

AN EXPERIMENTAL INVESTIGATION
OF SOIL-CEMENT AS A BUILDING
MATERIAL

Thesis for the Degree of B. S.
MICHIGAN STATE COLLEGE

G. A. Prusi
1942

THESIS

Chap. 1

An Experimental Investigation of Soil-Cement as a
Building Material

A Thesis Submitted

to

The Faculty of

MICHIGAN STATE COLLEGE

of

AGRICULTURE AND APPLIED SCIENCE

by

G. A. Prusi

Candidate for the Degree of

Bachelor of Science

June 1942

THESIS

Cap. 1

ACKNOWLEDGMENT

The author desires to express appreciation to C. A. Allen, professor and head of the Civil Engineering Division, and to D. J. Hall, formerly a member of the Michigan State Highway Department's Soil Research Division and at the present an instructor in Civil Engineering at Michigan State College, for their helpful suggestions and criticisms offered during the running of this investigation.

The study of soil-cement durability when subjected to alternate freezing and thawing was made possible in this investigation by the use of the refrigerator owned by the Michigan State Highway Department.

G. A. Prusi

TABLE OF CONTENTS

	<u>Page</u>
INTRODUCTION _ _ _ _ _	1
LABORATORY INVESTIGATION, DATA, AND RESULTS _ _ _ _ _	4
Test to Determine Apparent Specific Gravity _	4
Mechanical Analysis of the Soil _ _ _ _ _	5
Blending of Soil Samples _ _ _ _ _	22
Apparent Specific Gravity of the Soil Mix _ _	23
Liquid Limit of Soil Mix _ _ _ _ _	23
Plastic Limit of Soil Mix _ _ _ _ _	24
Plasticity Index of Soil Mixture _ _ _ _ _	25
Shrinkage Ratio and Shrinkage Limit of Soil Mix _ _ _ _ _	25
Optimum Moisture Density Relations of Soil Mix _ _ _ _ _	27
Determining of Moisture Density Relations of Soil-Cement _ _ _ _ _	31
DURABILITY TESTS AND RESULTS _ _ _ _ _	43
Freezing and Thawing Test _ _ _ _ _	43
Wetting and Drying _ _ _ _ _	49
Compression Test _ _ _ _ _	55
Wash Test _ _ _ _ _	57
Heating and Cooling Test _ _ _ _ _	59
Outdoor Test _ _ _ _ _	60
CONCLUSIONS _ _ _ _ _	61

INDEX OF TABLES

	<u>Page</u>
Table I Data and Results for Determining the Apparent Specific Gravity _ _ _ _ _	5
Table II Maximum Diameters of Grain Size in Suspension Under Assumed Conditions _ _	8
Table III Proportionality Factor, a, and Specific Gravity Correction Factor K_G _ _ _ _ _	9
Table IV Viscosity Correction Factor K_n _ _ _ _ _	10
Table V Hydrometer Correction K_L _ _ _ _ _	12
Table VI Hydrometer and Sieve Analysis Data (A)_	13
Table VII " " " " " (B)_	14
Table VIII " " " " " (C)_	15
Table IX " " " " " Mix_	16
Table X Grading Curves _ _ _ _ _	17
Table XI Triaxial Chart _ _ _ _ _	18
Table XII Optimum Moisture Density Relations Data _	30
Table XIII Optimum Moisture Density Curve _ _ _ _ _	30A
Table XIV Optimum Moisture Density Relations Data for 6% Soil-Cement _ _ _ _ _	35
Table XV Optimum Moisture Density Relations Data for 12% Soil-Cement _ _ _ _ _	36
Table XVI Optimum Density Moisture Curves for 6 and 12% Soil-Cement _ _ _ _ _	37

INDEX TO TABLES (cont.)

Page

DATA ON FREEZING AND THAWING TESTS

Table XVIIIA	6% Cement Content Specimen A	_____	45A
Table XVIIIB	" " " "	B _____	45B
Table XVIIIIA	8% " " "	A _____	46A
Table XVIIIIB	" " " "	B _____	46B
Table XIXA	10% " " "	A _____	47A
Table XIXB	" " " "	B _____	47B
Table XXA	12% " " "	A _____	48A
Table XXB	" " " "	B _____	48B

DATA ON WETTING AND THAWING TESTS

Table XXIA	6% Cement Content Specimen A	_____	51A
Table XXIB	" " " "	B _____	51B
Table XXIIA	8% " " "	A _____	52A
Table XXIIB	" " " "	B _____	52B
Table XXIIIA	10% " " "	A _____	53A
Table XXIIIB	" " " "	B _____	53B
Table XXIVA	12% " " "	A _____	54A
Table XXIVB	" " " "	B _____	54B
Table XXV	Comparative Compression Data	_____	56
Table XXVI	Wash Test Data	_____	58
Table XXVII	Heating and Cooling Test Data	_____	60

AN EXPERIMENTAL
INVESTIGATION OF SOIL-CEMENT
AS A
BUILDING MATERIAL

An Experimental Investigation of Soil-Cement as a Building Material

In recent years much attention has been given to soil-cement as an improvement to secondary roads. This increased interest in soil-cement as an all weather surfacing for highways has primarily been stimulated by the fact that soil-cement is proving itself economical. Now if a low cost, stable, all weather surface for highways can satisfactorily be constructed from soil-cement; why is it not possible to use soil-cement as a building material?

With priorities bearing down on a lot of the materials used in the construction of homes, and with the increased demand for inexpensive homes that can be constructed quickly has lead me to this investigation on the properties of the various soil-cement mixes made from locally obtained soils, and through the following experiments and test draw some conclusions as to the advisablity of using soil-cement as a building material.

Three samples of soil where obtained from the college properties. Samples A and B were taken from the college field south of the Pere Marquette Railroad and west of Farm Lane Road. Sample A was a representative sample of soil from the base of the sod to a depth of 1.5 feet. Soil B

was also a representative sample taken from the same place as sample A, but since the grain size of the soil particles seemed to change at the depth of 1.5 feet sample B was taken from 1.5 to 3.0 feet below the surface. These two samples, although taken from the same spot, were kept apart so that an accurate analysis for grain size of the soil particles could be made on each of the samples.

Sample C was obtained from the college clay pit. The intention being to blend sample C with samples A and B if the grading curves of samples A and B fall very far from the ideal grading curves designed by Weymouths Theory. However it was not intended to make a perfect blend or to approach the ideal curves too closely, because that would have been to defeat the purpose of this test. If the ideal curves, determined by Weymouths Theory of partical interference, were to be followed completly many more soil smples would be needed, and the cost would be increased.

The raw soil samples obtained in the field were air dried in the labratory. When the samples where dry they were screened. Samples A and B being sandy soils passed the No. 10 sieve 100% upon drying. Sample C, the clay, was quite lumpy upon drying, so it was placed into the Ball Mill pulverizer where the lumps were broken down, and then upon screening through a NO. 10 sieve it was found 100% passing.

With all the soil samples air dry and passing the NO. 10 sieve the follwing tests were for each sample.

1. The apparent specific gravity of each sample was

determined.

2. By the mechanical analysis of the partical sizes the grain sizes contained in each sample was determined and with the aid of the Triaxial Chart the soils were placed into their proper groups.

With the above facts obtained for each of the soil samples the blend or mix of raw soils was determined from the grading curves. Blending completed the above two tests were repeated upon the mix, and in addition the following tests were performed.

3. Plastic Limit Test
4. Liquid Limit Test
5. Plasticity Index Test
6. Shrinkage Ratio Test
7. Shrinkage Limit Test
8. Optimum Moisture Density Relation Test

When all the previously mentioned tests are known the next step was to determine the soil cement optimum moisture density relations for the various cement percentages by volume these percentages being arbitrarily choosen.

Knowing the soil-cements optimum moisture-density relations for the various cement contents that shall be taken the test samples can be molded. A total of nine (9) samples will be used for each of the chosen cement contents. These nine samples shall be tested in a manner that will be similar to the actual conditions that the material would have to take if it were a part of a wall.

LABORATORY INVESTIGATION INCLUDING DATA, RESULTS , AND
SAMPLE CALCULATIONS.

The purpose of this project is to take samples of easily obtainable local soils and through accurate laboratory tests design soil-cement test cylinders containing varying percent off cement by volume. To take these cylinders and subject them to tests similar to the actual conditions that a exterior wall of a building and similar structures would have to undergo. From these tests a determination of the practicability of using soil-cement as a building material shall be made.

Test of raw soil to determine the apparent specific gravity.

Approximately 40 gms of oven-dried soil shall be ground in a mortar with a pestle to a fine floury texture, being careful not to break the actual grain structure, only loosening each partical from the next. Place about 30 gms of this material into a volumetric flask the weight of which is known and weigh on an analytical balance. Fill a burette with kerosene; draining excess kerosene off at the bottom so that the kerosene level is exactly at the 100cc mark. Introduce about 40cc of kerosene from burette into Flask twirled between the hands until the powdery material is completly in suspension. Subject the flask and contents to a vacuum to remove all entrained air. Rotate flask gently while vacuum is being applied this further assuring that each partical of material is in suspension. When all entrained air has been removed

fill the flask to the 100cc mark from the burette. The vol-
of the remaining kerosene is recorded as the volume of the
contained soil.

Soil Sample		A		B		C	
Flask No.		3	4	5	6	1	2
W_3	Wt of powdered soil & flask	78.09	78.22	75.53	77.75	72.79	74.49
W_f	Wt of flask	48.40	48.35	45.81	47.98	42.80	44.51
W_s	Wt of powdered soil	29.69	29.87	29.72	29.77	29.99	29.98
V_s	Vol of soil particles	11.6	11.6	11.4	11.38	10.4	10.48
G_A	Apparent Specific Gravity	2.58	2.582	2.61	2.62	2.88	2.86
G_A	Mean App. Sp. Gr.	2.58		2.61		2.88	

TABLE I

All the items in the above table are self explanatory.
 W_3 and W_f are the values obtained by weighing the respective
items, and V_s is the amount of kerosene remaining in the
burette after the flask has been filled to the 100cc mark.
The mean specific gravity G_A is equal to $\frac{W_s}{V_s}$.

Mechanical Analysis Of The Soil Samples

This is to determine the grading or the per centage
of the various particle sizes contained in the soil samples.

A representative soil sample was selected from oven-
dried material passing the No. 10 sieve. The weight of the
sample shall be 100gms for sandy soils and 50 gms for silt

and clay soils.

The soil was placed in a glass beaker and covered with about 200cc of distilled water to which was added 20cc of sodium silicate solution by means of a pipette. The sodium silicate is to act as a defloculating agent. The soil solution was then allowed to stand for 18 hours to assure that each particle is loosened from the next and also at the end of this period the clay will have softened enough to be easily broken down in the dispersion apparatus.

After tempering the soil was poured into the dispersion cup all material was carefully washed from the beaker into the cup. The dispersion cup was filled to within 2 inches of the top with distilled water and placed into position on the milk shaker which was used as a mixer. The mixing time was 5 minutes for sandy soils and 9 minutes for clay and silt soils.

At the conclusion of the mixing time the contents of the dispersion cup was poured into a 1000cc glass graduate again carefully washing all the soil particles from the cup into the graduate, then the graduate was filled with additional distilled water until the 1000cc mark was reached. Covering the open end of the graduate with the palm of one hand, the graduate was then vigorously shaken for a period of one minute, quickly setting down graduate into a position where it will not be disturbed for the remainder of the test.

Place the hydrometer and thermometer into the solution and begin taking readings at the end of 1, 2, 5, 10, 15, 30, 60, 120 minutes. Will not be necessary to run the 1440 minute test. Due to the large particles settling on the hydrometer bulb the first few minutes; these readings are frequently low and may be discovered from the final grading curves. After the first two readings have been taken remove the hydrometer from the solution and rinse the bulb; placing back into the solution about 20 seconds previous to the next reading.

Upon completion of all the readings through the 120 min reading pour the content of the graduate upon a No. 200 sieve washing all the material from the graduate on to the sieve. Wash the material upon the sieve and then set sieve into an oven and allow to dry. When the material is dry place it upon a No. 10 sieve of a nest of sieves that are arranged in the following order, Nos. 10, 20, 40, 60, 140, 200, and the pan. Place the nest and materials into a Ro-Tap and shake for 20 minutes. Record the weight of the material retained upon each sieve.

Corrections must be applied in the hydrometer analysis for temperature of solution and the specific gravity of the soil since the hydrometers have been graduated or calibrated at 67 and 19.4 degrees fahrenheit and centigrade respectively, and for an apparent specific gravity G_A of the soil as being 2.65.

Table II gives the maximum grain diameters in suspension under assumed conditions.

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 0.9984 at 67°F or 19.4° C.
3. That the coefficient of viscosity, η is equal to that of water 0.0102 at 67°F or 19.4° C.
4. That the distance, L, through which the particles in a given time period is constant and equal to 32.5 cm.

The above listed standard conditions were not the conditions of the test, so corrections must be applied.

Table II

Maximum Diameters Of Grain Size In Suspension Under
Assumed Conditions

Time Minutes	Maximum Grain Size in Suspension in Millimeters
1	0.078
2	0.055
5	0.035
15	0.020
30	0.014
60	0.010
120	0.007
1440	0.002

The temperature correction of the hydrometer designated as ΔR is taken 0.2 per degree change in Fahrenheit and as 0.36 per degree change in Centigrade. The correction is added to the original reading when the temperature of the solution is above the standard 67°F or 19.4°C and subtracted from the original hydrometer reading for temperatures below the above mentioned standard.

When the specific gravity of the soil varies from 2.65 the specific gravity of the solution will vary likewise so a soil with an apparent specific gravity of more than 2.65 will cause the hydrometer to float higher than if under standard conditions, and will register a higher percentage which must be reduced by a proportionality factor, a , as given in Table III.

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

The correction factor for the variation in specific gravity of the soil is designated as K_G And it depends upon the net 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 have been tabulated in Table III.

The correction factor for the coefficient of viscosity of water is designated as K_n and may be expressed in the following form.

$$K_n = \sqrt{\frac{\text{Coefficient of viscosity, } \eta, \text{ at a given temperature}}{0.0102}}$$

The values of K_n have been tabulated into Table IV

Temperature		K_n	Temperature		K_n
Degree F	Degree C		Degree F	Degree C	
60.8	16	1.04	77.0	25	0.93
62.6	17	1.03	78.8	26	0.92
64.4	18	1.02	80.6	27	0.91
66.2	19	1.00	82.4	28	0.90
68.0	20	0.99	84.2	29	0.89
69.8	21	0.98	86.0	30	0.88
71.6	22	0.97	87.8	31	0.88
73.4	23	0.96	89.6	32	0.87
75.2	24	0.95	91.4	33	0.86

Table IV

The correction to correlate the particle size with the distance that the particle falls within a given sedimentation period is designated as K_L . L' is the distance from the surface of the suspension to the bottom of the hydrometer. By experiment the equivalent distance of fall has been established as $0.42L'$. The correction K_L is given by the formula

$$K_L = \sqrt{\frac{0.42L'}{32.5}}$$

In testing soil samples A, B, and C three hydrometers were used and table V giving the correction K_L for each hydrometer was compiled.

The product of the three corrections K_G , K_L , and K_n times the nominal size of the particles will give the actual particle size at the given period.

The combination of the sieve and hydrometer analysis shall be plotted on a graph having an arithmetic ordinate of total per cent passing and a logarithmic abscissa of particle size.

Tables VI, VII, and VIII are the mechanical analysis data sheets tabulated in full for soil samples A, B, and C respectively. The grading curves are all plotted on one graph as shown in table X, which also contains the grading curve for the blend or mix.

Rdg.	Hydro- meter 344253	Hydro- meter 344272	Hydro- meter 381032	Rdg.	Hydro- meter 344253	Hydro- meter 344272	Hydro- meter 381032
	K _L	K _L	K _L		K _L	K _L	K _L
-2	0.568	0.553	0.568	30	0.500	0.483	0.500
0	0.565	0.548	0.564	32	0.496	0.478	0.496
2	0.561	0.545	0.560	34	0.492	0.473	0.491
4	0.557	0.540	0.556	36	0.488	0.469	0.487
6	0.554	0.536	0.552	38	0.484	0.465	0.483
8	0.549	0.532	0.548	40	0.479	0.460	0.478
10	0.545	0.528	0.543	42	0.475	0.456	0.473
12	0.541	0.523	0.539	44	0.471	0.452	0.469
14	0.536	0.519	0.535	46	0.467	0.448	0.464
16	0.531	0.514	0.531	48	0.463	0.443	0.459
18	0.527	0.510	0.526	50	0.458	0.438	0.455
20	0.523	0.505	0.522	52	0.454	0.434	0.450
22	0.519	0.501	0.518	54	0.450	0.430	0.445
24	0.513	0.496	0.514	56	0.445	0.425	0.441
26	0.509	0.492	0.510	58	0.441	0.420	0.436
28	0.505	0.488	0.505	60	0.436	0.415	0.431

Values of K_L

Table V

SIEVE ANALYSIS FROM HYDROMETER ANALYSIS					
Sieve Number	Particle Size mm.	Retained		Cumulative	
		Weight gm.	Percent	% Ret.	% Pass
10	1.98	0.00	0.00	0.00	100.00
20	0.833	1.21	1.21	1.21	98.79
40	0.417	11.59	11.59	12.80	87.20
60	0.246	26.82	26.82	39.62	60.38
140	0.104	30.50	30.50	70.12	29.88
200	0.074	5.77	5.77	75.89	24.11
Pass	No. 200	24.11	24.11	100.00	0.00
	Total	100.00	100.00		

TABLE VI Hydrometer Analysis of Material Passing No. 10 Sieve

Hydrometer No. 344272 Sp. Gr. Corr 1.02 % of Sample 100gms. (Sample A)

Time	Time Min.	Temp. C.	Hydrometer Reading		% Pass 100gms W	Corr: Coeff.			Diameter mm.	Corrected Diameter	% Pass
			Orig.	R		K _L	K _G	K _D			
2:15	1	27	16.0	2.7	13.7	5.08	1.03	.91	0.078	0.0372	19.1
2:16	2	27	14.0	2.7	11.7	5.12	1.03	.91	0.055	0.0264	17.0
2:19	5	27	12.0	2.7	9.7	5.16	1.03	.91	0.035	0.0169	15.0
2:24	10	27	10.5	2.7	8.2	5.21	1.03	.91	0.025	0.0122	13.5
2:29	15	27	9.0	2.7	6.7	5.23	1.03	.91	0.020	0.0098	11.3
2:44	30	27	7.1	2.7	4.8	5.28	1.03	.91	0.014	0.0069	10.0
3:14	60	27	5.5	2.7	3.2	5.32	1.03	.91	0.010	0.0050	8.36
4:14	120	27	4.5	2.7	2.2	5.34	1.03	.91	0.007	0.0035	7.35

Sieve Analysis From Hydrometer Analysis				
Sieve Number	Particle Size mm.	Retained		Cumulative
		Weight gms.	Percent % Ret.	% Pass
10	1.98	0.00	0.00	100.00
20	0.833	0.18	0.18	99.82
40	0.417	4.91	4.91	94.91
60	0.246	30.98	30.98	63.93
140	0.104	53.45	53.45	10.48
200	0.074	4.90	4.90	5.58
Pass	No. 200	5.58	5.58	0.00
	Total	100.00	100.00	

TABLE VII Hydrometer Analysis of Material Passing No 10 Sieve (Sample B)
Hydrometer No. 331032 Sp. Gr. Corr a 1.01 Wt of Sample (%) 100 Gms

Time	Time Min.	Temp. C.	Hydrometer Rdg.		% Pass $100 \frac{W}{W + W_s}$	Corr. Coeff.			Diameter mm.	Corrected Diameter	% Pass
			Orig.	Adj.		K ₁	K ₂	K ₃			
2:30	1	27	1.0	2.7	3.7	.557	1.02	.91	0.074	0.0403	3.74
2:31	2	27	0.9	2.7	3.6	.557	1.02	.91	0.055	0.0284	3.64
2:34	5	27	0.8	2.7	3.5	.557	1.02	.91	0.035	0.0181	3.53
2:39	10	27	0.5	2.7	3.2	.558	1.02	.91	0.025	0.013	3.23
2:44	15	27	0.5	2.7	3.2	.558	1.02	.91	0.020	0.0104	3.23
2:59	30	27	0.3	2.7	3.0	.558	1.02	.91	0.014	0.00725	3.03
3:29	60	27	0.0	2.7	2.7	.559	1.02	.91	0.010	0.00518	2.72
4:29	120	27	-0.5	2.7	2.2	.560	1.02	.91	0.007	0.00364	2.22

Sieve Analysis From Hydrometer Analysis					
Sieve Number	Particle Size mm.	Retained		Cumulative	
		Weight gms.	Percent	% Ret.	% Pass
10	1.98	0.00	0.00	0.00	100.00
20	0.833	0.08	0.16	0.16	99.84
40	0.417	1.11	2.12	2.28	97.72
60	0.246	3.30	6.60	8.88	91.12
140	0.104	8.62	17.20	26.08	73.92
200	0.074	3.76	7.53	33.61	66.39
Pass	No. 200	33.13	66.39	100.00	0.00
	Total	50.00	100.00		

Table VIII Hydrometer Analysis of Material Passing No. 10 Sieve (Sample C)
Hydrometer No. 344253 Sp. Gr. Corr a 0.95 Wt of Sample (W) 50 gms

Time	Time Min.	Temp. C.	Hydrometer Rdg.			% Pass $100Ra \div W$	Corr. Coeff.			Diameter mm.	Corrected Diameter	% Pass
			Orig.	Δ	R		KL	KG	Kn			
2:46	1	26	25.5	2.4	27.9	53.0	.505	.94	.92	0.078	0.034	53.0
2:47	2	26	22.0	2.4	24.4	46.4	.513	.94	.92	0.055	0.0244	46.4
2:50	5	26	19.0	2.4	21.4	40.6	.523	.94	.92	0.035	0.0158	40.6
2:55	10	26	16.5	2.4	18.9	35.9	.525	.94	.92	0.025	0.0114	35.9
3:00	15	26	15.0	2.4	17.4	33.1	.529	.94	.92	0.020	0.00915	33.1
3:15	30	26	12.0	2.4	14.4	27.4	.536	.94	.92	0.014	0.0065	27.4
3:45	60	26	9.1	2.4	11.3	21.5	.543	.94	.92	0.010	0.0047	21.5
4:45	120	26	7.5	2.4	9.9	18.8	.545	.94	.92	0.007	0.0033	18.8

Sieve Analysis From Hydrometer Analysis				
Sieve Number	Particle Size mm.	Retained		Cumulative
		Weight Gms	Percent	% Pass
10	1.98	0.00	0.00	100.00
20	0.833	0.85	0.85	99.15
40	0.417	7.30	7.30	91.85
60	0.246	24.91	24.19	66.94
140	0.104	39.14	39.14	27.50
200	0.074	5.62	5.62	21.88
Pass	No. 200	21.88	21.88	100.00
Total		100.00	100.00	

Hydrometer Analysis of Material Passing No. 10 (Mixture of samples)
 Hydrometer No. 344272 Sp. Gr. Corr a 1.00 wt of sample (W) 100gms

Table IX

Time	Time Min.	Temp. C.	Hydrometer Rdg.			%Pass 100R _a ÷ W	Corr. Coeff.			Diameter mm.	Corrected Diameter	% Pass
			Orig.	ΔR	R		K _L	K _G	K _N			
2:01	1	28.5	17.8	3.28	21.08	21.08	.503	1.01	.89	0.078	0.035	21.08
2:02	2	28.5	15.5	3.28	18.78	18.78	.508	1.01	.89	0.055	0.025	18.78
2:05	5	28.5	13.5	3.28	16.78	16.78	.516	1.01	.89	0.035	0.0163	16.78
2:10	10	28.5	11.2	3.28	14.48	14.48	.518	1.01	.89	0.025	0.0116	14.48
2:15	15	28.5	9.5	3.28	12.78	12.78	.521	1.01	.89	0.020	0.0094	12.78
2:30	30	28.0	7.9	3.10	11.00	11.00	.526	1.01	.89	0.014	0.0066	11.00
3:00	60	27.5	6.0	2.92	8.92	8.92	.530	1.01	.89	0.010	0.0048	8.92
4:00	120	27.0	5.0	2.74	7.74	7.74	.534	1.01	.89	0.007	0.00344	7.74

Clay	Silt	Very Fine Sand	Fine Sand	Med. Sand	Coar-Fine Sand	Gravel	
		Fine Aggregate					Coarse Aggregate
Binder		Fine Aggregate					Coarse Aggregate
Sieve sizes		270	140	60	40	10	4 1/8 1/2

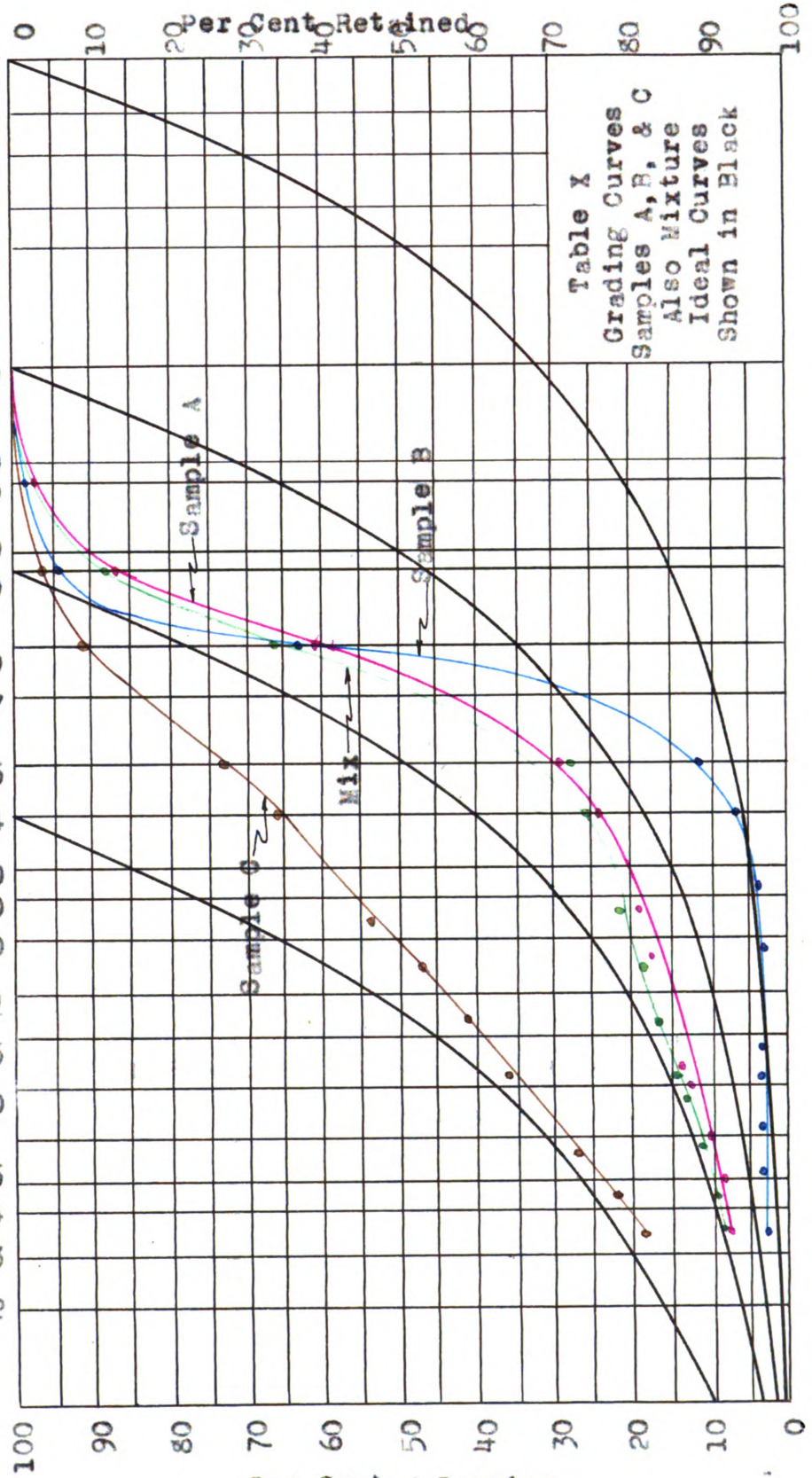


Table X
Grading Curves
Samples A, B, & C
Also Mixture
Ideal Curves
Shown in Black

TRIAxIAL CHART

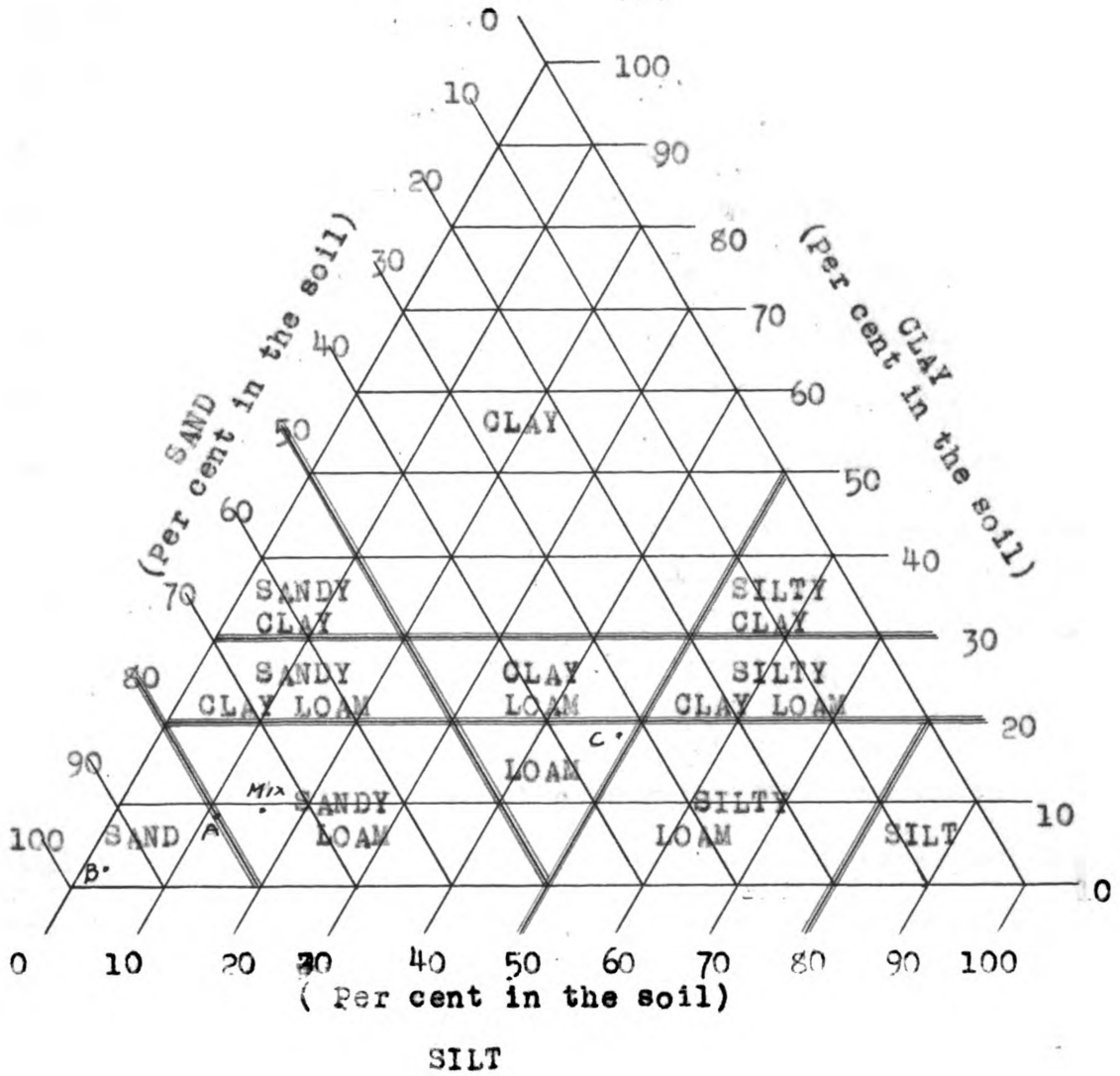


Table XI

Sample Calculations for the Hydrometer Analysis

From Table VII giving the observed data and information taken on sample A in the test the temperature of the solution when the one minute reading was recorded was 27° C and the hydrometer reading was 16 (using hydrometer No. 344272) the apparent specific gravity as found previously was 2.57.

The first correction to be applied to the hydrometer reading will be ΔR and since the temperature readings are centigrade the correction shall be 0.36 per degree change in temperature from the standard (19.4). With the temperature of the solution above the standard the correction is to be added.

$$\Delta R = (0.36) (27 - 19.4) = 2.7$$

$$\text{Corrected Reading} = R = 16 + 2.7 = 18.7$$

The per cent of material passing at this point is equal to one hundred times the corrected hydrometer reading times the proportionality factor (obtained from Table III) divided by the weight of the sample being analyzed.

$$\text{Per cent Passing} = 100Ra \div W$$

$$= 100 \times 18.7 \times 1.02 \div 100$$

$$= 19.1\%$$

The correction factors to correct the particle diameter at this point are obtained as follows:

K_L is had from Table V. The corrected hydrometer reading was found to be 18.7 then for hydrometer No. 344272 the correction K_L for a hydrometer reading of

18.0 is 0.510 and for a hydrometer reading of twenty (20) the correction is 0.505. The correction for a hydrometer reading of 18.7 is found by straight line interpolation and is equal to 0.508.

The correction K_G may be had from Table III. The apparent specific gravity of the soil being 2.57 and from the compiled table a correction of 1.03 is found for an apparent specific gravity of 2.55 and a correction factor of 1.02 for an apparent specific gravity of 2.60. Again the correction factor wanted can be had by straight line interpolation between the above mentioned points, and is found to be equal to 1.03.

Correction K_n , the viscosity correction is obtained from Table IV. K_n is equal to 0.91 when the temperature of the suspending solution is equal to 27° C.

The corrected particle diameter is acquired by multiplying the maximum in suspension at the time of the reading by the correction factors K_G , K_L , and K_n .

$$\begin{aligned}\text{Corrected Diameter} &= (0.078) \times K_G \times K_L \times K_n \\ &= 0.078 \times 0.508 \times 1.03 \times 0.91 \\ &= 0.0372 \text{ mm}\end{aligned}$$

The material retained on the No. 200 sieve after the fines have been washed out through the sieve is broken up into groups that are retained on the next of sieve by sieve analysis. The weight retained on each sieve being recorded, and the per cent retained of the total weight was computed.

Knowing the weight of the material retained on any of the sieves and also knowing the total weight of the sample the per cent retained on any sieve is equal to the weight of material retained upon that sieve divided by the total weight of the sample and multiplied by 100. When 1.21 gms of a total of 100 gms are retained by a sieve the per cent retained by that sieve is equal to $1.21 \div 100 \times 100 = 1.21\%$.

The column head as Cumulative is the cumulated per cent passing or retained up to that point. It is the addition of all per cents of material retained up to that point. To get the cumulative per cent passing at any point just take the cumulative retained to that point and subtract from one.

From the data and results compiled in Tables VI, VII, and VIII can be drawn as shown in Table X. The grading curves can be used to determine the percentage of clay, silt, and sand in the samples A, B, and C. Referring to Table X studying the grading curve for sample A it can readily be seen that 8% of the sample passed 0.005 mm mark or the division point between clay and silt. Likewise it can be seen that 20% of the sample passed the division point between silt and sand giving $20\% - 8\% = 12\%$ silt, also since 100% passed the No. 10 sieve the remainder of the sample is $100\% - 20\% = 80\%$ sand.

So,

Sample A is 8% clay 12% silt 80% sand

Sample B is 2% clay 2.5% silt 95.5% sand.

Sample C is 18% clay 49% silt 33% sand

Locating these samples on the Triaxial Chart given in Table XI the classification of the samples can be secured.

Sample A falls on the division point between sand and a sandy loam. Soil sample B is unquestionably a sand. Soil sample C into a group known as loam.

Mixture or Blend of Soil A, B, and C

To start of with an assumption was made that in practice the sample A and B would not be separated, So equal amounts of soils A and B were combined. With the aid of the Ideal grading curves as given in Table XI a mixture was designed to bring the grading curve closer to the Ideal curve. There are many ways in which a theoretical grading curve can be established. In designing the mixture used in this test the per cent of sand and silt and clay contained in the Ideal curve was determined from the graphs, and by combining sample A and B on the 50-50 basis the per cent of clay, silt, and sand contained in this part of the mix can readily be determined. This mixture will contain 5% clay, 7.25% silt and 87.75% sand, whereas the Ideal curve contains 12% clay, 23% silt, and 65% sand. By combining the above mixture with 20% of sample C will give a final theoretical mixture of 7.6% clay, 15.6% silt, and 76.8% sand. This does not compare very closely with the Ideal grading, but as stated previously by try to approach the Ideal curve too much would

prove to be impractical because in practice such minute blending could not be maintained without complete laboratory supervision.

After the mix had been established the previous two tests were repeated on the blend or mixture. The apparent specific gravity was found to be 2.64 determined in the manner previously described. Below is given the data and results of the specific gravity determination.

Apparent Specific Gravity of Mixture

Flask No.		4	5
W_3	Wt of powdery soil & flask	78.25	89.99
W_f	Wt of flask	48.38	45.79
W_s	Wt of powdery soil	29.87	44.20
V_s	Vol of soil particles	11.30	16.80
G_A	Apparent Specific Gravity	2.64	2.64
Mean App. Sp. Gr.		2.64	

Then the mechanical analysis test of the mixture was carried out and the data and results are compiled into Table IX. From this data the grading curve of the mix was plotted was actually found to be 9% clay, 14.5% silt, and 76.5% sand, which compares favorably with the theoretical values 7.6% clay, 15.6% silt, and 76.3% sand. Plotting the actual values on the Triaxial Chart Table XI the soil mix is found to fall into the sandy loam group.

Liquid Limit of the Soil Mix

This test is to determine the liquid limit of the soil

mixture, which is the moisture content, expressed as a percentage of oven-dried weight, at which the soil will just begin to flow when jarred lightly ten times.

A sample of about 30 gms shall be taken from a thoroughly mixed portion of dried soil passing a No. 40 sieve. Place this soil into the brass dish of the liquid limit machine, and mix adding small amounts of water until it becomes a thick paste. Level wet soil into dish with a spatula, leaving a thickness of about $\frac{3}{8}$ " in the middle of the dish.

The layer thus formed shall be separated into two parts by means of a grooving tool, and the machine cranked, so that the dish will be jarred lightly ten times. The rate of cranking shall be two turns per second.

If the two sections of the soil pat fail to flow together on the tenth jar, more water must be added.

Repeat process until a point is reached where on the tenth jar the soil pat just flows together for a distance of approximately $\frac{1}{2}$ " on the tenth jar.

Immediately after the soil has been found to be at the liquid limit place a quantity of the soil pat into a low form and cover securely and weigh. Remove cover and place low form and wet soil into the oven and allow to dry then re-weigh.

Data and Results on the next page.

Data and Results for the Liquid Limit Test

Low Form No.		74	94
W_1	Wt Wet Soil & Low Form	40.8192	33.8860
W_2	Wt of Low Form	18.8868	17.1354
W	Wt of Wet Soil	21.9324	16.7506
W_3	Wt Dry Soil & Low Form	38.1213	31.7726
	Wt of Water is $W_1 - W_3$	2.6979	2.1134
W_o	Wt of Dry Soil	19.2345	14.6372
Liquid Limit		14.0	13.8

$$\text{Liquid Limit} = \frac{W - W_o}{W_o} = \frac{2.6979}{19.2345} = 14.0$$

Plastic Limit Test of Mix

This test is to determine the plastic limit of the soil mixture, which is the soils lowest moisture content, expressed as per cent of weight of oven-dried soil, at which the soil can be rolled into a thread 1/8 " in diameter without breaking up.

The soil mixture being tested could not be rolled into a 1/8" diameter without breaking regardless of the amount of water used, so the mixture has no plastic limit. Granular material generally does not have a plastic limit.

Elasticity Index

The plasticity index of a soil is the difference between the liquid limit and the plastic limit. Plasticity index is one measure of the capacity of a soil to absorb moisture without becoming fluid and is one of the approximate indexes to the potential cohesion which may be developed under certain conditions. But since the soil had no plastic limit no plasticity index for the same could be obtained.

Shrinkage Ratio and Shrinkage Limit of Soil Mixture

Approximately 30 gms of air dried material passing the No. 40 sieve shall be mixed with enough water to form a semi-fluid paste. This paste shall be placed into a small dish, which has previously been coated with a thin layer of vaseline or other grease, in three equal layers, tapping the dish on a firm surface after each layer has been added. Fill dish with paste level full.

Determine the weight of dish and material contained immediately on an analytical balance, and place dish and content into an oven and allow to dry to a constant weight. Reweigh after drying, and remove soil out from dish, and weigh dish alone. The volume of the dish shall be determined by filling it with mercury and pressing a glass plate firmly over its top to remove the mercury meniscus. The volume of the mercury may be computed from the weight, assuming the specific gravity of mercury as 13.6.

The volume of the soil pat may be found by the displacement of mercury by the soil pat. Mercury shall be poured into a large glass dish nested within a larger dish. A glass plate with prongs shall be pressed over the top of the dish containing the mercury to squeeze out all the excess mercury. Wipe both dishes so that no excess mercury remains on either of the dishes. Place pat on the mercury surface and press down with the glass plate having the prongs forcing out all excess mercury that is displaced by the soil pat this excess mercury is caught in the outer dish. Weigh the mercury that is forced out and using specific gravity of mercury as 13.6 the volume of the soil pat can be computed.

Data and Results of the Shrinkage Test

Dish No.		16	21
W_1	Wt of Dish & wet soil	37.5628	35.9420
W_2	Wt of dish	11.2200	12.2478
W	Wt of wet soil $W_1 - W_2$	26.0560	23.6942
W_3	Wt of dish & dry soil	34.0180	32.6683
W_0	Wt of dry soil $W_3 - W_2$	22.7980	20.4205
w_0	% water in soil paste, dry basis	14.9	15.9
V	Volume of dish	12.86	11.89
V_0	Volume of soil pat (dry)	12.25	11.01
	Volume of shrinkage $V - V_0$	0.61	0.88
	Shrinkage in % weight of dry soil	2.68	4.30
	Shrinkage Limit	12.2	11.70
	Shrinkage Ratio	1.86	1.86

Sample Calculations

$$\text{Shrinkage in \% weight of dry soil} = \frac{V - V_o}{W_o} \times 100$$

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

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

Optimum Moisture Density Relations of Soil Mixture

This test is to determine the relationship in cohesive soil mixture between the moisture content, dry density, and and theoretical maximum density at a given moisture content. The procedure is intended to duplicate the standard compaction method, which by other test has been shown to give the best results.

A 4000 gm representative sample of the soil mixture was selected. This sample shall be air-dried and prepared for compaction by pulverizing all lumps taking care not to break down the individual particles.

Water shall be added to the sample in varying amounts over a range of sufficient expanse to include the optimum moisture content which will produce a maximum density. The moisture content is expressed in per cent of oven-dry weight of the mixture and the usual range may be taken from 5 to 20%. The water must be thoroughly mixed into the sample by vigorous troweling or by suitable clay mixer. When it is possible the water should be applied by means of an air spray similar to a regular paint spraying machine this method

will assure an even distribution of moisture through the mix. Enough of the moist soil shall be placed into the tamping mold to fill it a little more than one-third full when the soil is compacted. Compaction shall be obtained by dropping a standard tamper ($5\frac{1}{2}$ pounds) 25 times through a distance of 12" using care in directing blows so that they will be evenly distributed over the complete surface of the sample. Two more layers shall be added and compacted in the same manner, so that the mold will be filled slightly above the top of the mold and into the collar after compaction.

Remove the collar and strike off the top even with the top of the tamping mold; remove the base plate and weigh to the nearest gram. By use of a counter weight equal to the actual weight of the empty mold the weight of the compacted soil in the mold can be arrived at quickly. Record the net weight of the compacted specimen.

The moist soil mix shall be immediately removed from the mold and a sample taken for moisture determination. Place this sample into a sample can and cover to prevent loss of moisture. The weight of the can must be known; weigh the can and sample to the nearest 0.1 gm and record this weight.

The sample and can shall then be placed into the oven and dried, reweigh and record the weight.

The same procedure shall be followed for each succeeding trial; adding water equal to about 2% of the original oven-

dried soil sample.

Table XII gives a complete tabulation of Data and Results for the test.

Sample Calculations in Determination of Optimum Moisture Density Relations.

Determination of Moisture Content

W_1 is the weight of wet soil and sample can.

W_2 is the weight of the can.

W_3 is the weight of dry soil and can.

W'_0 is equal to $W_3 - W_2$ and is the weight of dry soil.

The loss in weight is equal to the weight of the water contained in the sample at this point and is equal to $W_1 - W_3$

w_o is the per cent of water in the sample based on weight of oven-dried soil, and is equal to the following:

$$w_o = \frac{W_1 - W_3}{W'_0} \times 100$$

Determination of dry density in pounds per cubic foot.

W is the weight of wet soil in mold.

W_o is the weight of dry soil in mold.

w_o is equal to $\frac{W}{100 - w_o} \times 100$

V is the volume of the mold and was determined to be equal to 1100cc.

G_o is the dry bulk specific gravity of the soil and is equal to $\frac{W_o}{V}$

Compaction Characteristics of Cohesive Soil Mixture
 Original Moisture Content 0.2% Apparent Sp. Gr. 2.64
 Wt of Air Dry Soil 4000 gms. Volume of Mold 1100 cc

Trial No.		1	2	3	4	5
Wt Water gm		200	120	120	120	120
Water % Water Dry Soil		5	3	3	3	3
Wt Wet Mold gm	W	1486	2137	2272	2272	2250
Area sq in		.1	.1	.1	.25	.5
Average Resist/sq in		1480	1350	1070	760	610
Can No		1	2	3	4	5
Can Wt gm	W ₂	4162	4080	4140	4065	4225
Wet Soil Can gm	W ₁	1256	1517	1765	1634	1665
Dry Soil Can gm	W ₃	1212	1441	1645	1501	1503
Moist Loss gm		4.4	7.6	12.0	13.3	15.7
Dry Soil gm	W ₀	796	1033	1231	1094	1085
Water % Dry Soil	W ₀	55.3	7.35	9.74	12.26	14.47
Dry Soil gm	W ₀	1408	1991	2070	2024	1966
Dry Bulk Sp. Gr.	G ₀	1.28	1.81	1.88	1.84	1.79
Dry Den.	D ₀	79.87	1129	1173	1148	1117
Total % Voids	V ₀	51.5	31.5	28.3	30.3	32.1
Total Water gm		78	146	202	248	284
Total Water by Vol.		7.1	13.3	18.4	22.5	25.8
% Air Voids		44.4	18.2	10.4	7.8	7.3

TABLE XII

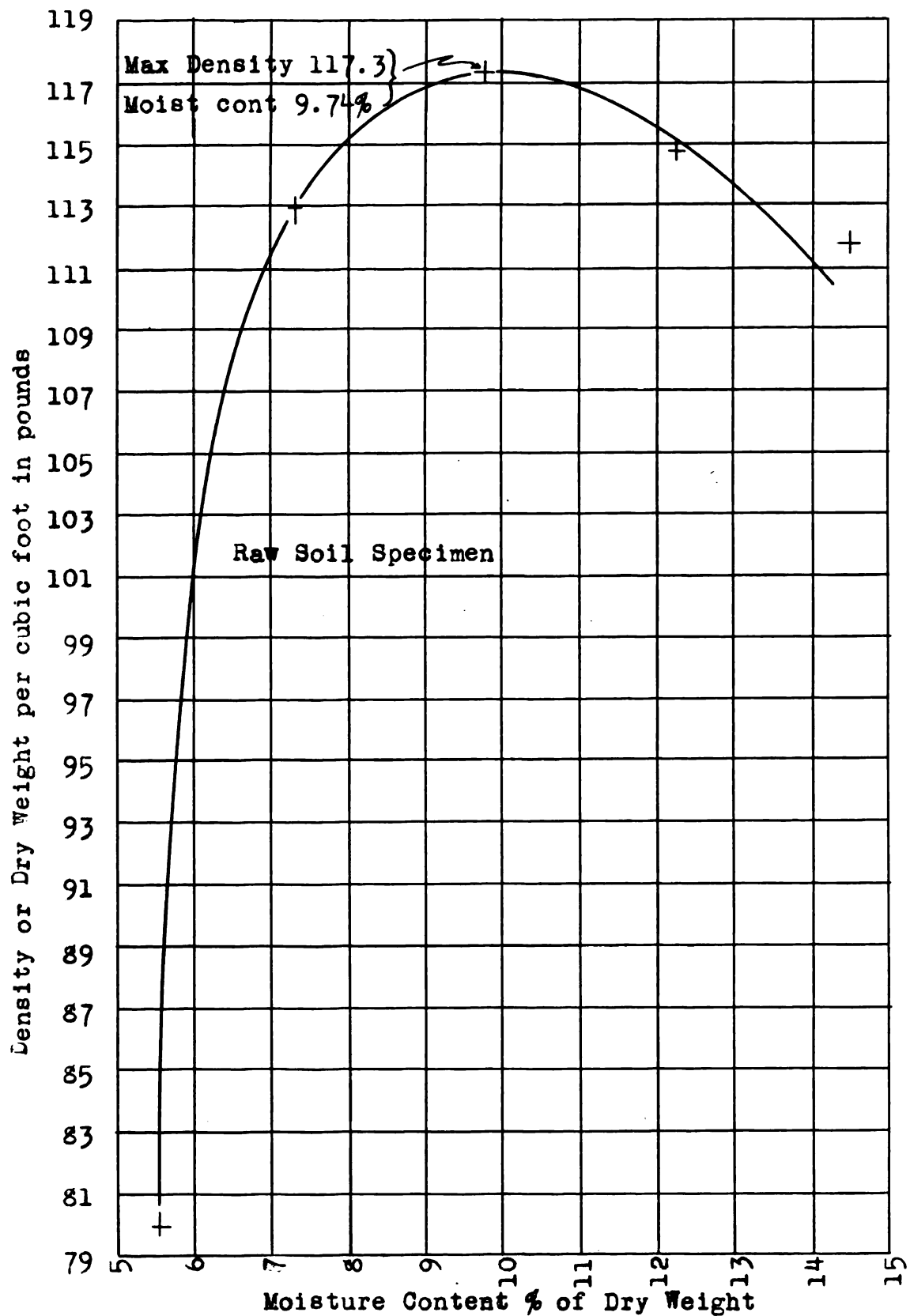


TABLE XIII

D_o is the dry density in pounds per cubic foot and is equal to $G_o \times 62.4$

Determination of Per Cent of Voids

O_o is the designation applied to the total per cent of voids in the compacted state and is equal to

$$(1 - \frac{G_o}{G_A}) \times 100$$

Per cent of water by volume is equal to the weight of water per specimen divided by the volume of the specimen.

Per cent of air voids is equal to the total per cent of voids minus the per cent of water by volume.

From the data obtained thus far in this test a curve can be drawn showing the relationship of Moisture Content by per cent of dry weight to the Density or dry weight per cubic foot (pounds). Table XIII shows the Optimum Moisture Density Curve for the soil sample tested.

Before determining the moisture-density relations of soil-cement mixtures it is first necessary to choose cement contents by volume to be used with the soil at maximum density to give satisfactory durability. By arbitrary means the cement content to be used were taken as 6%, 8%, 10%, and 12% by volume

It is first necessary to estimate, by comparison with previous work, what the densities of the soil-cement mixtures

will be at optimum moisture content. Basing the judgment of these densities on the moisture-density relations for the raw soil, estimate the maximum density which will be obtained with the raw soil-cement mixture containing the cement content to be used and investigated. This estimate will provide the oven-dry weight, in pounds per cubic foot, for the mixture of soil and cement compacted at optimum moisture content. The cement content by volume at maximum density and optimum moisture content must be converted to a weight basis to permit the design of the mixtures in the laboratory with ease and accuracy. Knowing the cement content by volume, this is converted to pounds of cement to be used per cubic foot of oven-dry soil by considering that a cubic foot of cement weighs 94 pounds. By dividing the number of pounds of cement per cubic foot by the number of pounds of oven-dry soil in a cubic foot of compacted mixture, the per cent of cement by weight of the oven-dry soil is obtained.

From previous experiments it is known that the maximum density of a sandy soil-cement is usually two to four pounds greater than the raw sand maximum density; whereas the maximum density of silty and clayey soil-cement mixtures is about equal to the raw soil density. The optimum moisture content will usually vary only about 1 or 2% on either side of the raw soil optimum. It now becomes necessary to estimate by comparison with previous work, what the densities of the soil-cement mixtures shall be at optimum moisture content. The above information as a basis base estimate of

the moisture-density relations of soil-cement upon the moisture-density relations of the raw soil. The raw soil in this test fell into the group known as loam so no increase in the maximum density shall be allowed for in the calculations.

Moisture-density relations are usually obtained for two cement contents. In this test shall determine the moisture-density relations for soil-cement mixes containing 6 and 12% cement by volume.

Design of a mixture of soil-cement containing 6% cement by volume converted into terms of weight is shown in the following calculations.

6% cement by volume is equal to $0.06 \times 94 = 5.64$ pounds per cubic foot.

Assuming that oven-dry soil cement weighs 117.0 pounds per cubic foot. (6% cement by volume)

Weight of oven-dry soil in a one cubic foot volume is $117.0 - 5.64 = 111.36$ pounds per cubic foot.

Per cent of cement by weight of oven-dry soil is

$$\frac{5.64}{111.36} \times 100 = 5.07\%$$

Assuming from previous test that about 4000 gms of material is needed for determining moisture density relation.

Material needed for the test are:

3800 gms of oven-dry soil

193 gms of cement or 5.07%

The design of the soil-cement mixture containing 12% cement by volume is carried on in the above manner but in this design the assumption was made that the oven-dry weight of the soil cement mixture would be 118.0 pounds per cubic foot.

12% cement by volume is equal to 11.28 pounds of cement per cubic foot of mix.

Weight of the oven-dry soil per cubic foot is 106.72 pounds.

% of cement by oven-dry soil is 10.57%.

The amounts needed to run the test are:

3600 gms of oven-dry soil

380 gms of cement

Using the above two mixes the optimum moisture-density relations shall be determined in the manner previously described. The results of the test have been tabulated into Tables XIV and XV, and also in Table XVI the moisture density relationship curves have been plotted for the 6 and 12% cement content soil-cements.

From the curves given in Table XVI the following information was established:

1. The soil-cement that was designed to contain 6% cement by volume or 5.07% by weight has a maximum density, D_o , equal to 117.4 pounds per cubic foot and a moisture content of 10.6% calculated on oven-dry basis.

Compaction Characteristics of a 6% Cement Soil-Cement
 Original Moisture Content 0.2% Apparent Specific Gr. 2.67
 Weight of Air Dry Soil 3800 gms Volume of Mold 1026 cc
 Weight of Cement 193 gms.

Trial No.		1	2	3	4	5	6	7	8
Water	Wt Water gm	440	160	80	80	80	80	80	80
	% Water Dry Soil	11	4	2	2	2	2	2	2
Wt Wet Mold gm		2027	2067	2132	2199	2252	2292	2292	2270
Resist.	Area Sq In	0.1	0.1	0.1	0.1	0.1	0.1	0.5	0.5
	Average #/ sq in	1380	1210	1165	1140	1000	740	412	370
Moisture Content	Can No.	2	4	5	6	7	8	9	10
	Can Wt gm W_2	40.8	40.7	42.3	41.1	41.6	41.3	41.5	42.1
	Wet soil & Can gm W_1	1737	1582	1745	1530	1792	1722	2114	2163
	Dry Soil & Can gm W_3	1674	1511	1656	1443	1672	1596	1931	1953
	Wt Loss gm	6.3	7.1	8.9	8.7	12.0	12.6	18.3	21.0
	Dry Soil gm W_0	1266	1104	1233	1032	1256	1183	1516	1532
	Water % Dry Soil W_0	5.0	6.4	7.2	8.4	9.6	10.6	12.1	13.7
Total Sample	Dry Soil gm W_0	1931	1943	1989	2029	2055	2072	2045	1997
	Dry Bulk Sp. Gr. G_0	1.76	1.77	1.81	1.84	1.87	1.88	1.86	1.82
	Dry Den. D_0	1100	1105	1130	1150	1170	1174	1160	1135
	Total % Voids O_c	34.1	34.5	33.7	32.2	31.0	29.9	29.5	30.3
	Water gm	96	124	143	170	197	220	247	273
	% Water by Volume	8.7	11.3	13.0	15.5	17.9	20.0	22.5	24.8
% Air Voids		25.4	22.4	19.2	15.5	12.0	9.5	7.8	7.0

Table XIV

Compaction Characteristics of a 12% Cement Soil-Cement
 Original Moist. Content 0.21 Apparent Sp. Gr. 2.70
 Weight of Air Dry Soil 3600 gm Volume of Mold 1006 cc
 Weight of Cement 380 gm.

Trial No.			1	2	3	4	5	6	7	8
Water	Wt Water gm		400	120	120	120	120	80	80	80
	% Water Dry Soil		10	3	3	3	2	2	2	2
Wt Wet Mold gm	W		2005	2025	2075	2159	2215	2265	2312	2292
Resist.	Area sq in		0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	Average #/ sq in		1260	1020	910	870	840	810	780	680
Moisture Content	Can No.		11	12	13	14	15	16	17	18
	Can Wt gm	W ₂	40.1	41.1	41.2	41.3	41.9	40.9	40.8	41.5
	Wet Soil & Can gm	W ₁	175.4	161.5	167.6	172.3	182.7	196.5	193.2	213.6
	Dry Soil & Can gm	W ₃	169.4	154.9	159.2	162.7	177.3	184.4	178.1	195.2
	Wt Loss gm		6.0	6.6	7.8	9.5	12.4	14.1	15.1	18.4
	Dry Soil gm	W ₀	129.3	113.8	113.6	121.4	135.4	143.5	137.3	153.7
	Water % Dry Soil	w ₀	4.6	5.8	6.6	7.8	9.2	10.3	11.0	12.0
Total Sample	Dry Soil gm	W ₀	191.7	191.4	194.7	200.3	202.8	205.4	208.3	204.6
	Dry Bulk Sp. Gr.	G ₀	1.74	1.74	1.77	1.82	1.84	1.87	1.89	1.86
	Dry Den.	D ₀	1085	1085	1105	1135	1150	1170	1180	1160
	Total % Voids	O _c	35.5	35.5	34.5	32.6	31.9	30.7	30.0	31.2
	Water gm		88	111	128	156	187	211	229	246
	% Water by Volume		8.0	10.1	11.6	14.2	17.0	19.2	20.8	22.4
% Air Voids			27.5	25.4	22.9	18.4	14.9	11.5	9.2	8.8

Table XV

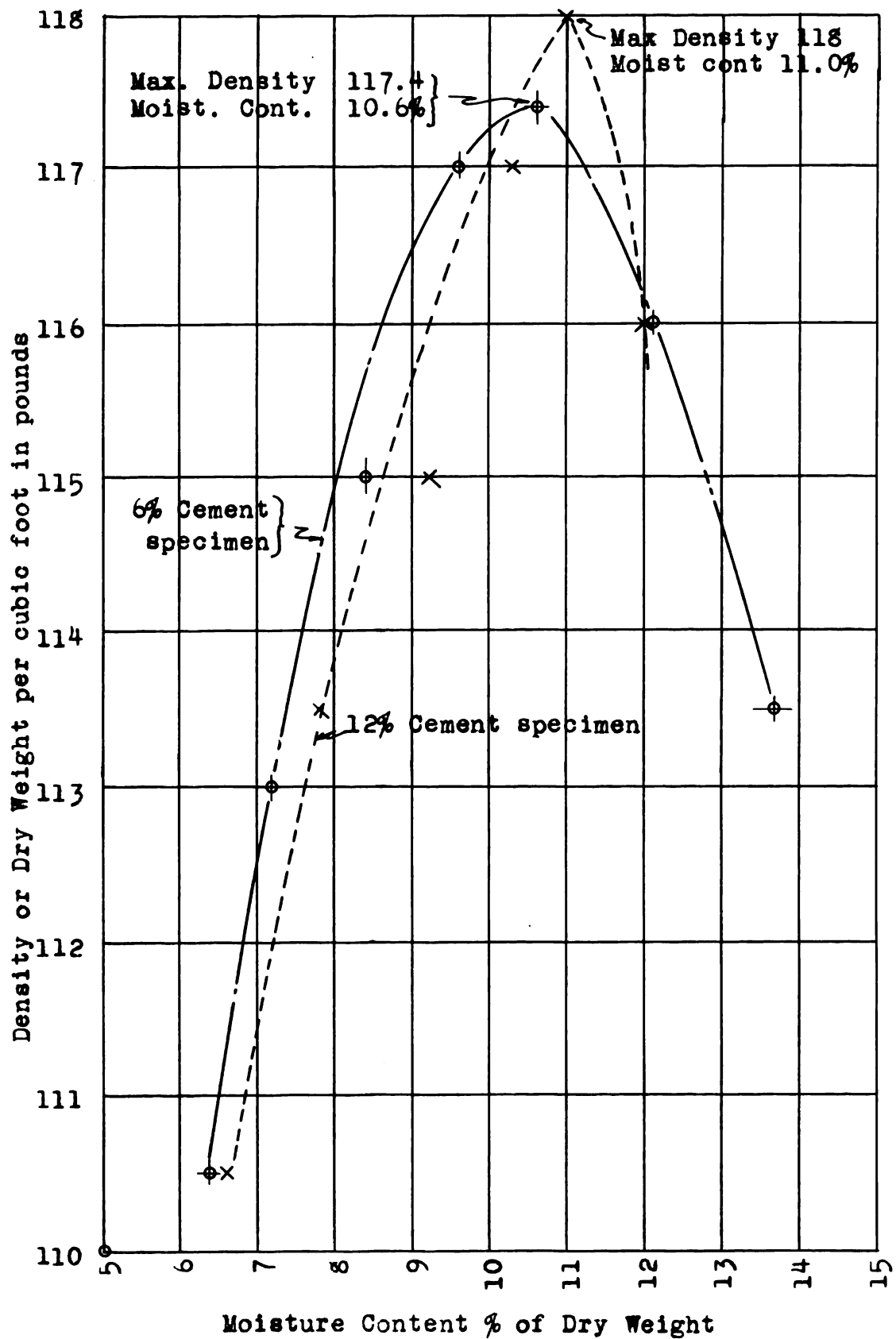


TABLE XVI

3. The soil-cement mix that was designed to contain 12% cement by volume or 10.57% by weight has a maximum density, D_0 , equal to 118.0 pounds per cubic foot and a moisture content of 11.0% calculated on oven-dry basis.

Since the actual figures vary slightly from the assumed values taken for the maximum density, the cement content by volume will vary a small amount and can be corrected in the following manner.

Per cent of cement by volume is equal to $\frac{D - \frac{D}{C}}{94} \times 100$

where:

D is equal to oven-dry density of the soil-cement in pounds per cubic foot.

C is equal to 100 plus the per cent of cement by weight of oven-dry soil, divided by a 100.

$D - \frac{D}{C}$ is the pounds of cement used per cubic foot of compacted soil-cement with 94 pounds equaling the weight per cubic foot of loose cement.

In what was designed to be a 6% mix the maximum density D_0 was 117.4 pounds per cubic foot.

so:

$$D = 117.4 \text{ \# / cu. ft.}$$

$$C = 100 + 5.07 \div 100 = 1.0507$$

$$\frac{D}{C} = \frac{117.4}{1.0507} = 111.73 \text{ \#/cu. ft. weight of oven-dry soil in the mix.}$$

$$D - \frac{D}{C} = 117.4 - 111.73 = 5.67 \text{ \#/cu. ft. weight of cement in the mix.}$$

$$\frac{D - \frac{D}{C}}{94} = \frac{5.67}{94} = 6.03 \% \text{ cement in the mixture by volume.}$$

In the design of the 12% mixture the assumption that the maximum density would be equal to 118.0 pounds per cubic foot was correct so no changes need be made in the cement content.

When the cement content at the maximum densities has been calculated for the two mixes and the moisture-density curves established the data thus obtained will be used for calculating the densities for soil-cement mixtures containing the cement contents to be investigated. The maximum-moisture density relations for the 8 and 10 % mixes may be had by straight line interpolation between the points given by the actual investigation just concluded for the 6 and 12 per cent mixes.

The moisture-density relations for the cement contents to be investigated in this report are:

6 % cement by volume	-	density 117.4	optimum moist.	10.6
8 %	"	"	"	10.73
10 %	"	"	"	10.87

12 % Cement by vol.- density 118.0 optimum moist.11.0%

The soil-cement mixture can be most accurately controlled in the laboratory by mixing by weight and therefore the volumetric cement content will be converted to an equivalent weight of cement. The conversion of cement by volume to cement content by weight of oven-dried soil at optimum moisture content of the soil-cement mixture is as follows.

It is desired to mold test specimens containing 6% cement by volume. From the moisture-density tests the following data is available for a soil-cement mixture containing 6% cement by volume at maximum density.

Maximum density of compacted soil-cement equals 117.4

lb./ cu. ft. oven-dry weight.

Optimum moisture of compacted soil-cement equals 10.6%

by oven dry weight.

Cement per cubic foot of compacted soil-cement containing

6% cement by volume equals 94×0.06 or 5.64 pounds.

Soil per cubic foot of compacted soil-cement equals

$117.4 - 5.64$ or 111.76 pounds.

Per cent cement by weight oven dry soil equals

$$\frac{5.64}{111.76} \times 100 \text{ or } 5.05\%$$

Oven dry weight of soil per specimen (Volume of mold

approximately $1/30$ of a cu. ft.) equals $\frac{111.76}{30}$ or

3.73 pounds. Use 3.8 pounds of oven dry raw soil for one specimen as the additional amount will be needed

for manipulation and for moisture determination.

Weights of Materials Needed for Molding One Test Spec.

Cement equals $3.8 \times \frac{5.05}{100}$ or 0.1919 pounds.

One pound is equal to 454 grams.

0.1919×454 or 87.12 gm.

Soil (oven dry) is equal to 3.8 pounds or 1725 gm.

Water equals $(3.8 - 0.19) \times \frac{10.6}{100} \times 454$ or 192 gm.

In like manner the weights of the materials needed per specimen for the other cement contents may be calculated.

Below is listed the materials needed per test specimen.

6% Cement by vol. - 87.12 gms cement - 1725 gm of soil
and 192 gms of water.

8% Cement by vol. - 115.0 gms cement - 1680 gms of soil
and 192.5 gms or cc of water.

10% Cement by vol. - 146.0 gms cement - 1630 gms of soil
and 193.4 gms of water.

12% Cement by vol. - 173.0 gms cement - 1635 gms of soil
and 199.0 gms or cc. of water.

The number of specimens needed for a complete investigation of the properties of the soil-cement mixtures designed in previous tests shall be nine (9).

2 samples or specimens shall be used in running of the Freezing and Thawing Test.

2 samples or specimens shall be used in running of the Wetting and Drying Test.

2 samples or specimens shall be used in the determination of the compressive strenght of the material.

One specimen shall be used in running of the wash or sprinkling test which will be fully described later in the report. The test was designed to determine the loss of soil-cement caused by continued action of water.

One specimen shall be used in running of the heat test. This test was designed to determine the behavior of soil-cement when it is subjected to heat.

One specimen shall be placed out-of-doors to determine the weathering properties of the soil-cement mixture. This test should be carried on over a long length of time for accurate results.

After the required number 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 has been previously described.

Durability Tests and Results

Freezing and Thawing Test

This test is designed for determining the soil-cement losses, moisture changes, and volume changes (swell and shrinkage) produced by repeated freezing and thawing of compacted specimens of soil-cement mixtures of known composition and of known uniform density and moisture content.

Two samples of each trial mix shall be used in this test, specimens shall be designated as A and B. After the 7 day curing period the A and B specimen of each trial mix shall be subjected to cycles of alternate freezing and thawing. The specimens and carriers shall be placed into a refrigerator having a constant temperature of 20° F below zero for a period of 22 hours and removed. The A specimen (volume and moisture change specimen) shall be weighed and measured and both A and B specimens placed into the moist room. Free water shall be available to the absorbent pads under the specimens to permit absorption of water by the specimens by capillarity.

After 22 hours in the moist room, both specimens shall be weighed and A specimen measured. Specimen B shall then be given two firm strokes on all areas with a wire scratch brush to remove all material loosened during freezing and thawing. The specimens shall again be weighed after brushing. The moisture content of the material brushed from the

specimens shall be determined or it may be assumed equal to the moisture content of the corresponding A specimen. The oven-dry (110° C., 230° F.) weight of material brushed from the specimen shall be calculated.

The procedure described above constitutes one cycle (48 hrs.) 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. B. T. M. method in that the standard test calls for a constant temperature of 23° C. or a minus 10° F. for a period of 22 hours, and a series of 12 cycles to the test. This test shall only be carried through a series of 7 cycles.

Calculations

The moisture content of specimen A at the time of molding and subsequent moisture contents shall be calculated as a percentage of the original oven-dry weight of the specimen.

The soil-cement loss of specimen B shall be calculated as a percentage of the original oven-dry weight of the specimen.

See Tables XVII, XVIII, XIX, and XX for complete data and tabulated results.

FREEZING AND THAWING DERIVILITY TEST

6% Soil-Cement Dry Weight of Sample 1807 gms Wet Weight 1908 gms
 Bulk Specific Gravity 1.81 Dry Density 113.0 lbs. / cu. ft.

SAMPLE 4

Date	Cycle No.	After Freeze				Date	After Thaw			
		Gross & Net wt gm	Moisture		Volume cc.		Gross & Net wt gm	Moisture		Volume cc.
			Gms	%				Gms	%	
5/12/42	1	2020	160	8.6	1014.89	5/13/42	2037	177	9.52	1014.89
5/14/42	2	2027	167	9.0	1014.89	5/15/42	2062	202	10.8	1014.89
5/16/42	3	2053	193	10.4	1016.89	5/17/42	2080	220	11.8	1014.89
5/18/42	4	2070	210	11.3	1014.89	5/19/42	2103	243	13.1	1014.89
5/20/42	5	2096	236	12.7	1018.89	5/21/42	2123	263	14.1	1016.89
5/22/42	6	2114	254	13.7	1016.89	5/23/42	2136	276	14.8	1014.89
5/24/42	7	2126	266	14.3	1014.89	5/25/42	2143	283	15.2	1014.89

TABLE XVII A

FREEZING AND THAWING DURABILITY TEST

6% Soil-Cement Dry Weight of Sample 1860 gms Wet Weight 1998 gms
 Bulk Specific Gravity 1.81 Dry Density 113.0 lbs. / cu. ft.

SAMPLE B

Date	Moist. cont. % from Cyl. #1	After Thawing		Calculated oven dry weight, gms.	Soil Loss			
		Weight before brushing, gms.	Weight after brushing, gms.		Wet, per cycle, gms.	Accumulative		
						From Previous Col. gms.	Dry Corrected gms. %	
5/13/42	9.52	2024	1984	1795.2	40	40	36.19	1.95
5/15/42	10.8	2019	1993	1777.7	26	66	59.38	3.20
5/17/42	11.8	2022	1977	1743.6	45	111	91.1	5.33
5/19/42	13.1	2033	1962	1704.8	71	182	153.8	8.70
5/21/42	14.1	1981	1947	1672.8	34	216	182.9	10.26
5/23/42	14.8	1959	1922	1637.7	37	253	224.4	11.96
5/25/42	15.2	1929	1855	1573.0	74	327	288.1	15.38

TABLE XVII B

FREEZING AND THAWING DURABILITY TEST

8% Soil-Cement Dry Weight of Sample 1906 gms Wet Weight 2071 gms
 Bulk Specific Gravity 1.86 Dry Density 116.1 lbs. / cu. ft.

SAMPLE A

Date	Cycle No.	After Freezing				Date	After Thawing			
		Gross & Net Wt gm	Moisture Gms.	%	Volume cc.		Gross & Net Wt gm	Moisture Gms.	%	Volume cc.
5/12/42	1	2086	180	9.45	1018.89	5/13/42	2102	196	10.3	1018.89
5/14/42	2	2093	187	9.8	1018.89	5/15/42	2119	213	11.2	1018.89
5/16/42	3	2113	207	10.9	1020.89	5/17/42	2149	243	12.2	1018.89
5/18/42	4	2141	235	12.4	1018.89	5/19/42	2165	259	13.6	1018.89
5/20/42	5	2157	241	12.7	1020.89	5/21/42	2174	268	14.1	1018.89
5/22/42	6	2169	253	13.3	1018.89	5/23/42	2181	275	14.4	1020.89
5/24/42	7	2173	257	13.5	1018.89	5/25/42	2185	279	14.6	1018.89

TABLE XVIII A

FREEZING AND THAWING DURABILITY TEST

8% Soil-Cement Dry Weight of Sample 1906 gms Wet Weight 2071 gms
 Bulk Specific Gravity 1.86 Dry Density 116.1 lbs. / cu. ft.

SAMPLE B

Date	Moist. cont. % from Cyl. A	After Thawing		Calculated oven dry weight, gms.	Soil Loss			
		Weight Before brushing, Gms.	Weight after brushing, gms.		Wet, per cycle, gms.	Accumulative		
						From Previous gms.	Dry Corrected gms. %	
5/13/42	10.3	2080	2062	1849.4	22	22	19.73	1.03
5/15/42	11.2	2082	2072	1850.0	10	32	28.63	1.50
5/17/42	12.2	2091	2078	1824.7	13	45	39.9	2.09
5/ 19/42	13.6	2100	2089	1804.9	11	56	49.4	2.59
5/21/42	14.1	2103	2093	1797.8	10	66	58.0	3.04
5/23/42	14.4	2104	2084	1783.8	20	86	75.1	3.94
5/25/42	14.6	2091	2071	1768.8	20	106	92.2	4.84

TABLE XVIII B

FREEZING AND THAWING DURABILITY TEST

10% Soil- Cement Dry Weight of Sample 1906 gms Wet Weight 2070 gms
 Bulk Specific Gravity 1.86 Dry Density 116.1 lbs. / cu. ft.

SAMPLE A

Date	Cycle No.	After freezing				Date	After Thawing			
		Gross & Net Wt gms	Moisture Gms.	%	Volume cc.		Gross & Net Wt gm	Moisture Gms.	%	Volume cc.
5/12/42	1	2000	94	4.93	1014.89	5/13/42	2015	109	5.71	1014.89
5/14/42	2	2009	103	5.41	1014.89	5/15/42	2028	122	6.4	1014.89
5/16/42	3	2020	114	5.98	1016.89	5/17/42	2065	159	8.35	1014.89
5/18/42	4	2058	152	7.98	1014.89	5/19/42	2088	182	9.55	1016.89
5/20/42	5	2082	176	9.25	1014.89	5/21/42	2108	202	10.6	1014.89
5/22/42	6	2100	194	10.2	1018.89	5/23/42	2120	214	11.2	1016.89
5/24/42	7	2112	206	10.8	1014.89	5/25/42	2131	225	11.8	1014.89

TABLE XIX A

FREEZING AND THAWING DURABILITY TEST

10% Soil-Cement Dry Weight of Sample 1906 gms Wet Weight 2070 gms
 Bulk Specific Gravity 1.86 Dry Density 116.1 lbs./ cu. ft.

SAMPLE B

Date	Moist. cont. % from Cyl. A	After Thawing		Calculated oven dry weight, gms.	Soil Loss			
		Weight before Brushing, gms.	Weight after brushing, gms.		Wet, per cycle, gms.	Accumulative		
						From Previous gms.	Dry Corrected gms. %	
5/13/42	5.71	2038	2027	1911.0	9	9	8.49	0.45
5/15/42	6.4	2042	2035	1904.8	7	16	15.04	0.79
5/17/42	8.35	2054	2044	1873.1	10	26	24.21	1.27
5/19/42	9.55	2067	2060	1863.2	7	33	30.54	1.60
5/21/42	10.6	2084	2079	1859.0	5	38	35.01	1.83
5/23/42	11.2	2099	2095	1856.3	4	42	38.56	2.02
5/25/42	11.8	2108	2102	1853.9	6	48	43.85	2.30

TABLE XIX B

FREEZING AND THAWING DURABILITY TEST

12% Sol-Cement Dry Weight of Sample 1927 gms Wet Weight 2152 gms
 Bulk Specific Gravity 1.88 Dry Density 117.3 lbs. /cu. ft.

SAMPLE A

Date	Cycle No.	After Freezing				Date	After Thawing			
		Gross & Net Wt gm	Moisture Gms	Volume cc.			Gross & Net Wt gm	Moisture Gms.	Volume cc.	
5/12/42	1	2154	227	1011.25		5/13/42	2164	237	1011.25	
5/14/42	2	2156	229	1011.25		5/15/42	2167	240	1011.25	
5/16/42	3	2159	232	1008.88		5/17/42	2171	244	1011.25	
5/18/42	4	2163	236	1011.25		5/19/42	2172	245	1008.88	
5/20/42	5	2166	239	1011.25		5/21/42	2173	246	1011.25	
5/22/42	6	2166	239	1011.25		5/23/42	2174	247	1011.25	
5/24/42	7	2166	239	1008.88		5/25/42	2174	247	1011.25	

TABLE XX A

FREEZING AND THAWING DURABILITY TEST

12% Soil-Cement Dry Weight of Sample 1927 gms Wet weight 2152 gms
 Bulk Specific Gravity 1.88 Dry Density 117.3 lbs. / cu. ft.

SAMPLE B

Date	Moist. cont. % form Cyl. A	After Thawing		Calculated oven dry weight gms.	Soil Loss			
		Weight before brushing, gms.	Weight after brushing, gms.		Wet, per cycle, gms.	Accumulative		
						From Previous gms.	Dry Corrected gms. %	
5/13/42	12.3	2182	2177	1909.7	5	5	4.39	0.23
5/15/42	12.5	2181	2179	1907.0	2	7	6.14	0.32
5/17/42	12.7	2182	2175	1898.9	7	14	12.25	0.64
5/19/42	12.7	2179	2174	1897.9	5	19	16.61	0.87
5/21/42	12.8	2177	2165	1889.0	12	31	27.08	1.41
5/23/42	12.8	2170	2166	1888.9	4	35	30.57	1.59
5/25/42	12.8	2167	2164	1887.8	3	38	33.19	1.73

TABLE XX B



Wetting and Drying Test

This test is intended to determine the soil-cement losses, moisture changes, and volume changes (swell and shrinkage) produced by repeated wetting and drying of the compacted specimens of soil-cement mixtures of known uniform density and moisture content.

Two samples of each trial cement content shall be used in carrying out of this test. One specimen shall be designated as the A series and shall be used obtain data on moisture and volume changes during the test. The second specimen shall be identified as the B series, and shall be used to obtain data on soil-cement losses during the test.

After the seven (7) day curing period the specimens shall be submerged in water at room temperature for a period of five hours and removed. The A specimens shall be weighed and measured.

Both specimens shall then be placed in an oven with a constant temperature of 71° C. (160° F.) for a period of 42 hours and removed. Then, both specimens A and B of each cement content shall be weighed and the A specimens measured. The B specimens shall then be given two firm strokes on all areas with a wire scratch brush to remove all material loosened during the wetting and drying process. The specimens shall again be weighed after brushing. The moisture content of the material brushed from the specimen may be taken as equal to the moisture content of the corresponding

A specimen. The oven-dry (110° C., 230° F.) weight of the material brushed from the specimen shall be calculated.

The procedure described above constitutes one cycle (48 hours) of wetting and drying. The standard A. S. T. M. specifications call for the running of 12 cycles for a complete test, but since the report must be turned in before the total of 12 cycles could be completed shall base conclusions on a 7 cycle test. In all other respects the test was as specified by A. S. T. M.

The volume and moisture changes and the soil-cement losses of the specimens shall be calculated as follows:

The moisture content of the A specimens at the time of molding and subsequent moisture contents shall be calculated as a percentage of the original oven-dry weight of the specimens.

The soil-cement losses of specimens B shall be calculated as percentage of the original oven-dry weight of the specimen.

See Tables XXI, XXII, XXIII, and XIV for complete data and tabulated results.

WETTING AND DRYING DURABILITY TEST

6% Soil-Cement Dry Weight of Sample 1860 gms Wet Weight 1998 gms
 Bulk Specific Gravity 1.81 Dry Density 113.0 lbs. / cu. ft.

SAMPLE A

Date	Cycle No.	After Saturation			Date	After Drying		
		Gross & Net Wt gm	Moisture Gms	Volume cc.		Gross & Net Wt gm	Moisture Gms	Volume cc.
5/12/42	1	2117	257	13.8	5/13/42	1887	27	1.45
5/14/42	2	2125	265	14.2	5/15/42	1886	26	1.40
5/16/42	3	2118	258	13.9	5/17/42	1892	32	1.72
5/18/42	4	2119	259	13.9	5/19/42	1888	28	1.51
5/20/42	5	2118	258	13.9	5/21/42	1889	29	1.56
5/22/42	6	2113	253	13.6	5/23/42	1888	28	1.51
5/24/42	7	2111	251	13.5	5/25/42	1891	31	1.67

TABLE XXI A

WETTING AND DRYING DURABILITY TEST

6% Soil-Cement Dry Weight of sample 1800 gms Wet Weight 1998 gms
 Bulk Specific Gravity 1.81 Dry Density 113.0 lbs / cu. ft.

SAMPLE B

Date	Moist. cont. %	After Drying		Calculated oven dry weight, gms.	Soil Loss		
		Weight before brushing, gms.	Weight after brushing, gms.		Wet, per cycle, gms.	Accumulative	
						From Previous Corrected, gms	Dry Corrected, %
5/13/42	1.45	1883	1835	1808.4	48	48	2.49
5/15/42	1.40	1835	1822	1796.5	13	61	3.18
5/17/42	1.72	1824	1811	1779.8	13	74	3.87
5/19/42	1.51	1810	1800	1772.8	10	84	4.40
5/21/42	1.56	1800	1789	1761.1	11	95	4.98
5/23/42	1.51	1790	1781	1754.1	9	104	5.46
5/25/42	1.67	1782	1772	1742.4	10	114	5.99

TABLE XXI B

WETTING AND DRYING DURABILITY TEST

8% Soil-Cement Dry Weight of Sample 1906 gms Wet Weight 2071 gms
 Bulk Specific Gravity 1.86 Dry Density 116.1 lbs / cu. ft.

SAMPLE A

Date	Cycle No.	After Saturation			Date	After Drying		
		Gross & Net Wt gm	Moisture Gms	Volume cc.		Gross & Net Wt gm	Moisture Gms	Volume cc.
5/12/42	1	2147	241	1016.89	5/13/42	1947	41	1016.89
5/14/42	2	2155	249	1014.89	5/15/42	1946	40	1016.89
5/16/42	3	2151	245	1012.89	5/17/42	1946	40	1014.89
5/18/42	4	2154	248	1014.89	5/19/42	1939	33	1016.89
5/20/42	5	2151	245	1014.89	5/21/42	1940	34	1014.89
5/22/42	6	2140	235	1016.89	5/23/42	1942	36	1014.89
5/24/42	7	2120	215	1014.89	5/25/42	1947	41	1014.89

TABLE XXII A

WETTING AND DRYING DURABILITY TEST

8% Soil-Cement Dry Weight of Sample 1906 gms. Wet weight 2071 gms.

Bulk Specific Gravity 1.86 Dry Density 116.1 lbs / cu. ft.

SAMPLE B

Date	Moist. cont. %	After Drying		Calculated oven dry weight gms	Soil Loss			
		Weight before brushing gms	Weight after brushing gms		Per cycle, gms	Accumulative		
						From previous gms	Dry corrected %	
5/13/42	2.15	1893	1869	1828.9	24	24	23.48	1.23
5/15/42	2.10	1869	1861	1821.9	8	32	31.32	1.64
5/17/42	2.10	1864	1856	1817.1	8	40	39.16	2.05
5/19/42	1.73	1854	1849	1817.0	5	45	44.08	2.31
5/21/42	1.78	1849	1844	1811.2	5	50	48.99	2.57
5/23/42	1.89	1844	1838	1803.3	6	56	54.88	2.88
5/25/42	2.15	1838	1835	1795.6	3	59	57.82	3.03

TANBLE XXII B

WETTING AND DRYING DURABILITY TEST

10% Soil-Cement Dry Weight of Sample 1906 gms Wet Weight 2070 gms
 Bulk Specific Gravity 1.86 Dry Density 116.1 lbs / cu. ft.

SAMPLE A

Date	Cycle No.	After Saturation			Date	After Drying		
		Gross & Net Wt gm	Moisture Gme	%		Gross & Net Wt gm	Moisture Gms	Volume cc.
5/12/42	1	2154	248	13.0	5/13/42	1937	31	1014.77
5/14/42	2	2151	245	12.9	5/15/42	1937	31	1014.77
5/16/42	3	2147	241	12.7	5/17/42	1945	39	1012.90
5/18/42	4	2096	190	9.95	5/19/42	1941	35	1014.77
5/20/42	5	2089	183	9.61	5/21/42	1941	35	1014.77
5/22/42	6	2087	181	9.50	5/23/42	1945	39	1014.77
5/24/42	7	2091	185	9.71	5/25/42	1942	36	1012.90

TABLE XXIII A

WETTING AND DRYING DURABILITY TEST

10% Soil-Cement Dry Weight of Sample 1906 gms Wet Weight 2070 gms
 Bulk Specific Gravity 1.86 Dry Density 116.1 lbs / cu. ft.

SAMPLE B

Date	Moist. cont. %	After Drying		Calculated oven dry weight gms	Soil Loss			
		weight before brushing gms	Weight after brushing gms		Per cycle, Col. gm	Accumulative		
						From previous gms	Dry corrected %	
5/13/42	1.63	1940	1932	1900.5	8	8	7.87	0.41
5/15/42	1.63	1933	1931	1897.6	2	10	9.84	0.51
5/17/42	2.05	1930	1928	1888.5	2	12	11.84	0.61
5/19/42	1.84	1924	1922	1886.6	2	14	13.80	0.71
5/21/42	1.84	1922	1920	1884.7	2	16	15.76	0.81
5/23/42	2.05	1923	1920	1881.6	3	19	18.70	0.91
5/25/42	1.89	1921	1918	1880.8	3	22	21.64	1.11

TABLE AXIII B

WETTING AND DRYING DURABILITY TEST

12% Soil-Cement Dry Weight of Sample 1927 gms Wet Weight 2152 gms

Bulk Specific Gravity 1.38 Dry Density 117.3 lbs / cu. ft.

SAMPLE A

Date	Cycle No.	After Saturation			Date	After Drying		
		Gross & Net Wt gm	Moisture Gms	Moisture %		Gross & Net Wt gm	Moisture Gms	Moisture %
5/12/42	1	2145	218	11.3	5/13/42	1965	38	1.99
5/14/42	2	2134	207	10.8	5/15/42	1965	38	1.99
5/16/42	3	2125	198	10.3	5/17/42	1961	34	1.76
5/18/42	4	2118	191	9.92	5/19/42	1976	49	2.54
5/20/42	5	2118	191	9.92	5/21/42	1975	48	2.49
5/22/42	6	2112	185	9.60	5/23/42	1978	51	2.64
5/24/42	7	2113	186	9.66	5/25/42	1975	48	2.49

TABLE XXIV A

WETTING AND DRYING DURABILITY TEST

12% Soil-Cement Dry weight of Sample 1927 gms Wet weight 2152 gms
 Bulk Specific Gravity 1.88 Dry Density 117.3 lbs. / cu. ft.

SAMPLE B

Date	Moist. cont. % from Cyl. A	After Drying		Calculated oven dry weight gms	Soil Loss			
		Weight before brushing gms	Weight after brushing gms		Per cycle gms	Accumulative		
						From previous gms	Dry corrected %	
5/13/42	1.99	2025	2022	1981.9	3	3	2.94	0.15
5/15/42	1.97	2015	2014	1974.3	1	4	3.92	0.20
5/17/42	1.76	2006	2005	1969.7	1	5	4.90	0.25
5/19/42	2.54	2000	1999	1948.3	1	6	5.87	0.30
5/21/42	2.49	1998	1997	1947.2	1	7	6.87	0.35
5/23/42	2.64	2000	1999	1946.2	1	8	7.84	0.40
5/25/42	2.49	1999	1998	1945.2	1	9	8.82	0.45

TABLE XXIV B



Compression Test

The intention of this test is to measure the compressive strength of the soil-cement specimens compacted to a specific density and with a controlled moisture content. No lateral support shall be given to the specimen.

The compressive strength test may be run immediately after the specimens have been cured. The results of this compression test shall be used in comparing the relative compressive strengths of specimens before and after they have past through other durability tests such as the freezing and thawing test, and the wetting and drying test.

One compression test shall be made by loading the entire bearing surface of the specimen, and one compression test shall be made by loading only 1 square inch of the entire bearing surface. The compressive strength shall be recorded at the point at which the balance beam of the testing machine can no longer be kept in a level position. In general, only the ultimate strength of the specimens need to be observed.

The unit compressive strength of each specimen shall be calculated in pounds per square inch based on the average diameter of the specimen. In the second compressive test, or the plunger test the load at the time of failure is all that need be recorded.

See Table XXV for record of complete data and tabulated results.

COMPRESSION TESTS

	Specimens after 22 days in moist room				Specimens after 7 cycles Freezing & Thawing				Specimens after 7 cycles Wetting & Drying				Specimens after wash test			
	Plung test per sq in	Load on total cross-section			Load on total cross-section			Load on total cross-section			Load on total cross-section			Load on total cross-section		
		Area sq in	Load lbs	lbs per sq in	Area sq in	Load lbs	lbs per sq in	Area sq in	Load lbs	lbs per sq in	Area sq in	Load lbs	lbs per sq in	Area sq in	Load lbs	lbs per sq in
6	632	12.44	1985	160	12.34	1705	139	12.34	5500	445						
8	943	12.44	3865	311	12.41	2645	216	12.34	7895	638	12.34	9995	806	12.40	11365	832
10	1750	12.34	5765	467	12.34	3450	280	12.36	12445	1006	12.41	13975	1123	12.46	12135	976
12	2570	12.44	6455	517	12.44	5200	419	12.41	13975	1123	12.41	13975	1123	12.46	12135	976

TABLE XXV

The Wash or Sprinkling Test

Most reports dealing with the properties of soil-cement state that the surface of soil-cement exposed to the elements should be water-proofed. This waterproofing is to be applied to prevent the penetration of moisture into the soil-cement. Also these reports state that the action of rain upon a soil-cement surface tends to wash some of the material loose from the surface. The amount of this loss (water action loss) has not clearly been studied. No standard test exists by which this loss due to water action could be studied and the amount of loss determined.

The method outlined in this test is entirely original and may prove of no value, but its intention was to determine the amount of soil-cement lost by specimens during a continuous period of water action upon the specimen. In this test the specimens were subjected to continuous water for a period of ten (10) days.

The equipment used in this test was a one gallon can that was designed to act as a central distribution and pressure regulating point. This central unit had 3 outlets in its side at one inch from the bottom and 120° apart on the circumference of the container, and one large orifice was located 4 inches above the 3 previously mentioned outlets. This large outlet was designed to act as an overflow and pressure regulator of the unit. The container was open at the top, so only 4 inches of water was the total pressure

at the lower outlets. The connection to the line and tap was adjusted so that the water coming into the container would at no time rise above nor settle below the overflow. The stream of water from the 3 lower outlets was conducted into a shallow metal container that was set upon the sample cylinders of soil-cement to be tested. The top of this shallow metal dish acted as a circular weir and prevented the water from coming into contact with the surface of the soil-cement specimens with any appreciable force. Once the water was in contact with the with the surface being tested for wear the water was allowed to trickle over the sample doing what damage it could.

Previous to testing the oven-dry weights of the 8, 10, and 12% test specimens was determined. Then the samples were placed into position for running the test. The specimens were allowed to remain in the test continuously for 10 days, and then the specimens were removed and dried in an oven. Upon drying to a constant weight the samples were reweighed and the loss in soil-cement taken as a percentage of the original oven-dry weight.

% Cement	Oven Dry Weight		Soil Loss	
	Before	After	Weight	%
8	1948	1928	20	1.03
10	1950	1939	11	0.57
12	1963	1956	7	0.36

Table XXVI

Heating and Cooling Test

This test is intended to study the behavior of soil-cement upon being heated to a temperature between 260° to 270° C. and then cooled suddenly by submerging the heated specimens into a container of water at room temperature.

The specimens were molded in the same fashion as the others; only now a cylinder of material was removed from the center of the molded specimen to allow the insertion of a thermometer for recording of the internal temperature of the specimens. No 6% sample shall be used in the running of this test. The 8 and 10% specimens were 5" high, but the 12% specimen was only 4½" high because this sample was defective in the upper ½" of the specimen and this portion was removed before testing.

The heating of the specimens was done with a bunsen burner. The heat was applied for a period of 24 hours to warrant that the specimen was thoroughly and uniformly of the same heat. The weight of the sample after the 24 hour heating period was determined, and then the specimens were submerged into the waterbath. The samples were allowed to remain in the bath until all the heat from the specimens was completely dispersed into the water bath. When cooled the specimens were removed from the water bath and placed into an oven and allowed to dry to a constant weight in a temperature of 120° C.

After drying the loose material was brushed off the



specimens and the loss of soil-cement shall be taken as a percentage of the original dry weight of the sample.

HEATING AND COOLING TEST

% Cement	Oven dry weights		Soil Loss	
	Before heat gms	After quick cooling	Weight gms	%
8	1895	1728	176	9.29
10	1871	1759	131	7.01
12	1726	1602	124	7.19

TABLE XXVII

Outdoor Durability Test

The purpose of this test was to study the characteristics of soil-cement exposed to the actual out-of-doors weathering conditions.

This is a long run test and in the 17 days that the samples were outside no effects were to be noted. The dry weight of the samples remained the same .

The samples of this test will be watched from time to time and a record of weathering shall be made.

Conclusions

The intention of this investigation was to determine the adviability of using soil-cement as a quick, economical, easy to obtain building material. As the work progressed on the investigation many new phases for further examination were encountered; due to lack of time to carry on these new examinations conclusions will be drawn from the material derived from test carried out thus far.

From the freezing and thawing test it is evident that the addition of a small quantity of cement to a soil makes the resulting product much more stable than it was in the original form.

The volume measurements taken after freezing and then upon thawing show that the material does not shrink or swell enough so that the difference could be registered on a vernier caliper. The variation that does appear in the tabulated data sheets is mostlikely caused by variation in the actual diameter of the specimen; in taking these volume measurements it was not possible to take readings at the same points each time.

The soil-cement loss per cycle decreased as the percentage of cement increased. The specimens upon being brushed lost material down to a depth of 1/8" and then the core seemed to resist brushing more fully after each cycle. This variation may be caused by the fact that it is very difficult to fully compact next to the sides of the mold

thus leaving a less compacted shell around the specimen which was lost rapidly.

The 6% specimen lost 3 times as much material as the 8% sample, about 6 times as much as the 10%, and about 9 times as much as the 12% specimen.

Upon testing the freeze and thaw specimens for compression after 7 cycles it was seen that the load bearing power of each specimen was noticeably reduced from the load carrying capacity of compression specimens that were only cured for a period of 22 days before loading.

From the wetting and drying test it is again evident that the resistance against soil-cement loss in wetting and drying increased as the cement content increased.

What was said under freezing and thawing about the variation in volume is also true in this test.

The soil-cement loss in this test was in the following order; the 6% specimen lost 2 times as much material as did the 8% sample, 6 times as much as the 10%, and 13 times as much as did the 12% specimen.

From the comparative compression test it can readily be seen that the compressive strength of the specimens after 7 cycles of wetting and drying is much more than the strength of the 22 day compression specimens. This variation may be due to the fact that the wetting and drying specimens were oven dry at the time of testing for compressive

strength. If the fact that the material receives this added strength upon being dry & waterproofing applied to an exterior wall will help to increase the strength of that wall. An investigation should be conducted to determine the effect of varying amounts of water upon the compressive strength of soil-cement.

Compression Specimens

The compressive strength increased as the cement content increased.

When the plunger was used, that is when a one square inch area of the bearing surface was loaded the load on that square inch was larger than when the entire bearing area was loaded and the load per square inch was solved by

$\frac{P}{A}$. The variation in this respect may have been caused by the spreading out of the load to the full cross-section.

It was also noted that the specimens upon being loaded would begin to show fracture and signs of failure, but still upon further loading would resist that load. In one case the first cracks or fractures began to show, but still the beam of the testing machine did remain horizontal and the specimen took an additional 3000 pounds of load. The possibilities are that since the material was rammed into shape the particles may have interlocked, and also the cohesion of the material may have effected this extra load carrying ability. This phases should also be studied

further to determine why soil-cements act in that way when in compression.

The government's specification as to compressive strength of soil-cement going into airport construction is that it must be able to take 400 pounds per square inch. The 10 and 12% specimens of this investigation would meet that requirement.

Wash Test Specimens

The loss of soil-cement caused by continuous (10 day) washing effect of the flow of water, decreased as the cement content increased in the specimen. In ten days the running time of this test the loss in terms of original dry weight was small and could further be reduced by a waterproofing agent.

The compressive strength of the specimens proved to be favorable when compared with the compressive strength of the 22 day specimens.

Heating And Cooling

The soil-cement loss caused by heating and rapid cooling of the specimens showed that under fire conditions soil-cement does not prove to be very satisfactory.

Summing up the complete investigation it seems soil-cement could be used in making building block to be used in the construction of moderate size family homes. The

soil taken from the basement excavation could be used to in making of the soil-cement block. This soil can be analyzed and the required fines can be added in the form of silt and clay.

The amount of cement per cubic yard of concrete in a 6 sack mix is 28.6% by volume of the aggregate; in the soil-cement specimens used only 6, 8, 10, and 12% of cement by volume was used. In the soil-cements of 10 and 12% cement content by volume a saving of 3 and 2 times the amount of will be made.

Further investigation should be carried out on the possible methods of forming the proposed blocks. The cost of manufacturing may off-set any savings that could be made in materials, and thereby defeating the original intent, which was the production of an economical building material.

Also the different possible methods of waterproofing the soil-cement surfaces should be studied. It may be possible that a wall of soil-cement could be constructed, and then after curing and setting a small amount of heat applied to the surface of the wall; then while the surface is abit warm if liquid paraffin is applied it will penetrate into the soil-cement and seal all its pores leading into the wall.

Too many uncertain facts still remain in the development of soils, and soil-cements, and these uncertain features can only be surmounted by consistent study and further

investigation.

From what has been gathered it seems more than likely that with a few small changes in the frame design of homes soil-cement will become the building material of the future.

BIBLIOGRAPHY

BIBLIOGRAPHY

Hogentogler, C. A. Engineering Properties of Soil
New York: McGraw - Hill. First Edition 1927

The American Association of State Highway Officials.
Standard Specifications for Highway Materials and Methods
of Sampling and Testing. Washington, D. C. Published by
the Association 1938.

The Portland Cement Association. Progress Report on
Exploratory Laboratory Investigation of Soil-Cement Mixtures.
Chicago, Illinois. Published by the Association 1936.

The Portland Cement Association. Detailed Laboratory
Procedures for Investigation on Soil-Cement. Chicago, Ill.
Published by the Association 1940.

Crum, Roy W. A Symposium on Soil-Cement Mixtures for
Roads. Washington, D. C. Published by the Highway Research
Board 1937.

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

The Portland Cement Association. Soil-Cement Roads.
Chicago, Illinois. Published by the Association. Second
Edition 1941.

Catton, Miles D. Research on the Physical Relations of Soil and Soil Cement Mixtures. Reprinted from Proceedings of the Twentieth Annual Meeting of the Highway Research Board December 1940 by the Portland Cement Association.

American Society for Testing Materials. A. S. T. M. Methods of Test for Soil-Cement Mixtures. Philadelphia, Pa. Published by the Society 1940.

ROOM USE ONLY.

Apr 21 '43

MICHIGAN STATE UNIVERSITY LIBRARIES



3 1293 03175 6376