A PROBLEM STUDY OF SOIL-CEMENT

Thesis for the Degree of B. S.

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THESIS

A Problem Study of Soil-Cement

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INTRODUCTION.

The title of this thesis intimates that it represents a technical problem. Like most engineering problems, the real value to be gained from it lies in the method or procedure of its solution rather than any specific answers obtained. I mention this merely to show the objectives more clearly.

The title also indicates that the subject to be delt with concerns soil-cement, a product which is best defined in a "Portland Cement" publication as, "A simple mixture of soil with measured amounts of Portland Cement and water, compacted to high density."

The use of soil-cement in the construction of low cost pavements, airfield runways, parking areas and similar projects, is constantly increasing. As of 1944 there were 40,000,000 sq. yds. of this type surface in use. At that date there were 44 highway departments equipped to investigate soil-cement problems.

It should be pointed out that the advantages of this type of wearing surface are not being fully exploited in this area. The reason for this is not due to the erroneous idea that soil-cement is not suitable in areas such as Michigan where a large differential in weather conditions occurs. The reason is due to its lack of promotion by cement producers.

This can be explained in this manner: In this area the supplies of gravel are large and convenient and therefore cheap. In areas where course aggregate must be shipped in the cost of producing concrete becomes much greater. Since the objective is to sell cement and soil-cement is a cement economizing measure, from the cement producers stand point the accent in this area is on concrete rather than soil-cement.

The suitability of using soil-cement in Michigan is limited only by, the type of soil present and the requirements of the project. As given in the previously mentioned "Portland Cement" publication, "a six-inch compacted depth of soil-cement will be adequate generally for roadways carrying up to 1,000 vehicles a day, providing not more than about 50 are trucks having a gross weight of more than two tons."

In order to illustrate the methods of procedure employed in soil-cement design and construction an original project will be presented. The details of design such as laboratory tests, analysis of their results, will be largely those accepted and set forth by such authorities as, "The Portland Cement Association," "The American Society of Testing Materials," "The American Association of State Highway Officials", etc. The more general method of procedure is entirely a personal one, confirmed by frequent consultations with Mr. G.C. Blomquist of the department.

The consideration of a suitable illustrative project was given a great deal of thought. After much deliberation on such points as, location, size, practicability, it was decided to use the campus area bounded on the south by the new Macklin Bowl and the tennis courts and on the north by the road running adjacent to the Red Cedar River. A more accurate picture of its actual location and boundaries may be obtained by referring to print no. 1 which show details of a transit tape survey made on the area.

This particular piece of ground has been designated by the college as a parking area. Its actual use as a parking area has been at best, intermittent, depending on weather conditions. Although the slope of the area is adequate for proper drainage, the soil has a comparitively high clay and silt content which makes it extremely unstable during the spring thaw and periods of wet weather. In short it is quite obvious from actual observations in the past that there is a definite need for stabilization of the soil in this area if it is expected to serve as a satisfactory year-round, all weather parking area.

The scope of the work presented here includes all the preliminary investigation necessary before actual construction could be started. A step by step procedure is outlined as follows:

1. Transit tape survey of the area.
   A. Determine actual size and boundaries of the area.
   B. Plot and determine location of soil samples.
2. Show by means of comparative soil tests that the soils to be stabilized can be considered homogeneous and therefore have similar physical and mechanical characteristics.
3. Selection of a soil-cement ratio that will give the most economical, durable surface.
4. Determination from soil-cement tests actual amounts of materials necessary in construction.

TRANSIT TAPE SURVEY OF THE AREA.

A transit tape survey of the area under consideration was made for several reasons. First of all, to establish a definite area from which design data may be computed. Secondly, to determine the size of the area to be designed for. Finally, to aid in the location of the representative soil samples.

The distances were taped to the nearest foot and the angles measured to the nearest minute. In explanation of the degree of accuracy used in running the survey it may be said that it is not necessary to find the exact size of the area merely an approximation.

The method of computing the area can best be followed by referring to print no. 1. From the survey notes the traverse was plotted to a scale of 1" equals 40'. The resulting polygon was divided into three triangles. Using conventional geometric methods, altitudes of these triangles were constructed and scaled. It was then possible to find the total area inclosed by the traverse by taking the sum of the areas of the triangles.

It should be stressed again that this figure can not represent the exact area due to the approximate methods used in computing it. However it serves to provide a picture for illustrating the methods used in the design as well as providing a basis for preparing subsequent estimates.

Considerable thought was given to the location of the soil samples. The object of course, being to locate them so as to obtain a true representation of the soil conditions occurring in the area. It was decided to base the study of these conditions on an analysis of five samples. Therefore the polygon was divided into five triangles and the position of each of the samples was located at the geometric center of each triangle. For a better picture of the sample location method refer to print no. 2.

Computation of the Traverse Area.

Scale 1" equals 40'

Side 1 - 2 .... 310'

" 2 - 3 .... 464'

" 3 - 4 .... 450'

" 4 - 5 .... 248'

" 5 - 6 .... 662'

Triangle 1-2-5: Altitude . . . 160' Base . . . 662'

Area . . $\frac{160 \times 662}{2} = 80 \times 662 = 52{,}960$ sq. ft.

Triangle 5-2-4: Altitude . . . 122' Base . . . 634'

Area . . $\frac{122 \times 634}{2} = 168 \times 61 = 38{,}674$ sq. ft.

Triangle 2-3-4: Altitude . . . 336' Base . . . 634'

Area . . $\frac{336 \times 634}{2} = 168 \times 634 = 106{,}512$ sq. ft.

	106,512 sq. ft.	
	38,674 " "	
	52,960 "	
Total:	197,146 sq. ft.	-- Total Area of Polygon

*Note: Sides and Altitudes scaled.

THE SOIL ANALYSIS

The first consideration is: Is the soil suitable for stabilization? This depends on gradation and position in the soil profile. The latter consideration does not affect the suitability of the soil to a depth of about 9" will be used. That is all the soil to be stabilized will come from the same horizon. Another factor contributing to the favorability of the problem is that the area has recently been filled and graded. The backfill material originating from the excavation on the construction of the women's dormitories.

On the subject of gradation, there are three general classifications of soil with respect to its suitability for stabilization:

1. Sandy and Gravelly Soils.

These soils are most ideal and present no unusual construction problems.

2. Sandy Soils without fines.

These types have equally good characteristics except for packing and finishing. Because of poor gradation and absence of fines, heavy rubber-tired equipment, may have trouble pulling through the mixtures during construction. The extreme cases of this type may require improvement of gradation. However usually addition of cement corrects this. Also, without a final bituminous wearing coat, the surface may not have as high wearing characteristics as unsurfaced soil-cement made from group 1.

3. Silty and Clayey Soils.

These soils make satisfactory soil-cement but sometimes require the added difficulty of pulverizing. Soils that are difficult to pulverize at dry moisture content, many times can be broken down, that is disced and harrowed, more easily if water is added and permitted to soak in. Also if the soil of this type is too wet pulverizing may be accomplished more easily if it is allowed to dry out a little. This means that stabilization of this type of soil requires close attention to the prevailing weather conditions. Also if it is desireable to ignore weather conditions and the available equipment is not satisfactory for pulverizing, it may be necessary to change the gradation by borrowing and backfilling.

Soils which have been tested and used successfully on a major portion of the soil-cement construction in the U. S., have the following limits for gradation and physical test constants:

Sieve Size	% by wt. passing	Liquid Limit	Plastic Index
3"	100%		
No.4	50%-100%		
NO.40	15%-100%	not over 40	
NO.200	0%-15%		not over 18

In applying the above considerations to the problem at hand, the suitability of the soil was determined by a foot reconnaissance. When obtaining soil samples it became apparent that the general tentitive soil classification of the area would be, sandy clay.

The samples were taken at the locations determined previously in the "survey". The manner of obtaining them was as follows: About 45lbs of soil was taken from a section approximately a foot square by 9" in depth.

2"	Sand
7"	Ranging from Sandy Clay to Clay

General Soil Profile of Area.

It was suspected that due to the previously mentioned origin of the soil, it would have fairly consistent characteristics. In order to prove this, certain laboratory tests were run on each sample to discover and compare these characteristics.

The ultimate purpose of these tests was to establish the treatment requirements of the soil such as trial soil-cement ratios. The range of treatment requirements of course depends on the number of soil types encountered. For instance, if tests prove only one type to be present, a single range of treatment requirements may be set up and a single set of durability tests run. However this will be considered in greater detail later.

The physical constants or soil characteristics which can best be used to establish a soil type are the following:

1. Test for Specific Gravity.
2. Mechanical Analysis.
3. Test for Hydrogen-ion Concentration.
4. Test for Liquid Limit.
5. Test for Plastic Limit.

Test No. 1: Test for Specific Gravity of Soils

Apparatus: Volumetric Flask, Glass Graduate, Balance, Pipette, Kerosene.

Procedure: The object of this test is to determine the apparent specific gravity of a soil.

Weigh out approximately 30 grams of soil and place in a 100 ml volumetric flask noting the exact weight of the flask when empty. Add 50 mls of Kerosene. Attach flask to vacuum pump and draw out all trapped air in soil. Continue to fill the flash with Kerosene up to the 100 ml mark. Note just how much Kerosene was added. The volume of the soil sample will be equal to the amount of Kerosene added.

Test For Specific Gravity

Sample "A" -- First Trial

Wt. of Flask--------------------- 44.45 grams

Wt. of Soil Sample and Flask----- 74.5 "

Wt. of Soil---------------------- 30.05 "

Total volume of Flask------------ 100 ml

Volume of Kerosene added--------- 81 "

Volume of Soil------------------- 11 "

Specific Gravity----------------- 30.05 ÷ 11 = 2.732

Sample "A" -- Second Trial

Wt. of Flask--------------------- 41.825 grams

Wt. of Soil Sample and Flask----- 71.997 "

Wt. of Soil---------------------- 30.172 "

Total volume of Flask------------ 100 ml

Volume of Kerosene added--------- 88.5 ml

Volume of Soil------------------- 11.5 "

Specific Gravity----------------- 30.172 ÷ 11.5 = 2.624

Final Specific Gravity of Sample "A" -- $\frac{2.732 - 2.624}{2} = 2.678$

Sample "B" -- First Trial

Wt. of Flask--------------------- 39.883 grams

Wt. of Sample and Flask---------- 69.91 "

Wt. of Soil---------------------- 30.027 "

Sample "B" -- First Trial con't.

Total Volume of Flask------------------- 100 ml

Volume of Kerosene added---------------- 88.75 ml

Volume of Soil-------------------------- 11.25 "

Specific Gravity------------------------ 30.027 ÷ 11.25 = 2.669

Sample "B" -- Second Trial

Wt. of Flask---------------------------- 43.047 grams

Wt. of Sample and Flask----------------- 70.23 "

Wt. of Soil----------------------------- 27.183 "

Total Volume of Flask------------------- 100 ml

Volume of Kerosene added---------------- 89.5 ml

Volume of Soil-------------------------- 10.5 "

Specific Gravity------------------------ 27.183 ÷ 10.5 = 2.579

Final Specific Gravity of Sample "B" $\frac{2.669 - 2.579}{2} = 2.624$

Sample "C" -- First Trial

Wt. of Flask---------------------------- 46.17 grams

Wt. of Soil and Flask------------------- 74.11 "

Wt. of Sample--------------------------- 27.94 "

Total volume of Flask------------------- 100 ml

Volume of Kerosene added---------------- 89.5 ml

Volume of Soil-------------------------- 10.5 "

Specific Gravity------------------------ 27.94 ÷ 10.5 = 2.662

Sample "C" -- Second Trial

Wt. of Flask-------------------------- 45.59 grams

Wt. of Soil and Flask----------------- 75.565 "

Wt. of Soil--------------------------- 29.975 "

Total Volume of Flask----------------- 100 ml

Volume of Kerosene added-------------- 89 "

Volume of Soil------------------------ 11 "

Specific Gravity---------------------- 29.975 ÷ 11 = 2.720

Final Specific Gravity of Sample "C" $\frac{2.662 - 2.720}{2} = 2.691$

Sample "D" -- First Trial

Wt. of Flask-------------------------- 46.17 grams

Wt. of Sample and Flask--------------- 75.805 "

Wt. of Sample------------------------- 29635 "

Total volume of Flask----------------- 100 ml

Volume of Kerosene added-------------- 88.25 ml

Volume of Soil------------------------ 11.75 "

Specific Gravity---------------------- 29.635 ÷ 11.75 = 2.522

Sample "D" -- Second Trial

Wt. of Flask-------------------------- 47.202 grams

Wt. of Sample and Flask--------------- 78.915 "

Wt. of Sample------------------------- 31.713 "

Total Volume of Flask----------------- 100 ml

Volume of Kerosene added-------------- 87 "

Volume of Soil------------------------ 13 "

Test No. 2: Mechanical Analysis of Soils

Apparatus: Balance, Stirring apparatus, Glass Graduate, Glass Beaker, Wash bottle and Distilled Water, Thermometer, Sieves No.'s 10-20-40-60-100-200, Clock, Soil Hydrometer.

Procedure: The object of the test is to determine the gradation or percentages of various partical sizes contained in a soil sample.

Weigh out a sample of soil, approximately 50 grams. Mix distilled water and sodium hydroxide, 25 grams, and let stand for 24 hours. Mix thoroughly for 6 minutes and pour into a glass graduate, filling it full. Place the hydrometer in solution along with the thermometer and record both hydrometer and thermometer readings for intervals noted in the tables. Wash the sample through a No. 200 sieve. Dry and weigh the soil failing to pass the No. 200 sieve. Run a sieve analysis using the No.'s 10-20-40-60-100-200. Determine the percentages retained and passed the individual sieves.

Data Record:

Mechanical Analysis of Sample "A"

Hydrometer No. 381030

Sp. Gr.2.624

		HYDROMETER READING			% PASS'G	CORRECTION COEFICIENTS				COR'ED
TIME	TEMP	ORIG.	ΔR	R	100RA%W	K_L	K_G	K_W	DIA.	DIA.
1	79	20.0	0.2	20.2	40.5	.478	1.02	.92	.078	.035
2	79	19.2	0.2	19.2	38.5	.524	1.02	.92	.055	.027
5	79	17.0	0.2	17.2	34.5	.528	1.02	.92	.035	.017
10	79	16.0	0.2	16.2	32.4	.531	1.02	.92	.025	.012
15	79	15.5	0.2	15.7	31.4	.531	1.02	.92	.020	.010
30	79	14.5	0.2	14.7	29.4	.533	1.02	.92	.014	.007
60	79	13.5	0.2	13.7	27.4	.535	1.02	.92	.010	.005
120	80	13.0	0.2	13.2	26.0	.537	1.02	.92	.007	.004

Sieve Analysis of material passing a No. 10 sieve.

SIEVE SIZE	WEIGHT RETAINED	% RETAINED	% PASS	CUMULATIVE %	
				RETAINED	PASSED
10	0.5	0.9	99.1	0.9	99.1
20	0.5	0.9	99.1	1.8	98.2
40	4.7	9.2	90.8	11.0	89.0
60	5.2	10.0	90.0	21.0	79.0
100	11.3	22.2	77.8	43.2	56.8
200	4.6	9.0	91.0	52.2	47.8

Summary:

Sand--- 52.2%

Silt--- 20.4%

Clay--- 27.4%

Therefor sample "A" is a "sandy clay loam".

Data Record:

Mechanical Analysis of Sample "B"

Hydrometer No. 381032

Sp; Gr. 2.579

		HYDROMETER READING			% PASS	CORRECTION COEFFICIENTS				CORRECTED
TIME	TEMP	ORIG	ΔR	R	100R/...	K_L	K_G	K_N	DIA	DIA.
1	79	20.0	0.2	20.2	40.5	.478	1.02	.92	.078	.035
2	79	19.0	0.2	19.2	38.5	.524	1.02	.92	.055	.027
5	79	17.5	0.2	17.7	35.4	.526	1.02	.92	.035	.017
10	79	16.5	0.2	16.7	33.4	.528	1.02	.92	.025	.017
15	79	16.0	0.2	16.2	32.4	.531	1.02	.92	.020	.010
30	79	15.5	0.2	15.7	31.4	.531	1.02	.92	.014	.007
60	79	14.0	0.2	14.2	28.4	.535	1.02	.92	.010	.005
120	79	13.5	0.2	13.7	26.4	.535	1.02	.92	.007	.004

Sieve Analysis of material passing a No. 10 sieve.

SIEVE SIZE	WEIGHT RETAINED	% RETAINED	% PASS	CUMULATIVE % RETAINED	CUMULATIVE % PASS
10	0.5	0.9	99.1	0.9	99.1
20	1,5	2.9	97.1	3.8	96.2
40	4.9	9.6	90.4	13.8	86.6
60	6.6	13.0	87.0	26.9	73.6
100	11.9	23.0	76.6	49.8	50.2
200	7.9	15.0	85.0	64.8	35.2

Summary:

Sand--- 64.8%

Clay--- 28.4%

Silt--- 6.8%

Therefore sample "B" is a "sandy clay loam".

Data Record:

Mechanical Analysis of Sample "C"

Hydrometer No. 344270

Sp. Gr. 2.720

		HYDROMETER READING			% PASS	CORRECTION COEFFICIENTS				CORR'ED
TIME	TEMP.	ORIG.	ΔR	R	100RA÷W	KL	KG	KN	DIA.	DIA
1	80	18.0	0.2	18.2	34.9	.510	.98	.92	.078	.037
2	80	15.0	0.2	15.2	29.2	.516	.98	.92	.055	.026
5	79	15.0	0.2	15.2	29.2	.516	.98	.92	.035	.016
10	79	15.0	0.2	15.2	29.2	.516	.98	.92	.025	.012
15	79	13.5	0.2	13.7	26.3	.519	.98	.92	.020	.009
30	79	13.0	0.2	13.2	25.4	.521	.98	.92	.014	.005
60	80	12.5	0.2	12.7	24.0	.521	.98	.92	.010	.005
120	79	12.0	0.2	12.2	23.5	.523	.98	.92	.007	.002

Sieve Analysis of material passing a No. 10 sieve.

SIEVE SIZE	WEIGHT RETAINED	% RETAINED	% PASS	CUMULATIVE %	
				RETAINED	PASS
10	0.5	0.9	99.1	0.9	99.1
20	0.8	1.6	98.4	2.5	97.5
40	3.4	6.7	93.3	9.2	90.8
60	8.0	15.7	84.3	24.9	75.1
100	18.3	36.0	64.0	60.9	39.1
200	7.5	14.7	85.3	75.6	24.4

Summary:

Sand--- 75.6%

Silt--- 0.4%

Clay--- 24.0%

Therefore sample "C" is a "sandy clay loam".

Data Report:

Mechanical Analysis of Sample "D"

Hydrometer No. 378173

Sp. Gr. 2.481

		HYDROMETER READING			% PASS	CORRECTION COEFFICIENTS				CORR'D
TIME	TEMP.	ORIG	ΔR	R	100R÷Ws	K_L	K_c	K_w	DIA.	DIA.
1	79	21.0	0.2	21.2	43.7	.520	1.05	.92	.078	.039
2	79	17.5	0.2	17.7	36.4	.527	1.05	.92	.055	.028
5	79	16.5	0.2	16.7	33.6	.529	1.05	.92	.035	.018
10	79	16.0	0.2	16.2	33.4	.531	1.05	.92	.025	.013
15	79	15.0	0.2	15.2	31.3	.533	1.05	.92	.020	.010
30	79	14.0	0.2	14.2	29.3	.536	1.05	.92	.014	.007
60	79	13.0	0.2	13.2	27.2	.538	1.05	.92	.010	.005
120	79	12.5	0.2	12.7	26.2	.538	1.05	.92	.007	.004

Sieve Analysis of material passing a No. 10 sieve.

SIEVE SIZE	WEIGHT RETAINED	% RETAINED	% PASS	CUMULATIVE %	
				RETAINED	PASS
10	0.5	0.9	99.1	0.9	99.1
20	1.1	3.1	97.9	3.0	97.0
40	2.9	5.7	94.3	8.7	91.3
60	4.1	8.0	92.0	16.7	83.3
100	8.2	16.1	83.9	32.8	71.2
200	11.2	22.0	78.0	54.8	45.2

Summary:

Sand--- 54.8%

Silt--- 18.0%

Clay--- 27.2%

Therefore sample "D" is a "sandy clay loam".

Data Record:

Mechanical Analysis of Sample "E"

Hydrometer No. 205707

Sp. Gr. 2.569

		HYDROMETER READING			% PASS	CORRECTION COEFFICIENTS				CORR'ED
TIME	TEMP	ORIG	ΔR	R	100RA/Ws	KL	KG	KN	DIA.	DIA.
1	80	26.0	0.2	26.2	51.4	.510	1.03	.92	.078	.038
2	80	22.0	0.2	22.2	43.5	.518	1.03	.92	.055	.027
5	80	20.0	0.2	20.2	39.6	.522	1.03	.92	.035	.017
10	80	18.5	0.2	18.7	36.8	.524	1.03	.92	.025	.012
15	80	17.5	0.2	17.7	34.7	.526	1.03	.92	.020	.010
30	80	16.5	0.2	16.7	32.8	.528	1.03	.92	.014	.007
60	80	14.5	0.2	14.7	29.7	.531	1.03	.92	.010	.005
120	80	14.0	0.2	14.2	28.7	.535	1.03	.92	.007	.004

Sieve Analysis of material passing a No. 10 sieve.

SIEVE SIZE	WEIGHT RETAINED	% RETAINED	% PASS	CUMULATIVE %	
				RETAINED	PASSED
10	0.5	0.9	99.1	0.9	99.1
20	1.2	2.4	97.5	3.3	96.1
40	3.4	6.7	93.3	10.0	90.0
60	4.3	8.5	91.5	18.5	82.5
100	8.1	16.0	84.0	34.5	65.5
200	8.1	16.0	84.0	50.5	49.5

Summary:

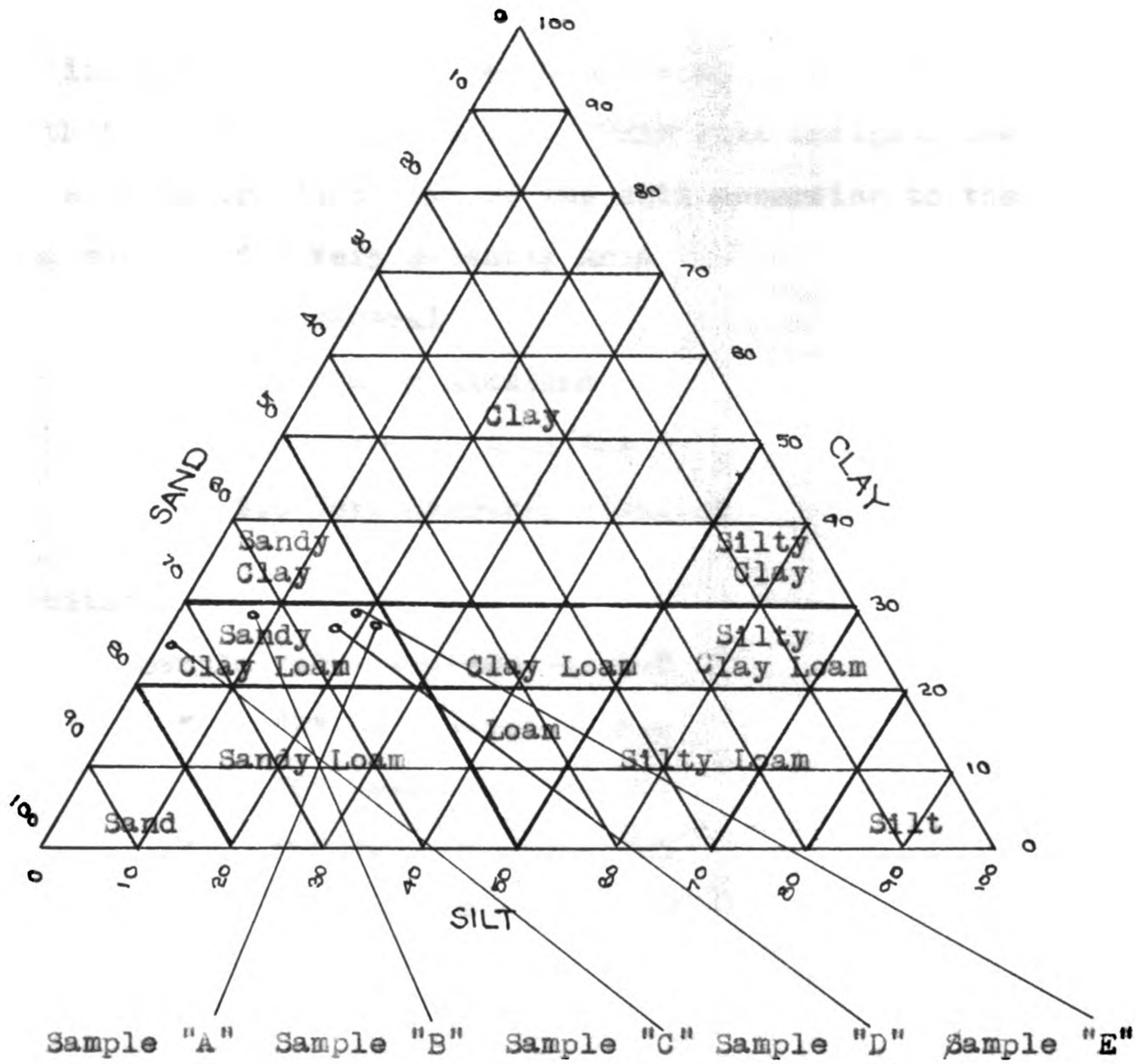
Sand--- 50.5%

Silt--- 19.8%

Clay--- 29.7%

Therefore Sample "E" is a "sandy clay loam".

Triaxial Chart For Textural Classification Of Soils



Test No. 3: Test for Hydrogen-ion Concentration of Soils

Apparatus: Indicator Solution, Color Chart, Waxed Paper.

Procedure: Place a few grams of the soil sample to be tested on a piece of waxed paper and add to it six or seven drops of indicator solution. Watch the sample, compare its color with that of the color chart. This will indicate the relative acidity or alkalinity of the soil according to the following scale:

6.5 Very Slightly Acid
7.0 Neutral
7.5 Medium Alkaline
8.0 Strongly Alkaline
9.0 Very Strongly Alkaline

Test Results:

Sample	"A"	8.0
"	"B"	8.0
"	"C"	8.0
"	"D"	7.5
"	"E"	8.0

Test No. 4: Test for the Liquid Limit of Soils

Apparatus: Mechanical Liquid Limit Device, Grooving Tool, Spatual, Balance, 60cc Weighing Bottles with Ground Glass Tops.

Procedure: The Liquid Limit of a soil is defined as the moisture content, expressed as a percentage of oven dried weight, at which the soil will just begin to flow when lightly jarred ten times.

Take a 30 gram sample, oven dried to a constant weight, place in brass dish of Liquid Limit machine. Mix with distilled water until it becomes a thick past. Level off with spatula until thickness at center is about 3/8". The layer of soil so formed shall be separated into two parts by means of the grooving tool and the machine crank turned so that the dish will be jarred lightly at the rate of ten times in 5 seconds. When the edges of the two sections meet and flow together just at the 10th turn, the soil is said to have reached its liquid limit.

Take a small portion of the sample adjacent to the groove and place in the weighing jar. Use two samples. Weigh the samples on the balance and place in oven at 110 degrees C. until dried to a constant weight. Weigh again to obtain loss of moisture during drying.

Test for Liquid Limit

Sample "A"	Trial No. 1		Trial No. 2	
Wt. of wet soil and weighing bottle	50.85	grams	47.714	grams
Wt. of weighing bottle	43.327	"	37.09	"
Wt. of wet soil	7.532	"	4.624	"
Wt. of dry soil and weighing bottle	49.875	"	41.11	"
Wt. of dry soil	6.548	"	4.02	"
Wt. of water in soil	.975	"	.604	"
Liquid Limit	14.92	"	15.05	"

Final Liquid Limit of Sample "A" --- 14.985

Sample "B"	Trial No. 1		Trial No. 2	
Wt. of wet soil and weighing bottle	45.045	grams	49.85	grams
Wt. of weighing bottle	35.08	"	40.953	"
Wt. of wet soil	9.965	"	8.897	"
Wt. of dry soil and weighing bottle	43.589	"	48.63	"
Wt. of dry soil	8.499	"	7.677	"
Wt. of water in soil	1.466	"	1.22	"
Liquid Limit	17.25	"	15.92	"

Final Liquid Limit of Sample "B" --- 16.585

Sample "C"	Trial No. 1		Trial No. 2	
Wt. of wet soil and weighing bottle	57.93	grams	52.025	grams
Wt. of weighing bottle	45.135	"	43.435	"
Wt. of wet soil	12.795	"	8.59	"

Sample "C" con't.	Trial No. 1	Trial No. 2
Wt. of dry soil and weighing bottle	56.205 grams	50.777 grams
Wt. of dry soil	11.07 "	7.432 "
Wt. of water in soil	1.725 "	1.248 "
Liquid Limit	13.5 "	16.99 "

Final Liquid Limit of Sample "C" --- 15.245

Sample "D"	Trial No. 1	Trial No. 2
Wt. of wet soil and weighing bottle	46.07 grams	47.375 grams
Wt. of weighing bottle	36.68 "	37.36 "
Wt. of wet soil	9.39 "	10.015 "
Wt. of dry soil and weighing bottle	44.81 "	45.945 "
Wt. of dry soil	8.13 "	8.585 "
Wt. of water in soil	1.26 "	1.43 "
Liquid Limit	15.49 "	16.65 "

Final Liquid Limit---------- Sample "D" -- 16.02

Sample "E"	Trial No. 1	Trial No. 2
Wt. of wet soil and weighing bottle	47.62 grams	44.615 grams
Wt. of weighing bottle	35.98 "	34.63 "
Wt. of wet soil	11.64 "	9.985 "
Wt. of dry soil and weighing bottle	45.945 "	43.235 "
Wt. of dry soil	9.965 "	8.605 "
Wt. of water in soil	1.675 "	1.38 "
Liquid Limit	16.8 "	16.02 "

Final Liquid Limit of Sample "E" --- 16.41

Test No. 5: Test for Plastic Limit of Soils

Apparatus: Spatula, Glass Plate about 12" x 6", Weighing Bottles, Balance.

Procedure: The plastic Limit of a soil may be defined as the lowest moisture content, expressed as a precentage of weight of oven dried soil, at which the soil can be rolled into 1/8" threads without breaking.

Take about 25 grams of soil mixed with enough water to become easily worked. Form the sample into a ball and place on the glass plate. Roll to form thread which if the Plastic Limit has been reached, will begin to break at about 1/8" in diameter.

Place a few grams of the sample in the weighing bottle, weigh, dry and weigh to determine moisture content. From the above data compute the Plastic Limit of the soil.

Test for Plastic Limit

Sample "A"	Trial No. 1	Trial No. 2
Wt. of wet soil and weighing bottle	49.64 grams	40.498 grams
Wt. of weighing bottle	43.35 "	37.085 "
Wt. of wet soil	6.29 "	3.413 "
Wt. of dry soil and weighing bottle	48.895 "	40.105 "
Wt. of dry soil	5.545 "	3.02 "
Wt. of water in soil	.745 "	.393 "
Plastic Limit	13.45	13.0

Final Plastic Limit of Sample "A" --- 13.225

Sample "B"	Trial No. 1	Trial No. 2
Wt. of wet soil and weighing bottle	43.36 grams	47.17 grams
Wt. of weighing bottle	35.07 "	40.945 "
Wt. of Wet soil	8.32 "	6.225 "
Wt. of dry soil and weighing bottle	42.39 "	46.41 "
Wt. of dry soil	7.32 "	5.465 "
Wt. of water in soil	.97 "	.76 "
Plastic Limit	13.32	13.9

Final Plastic Limit of Sample "B" --- 13.575

Sample "C"	Trial No. 1	Trial No. 2
Wt. of wet soil and weighing bottle	50.274 grams	46.322 grams
Wt. of weighing bottle	37.35 "	43.425 "
Wt. of wet soil	12.924 "	2.897 "

Sample "C" con't.	Trial No. 1	Trial No. 2
Wt. of dry soil and weighing bottle	49.225 grams	45.935 grams
Wt. of dry soil	11.875 "	2.51 "
Wt. of water in soil	1.149 "	.387 "
Plastic Limit	9.68	15.4

Final Plastic Limit of Sample "C" --- 12.540

Sample "D"	Trial No. 1	Trial No. 2
Wt. of wet soil and weighing bottle	42.87 grams	51.657 grams
Wt. of weighing bottle	36.68 "	45.13 "
Wt. of wet soil	6.19 "	6.527 "
Wt. of dry soil and weighing bottle	42.22 "	50.996 "
Wt. of dry soil	5.54 "	5.866 "
Wt. of water in soil	.65 "	.661 "
Plastic Limit	11.75	11.268

Final Plastic Limit of Sample "D" --- 11.509

Sample "E"	Trial No. 1	Trial No. 2
Wt. of wet soil and weighing bottle	41.425 grams	42.097 grams
Wt. of wet soil	5.44 "	7.482 "
Wt. of weighing bottle	35.985 "	34.615 "
Wt. of dry soil and weighing bottle	40.835 "	41.302 "
Wt. of dry soil	5.54 "	6.687 "
Wt. of water in soil	.59 "	.795 "
Plastic Limit	12.15	11.888

Final Plastic Limit of Sample "E" --- 12.019

ANALYSIS OF SOIL TEST RESULTS.

One of the primary objectives in running the soil tests was to show by means of the comparative data that the five soil samples taken from the area were of a similar type.

Beginning with the very simple Hydrogen-ion Concentration test, results show that all samples are on the alkaline side. Next, the Specific Gravity test showed a variation of from 2.481 to 2.691. A difference of only 2 tenths with an average sp. gr. of 2.608.

The differences in specific gravities is just enough to support the small differences in the physical constants of each soil sample. For instance the maximum liquid limit of any sample was 16.584 while the minimum was 14.980. The highest plastic limit was 13.575 as compared with the lowest of 11.509.

The most conclusive proof however is found in a study of the results from the mechanical analysis. This test shows a textural comparison and classification of each sample. Although, again there are variations in the different percentages of sand, silt and clay of each sample, when located on the triaxial chart each representative soil sample and therefore the entire area may be classified as sandy clay loam.

Another important application of the soil test data makes possible a classification of the soil according to the U. S. Public Roads Administration as type A-2. This becomes important when estimating cement requirements.

SOIL-CEMENT TESTING

There are three basic control factors which must be investigated before successful soil-cement construction may be expected. They are:

1. Adequate Cement Content.
2. Proper Moisture Content.
3. Proper Density.

The quantities of cement and water to add and the density to which the mixture should be compacted were determined by four fundemental soil-cement tests.

1. Optimum Moisture-Maximum Density Test.
2. Freeze-Thaw Test.
3. Wet-Dry Test
4. Compressive Strength Test.

Before any of the above tests can be run a range of soil-cement ratios must be selected. The range, that is the maximum and minimum percentages by volume of soil and cement, to be investigated depends on the type of soil under consideration. With reference to a Portland Cement publication, "Soil-Cement Laboratory Handbook", a range of from 6 to 10 per cent was selected. Previous investigation has shown this range to be adequate for an A-2 soil.

All soil-cement testing procedures were those as outlined by the A.S.T.M. The first test, "Standard Method of Test for Moisture-Density Relations of Soil-Cement Mixtures", A.S.T.M. designation D-588-44 may be outlined as follows:

Title: Test for Optimum-Moisture Maximum Density

A.S.T.M. Desig. D-588-44

Object: This method of test is intended for determining the relationship between the moisture content of the soil-cement mixtures and the resulting densities, oven dry weights per cubic foot, when the soil-cement mixture is compacted in the laboratory, before hydration takes place.

Apparatus: Mold-A cylindrical metal mold having a capacity of 1/30 cu. ft. With an internal diameter of 4" and a height of approximately 4.6" which has a volume of 1/30 cu. ft. The mold and collar shall be fastened to a detachable base.

Rammer-A metal rammer having a 2" diameter circular face and weighing 5.5 lbs. The rammer shall be equipped with a suitable arrangement to control the specified drop.

Balances-A balance or scale of 25 lb. capacity sensitive to .01 lb; and a 100 gram capacity balance sensitive to .1 gram.

Drying Oven-A thermostatically controlled drying oven capable of maintaining temperatures of about 110 degrees C. for drying moisture samples.

Procedure: The air dry soil first shall bo pulverized to pass a No. 4 sieve so as to separate the soil particles without reducing the particle size. The required cement shall be added to the soil.

A quantity of water sufficient to produce slight cohesion shall then be thoroughly mixed with the soil-cemtn sample to permit ready compaction. The thoroughly mixed soil-cement sample shall be immediately compacted in the mold in three equal layers to give a total compacted depth of about 5"; each layer being compacted by 25 blows of the rammer dropping from a height of 12" above the elevation of the soil when a sleeve type rammer is used. During compaction, the mold shall rest on a uniform, rigid foundation weighing 200 lb. or its equivalent. The blows shall be uniformly distributed over the surface of the layer being compacted. After compacting, the collar shall be removed and the top carefully trimmed to the exact height of the mold with a steel straight edge to produce a speciment approximately 4.6" in height and having a volume of 1/30 cu. ft.

The weight of the compacted soil-cement mixture shall be determined, the material removed from the cylinder, sliced vertically in the center and a 100 gram sample taken from the center, weighed immediately, dried in an oven at 110 degrees C. for at least 12 hrs. or to a constant weight. This procedureestablishes the moisture-density relation of the initial soil-cement mixture.

The soil-cement mixture shall be again finely pulverized, so as to separate the soil particles without reducing the particle size, to pass a No. 4 sieve and a small increment of moisture carefully added and thoroughly mixed to insure uniform distribution. The mixture is then compacted as previously mentioned and a moisture density determining is made. This procedure is repeated until the moisture content appraaches the Liquid Limát. This procedure will establish the moisture density relations of a soil-cement mixture for the moisture contents practicable to handle in the field.

The calculations are made to determine the moisture content and corresponding compacted oven dry weight of the compacted soil-cement for each test made on the mixture. The oven dry weights per cubic foot shall be plotted as ordinates and the corresponding moisture contents as abscissas.

When the moisture-density relations have been determined for a soil cement mixture and the results plotted, the connected plotted points will produce a curve which is parabolic in form. The moisture content producing the peak of the curve is termed the "optimum moisture content" of the soil-cement mixture under the above compaction.

The oven dried weight per cubic foot of the moist soil-cement mixture at "optimum moisture content" shall be termed "maximum density" under the above compaction.

Determination of Optimum-Moisture Maximum-Density

For Estimation of Soil-Cement Ratio

Data for 6% by volume of Portland Cement:

TRIAL NO.	WET WT. OF SPECIMEN GRAMS	DRY WT. OF SPECIMEN GRAMS	% MOISTURE CONTENT	WET WT. OF SAMPLE GRAMS	COMPUTED DRY WT OF SAMPLE GRAMS	DRY DENSITY #/CU. FT.
1	35.7	32.8	8.9	2119	1931	127
2	25.7	23.0	11.7	2189	1932	128
3	33.8	37.7	13.2	2184	1898	125

Sample Calculations:

Wt. of weighing jar and wet soil . . . . 80.2 grams

Wt. " " " " dry " . . . . 77.3 "

Wt. " " " . . . . 44.5 "

Wt. of Wet Soil . . . . 35.7 "

Wt. " Dry " . . . . 32.8 "

Wt. " Moisture . . . . 2.9 "

Therefore % Moisture Content $\frac{2.9 \times 100}{32.8} = 8.9\%$

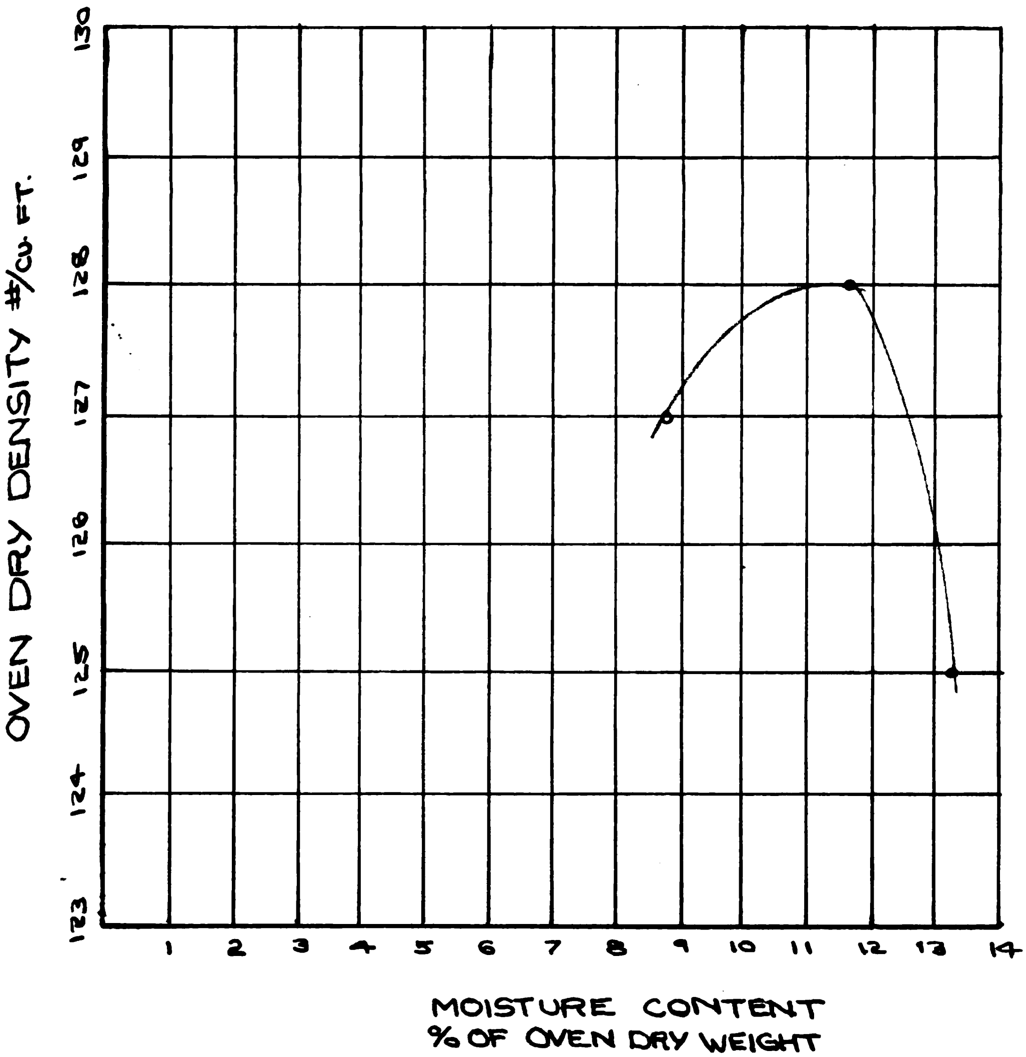
Wet weight of sample . . . . 2119 grams

Computed dry weight of sample. . 2119 - (.089 × 2119) = 1931

Dry density $\frac{1931 \times 30}{454} = 127$ lbs. per cubic foot

Moisture Density Curve For 6%

Soil-Cement Ratio



OPTIMUM MOISTURE – 11.7%
MAXIMUM DENSITY – 128.0 #/CU.FT.

Determination of Optimum-Moisture Maximum-Density

For Estimation of Soil-Cement Ratio

Data for 8% by volume of Portland Cement:

TRIAL NO.	WET WT. OF SPECIMEN GRAMS	DRY WT. OF SPECIMEN GRAMS	% MOISTURE CONTENT	WET WT. OF SAMPLE GRAMS	COMPUTED DRY WT OF SAMPLE GRAMS	DRY DENSITY #/CU FT.
1	43.9	41.3	6.3	2041	1912.5	126.0
2	47.0	43.4	8.3	2100	1926.0	127.0
3	29.7	26.7	11.3	2213	1963.0	129.5
4	31.5	27.8	12.7	2234	1951.0	129.0
5	10.2	9.5	13.6	2149	1836.0	123.0

Sample Calculations:

Wt. of weighing jar and wet soil . . . . . 84.1 grams

Wt. " " " " dry " . . . . . 80.5 "

Wt. " " " . . . . 37.1 "

Wt. of wet soil . . . . 47.0 "

Wt. " dry " . . . . 43.4 "

Wt. " Moisture. . . . . 3.6 "

Therefore % moisture content $\frac{3.6 \times 100}{43.4} = 6.3\%$

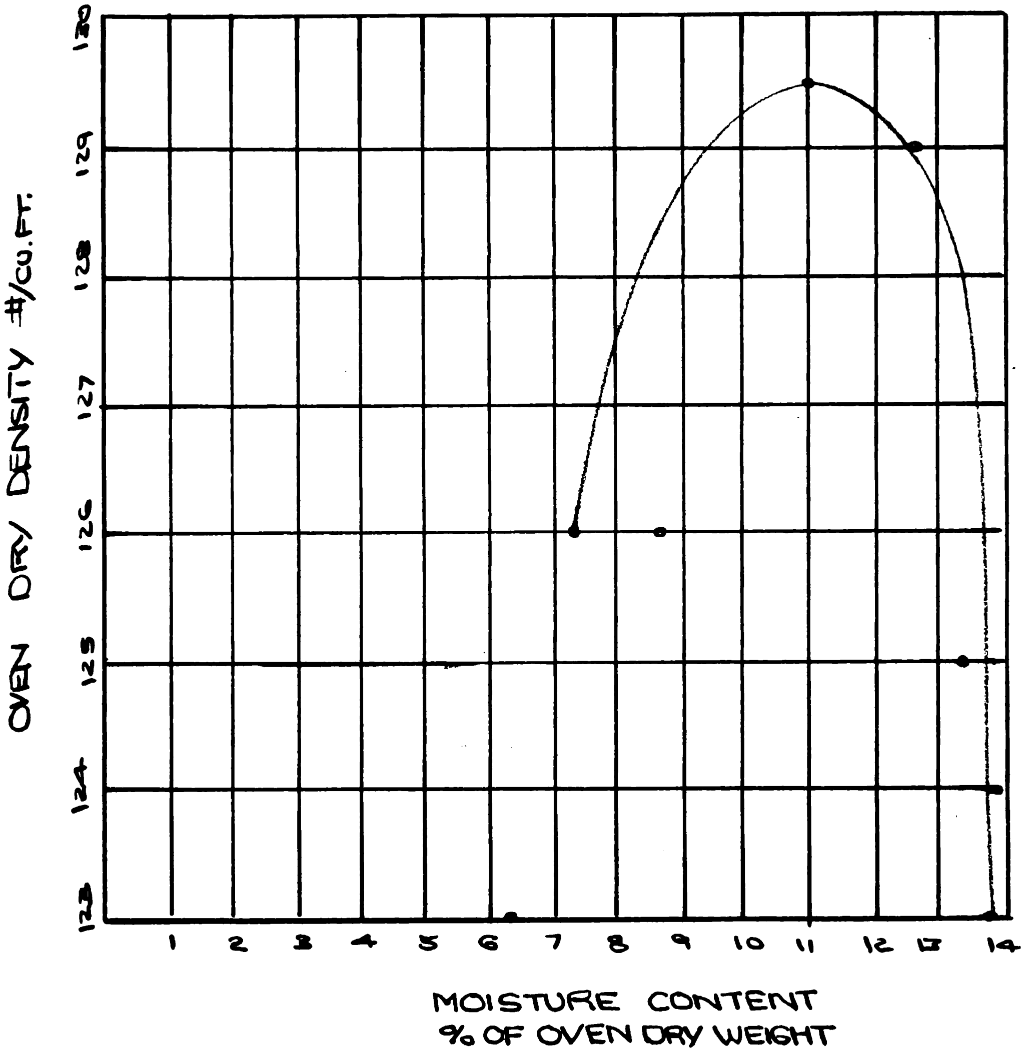
Wet weight of sample. . . . . 2041 "

Computed dry weight of sample 2041 - (2041 × .063) = 1912.5

Dry density $\frac{1912.5 \times 30}{454} = 126$ lbs per cubic foot

Moisture Density Curve For 8%

Soil-Cement Ratio



OPTIMUM MOISTURE - 11.3%
MAXIMUM DENSITY - 129.5#/CU.FT

Determination of Optimum-Moisture Maximum-Density

For Estimation of Soil-Cement Ratio

Data for 10% by volume of Portland Cement:

TRIAL NO.	WET WT. OF SPECIMEN GRAMS	DRY WT. OF SPECIMEN GRAMS	% MOISTURE CONTENT	WET WT. OF SAMPLE GRAMS	COMPUTED DRY WT. OF SAMPLE GRAMS	DRY DENSITY #/CU. FT.
1	38.2	35.8	6.3	1974	1850	123.0
2	46.7	42.9	8.9	2098	1903	129.0
3	45.9	41.4	11.0	2204	1959	129.5
4	40.8	36.0	13.3	2179	1890	125.0

Sample Calculations:

Wt. of weighing jar and wet soil . . . . 83.3 grams

Wt. " " " " dry " . . . . . 80.9 "

Wt. " " " . . . . 45.1 "

Wt. of wet soil . . . . 38.2 "

Wt. " dry " . . . . 35.8 "

Wt. " moisture . . . . 2.4 "

Therefore % moisture content. . . . 6.3%

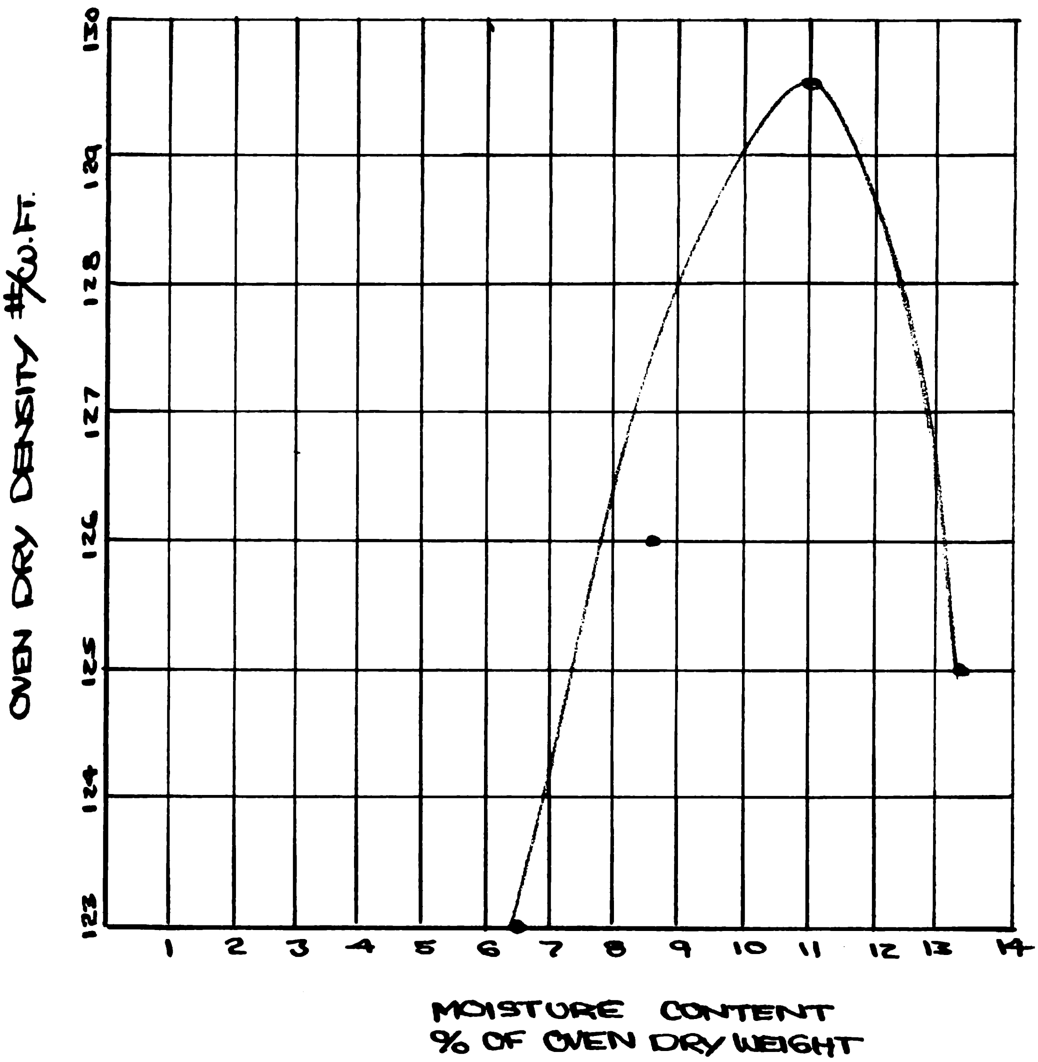
Wet weight of sample . . . . 1974 "

Computed dry weight of sample 1974 - (1974 × .063) = 1850 grms

Dry density $\frac{1850 \times 30}{454}$ = 123 lbs. per cubic foot

Moisture Density Curve For 10%

Soil-Cement Ratio



OPTIMUM MOISTURE – 11.0%
MAXIMUM DENSITY – 129.5 #/CU.FT.

SOIL-CEMENT TEST FOR DURABILITY

In order to determine an adequate cement content, thatis the most economical cement content that will produce strong, durable soil-cement, samples representing the desired testing range were mixed and compacted to maximum density at optimum moisture. These samples were then subjected to the "Freeze-Thaw", "Wet-Dry" and "Compressive Strength" test. The procedures and apparatus used in these tests were for the most part those as given by the American Society for Testing Materials. The durability and compressive tests are outlined in the following section.

Title: Standard Method of Wetting and Drying Test of Compacted Soil-Cement Mixtures.

Object: This method of test is intended for determining the soil-cement losses produced by repeated wetting and drying of compacted mixtures of known composition and of known uniform density and moisture content.

Apparatus: Same equipment used for construction of samples for A.S.T.M. desig. D-558-44.

Drying Oven-A thermostatically controlled drying oven capable of maintaining temperatures of about 110 degrees C. for drying moisture samples and compacted soil-cement specimens.

Moist Room-A moist room capable of maintaining a temperature of 21 plus of minus 1.7 degrees C. and a relative humidity of not less than 90% for seven day storage of specimens.

Water Bath-Suitable tank for submerging compacted specimens in water at about 21 degrees C.

A Wire Scratch Brucsh - A brush made of 2" by 1/16" flat No. 26

gage wire bristles assembled in 50 groups of 10 bristles each and mounted to form five longitudinal rows and ten transverse rows of bristles on a 7.5" by 2.5" hardwood block.

Procedure: At the end of storage in the moist room, the specimens shall be submerged in tap water at room temperature for a period of five hours, and removed. The specimen shall be placed in an oven at about 71 degrees C. for 42 hours and removed. The specimen shall then be weighed, given two firm strokes on all areas with the wire brush to remove all material loosened during wetting and drying. The specimen shall then be weighed again after brushing.

This completes one cycle, 48 hours, of wetting and drying. The procedure whall be continued for 12 cycles or discontinued prior to 12 cycles should the measurements become inaccurate due to distortion or soil-cement loss of the specimen.

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

Title: Standard Method of Test for Freezing-and-Thawing of Compacted Soil-Cement Mixtures.

Object: This method of test is intended for determining the soil-cement losses produced by repeated freezing and thawing of compacted specimens of soil-cement mixtures of known composition and known density.

Apparatus: Same as used in A.S.T.M. desig. D-558-44 with the addition of a freezing cabinet capable of maintaining temperatures of minus 23 degrees C. or lower.

Procedure: At the end of the storage period in the moist room, water saturated felt pads, blotters or similar absorptive material shall be placed between the specimens and the holders, and the assembly placed in a refrigerator having a constant termperature not warmer than 23 degrees C. for 22 hours and removed.

Free water should be made available to the absorbent pads under the specimens to permit absorbtion of water by the specimens by capillarity.

After 22 hours in the moist room, the specimen shall be weighed, brushed and reweighed. The oven-dry weight of the material brushed from the specimen shall then be calculated. This constitutes a cycle of freezing and thawing.

The specimen shall then be placed in the refrigerator and the procedure continued for 12 cycles or discontinued prior to 12 cycles should the measurements become inaccurate due to distortion or soil-cement losses. The soil-cement loss of the specimen shall be calculated as a percentage of the original oven-dried weight of the sample.

The compressive strength test consists of breaking specimens which have been allowed to cure for periods of 7, 17 and 28 days. Data from a 17 day curing period compressive strength test is as follows:

6%	Cement	Content.	500	lbs	per	sq.	in.
8%	"	"	650	"	"	"	"
10%	"	"	700	"	"	"	"

ANALYSIS OF SOIL-CEMENT TESTS.

It is regretted that there was not sufficient time to completely investigate the durability and strength characteristics of the soil under study.

Three cycles on the "Wet-Dry" and "Freeze-Thaw" tests were completed. During these tests no appreciable soil loss occurred. The Portland Cement Association specifies, in their Soil-Cement Mixtures Laboratory Handbook, a limit of 14% soil loss during the 12 cycles for A-2 soils. Although no proof is available, there is every reason to believe the compacted samples would meet this specification.

The compressive strength specification from the same source reads as follows: "Compressive strengths shall increase with age and with increases in cement content". The extent of the compressive strength tests showed favorable results both with respect to necessary minimum strengths and increased strength with increased cement content. Further tests at different stages during the curing period would have been helpful in analizing the stabilized soil.

One extremely good reason for anticipating favorable performance from this soil is the extremely high density of the mixture. The data from the moisture-density test is complete for the treatment range chosen.

CONCLUSIONS, RECOMMENDATIONS AND CRITICISMS

The soil-cement tests, although incomplete, answer the fundemental question: Is the soil suitable for stabilization? The answer is quite definitely yes. The lack of comparative data makes it difficult to select a final soil-cement ratio, however in order to insure satisfactory results a minimum percentage of 10% cement content is advised. In support of this, the Portland Cement Association recommends that for practical reasons, no cement contents less than 7% by volume for field use in the construction of soil-cement.

A summation of the results from the soil-cement tests leads to the following recommendations concerning actual soil-cement construction:

Optimum Moisture . . . 11% by volume
Maximum Density . . . 129.5 lbs. per. cu. ft.
Cement Content . . . 10% by volume

With a soil-cement ratio of 10%, and a final compacted depth of 6", a simple calculation shows the number of bags of cement necessary to stabilize the entire parking area to be 12,068.

129.5 x 1/2 x 197,146 = 12,765,203 lbs. of stabilized soil
11% x 12,765,203 = 1,404,172 lbs. of water
12,765,203 - 1,404,172 = 11,361,031 lbs. of dry soil
11,361,031 x 10% = 1,136,103 lbs. of cement
1,136,103.1 - 94 = 12,068 bags of cement

Also, in regard to actual construction, due to the high clay content, special equipment will be necessary to pulverize the soil where it has been compacted by traffic. Due to the existing slope of the area, run-off during wet weather would cause detrimental wearing action on the soil-cement surface. Therefore it is recommended that the final surface be treated with a bituminous and crushed rock surface coating.

A criticism of this paper should re-emphasize the lack of soil-cement date. Less time should have been spent on the soil tests. Probably the mechanical analysis alone would have been conclusive enough to show the single soil type existing. This would have allowed more time for the durability tests.

If more time had been available the information obtained could have been used with a bit more on construction costs to establish the materials and costs covering the project.

As a final constructive criticism, I would say that this "problem study" has been both interesting and educational.

BIBLIOGRAPHY:

Portland Cement Publications:

1. "Soil-Cement Mixtures Laboratory Handbook"
2. "Summary of Soil-Cement Testing and Construction"
3. "Soil-Cement Roads Construction Handbook"
4. "Preliminary Report - Field and Laboratory Studies of Cement Treated Base"
5. "Tentitive Specifications for Cement Treated Base"

American Society of Testing Materials Standard Tests:

1. Designation No. D-558-44
2. " " D-559-44
3. " " D-560-44

Miscellaneous:

1. "Basic Principles of Soil-Cement Mixtures" by P.T. Sheets and M.D. Catton.
2. "Soil Tests and Their Significance" publication distributed in C.E. 442
3. "Applied Soil Mechanics - Laboratory Manual of Soil Testing" by Wm. Housel.
4. "Applied Soil Mechanics - Part 1 Soil As An Engineering Material" by Wm. Housel.

[redacted]

[redacted]

PARKING AREA

LOCATION OF SOIL SAMPLES

APRIL-7 1948 D.E.ENOS

NOTE:

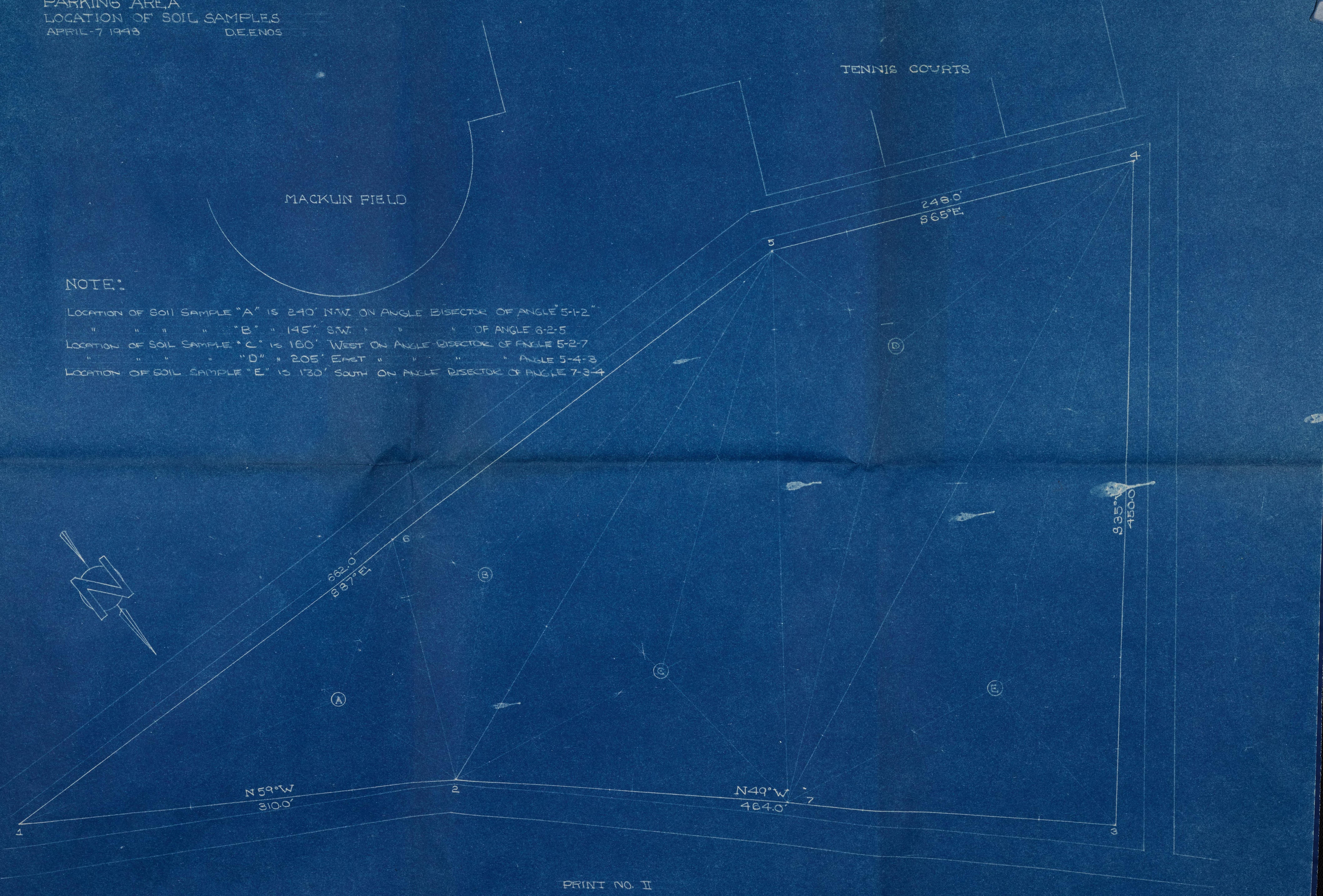
LOCATION OF SOIL SAMPLE "A" IS 240' N.W. ON ANGLE BISECTOR OF ANGLE "5-1-2"

" " " " "B" " 145' S.W. " " " OF ANGLE 6-2-5

LOCATION OF SOIL SAMPLE "C" IS 160' WEST ON ANGLE-BISECTOR OF ANGLE 5-2-7

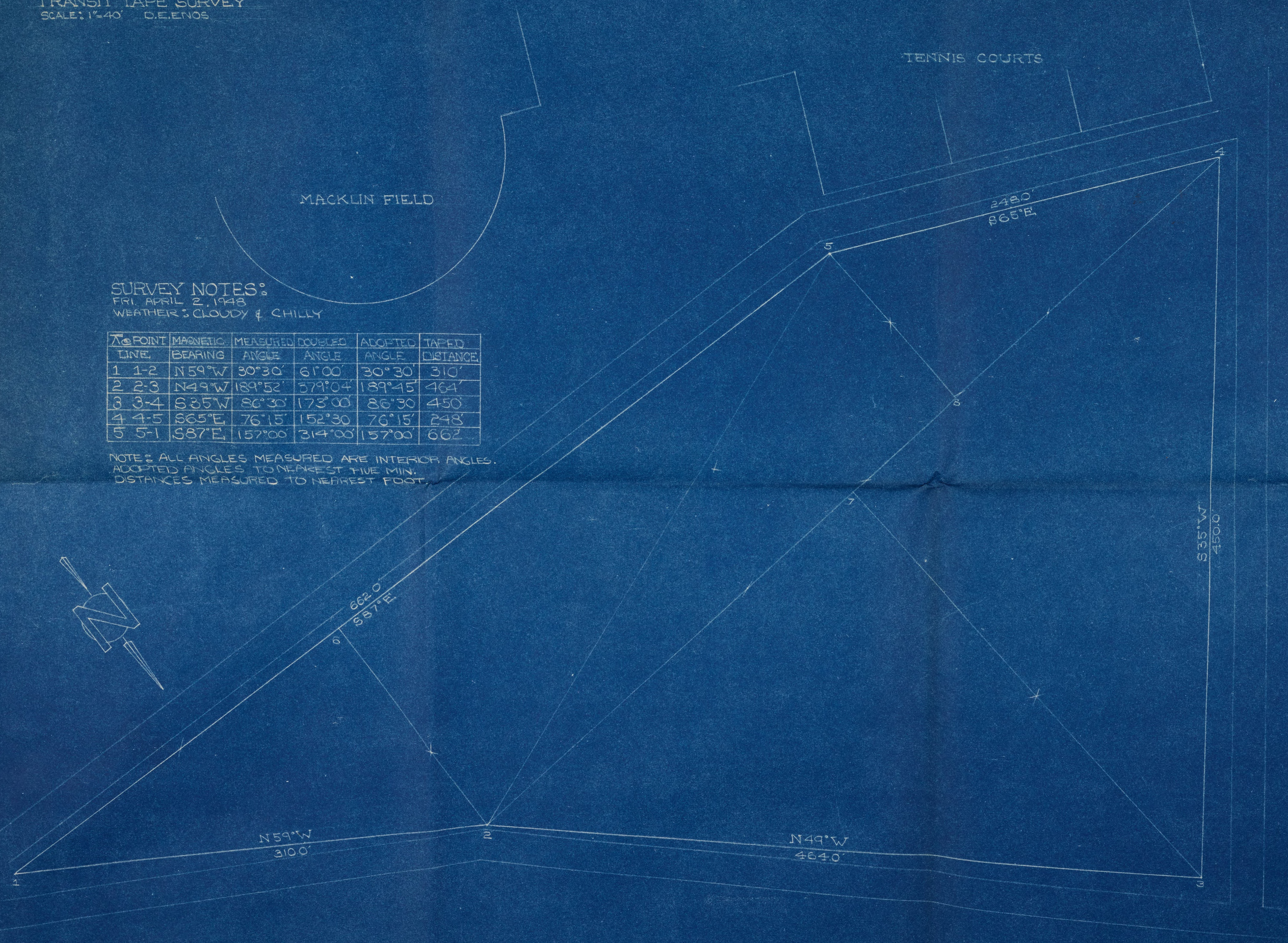
" " " " "D" " 205' EAST " " " " ANGLE 5-4-3

LOCATION OF SOIL SAMPLE "E" IS 130' SOUTH ON ANGLE BISECTOR OF ANGLE 7-3-4



PRINT NO. II

PARKING AREA
TRANSIT TAPE SURVEY
SCALE: 1"=40' D.E. ENOS



SURVEY NOTES:
FRI. APRIL 2, 1948
WEATHER: CLOUDY & CHILLY

⊼ @ POINT LINE		MAGNETIC BEARING	MEASURED ANGLE	DOUBLED ANGLE	ADOPTED ANGLE	TAPED DISTANCE
1	1-2	N59°W	30°30'	61°00'	30°30'	310'
2	2-3	N49°W	189°52'	379°04'	189°45'	464'
3	3-4	S35°W	86°30'	173°00'	86°30	450'
4	4-5	S65°E	76°15'	152°30	76°15'	248'
5	5-1	S87°E	157°00'	314°00'	157°00'	662

NOTE: ALL ANGLES MEASURED ARE INTERIOR ANGLES.
ADOPTED ANGLES TO NEAREST FIVE MIN.
DISTANCES MEASURED TO NEAREST FOOT.

PRINT NO. I