constant and equal to 32.5 cm.

The above standard conditions were not the conditions for this test, so corrections must be applied.

The temperature correction of the hydrometer is designated as ΔR, and is taken as .2 per degree change in Fahrenheit. The correction is added to the original reading when the temperature is above the standard 67°F., and subtracted when the temperature is below this.

When the specific gravity of the soil varies from 2.65, the specific gravity of the solution will also vary. Thus, a specific gravity of more than 2.65 will cause the hydrometer to float higher and give a higher reading. This reading must be reduced by a proportionality factor, A, as given in table II.

Apparent Specific Gravity G_A	Correction a	Factors K_G
2.45	1.05	1.07
2.50	1.04	1.05
2.55	1.02	1.03
2.60	1.01	1.02
2.65	1.00	1.00
2.70	0.99	0.98
2.75	0.98	0.97
2.80	0.97	0.96
2.85	0.96	0.95
2.90	0.95	0.93

Table II

The correction factor for the variation in specific gravity of the soil is designated as K_G, and depends upon the density of the suspended soil. The values of K_G are computed by the formula $K_G = \sqrt{\frac{1.65}{G_A-1}}$, where G_A is the apparent specific gravity of the soil being tested. Values of K_G are also tabulated in table II.

The correction factor for the coefficient of viscosity of water is designated as K_N and may be expressed in the following form, $K_N = \sqrt{\frac{N}{.0102}}$ where N is equal to the coefficient of viscosity.

The values of K_N are tabulated in table III.

Temperature	K_n		Temperature	K_n
16 °C	1.04		25	.93
17	1.03		26	.92
18	1.02		27	.91
19	1.00		28	.90
20	.99		29	.89
21	.98		30	.88
22	.97		31	.88
23	.96		32	.87
24	.95		33	.86

TABLE III

The correction to correlate the particle size with the distance that the soil particle falls in a given time is designated as K_L. The correction K_L is given by the formula $K_L = \sqrt{\frac{.42\ L}{32.5}}$ where L' is the distance from the surface of the solution to the bottom of the hydrometer.

Values for K_L are given in Table IV. for each hydrometer.

Rdg.	Hydro-meter 381037	Hydro-meter 344272	Hydro-meter 344253	Rdg.	Hydro-meter 381037	Hydro-meter 344272	Hydro-meter 344253
	K_L	K_L	K_L		K_L	K_L	K_L
-2	.568	.553	.568	30	.500	.483	.500
0	.564	.548	.565	32	.496	.478	.496
2	.560	.545	.561	34	.491	.473	.492
4	.556	.540	.557	36	.487	.469	.488
6	.552	.536	.554	38	.483	.465	.484
8	.548	.532	.549	40	.478	.460	.479
10	.543	.528	.545	42	.473	.456	.475
12	.539	.523	.541	44	.469	.452	.471
14	.535	.519	.536	46	.464	.448	.467
16	.531	.514	.531	48	.459	.443	.463
18	.526	.510	.527	50	.455	.438	.458
20	.522	.505	.523	52	.450	.434	.454
22	.518	.501	.519	54	.445	.430	.450
24	.514	.496	.513	56	.441	.425	.445
26	.510	.492	.509	58	.436	.420	.441
28	.505	.488	.505	60	.431	.415	.436

TABLE IV

The product of the three corrections K_G, K_L, and K_N times the nominal size of the particles will give the corrected particle size.

The data and results from the sieve and hydrometer analyses are shown on pages 11-16. One complete analysis was run for each soil sample, and one for the blended mix.

Each soil sample was plotted on a grading curve, and also on the Tri-Axial chart, as shown on pages 17 and 18.

SIEVE ANALYSIS FROM HYDROMETER ANALYSIS					
Sieve Number	Particle Size mm.	Retained		Cumulative	
		Weight gm	Percent	% Ret.	% Pass
10	2.0	0.00	0.00	0.00	100.00
20	.840	1.1	1.1	1.1	98.9
40	.420	5.0	5.0	6.1	93.9
60	.250	12.5	12.5	18.6	81.4
140	.100	35.1	35.1	53.7	46.3
200	.074	9.00	9.00	62.7	37.3
Pass	# 200	37.3	37.3	100.00	0.00
	Total	100.00	100.00		

TABLE V Hydrometer Analysis Sample W

Time	Time Min.	Temp. °C	Hydrometer Rdg.			% Pass	Corr:	Coeff.		Diameter mm.	Corrected Diameter	% Pass W
			Orig.	Δ R	R	100 Ra ÷ W	K_L	K_G	K_N			
3:28	1	26.0	28.0	.20	28.2	28.3	.504	1.01	.92	.078	.0366	28.3
3:29	2	26.0	25.0	.20	25.2	25.3	.512	1.01	.92	.055	.0262	25.3
3:32	5	26.0	20.2	.20	20.4	20.5	.521	1.01	.92	.035	.017	20.5
3:37	10	26.0	17.5	.20	17.7	17.8	.525	1.01	.92	.025	.0122	17.8
3:42	15	26.0	16.0	.20	16.2	16.2	.530	1.01	.92	.020	.0099	16.3
3:57	30	26.0	13.5	.20	13.7	13.8	.535	1.01	.92	.014	.0070	13.8
4:27	60	26.0	11.0	.20	11.2	11.28	.541	1.01	.92	.010	.0050	11.28
5:27	120	26.0	8.5	.20	8.70	8.75	.546	1.01	.92	.007	.0036	8.75

SIEVE ANALYSIS FROM HYDROMETER ANALYSIS

Sieve Number	Particle Size mm.	Retained Weight gm	Retained Percent	Cumulative % Ret.	Cumulative % Pass
10	2.0	0.00	0.00	0.00	100.00
20	.840	.20	.20	.20	99.8
40	.420	2.7	2.7	2.9	97.1
60	.250	12.2	12.2	15.1	84.9
140	.100	57.3	57.3	72.4	27.6
200	.074	9.8	9.8	82.2	17.8
Pass	#200	17.8	17.8	100.00	0.00
	Total	100.00	100.00		

TABLE VI Hydrometer Analysis Sample A

Time	Time Min.	Temp. °C	Hydrometer Rdg. Orig	Hydrometer Rdg. ΔR	Hydrometer Rdg. R	% Pass 100 Ra÷W	Corr: Coeff. K_L	Corr: Coeff. K_G	Corr: Coeff. K_N	Diameter mm.	Corrected Diameter	% Pass W
3:28	1	25.0	13.5	.16	13.7	13.8	.519	.98	.93	.078	.0368	13.8
3:29	2	25.0	12.0	.16	12.2	12.3	.523	.98	.93	.055	.0261	12.3
3:32	5	25.0	11.0	.16	11.2	11.3	.526	.98	.93	.035	.0168	11.3
3:37	10	25.0	9.0	.16	9.16	9.25	.530	.98	.93	.025	.0121	9.25
3:42	15	25.0	8.5	.16	8.66	8.75	.532	.98	.93	.020	.0097	8.75
3:57	30	25.0	7.0	.16	7.16	7.23	.534	.98	.93	.014	.0069	7.23
4:27	60	25.0	5.5	.16	5.66	5.72	.536	.98	.93	.010	.0049	5.72
5:27	120	25.0	4.2	.16	4.36	4.40	.540	.98	.93	.007	.00344	4.40

SIEVE ANALYSIS FROM HYDROMETER ANALYSIS					
Sieve	Particle Size mm.	Retained		Cumulative	
		Weight	Percent	% Ret.	% Pass
10	2.0	0.00	0.00	0.00	100.00
20	.840	2.3	2.3	2.3	97.7
40	.420	7.0	7.0	9.3	90.7
60	.250	13.4	13.4	22.7	77.3
140	.100	30.8	30.8	53.5	46.5
200	.074	8.1	8.1	61.6	38.4
Pass	# 200	38.4	38.4	100.00	0.00
	Total	100.00	100.00		

TABLE VII Hydrometer Analysis Sample B

Time	Time Min.	Temp. °C	Hydrometer Rdg.			% Pass 100 Ra÷W	Corr: Coeff.			Diameter mm.	Corrected Diameter	% Pass W
			Orig.	ΔR	R		K_L	K_G	K_N			
2:32	1	25.0	29.0	.16	29.16	29.5	.502	1.02	.93	.078	.0372	29.5
2:33	2	25.0	25.0	.16	25.16	25.4	.511	1.02	.93	.055	.0267	25.4
2:36	5	25.0	23.0	.16	23.16	23.4	.516	1.02	.93	.035	.0172	23.4
2:41	10	25.0	19.2	.16	19.36	19.6	.524	1.02	.93	.025	.0124	19.6
2:46	15	25.0	16.8	.16	16.96	17.2	.529	1.02	.93	.020	.0100	17.2
3:01	30	25.0	14.0	.16	14.16	14.4	.536	1.02	.93	.014	.0070	14.4
3:31	60	25.0	11.0	.16	11.16	11.3	.543	1.02	.93	.010	.0052	11.3
4:31	120	25.0	8.5	.16	8.66	8.8	.547	1.02	.93	.007	.0036	8.8

SIEVE ANALYSIS FROM HYDROMETER ANALYSIS					
Sieve	Particle Size mm.	Retained		Cumulative	
		Weight	Percent	% Ret.	% Pass
10	2.0	0.00	0.00	0.00	100.00
20	.840	2.1	2.1	2.1	87.9
40	.420	7.6	7.6	9.7	90.3
60	.250	11.4	11.4	21.1	78.9
140	.100	23.3	23.3	44.4	55.6
200	.074	6.7	6.7	51.1	38.9
Pass	# 200	38.9	38.9	100.00	0.00
	Total	100.00	100.00		

TABLE VIII Hydrometer Analysis Sample C

Time	Time Min.	Temp. °C	Hydrometer Rdg.			% Pass 100 Ra÷W	Corr: Coeff.			Diameter mm.	Corrected Diameter	% Pass W
			Orig.	ΔR	R		K_L	K_G	K_N			
2:15	1	26.0	40.00	.20	40.2	40.4	.460	1.01	.92	.078	.0334	40.4
2:16	2	26.0	35.8	.20	36.0	36.2	.469	1.01	.92	.055	.0240	36.2
2:19	5	26.0	29.0	.20	29.2	29.4	.481	1.01	.92	.035	.0157	29.4
2:24	10	26.0	25.0	.20	25.2	25.3	.494	1.01	.92	.025	.0115	25.3
2:29	15	26.0	22.5	.20	22.7	22.8	.498	1.01	.92	.020	.0093	22.8
2:44	30	26.0	19.0	.20	19.2	19.3	.508	1.01	.92	.014	.0063	19.3
3:16	60	26.0	15.5	.20	15.7	15.8	.514	1.01	.92	.010	.00477	15.8
4:16	120	26.0	12.2	.20	12.4	12.5	.523	1.01	.92	.007	.0034	12.5

SIEVE ANALYSIS FROM HYDROMETER ANALYSIS					
Sieve Number	Particle Size mm.	Retained		Cumulative	
		Weight	Percent	% Ret.	% Pass
10	2.0	0.00	0.00	0.00	100.00
20	.840	.9	.9	.9	99.1
40	.420	5.0	5.0	5.9	94.1
60	.250	9.4	9.4	15.3	84.7
140	.100	27.1	27.1	42.4	57.6
200	.074	9.3	9.3	51.7	48.3
Pass	# 200	48.3	48.3	100.00	0.00
	Total	100.00	100.00		

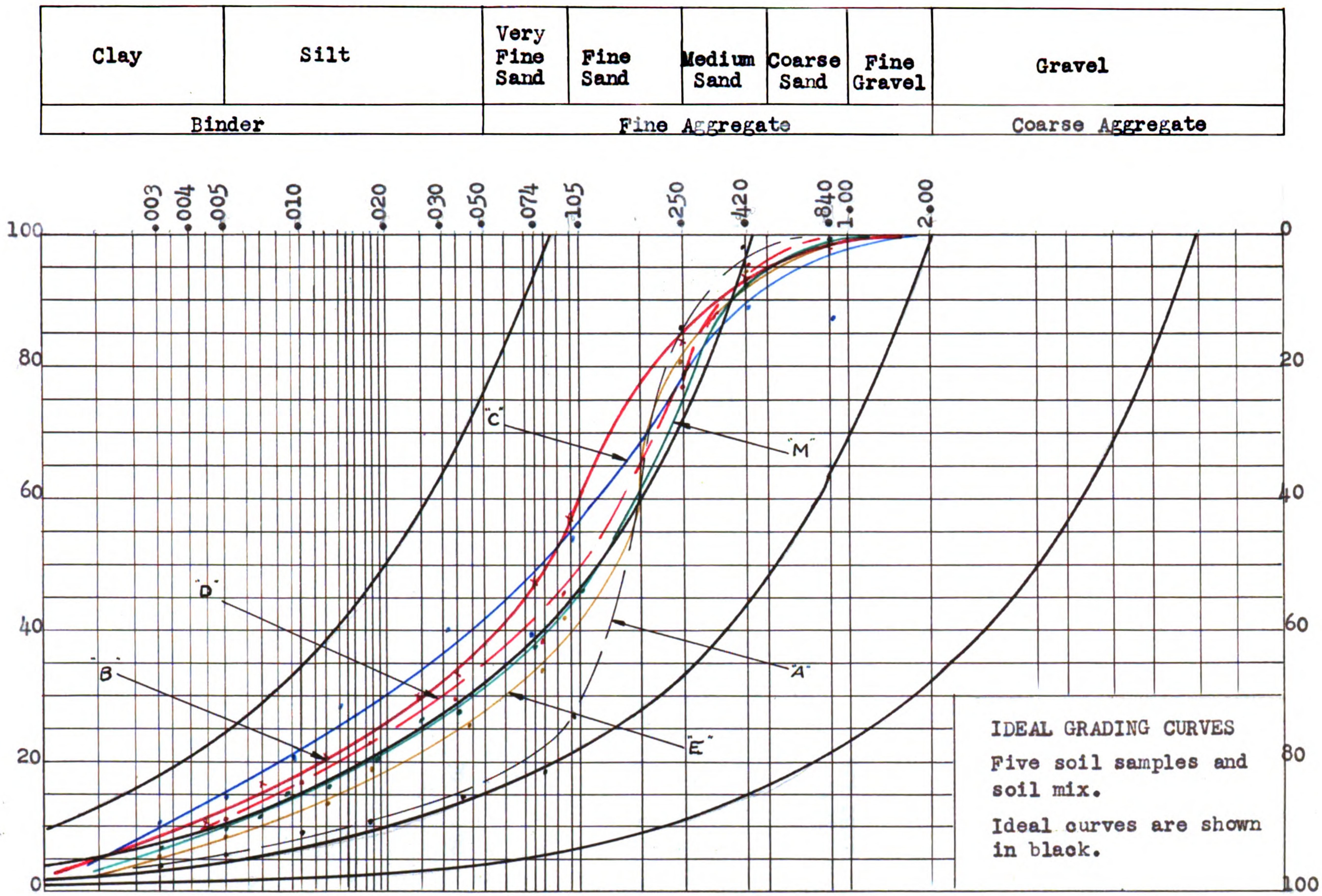
TABLE IX Hydrometer Analysis Sample D

Time	Time Min.	Temp. °C	Hydrometer Rdg.			% Pass 100 Ra÷W	Corr. Coeff.			Diameter mm.	Corrected Diameter	% Pass W
			Orig.	ΔR	R		K_L	K_G	K_N			
2:32	1	25.2	33.0	1.7	34.7	34.9	.489	1.01	.93	.078	.0358	34.7
2:33	2	25.2	29.0	1.7	30.7	30.9	.498	1.01	.93	.055	.0257	30.7
2:36	5	25.2	23.2	1.7	24.9	25.1	.512	1.01	.93	.035	.0169	24.9
2:41	10	25.2	19.6	1.7	21.3	21.4	.520	1.01	.93	.025	.0120	21.3
2:46	15	25.2	17.0	1.7	18.7	18.8	.524	1.01	.93	.020	.0099	18.7
3:01	30	25.2	14.0	1.7	15.7	15.8	.531	1.01	.93	.014	.0070	15.7
3:31	60	25.2	11.0	1.7	12.7	12.8	.537	1.01	.93	.010	.0051	12.7
4:31	120	25.2	8.0	1.7	9.7	9.75	.543	1.01	.93	.000	.0036	9.7

SIEVE ANALYSIS FROM HYDROMETER ANALYSIS					
Sieve Number	Particle Size mm.	Retained		Cumulative	
		Weight	Percent	% Ret.	% Pass
10	2.0	0.00	0.00	0.00	100.00
20	.840	.7	.7	.7	99.3
40	.420	5.3	5.3	6.0	94.0
60	.250	14.2	14.2	20.2	79.8
140	.100	36.7	36.7	56.9	43.1
200	.074	9.0	9.0	65.9	34.1
Pass	# 200	34.1	34.1	100.00	0.00
	Total	100.00	100.00		

Time	Time Min.	Temp. °C	Hydrometer Rdg.			% Pass 100 Ra÷W	Corr: Coeff.			Diameter mm.	Corrected Diameter	% Pass W
			Orig.	ΔR	R		K_L	K_G	K_N			
2:52	1	26.0	24.2	.20	24.6	24.7	.511	1.01	.92	.078	.0370	24.7
2:53	2	26.0	21.0	.20	21.2	21.3	.521	1.01	.92	.055	.0267	21.3
2:56	5	26.0	17.5	.20	17.7	17.8	.527	1.01	.92	.035	.0172	17.8
3:01	10	26.0	15.0	.20	15.2	15.3	.533	1.01	.92	.025	.0124	15.3
3:06	15	26.0	13.5	.20	13.7	13.8	.536	1.01	.92	.020	.0115	13.8
3:21	30	26.0	10.0	.20	10.2	10.3	.545	1.01	.92	.014	.0071	10.3
3:51	60	26.0	8.0	.20	8.2	8.25	.549	1.01	.92	.010	.0051	8.25
4:51	120	26.0	5.5	.20	5.7	5.73	.554	1.01	.92	.007	.0036	5.73

TABLE X Hydrometer Analysis Sample E



Clay
Silt
Very Fine Sand
Fine Sand
Medium Sand
Coarse Sand
Fine Gravel
Gravel
Binder
Fine Aggregate
Coarse Aggregate
.003
.004
.005
.010
.020
.030
.050
.074
.105
.250
.420
.840
1.00
2.00
100
80
60
40
20
0
0
20
40
60
80
100
"C"
"M"
"D"
"B"
"A"
"E"
IDEAL GRADING CURVES
Five soil samples and soil mix.
Ideal curves are shown in black.

TABLE XI

TRI AXIAL CHART

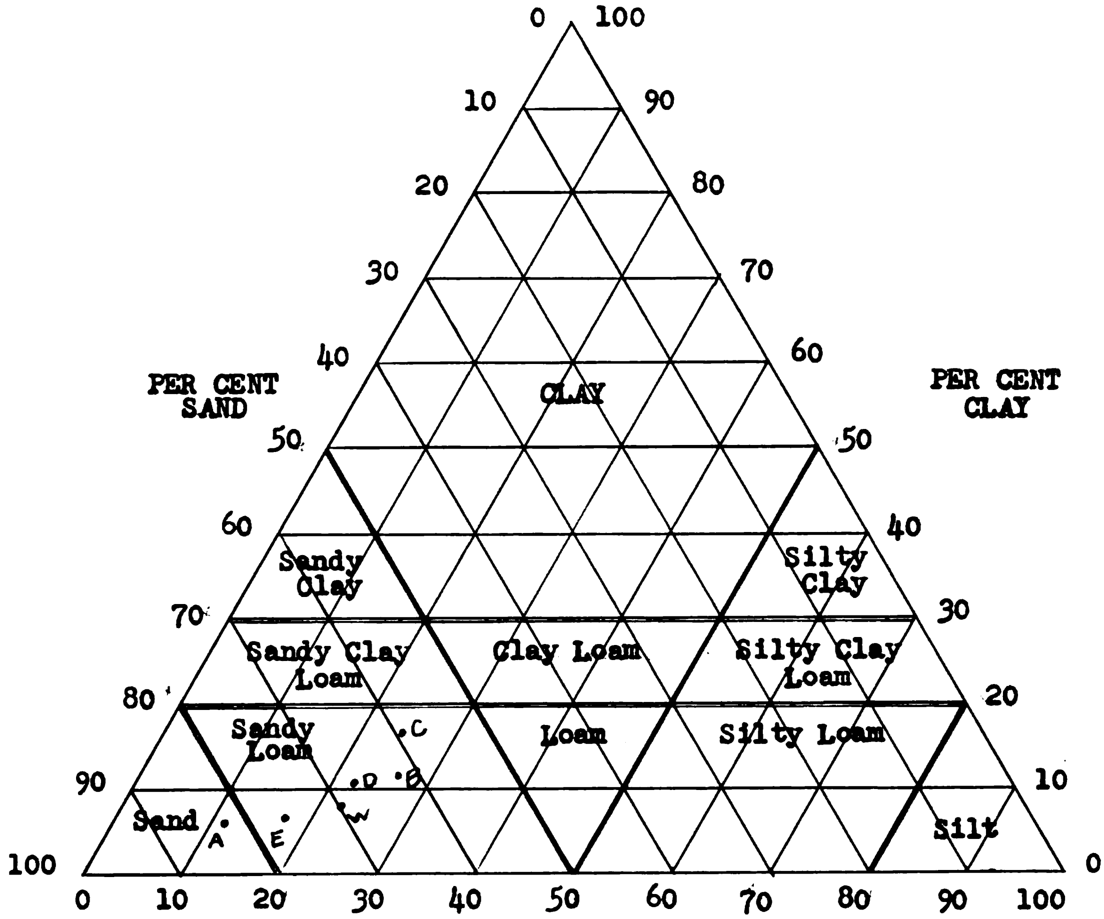


TABLE XII

From the grading curves shown on page 17, it can be determined what per cent of sand, silt, and clay are in each sample. From these curves it can be seen that:

Sample	A	contains	6% clay,	11% silt,	and 83% sand.
"	B	"	12% clay,	26% silt,	and 62% sand.
"	C	"	17% clay,	24% silt,	and 59% sand.
"	D	"	10% clay,	22% silt,	and 68% sand.
"	E	"	8% clay,	17% silt,	and 75% sand.
"	W	"	9% clay,	21% silt,	and 70% sand.

BLEND OF SOILS

It is desired to blend these five samples of soil so that a mixture may be arrived at that will approach one of the Ideal Grading Curves shown in black, and also contain the approximate percentages of clay and sand that will require a small cement content in mixing the soil-cement cylinders.

By taking 20% of each of the five soil samples and blending, the mixture arrived at is shown by the grading curve labeled "W".

As this very closely approaches the Ideal Grading Curve, and contains a sufficient per cent of sand, this blend will be used. The five soil samples and the soil mixture are plotted in their respective groups on the Tri-Axial chart, as shown on page 18.

APPARENT SPECIFIC GRAVITY OF MIX

Flask No.	12	8
Wt. Soil and Flask	77.46	79.30
Wt. Flask	46.70	46.60
Wt. Powdered Soil	30.76	32.70
Vol. Soil Particles	11.70	12.41
Appar. Spec. Grav.	2.63	2.64
Mean	2.635	

TABLE XIII

Shrinkage Ratio and Shrinkage Limit of Soil Mix

Approximately 30 grams of air dried material passing the #40 sieve was mixed with sufficient water to form a semi-fluid paste. This paste was placed in a small porcelain dish, which had previously been coated with a thin layer of vaseline, in three equal volumes, tapping the dish on a firm surface after each layer had been added. The excess material protruding above the dish after the third layer had been tapped, was struck off, so that the paste would fill the dish level full.

The dish and its contents were immediately weighed on the analytical balance, and placed in the oven, allowing to dry to a constant weight. It was then reweighed, the dried soil pat removed from the dish, and the dish weighed alone. The volume of the dish was found by filling with mercury

and pressing a glass plate firmly over the top to remove the mercury meniscus. The volume of the mercury may be measured in a glass graduate, or may be computed from the weight, assuming the specific gravity of mercury to be 13.6.

The volume of the soil pat was found by the displacement of mercury by the pat. Mercury was poured into a large glass dish nested within a larger dish. A glass plate with prongs was pressed over the dish containing the mercury to squeeze out all of the excess mercury. The pat was placed on the mercury surface, and pressed down with the prongs of the plate, thus forcing out all excess mercury that is displaced by the soil pat. This mercury was caught in the outer dish, and weighed. Again using the specific gravity of mercury as 13.6, the volume of the soil pat was computed.

<u>Data and Results of Shrinkage Test</u>

	Dish No.	5	14
W_1	Wt. Dish and Wet Soil	34.90	36.30
W_2	Wt. of Dish	13.260	11.60
W	Wt. of Wet Soil	21.640	24.70
W_3	Wt. of Dish and Dry Soil	29.050	30.60
W_o	Wt. of Dry Soil	15.79	19.00
W_o	% Water in Soil Paste (dry basis)	3.71	30
V	Vol. of Dish	12.15	13.38
V_o	Vol. of Soil Pat (dry)	8.20	9.94
	Vol. of Shrinkage	3.95	3.44
	Shrinkage in % Wt. of Dry Soil	25%	18.1%
	Shrinkage Limit	12.1	11.9
	Shrinkage Ratio	1.91	1.89

Sample Calculations from Shrinkage Tests

$$\text{Shrinkage in \% Wt. of Dry Soil} = \frac{V-V_o}{W_o} \times 100$$

$$\text{Shrinkage limit} = w_o - \frac{V-V_o}{W_o} \times 100$$

$$\text{Shrinkage Ratio} = \frac{W_o}{V_o}$$

Test for Ph of Soil Mix

The test for the Ph of the soil mix was run by using the Soil-tex kit of the Michigan State College Soils Department. The test is as follows:

A piece of waxed paper was folded and opened to form a small paper boat. Using a clean knife blade, a small amount of the soil was placed in the middle of the boat. Eight or ten drops of the Soiltex solution was added, and the boat shaken endwise to mix the materials. The soil was then shaken to the back end of the paper, and the liquid run out to the front. By comparing the color of the liquid with the color chart provided in the Kit, the Ph of the soil may be determined.

Five tests were run on the soil sample, and a Ph range of 6.0 (slightly acid) to 6.5 (very slightly acid) resulted. The general color of the liquid was green.

Liquid Limit of Soil Mix

This test is to determine the liquid limit of the soil mixture, which is the moisture content, expressed as a percentage of the oven-dry weight, at which the soil will just begin to flow together when jarred 10 times on the liquid limit apparatus.

Approximately 30 grams of oven dried soil passing the #40 sieve was

mixed with small amounts of water until it becomes a thick paste. This mixture was placed in the brass dish of liquid limit machine, and leveled off, leaving a thickness of 3/8" in the middle of the dish.

The layer thus formed was separated into two parts by means of a grooving tool, and the machine cranked so that the dish is jarred slightly. Water or soil (as the case may be) was added until the soil would flow together for a distance of about a half inch on the tenth jar.

Immediately after the soil was found to be at the liquid limit, a sample of it was placed in a container of known weight, weighed, and placed in the oven. When thoroughly dry, it was removed and reweighed.

Data on Liquid Limit Test

Container No.		1	2
W_1	Wt. of Wet Soil and Container	40.03	36.37
W_2	Wt. Container	17.56	18.74
W	Wt. Wet Soil	22.47	17.63
W_3	Wt. Dry Soil and Container	37.28	34.18
$W_1 - W_3$	Wt. Water	2.75	2.19
	Liquid Limit	13.92	14.16

TABLE XIV

Plastic Limit and Plasticity Index of Soil Mix

The plastic limit is defined as the lowest moisture content, expressed as a percent of the weight of oven-dry soil, at which the soil can be rolled into threads 1/8" in diameter without breaking.

The soil mix being tested could not be rolled into 1/8" threads. The threads broke regardless of the amount of water that was added, therefore the mixture does not have a plastic limit. This is not unusual, as granular material generally does not have a plastic limit.

Since the soil mixture has no plastic limit, it cannot have a plasticity index, as plasticity index is defined, as the difference between the liquid limit and the plastic limit.

Optimum Moisture and Density Relations of Soil Mix

This test is to determine the relationship, in cohesive soil mixtures, between the moisture content, dry density, and theoretical maximum density at any given moisture content. The procedure followed is intended to duplicate the degree of compaction obtained under standard field conditions.

A 4000 gram representative sample of the soil mixture was used. This sample was air-dried, and prepared for compaction by pulverizing all lumps.

Water was added in varying amounts over a sufficient range to include the optimum moisture content which produces maximum density. Moisture is expressed in per cent of oven-dry weight of the mixture, and the range used in this test was from 8% to 16%. The water was thoroughly mixed into the sample by vigorous troweling.

Enough of the moist soil was placed into the mold to fill it a little more than one-third full when the soil is compacted. Compaction was obtained by dropping a standard tamper (5½ pds.) 25 times through a distance of 12", spreading the blows uniformly over the surface of the sample.

Two more layers were added, and compacted in the same manner, so that the mold would be filled above the top and into the collar after compaction.

The collar was removed, and the top leveled off evenly. By use of a counter weight equal to the weight of the empty mold, the actual weight of the compacted specimen was quickly and accurately determined.

The moist soil mold was immediately removed, and a representative sample taken for moisture determination. This sample was placed in a can of known weight, and weighed; placed into the oven, dried to a constant weight, and reweighed.

The same procedure was followed for each succeeding trial, adding 2% more water each time.

The resistance was taken by penetrating the sample with a penetrometer needle at the rate of 1/2 " per second.

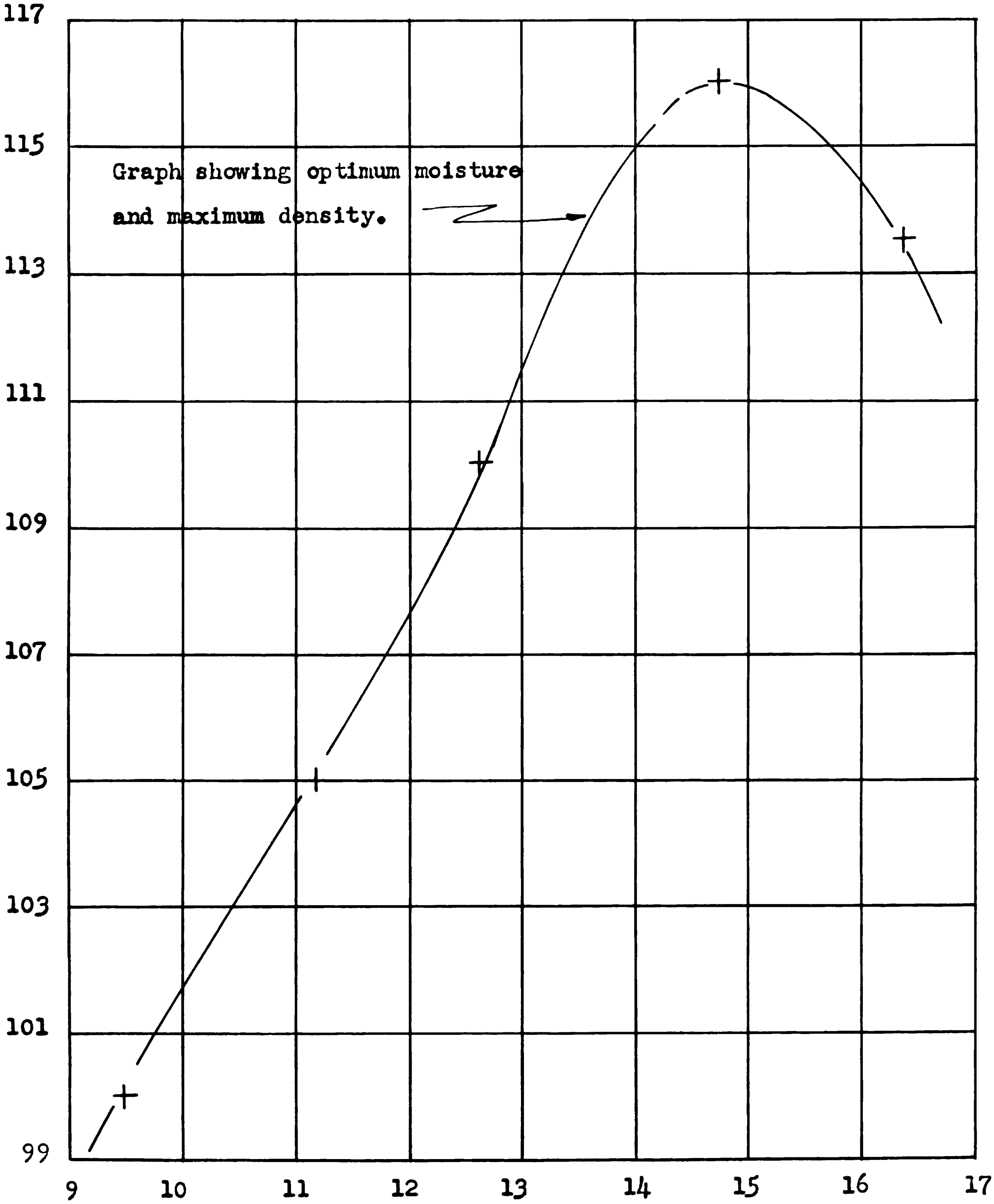
The size of the needle used and the resistance values are also shown in table XV.

A Proctor curve is plotted on page 27 which shows the relationship between optimum moisture and maximum density.

Data and Result of Moisture-Density Test

Trial No.	Water Added		Wt.	Resistance		Moisture Content						Total Sample					
	gms.	Per Cent Soil	Wet Soil gms.	Area in.^{2}	Average lbs./in.^{2}	Can Wt.	Wet Soil & Can	Dry Soil & Can	Loss in Wt. Water	Dry Soil	Water % dry Soil	Dry Soil	Dry Bulk Sp.Gr.	Dry Dens.	Total % Voids	Water	Per Cent Water by Vol.
1	320	8	1820	.10	1600	42.4	197.6	184.3	13.3	141.9	9.4	1760	1.60	100.0	39	60	5.45
2	80	2	1958	.1	1410	41.0	180.4	166.5	13.9	125.5	11.1	1850	1.69	105.0	36	110	10.0
3	80	2	2070	.1	1130	41.4	166.7	152.3	14.4	110.9	12.7	1970	1.79	110.0	32	165	15.0
4	80	2	2180	.25	800	41.5	164.7	148.7	16.0	107.2	14.8	2060	1.87	116.0	29	202	18.4
5	80	2	2165	.50	670	41.1	193.7	172.2	21.5	131.1	16.4	2010	1.83	113.5	31	270	23.5

TABLE XV



Moisture Content % of Dry Weight

TABLE XVI

Molding of Test Cylinders

With the maximum density and optimum moisture content of the soil known, and the percentages of cement decided upon, the test cylinders are ready to be molded.

It is assumed in this test that the optimum moisture and maximum density of the specimens (after the cement has been added) will be the same as that of the raw soil. Although this is slightly erroneous, the degree of error is so small that to compute the values for each cylinder would not be worth the time, and would only tend to defeat the purpose of this report.

The amount of soil, cement, and water to be used for each test cylinder is computed in the following manner.

Cylinders (8% cement)

Maximum density = 116.0   Optimum moisture = 14.8%

Wt. of cement = .08 x 94 = 7.52

Wt. of dry soil = 116 - 7.52 = 108.48lbs.

% cement by wt. of oven dry soil = $\frac{7.52}{108.48}$ = 6.93%

Oven dry wt. of soil per specimen = $\frac{108.48}{30}$ = 3.61 lbs. of dry soil

Usually add 10% for manipulation and 1/20th for moisture content.
Total dry soil = 3.61 + .36 + .20 = 4.17 lbs.

Cement: 4.17 x $\frac{6.93}{100}$ = .289 x 454 = 131 gms.

Air-Dry Soil: 4.17 x 454 = 1890 gms.

Water: (4.17 + .289) x $\frac{14.8}{100}$ = .84 x 454 = 300 cc.

Add 1 1/2% of dry soil to take care of evaporation. As there are 3 cylinders of each % cement to be made each quantity shall be multiplied by 3.

Cylinders (10% cement)

Maximum density = 116.0 Optimum moisture = 14.8%

Wt. of cement = .10 x 94 = 9.4 lbs.

Wt. of dry soil = 116 - 9.4 = 106.6 lbs.

% cement by wt. of oven dry soil $= \frac{9.4}{106.6} \times 100 = 8.3\%$

Oven dry wt. of soil per specimen $= \frac{106.6}{30} = 3.55$ lbs. of dry soil

Usually add 10% for manipulation and 1/20th for moisture content.

Total dry soil = 3.55 + .55 + .20 = 4.11 lbs.

Cement: $4.11 \times \frac{8.3}{100} = .342 \times 454 = 155$ gms.

Air-dry Soil: 4.11 x 454 = 1860 gms.

Water: $(4.11 + .342) \times \frac{14.8}{100} = 298$ cc.

Add 1 1/2% of dry soil to take care of evaporation. = 298+45 = 343 cc.
As there are 3 cylinders of each % cement to be made each quantity shall be multiplied by 3.

Cylinders (12% cement)

Maximum density = 116.0 Optimum moisture = 14.8%

Wt. of cement = .12 x 94 = 11.3 lbs.

Wt. of dry soil = 116 - 11.3 = 104.7 lbs.

% cement by wt. of oven dry soil $= \frac{11.3}{104.7} \times 100 = 10.8\%$

Oven dry wt. of soil per specimen $= \frac{104.7}{30} = 3.49$ lbs. of dry soil

Usually add 10% for manipulation and 1/20th for moisture content.

Total dry soil = 3.49 + .35 + .20 = 4.04 lbs.

Cement: $4.04 \times \frac{10.8}{100} = 4.36 \times 454 = 198$ gms.

Air-Dry Soil: 4.04 x 454 = 1830 gms.

Water: $(4.04 + .436) \times \frac{14.8}{100} \times 454 = 301$ cc.

Add 1 1/2% of dry soil to take care of evaporation. = 346 cc. As there are 3 cylinders of each % cement to be made each quantity shall be multiplied by 3.

__Cylinders__ (14% cement)

Maximum density = 116.0 Optimum moisture = 14.8%

Wt. of cement = .14 x 94 = 13.2 lbs.

Wt. of dry soil = 116 - 13.2 = 102.8 lbs.

% cement by wt. of oven dry soil = $\frac{13.2}{102.8}$ = 12.8%

Oven dry wt. of soil per specimen = $\frac{102.8}{30}$ = 3.43 lbs. of dry soil

Usually add 10% for manipulation and 1/20th for moisture content.

Total dry soil = 3.43 + .34 + .20 = 3.98 lbs.

__Cement__: $3.98 \times \frac{12.8}{100} = .510 \times 454 = 231$ gms.

__Air-dry Soil__: 3.98 x 454 = 1810 gms.

__Water__: $(3.98 + .510) \times \frac{14.8}{100} \times 454 = 302$ cc.

Add 1 1/2% of dry soil to take care of evaporation. = 302 + 45 = 347 cc.
As there are 3 cylinders of each % cement to be made each quantity shall be multiplied by 3.

Twelve specimens shall be molded for a complete investigation of the properties of soil-cement mixtures - three for each cement per cent.

One sample or specimen of each cement content shall be used in running the Wetting and Drying Test. These specimens shall be brushed.

Two samples or specimens of each cement content shall be used in running the Freezing and Thawing Test. One sample of each shall be brushed. The remaining sample shall be used in the determination of the compressive strength of the material.

After the required number of specimens have been molded and properly identified, they shall be placed into the moist room for a seven day curing period. The molding of the specimens shall be carried out as previously outlined.

LABORATORY DURABILITY TESTS AND RESULTS

Freezing and Thawing Test

If the soil-cement were to be part of an airport runway, it naturally must be tested under alternate freezing and thawing. This test is designed for determining the soil-cement losses and changes of volume of the compacted specimens due to repeated freezing and thawing.

Two samples of each trial mix will be used in this test, designated as specimens B and C. After the seven day curing preiod the B and C specimens shall be subjected to cycles of alternate freezing and thawing. The specimens and stands shall be placed into a refrigerator having a constant temperature of 10°F belowzero and frozen for a period of 22 hours. The specimen B shall then be weighed and both specimens put in the moist room, also for a period of 22 hours. During the cycles, free water shall be available to the samples by means of absorbent pads placed under them.

After 22 hours in the moist room, specimen B shall be weighed and given two firm strokes on all areas with a standard wire brush. This is to remove all the material which has been loosened during freezing and thawing. Sample B shall be reweighed after brushing, and the oven-dry (110°C) weight of the material brushed off calculated.

The procedure described above constitutes one cycle (48 hours) of freezing and thawing. The specimens shall then be placed back into the refrigerator and the process repeated.

This test varies from the standard A. S. T. M. test in that only 7 cycles were run. The standard test calls for a series of 12 cycles; otherwise the tests are identical.

Data and results of this test are shown in the tables XVII - XXI.

FREEZING AND THAWING TEST

8 % Soil-Cement

Cycle No.	Wet Weights and Moisture Contents: Start Cycle						Dry Weights: Specimen		Soil Loss Per Cent Original Dry Wt.	Date
	Start Cycle W_1^n	W_2^n	After dry or freeze $\frac{W_2^n - W_o^{n-1}}{W_o^{n-1}} \times 100$	After immerse or thaw W_3^n	$\frac{W_3^n - W_o^{n-1}}{W_o^{n-1}} \times 100 = W_o^n$	After Brush W_4^n	Specimen $\frac{W_4^n \times 100}{100 + W_o^n} = W_o^n$	Soil Loss $\frac{W_3^n - W_4^n}{100 + W_o^n} = dW_o^n$	$\frac{dW_o^n}{W_o} \times 100$	
n	g.	g.	%	g.	%	g.	g.	g.	%	
1	1986	1979	15.4	2008	16.8	1945	1690	47	2.8	May 14
2	1945	1936	14.7	1958	16.5	1842	1620	101	6.2	" 16
3	1842	1828	14.4	1855	15.6	1643	1460	182	12.0	" 18
4	1643	1633	12.9	1659	15.3	1530	1330	110	8.3	" 20
5	1530	1519	14.3	1553	16.9	1501	1280	45	3.5	" 22
6	1501	1483	15.9	1502	17.5	1432	1240	59	4.8	" 24
7	1432	1407	14.3	1479	19.4	1411	1194	57	4.7	" 26

TABLE XVII

FREEZING AND THAWING TEST

10% Soil-Cement

Cycle No.	Start Cycle	Wet Weights and Moisture Contents: After dry or freeze		After immerse or thaw		After Brush	Dry Weights: Specimen	Soil Loss	Soil Loss Per Cent Original Dry Wt.	Date
	W_1^n	W_2^n	$\frac{W_2^n - W_o^{n-1}}{W_o^{n-1}} \times 100$	W_3^n	$\frac{W_3^n - W_o^{n-1}}{W_o^{n-1}} \times 100 = w_o^n$	W_4^n	$\frac{W_4^n \times 100}{100 + w_o^n} =$	$\frac{W_8^n - W_4^n}{100 + w_o^n} =$ dW_o^n	$\frac{dW_o^n \times 100}{W_o}$	
n	g.	g.	%	g.	%	g.	g.	g.	%	
1	1965	1957	17.7	1986	19.4	1943	1630	36	2.2	May 14
2	1943	1933	18.3	1962	20.2	1887	1580	63	4.0	" 16
3	1887	1872	18.7	1910	20.8	1676	1390	195	14.0	" 18
4	1676	1665	19.7	1694	21.6	1582	1300	92	7.05	" 20
5	1582	1574	21.0	1602	23.0	1534	1250	55	4.4	" 22
6	1534	1529	22.0	1530	22.5	1514	1240	13	1.1	" 24
7	1514	1519	22.5	1521	22.6	1495	1215	23	1.9	" 26

TABLE XVIII

FREEZING AND THAWING TEST

12 % Soil-Cement

Cycle No.	Wet Weights and Moisture Contents						Dry Weights		Soil Loss Per Cent Original Dry Wt.	Date
	Start Cycle	After dry or freeze		After immerse or thaw		After Brush	Specimen	Soil Loss		
	W_1^n	W_2^n	$\frac{W_2^n - W_o^{n-1}}{W_o^{n-1}} \times 100$	W_3^n	$\frac{W_3^n - W_o^{n-1}}{W_o^{n-1}} \times 100 = w_o^n$	W_4^n	$\frac{W_4^n \times 100}{100 + w_o^n} = W_o^n$	$\frac{W_3^n - W_4^n}{100 + w_o^n} = dW_o^n$	$\frac{dW_o^n \times 100}{W_o}$	
n	g.	g.	%	g.	%	g.	g.	g.	%	
1	2023	2014	14.5	2045	16.8	2011	1730	29	1.70	May 14
2	2011	2000	15.5	2028	15.6	1975	1700	46	2.72	" 16
3	1975	1960	15.5	1984	16.8	1798	1540	160	10.3	" 18
4	1798	1785	15.9	1816	17.8	1724	1460	78	5.3	" 20
5	1724	1714	17.3	1730	18.4	1719	1440	9	.62	" 22
6	1719	1710	18.4	1722	19.3	1715	1435	6	.43	" 24
7	1715	1703	18.6	1715	19.5	1703	1420	9	.63	" 26

TABLE XIX

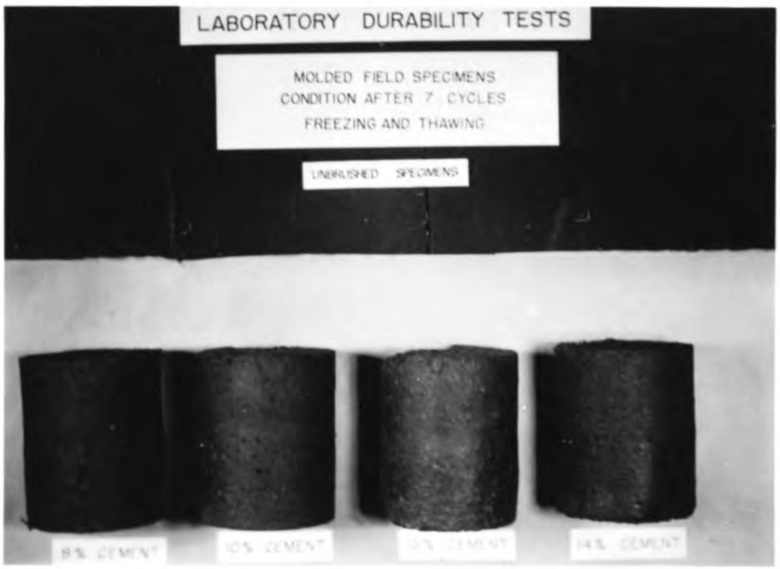
FREEZING AND THAWING TEST

14% Soil Cement

Cycle No.	Wet Weights and Moisture Contents: Start Cycle	After dry or freeze		After immerse or thaw		After Brush	Dry Weights: Specimen	Soil Loss	Soil Loss Per Cent Original Dry Wt.	Date
	W_1^n	W_2^n	$\frac{W_2^n - W_o^{n-1}}{W_o^{n-1}} \times 100$	W_3^n	$\frac{W_3^n - W_o^{n-1}}{W_o^{n-1}} \times 100 = w_o^n$	W_4^n	$\frac{W_4^n \times 100}{100 + w_o^n} = W_o^n$	$W_3^n - \frac{W_4^n}{100 + w_o^n} = dW_o^n$	$\frac{dW_o^n \times 100}{W_o}$	
n	g.	g.	%	g.	%	g.	g.	g.	%	
1	2053	2038	16.9	2065	18.2	2051	1745	8	.46	May 14
2	2051	2042	17.1	2069	17.2	2047	1740	18	1.07	" 16
3	2047	2036	17.1	2062	18.5	1997	1695	55	3.24	" 18
4	1997	1985	17.2	2017	18.9	1984	1670	27	1.66	" 20
5	1984	1967	17.8	2000	19.6	1963	1640	31	1.90	" 22
6	1963	1946	18.2	1952	19.5	1920	1610	27	1.70	" 24
7	1920	1901	18.3	1923	19.0	1899	1595	20	1.25	" 26

TABLE XX


LABORATORY DURABILITY TESTS
MOLDED FIELD SPECIMENS
CONDITION AFTER 7 CYCLES
FREEZING AND THAWING
BRUSHED SPECIMENS
8% CEMENT
10% CEMENT
12% CEMENT
14% CEMENT


LABORATORY DURABILITY TESTS
MOLDED FIELD SPECIMENS
CONDITION AFTER 7 CYCLES
FREEZING AND THAWING
UNBRUSHED SPECIMENS
8% CEMENT
10% CEMENT
14% CEMENT

Wetting and Drying Test

This test is to determine the soil-cement losses and volume changes produced by repeated wetting and drying of the soil-cement mixtures.

One specimen of each cement content shall be used in running this test.

After the seven day curing period, the specimens shall be submerged in water for a period of 4 hours, removed and weighed.

One sample shall then be placed in an oven with a constant temperature of 110°C for a period of 20 hours, and then weighed.

After the 4 hour wetting period, each specimen shall be given two firm strokes on all areas with a standard wire brush. Immediately after brushing, each sample shall be weighed, and the weight of the loosened material calculated on the oven-dry basis.

The procedure outlined above constitutes one cycle (24 hours) of wetting and drying. This test varies from the standard A. S. T. M. procedure in that the latter calls for 40 hours of drying, while these specimens shall be dryed for only 20 hours. Otherwise this procedure and the A. S. T. M. standard procedure are identical.

The date and results of this test are shown in tables XXI - XXIV.

WETTING AND DRYING TEST

8 % Soil Cement

Cycle No.	Wet Weights and Moisture Contents: Start Cycle W_1^n	After dry or freeze W_2^n	After dry or freeze $\frac{W_2^n - W_o^{n-1}}{W_o^{n-1}} \times 100$	After immerse or thaw W_3^n	After immerse or thaw $\frac{W_3^n - W_o^{n-1}}{W_o^{n-1}} \times 100 = w_o^n$	After Brush W_4^n	Dry Weights: Specimen $\frac{W_4^n \times 100}{100+w_o^n} = W_o^n$	Soil Loss $\frac{W_3^n - W_4^n}{100+w_o^n}$ dW_o^n	Soil Loss Per Cent Original Dry Wt. $\frac{dW_o^n \times 100}{W_o}$	Date
n	g.	g.	%	g.	%	g.	g.	g.	%	
1	2019	1724	0	2041	19.4	2017	1680	20	1.2	May 15
2	2017	1711	.18	2002	19.2	1969	1650	26	1.6	May 16
3	1969	1682	.19	1972	19.5	1882	1580	76	4.8	May 17
4	1882	1602	.18	1885	19.4	1827	1550	49	3.2	May 18
5	1827	1555	.07	1823	19.8	1778	1490	43	3.0	May 19
6	1778	1519	.20	1761	18.4	1724	1460	47	3.1	May 20
7	1724	1490	.22	1700	17.9	1650	1400	44	2.7	May 21
8	1650	1300	0	1600	15.0	1540	1360	57	3.4	May 22
9	1360	1200	0	1370	16.0	1300	1290	63	3.9	May 23
10	1290	1106	0	1263	17.2	1197	1140	61	3.8	May 24
11	1140	1043	0	1191	17.6	1127	1092	57	3.9	May 25
12	1092	989	0	1132	17.3	1075	1007	39	2.5	May 26

TABLE XXI

[illegible]

WETTING AND DRYING TEST

10% Soil Cement

Cycle No.	Wet Weights and Moisture Contents: Start Cycle	Wet Weights and Moisture Contents: After dry or freeze		Wet Weights and Moisture Contents: After immerse or thaw		Wet Weights and Moisture Contents: After Brush	Dry Weights: Specimen	Dry Weights: Soil Loss	Soil Loss Per Cent Original Dry Wt.	Date
	W_1^n	W_2^n	$\frac{W_2^n - W_o^{n-1}}{W_o^{n-1}} \times 100$	W_3^n	$\frac{W_3^n - W_o^{n-1}}{W_o^{n-1}} \times 100 = w_o^n$	W_4^n	$\frac{W_4^n \times 100}{100 + w_o^n} = W_o^n$	$\frac{W_3^n - W_4^n}{100 + w_o^n} = dW_o^n$	$\frac{dW_o^n \times 100}{W_o}$	
n	g.	g.	%	g.	%	g.	g.	g.	%	
1	1977	1673	0	1971	17.3	1958	1670	11	.66	May 15
2	1958	1669	0	1975	18.2	1937	1645	32	1.95	" 16
3	1937	1632	0	1936	17.7	1859	1590	66	4.1	" 17
4	1859	1571	0	1855	16.7	1824	1570	27	1.7	" 18
5	1824	1546	0	1812	15.4	1768	1540	38	2.48	" 19
6	1768	1505	0	1773	15.4	1524	1330	217	16.3	" 20
7	1524	1292	0	1509	13.4	1463	1280	40	3.1	" 21
8	1463	1237	0	1468	14.7	1421	1240	41	3.3	" 22
9	1421	1200	0	1427	15.2	1380	1210	41	3.4	" 23
10	1380	1158	0	1381	14.3	1337	1180	38	3.3	" 24
11	1337	1120	0	1337	13.6	1332	1170	6	.53	" 25
12	1170	1002	0	1190	17.0	1167	1000	22	2.2	" 26

TABLE XXII

WETTING AND DRYING TEST

12 % Soil Cement

Cycle No.	Start Cycle W_1^n	Wet Weights and Moisture Contents: After dry or freeze W_2^n	After dry or freeze $\frac{W_2^n - W_o^{n-1}}{W_o^{n-1}} \times 100$	After immerse or thaw W_3^n	After immerse or thaw $\frac{W_3^n - W_o^{n-1}}{W_o^{n-1}} \times 100 = w_o^n$	After Brush W_4^n	Dry Weights: Specimen $\frac{W_4^n \times 100}{100+w_o^n}$ W_o^n	Soil Loss $\frac{W_3^n - W_4^n}{100+w_o^n}$ dW_o^n	Soil Loss Per Cent Original Dry Wt. $\frac{dW_o^n}{W_o} \times 100$	Date
n	g.	g.	%	g.	%	g.	g.	g.	%	
1	2041	1707	0	2019	16.7	2006	1740	11	.63	May 15
2	2006	1707	0	1994	14.6	1970	1720	21	1.20	" 16
3	1970	1678	0	1971	14.6	1942	1690	25	1.47	" 17
4	1942	1658	0	1952	15.5	1928	1670	21	1.25	" 18
5	1928	1638	0	1928	15.6	1906	1650	19	1.15	" 19
6	1906	1619	0	1912	15.9	1894	1630	16	1.00	" 20
7	1894	1604	0	1888	15.9	1864	1605	21	1.30	" 21
8	1864	1592	0	1868	16.4	1831	1570	32	2.02	" 22
9	1831	1578	.1	1855	18.0	1828	1545	23	1.50	" 23
10	1828	1569	.16	1843	19.2	1824	1530	16	1.05	" 24
11	1824	1552	.16	1832	19.4	1802	1510	17	1.20	" 25
12	1802	1512	.1	1812	19.6	1796	1500	14	.93	" 26

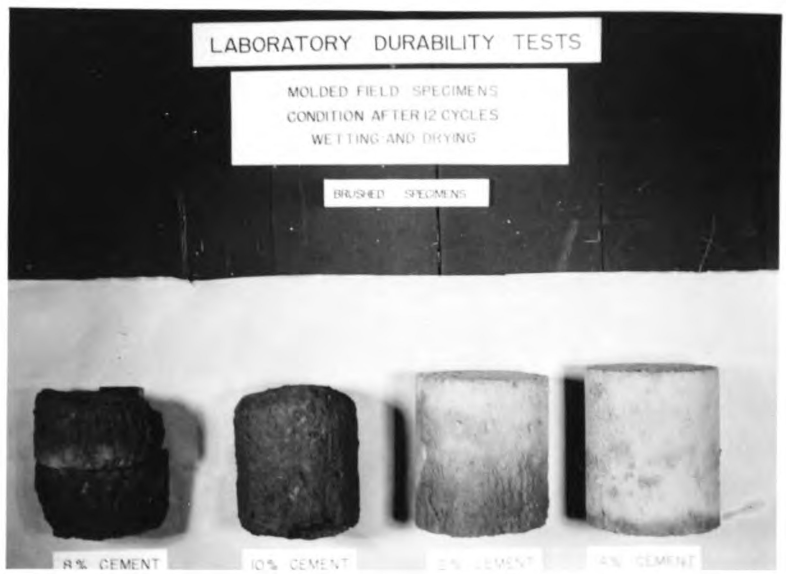
TABLE XXIII

WETTING AND DRYING TEST

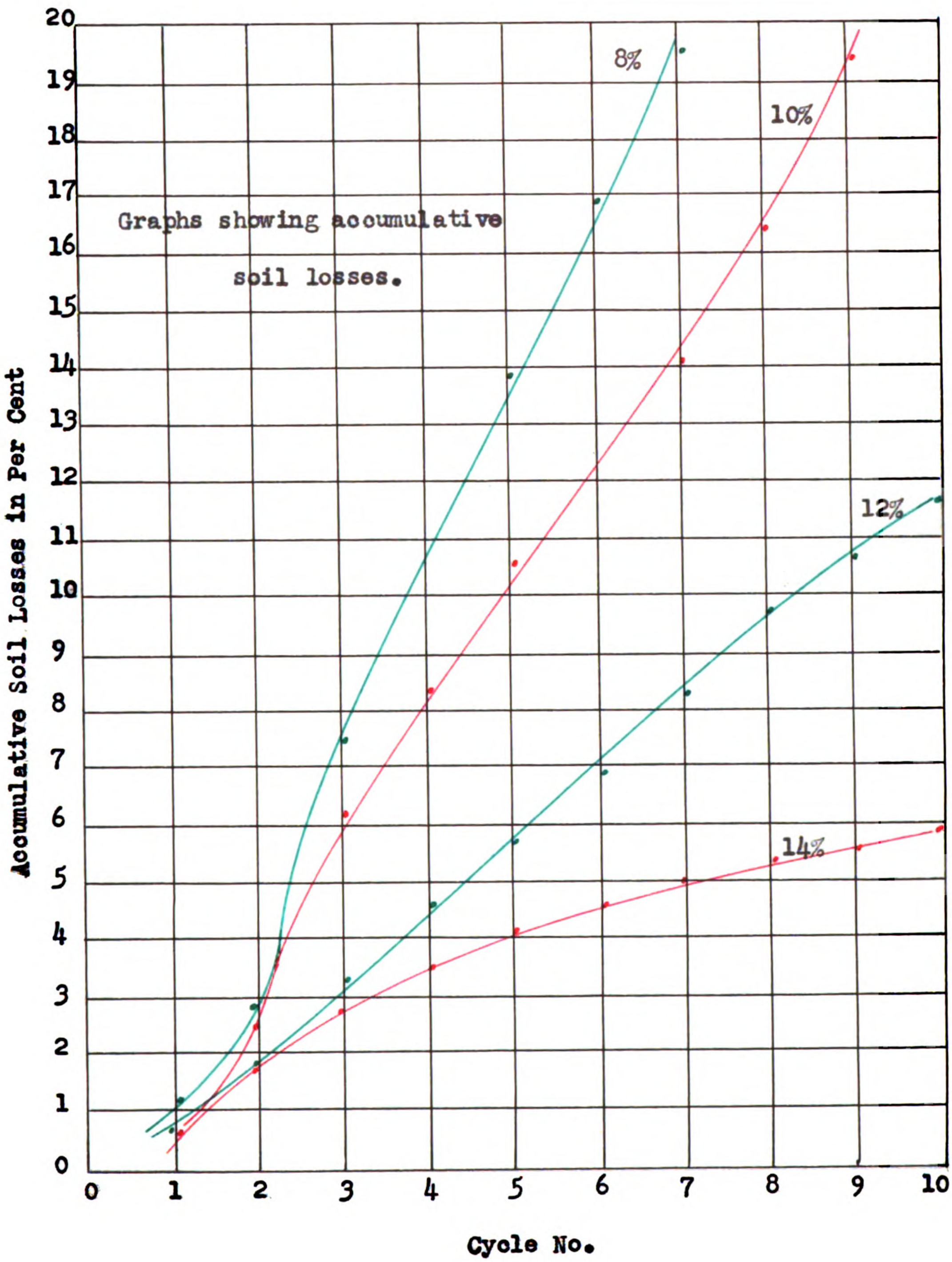
14% Soil Cement

Cycle No.	Wet Weights and Moisture Contents: Start Cycle W_1^n	After dry or freeze W_2^n	After dry or freeze $\frac{W_2^n - W_o^{n-1}}{W_o^{n-1}} \times 100$	After immerse or thaw W_3^n	After immerse or thaw $\frac{W_3^n - W_o^{n-1}}{W_o^{n-1}} \times 100 = w_o^n$	After Brush W_4^n	Dry Weights: Specimen $\frac{W_4^n \times 100}{100 + w_o^n}$ W_o^n =	Soil Loss $\frac{W_3^n - W_4^n}{100 + w_o^n}$ dW_o^n	Soil Loss Per Cent Original Dry Wt. $\frac{dW_o^n \times 100}{W_o}$	Date
n	g.	g.	%	g.	%	g.	g.	g.	%	
1	2029	1722	0	1993	14.5	1987	1735	5	.3	May 15
2	1987	1720	0	2007	15.6	1972	1700	31	1.7	" 16
3	1972	1719	.11	2007	18.0	1990	1685	14	.86	" 17
4	1990	1709	.14	1993	18.3	1983	1680	9	.57	" 18
5	1983	1701	.13	1989	18.4	1977	1670	10	.71	" 19
6	1977	1687	.11	1980	18.6	1972	1645	7	.43	" 20
7	1972	1697	.21	1972	19.5	1962	1640	9	.55	" 21
8	1962	1684	.27	1963	19.7	1959	1635	3	.18	" 22
9	1959	1682	.29	1960	19.8	1957	1625	3	.19	" 23
10	1957	1675	.31	1950	18.0	1945	1630	4	.20	" 24
11	1945	1651	.13	1939	18.5	1933	1630	5	.31	" 25
12	1933	1340	0	1921	17.3	1916	1625	4	.25	" 26

TABLE XXIV



LABORATORY DURABILITY TESTS
MOLDED FIELD SPECIMENS
CONDITION AFTER 12 CYCLES
WETTING AND DRYING
BRUSHED SPECIMENS
8% CEMENT
10% CEMENT



Graphs showing accumulative soil losses.
Accumulative Soil Losses in Per Cent
Cycle No.
8%
10%
12%
14%
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20

TABLE XXV

Compression Tests

The remaining unbrushed samples of the freeze-thaw test shall be subjected to compression loads. The test shall be run by placing each sample in the compression machine and noting the load (in pounds) at the time of failure. Failure occurs when the beam can no longer be kept balanced. Then, by calculating the area of the specimen, the pounds per square inch may be computed.

The data and results of the compression tests are shown in table XXVI.

Sample	Area in sq. in.	Load in pounds at failure.	Strength Lbs./sq. in.
8 C	12.50	2750	220
10 C	12.50	3680	295
12 C	12.50	5130	411
14 C	12.50	5980	478

TABLE XXVI

Weathering Tests

One soil-cement cylinder was put out-doors to be exposed to continual weather changes. After 15 days of continual exposure, no ill-effects of the sample were noted. Although this period was not of sufficient length to determine accurate results, soil-cement is very rarely seriously effected by weathering during the months of mild climate.

Additional Tests

It was desired, in this report, to run additional tests on the soil-cement specimens to test the durability and strength of the samples with various cement contents.

For example it was desired to run a test to determine the effect of 100 Octane gasoline on soil-cement, but due to rationing, it was impossible to obtain even a small amount of this airplane fuel.

As it is obvious that the soil-cement would be subjected to continuous drippings of gasoline, oil, grease etc., if part of an airport runway, this test would be imperative to the soils engineer if any detrimental effects were possible.

Conclusions from Durability Tests

From the freezing and thawing test, it is easily seen that the addition of a small amount of cement to the soil makes the material much more resistant to the cycles it must undergo. The soil-cement loss per cycle decreased (on an average) as the cement content increased. The soil-cement losses for each specimen are shown in the freezing and thawing tables XVII - XX.

Various factors have been set up, through long years of testing and field experience, as criteria of cement contents required to produce specimens of satisfactory hardness, durability and serviceability. One of these standards is that all soil classifications A-1, A-2 and A-3 (which includes the sandy-loam soil contained in the cylinders being tested), shall not lose over 14 per cent by weight during 12 cycles of either the freeze-thaw test or the wet-dry test.

Table XXV on page 44 shows the accumlative soil losses for a sample of each of the cement contents. From this graph, it is evident that both the 12% and 14% cylinders conform to the requirements. Thus, it is obvious that the additional 2% of cement does not increase the strength and durability of the product enough to warrant using 14% cement in the mixture.

The photographs of the soil-cement samples show the effects of brushing upon the cylinders of various cement contents. They are compared to the unbrushed samples to show the loss in shape as well as the loss in weight.

From the wetting and drying test, similiar conclusions are drawn. The addition of a small per cent of cement greatly increases the stability of the material. Photographs of the wet-dry specimens are shown, but are not compared to pictures of unbrushed samples. It is again evident that the 12% cement content is much more practical than the 14%, and since it passes the necessary qualifications, the 12% cement content is recommended for use.

For soil-cement used in airport construction, specifications state that the compressive strength shall not be less than 400 lbs. per sq. in. Table XXVI on page 45 gives the compressive strength of the soil-cement specimens after 7 cycles of freezing and thawing. It is apparent that the greater the cement content, the greater will be the compressive strength.

Thus, from this test, it is shown that both the 12% and the 14% cylinders exceed the 400 lbs. per sq. in. compressive strength required.

Protection, or Armor Coats

The soil-cement type of construction, if properly controlled and supervised, will produce a surface capable of withstanding considerable traffic. The soil-cement surface should be exposed before any bituminous mat is applied so that the mat may be firmly bonded to the soil-cement pavement.

The surface should be bladed, cleaned with a power broom and blower before applying the bituminous prime. All areas in the surface which are exceptionally rough or not hard and knit together, should be removed or repaired as they may later cause the bituminous top to loosen, shove, or produce ruts.

It is recommended that the soil-cement surface be left open for use, without a bituminous covering, for several months, or for at least the first winter. On military construction work, however, the surface must be used almost immediately. Therefore, on this type of construction, the mat may be placed immediately after 7 days of moist covering and 14 days exposure.

On military construction work, the bituminous covering should be part of the contract, and should not be forgotten!

During the past several years, it has been advocated to build extra cement surfaces into soil-cement as a part of final finishing operations, where the surfaces are to serve special purposes. Several trial sections of extra cement surface have been built, which have demonstrated the ease of construction, and the completed sections have given good results.

A very significant installation of extra cement surface was made on a soil-cement runway in the northeastern part of the United States in 1940. Inspection of the product two years later, after considerable freezing and thawing weather, showed the project was giving excellent service. A normal crack pattern at 25 feet intervals had developed, but the surface texture was very good. This method is usually not recommended in military construction work, however, as the added cost, and especially the added time are definitely not desirable.

AIRPORTS AND AIRPORT RUNWAYS

Private and Commercial Flying

From the very beginning of aviation, there has been a demand for airports. It was relatively unimportant in the earlier days, and was not given much notice, but with each succeeding year the industry developed, the demand became more acute. Today the aviation industry has taken, and is continuously increasing, its place among the leading industries of the nation. Airport development, however, has not matched this pace - due primarly to the fact that there never has been an organized planned program, either national, state or local. National planning is fundamental for the reason that civil aviation, perhaps more than any other type of transportation, benefits the nation as a whole, rather than any particular state or city.

Increased activity in private flying, especially in the largely populated cities, will necessitate constructing several additional airports, for it is to the best interests of both private and commercial flyers that private activity be separate from scheduled airline operations, thus, reducing congestion at terminal airports. The provision of additional airports for the use of private flyers will enable them to more conveniently house and store their planes and equipment, in addition to providing an added stimulus to private ownership and private flying.

Performance characteristics of commercial and private aircraft, together with the military aircraft, determine to a large extent the facilities that an airport must provide for the safe operation of such craft. These requirements, when established, remain constant, and as a result, the minimum landing area requirements of the aircraft may be readily established.

In order to determine whether or not a given airplane may be safely operated in or out of a given airport, it is necessary to compare the distances required for the airplane to take off or land at that airport with the distances available. The available distances obviously remain fixed for a given airport. The various factors which influence the distance required for an airplane to take off and reach a certain height above the ground or to clear a certain height above in landing may be classified as follows: *

A. Characteristics of the site:
  1. Actual altitude.
  2. Nature of runway surface.

B. Weather conditions:
  1. Barometric pressure.
  2. Temperature.
  3. Wind direction and velocity.

C. Characteristics of the airplane:
  1. Wing loading.
  2. Power loading.
  3. Maximum lift
  4. Engine characteristics.
  5. Propeller characteristics.

D. Operating technique:
  1. Mostly a collect selection of throttle speeds.

From the Civil Aeronautics Authority, the following specifications for Class 2 landing areas, (landing areas which are not built to take care of exceptionally heavy planes), are taken: "Class 2 landing areas shall have sufficient size to permit the safe operation of the larger sized private and smaller sized transport planes, as well as all military planes except the heavier bombers. For purposes of airport planning, a landing area located at sea level, whether its landing area be of the all-way or landing strip type, will be considered qualified for inclusion under the "2" classification if the landing area provides a sufficient number of landing strips at least 500 ft. wide and having a minimum effective length of 2500 ft., or permits

* From Civil Aeronautics Authority

the possibility of laying out such strips if an all-way landing area, making possible landings and take-offs to be made within 22 1/2° of the prevailing wind direction for at least 80% of the total winds of over 5 miles per hour velocity. In addition, the landing area shall have one hard surfaced runway, or its equivalent, usuable under all weather conditions for each landing strip; the runway to have a minimum width of 100 feet, an effective length equal to that of the landing strip, and the center line of the runway to coincide with that of the landing strip. Air navigational equipment and ground facilities provided shall include modern lighting equipment, satisfactory drainage, hangar and fueling equipment, weather bureau facilities, and adequate shop, office and waiting room space. All landing areas should be adequately fenced."

Flight Strips For Military and Civilian Use

As the war has taught us, it is a mistake to concentrate a large number of aircraft on one airport. It is equally foolish to depend upon a few large airports in any defense area as enemy air action would quickly put these few out of commission. It is desirable to have not only a large number of airports but also a large number of "flight strips" upon which to base and disperse our military aircraft. A "flight strip" is defined as an area of land with clear approaches located adjacent to a public highway for use as an auxiliary landing area for aircraft."

By means of flight strips, landing areas may be provided at many places where the cost of an airport would not be justified, in terms of money, materials, transportation, and man power. Although a flight strip has only one runway, it is believed that, by a careful study of the winds prevailing at any location, the runway can be located so as to be available for safe operation during the greater part of the time.

Although military considerations are naturally uppermost in our minds at the present time, some thought must be given to the post-war aspect. With the army program training thousands of pilots, immediately after the war there will be a very large number of people in the country who have learned to fly. It is an important responsibility of the government to see that future air transportation is not retarded due to lack of planning and lack of ground facilities.

The part that the flight strip program is expected to play in the post-war world may be listed as follows:

1. Provide landing facilities for the civilian flier.
2. Provide basic landing facilities for small cities for air cargo service.
3. Provide auxiliary landing facilities for all types of aircraft.

While the flight strip serves the same purpose for take-off and landing as an airport, it does not have the various facilities found at an airport, such as terminal buildings, hangars, gasoline storage, and lighting systems. Therefore, the cost of a flight strip represents only a part of the cost of an airport. While a flight strip provides only one runway, these that are contemplated for the future provide for long runways and approach areas of greater widths and flatter glide angles than can be found at most airports. Flight strips have the twofold purpose of providing facilities for military and civilian aircraft.

Although flight strips have been thought about and experimented with for years, no suggestion of using soil-cement has been brought forth. It is the author's opinion that soil-cement would be the final touch and ultimate goal for flight strips! Table XXVII shows the loads and pressures on surfaces caused by the loads of modern aircraft, and it is easily seen that soil-cement would be ideal for all types of craft with the exception of heavy bombers. This would not only cut the cost of the "flight strip program" a thousand-fold, but it would enable the program to be completed in a phenomenally short time.

The practicability of building numerous relatively inexpensive landing fields has been demonstrated by the operations of great numbers of military aircraft. Following the settlement of the present time conflict, and progressing into a post-war world, the great turnover in all kinds of aviation will give rise to an expansion of air transport facilities which will find widely dispersed landing areas not only essential, but imperative! Thus a dual purpose - military and civilian is served, and soil-cement flight-strips certainly seem destined to play a major role.

Approximate Bearing Pressures of Four Classes of Planes, Used for the Design of Runways.

Type of Plane Traffic	Approximate Loaded Weight	Approximate Static Pressure Load of Tire on Runway Surface
Trainers and Pursuit Planes	6000 lbs. to 16,000 lbs.	10-25 lbs. per sq. in.
Light Bombers and Transports	25,000 lbs. to 35,000 lbs.	15-50 lbs. per sq. in.
Heavy Bombers	50,000 lbs. to 60,000 lbs.	30-75 lbs. per sq. in.
Heavy Bombers of the Future (Douglas B-19 etc.)	100,000 lbs. to 160,000 lbs.	50-90 lbs. per sq. in.

TABLE XXVII

BIBLIOGRAPHY

BIBLIOGRAPHY

Housel, William S. *Applied Soil Mechanics* Ann Arbor, Michigan. Lithoprinted by Edwards Bros. Inc., 1939.

American Society of Civil Engineers. *Civil Engineering* Volume 13, Number 2, 1943.

United States of Agriculture, Bureau of Plant Industry *Soil Survey of Ingham County, Michigan.* Series 1933, No. 36 March 1941.

The Portland Cement Association. *Soil-Cement Roads.* Chicago, Illinois. Second Edition 1941 and Third Edition 1942.

The Portland Cement Association. *Soil-Cement Mixtures* Chicago, Illinois 1942.

Civil Aeronautics Authority. Planning and Development Division. *Proposed National Airport Plan* (A typewritten paper, 1942.)

Ross, B. M. Materials Engineer, Barber-Greene Company *Materials and Methods for Military Airport Construction.* Aurora, Ill. B-G Manual 1001 1943.

The Portland Cement Association - *Soil-Cement News* and papers and pamphets put out by the Association. 1941-1943.

ROOM USE ONLY