HIGHWAY RESEARCH BOARD
Bulletin 122

Soil-Testing Methods

MOISTURE, DENSITY, CLASSIFICATION
SOIL-CEMENT

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Contents

Preparing Base-Course Materials for Disturbed-Soil Indicator Tests

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There are two approved methods for preparing base-course materials for the disturbed soil indicator tests: (1) dry preparation of disturbed soil samples for test (AASHO designation T-87-49) and (2) wet preparation of disturbed soil samples for test (AASHO designation T-146-49 or T.H.D. No. 53).

This cooperative research study was undertaken to ascertain the differences that would be obtained in the end results of the disturbed soil indicator tests when one laboratory used the dry method and the other laboratory used the wet method of preparing the same sample for the disturbed-soil indicator tests.

In this cooperative research study which included caliche, shell, gravel and crushed stone base course materials, 17 samples were taken in three states: ten in Texas, five in Oklahoma, and two in Louisiana. The author supervised the digging and preparation of each sample at the site where each sample was taken, previous to the shipment of the samples to the laboratories. Four samples were prepared at each of the 17 sites. One sample so prepared was forwarded to each of the three laboratories. The fourth sample was kept for check purposes.

In the Texas State Highway Department laboratory the 17 different samples were prepared for the distrubed soil indicator tests by the wet method. In the Oklahoma State Highway Department laboratory and in the Louisiana State Highway Department laboratory the seventeen samples of base course materials were prepared for test by the dry method. Each laboratory then made the disturbed soil tests by the standard AASHO methods. The results of the disturbed indicator tests of the seventeen samples of base course materials from each of the three state laboratories were assembled and arranged in a report by this author.

The results indicate the maximum difference between the methods of preparation in determining the liquid limit varied in this series of tests from 4 to 14 and the plasticity index varied from 3 to 14.

The test results indicate that wide variation may occur in the results of the liquid-limit test and the plasticity-index test, not only between the wet and the dry methods of preparation of the base course samples but also, to a lesser degree, between two laboratories using the same dry method of preparation.

● THE research reported in the following paragraphs was initiated and carried to conclusion for the purpose of measuring the maximum difference that is obtained in the soil constants of base-course-material samples when the given samples are prepared for the disturbed indicator soil tests by two different methods namely: (1) dry preparation of disturbed soil samples for test (AASHO Designation T-87-49) and (2) wet preparation of disturbed soil samples for test (AASHO Designation T-146-49, or T.H.D. No. 53).

Three state highway department soil laboratories cooperated with the writer in this base course material research study, namely, the Texas State Highway Department laboratory at Austin, Texas; the Oklahoma State Highway Department Laboratory at Oklahoma City, Oklahoma, and the Louisiana State Highway Department Laboratory at Baton Rouge, Louisiana.

Samples of base course materials were taken at 17 different locations in the three states by the author assisted by members of the soil laboratories of the state where the specific samples were taken. Ten samples were dug in Texas, five in Oklahoma, and two in Louisiana. At the outset of this research study, it was planned to select samples of caliche, shell, and gravel base-course materials in the three states where samples were taken. The general location where each sample was taken is outlined in Figure 1. The specific location where each sample was taken as well as other pertinent data such as kind, depth, and age of base course and surface course, and present condition of surface course is outlined in Table 1.

The method of taking the samples was as follows: First the bituminous surface was

TABLE 1

Sample No	State	County	Kind of Base	Location	Base Depth	Type of Surface	Built	Surface Condition	Sub-grade
1	Tex	Reffugio	Shell	F.M. Highway 136, between Bayside and Woodsboro	6"	1" Single Bituminous Resurfaced 1949	1941	Good where sample was taken	Clay
2	Tex	Reffugio	Shell	F M. Highway 1039 4 mi. S of Woodsboro	5"	1" Single Bituminous	?	Poor Edge failures where sample was taken	Clay
3	Tex.	San Patricio	Caliche	U.S. Highway 50 in the business district of Mathis, Tex.	10"	1¼" Cold Uvalde Rock Asphalt	1947	very good	Clay
4	Tex	Bee	Caliche	State Highway 202-3 mi east of Beerville	7"	2" Caliche treated with emulsion ¼" Seal Coat	1936	very good where sample was taken	Clay
5	Tex.	Bexar	Grav.	State Highway 346-3 mi North of Bexar-Atascosa Co line	10"	2" Uvalde Rock Asphalt	1930	Fair where sample was taken	Clay
6	Tex	Bexar	Grav.	2,000 feet North of Lackland Air Base Gate on loop No 13	12"	2¼" of Bituminous Concrete	1941	very good	Clay
7	Tex.	Bexar	Grav.	1,000 feet East of Kelly Field Overpass on loop No. 13	12"	2" of Bituminous Concrete	1939	very good	Clay
8	Okla	Pontotoc	Cr. Stone	2½ mi South of Wye on State Highway No. 99	10"	2½" Okla Rock Asphalt	1946	very good	Sand Clay
9	Okla	Murray	Cr. Stone	Platt National Park Highway 18-½ mile of Sulphur Okla gate	4"	2" Okla Rock Asphalt	1931	very good	Clay
10	Okla.	Carter	Grav	S end of Expressway-S Service road U S. 77 Ardmore, Okla	6"	2" Okla. Rock Asphalt	1948	Poor Surface Alligatored	Clay
11	La.	Jeff.-Davis	Grav.	State Highway 105-0.3 mi South of Square in Welsh, La.	7"	Triple Bituminous	1946	very good	Sand
12	La	Calcasieu	Grav.	State route 240-1½ mi. to intersection of U.S No. 90	7"	Triple Bituminous	1947	very good	Sand Clay
13	Tex	Hale	Caliche	½ mi. -North of Intersection F.M. 54 and F M. 400 on F.M. 400	10"	Double Bituminous Resealed 1950	1935	good where sample was taken	Clay
14	Tex.	Floyd	Caliche	U.S 70-7 mi., East of Plainview and 0.4 mi East of Hale Co. line	9"	Double Bituminous Resealed 1950	1936	very good	Clay
15	Tex.	Crosby	Caliche	U.S. 62-1 mile South of Floyd-Crosby Co. line	7"	Double Bituminous Resealed 1949	1939	Good where sample was taken	Clay
16	Okla.	Kiowa	Grav	½ mile North of Snyder Oklahoma on U S. 183	6"	2" Okla. Rock Asphalt	1934	Poor Surface Alligatored	Sand Clay
17	Okla.	Kiowa	Grav.	2½ mi. South of Snyder Oklahoma on U S. 183	7"	2" Okla. Rock Asphalt	1935	very good	Sand Clay

carefully peeled from the surface of the base course, after which the base course surface was carefully broomed. Thereafter the compacted base course was picked loose with a pickaxe. Following this the loosened base course was shoveled into a soil sample splitter and fell therefrom into steel buckets. Four bucketfuls were collected in this manner at the 17 different locations. After this the four bucketfuls were emptied into four different sacks.

The soil or base course sample splitter is shown in Figures 2 and 3. It consists of a hopper with bottom perforated in logitudinal sections which deliver into chutes alternately faced in opposite directions and delivering into two receiving pans. The soil or base course sample is poured into the riffle at the top, and is divided into two equal parts by means of the parallel troughs or chutes, the alternate ones emptying into the same pan. Thus the sample introduced into the hopper is divided into two equal parts, each part receiving an approximately equal fraction of mixture from all points in the hopper area. By subsequently passing through the sampler each of the first two portions obtained four separate samples are secured of substantially identical composition. This process may be continued to secure a representative sample of any desired size. The hopper and chutes are made of heavy rugged tin plate and are removably supported in a strong iron frame allowing space to insert receiving pans.

Thus four sacks of the same base course material was obtained from each hole dug in the surface of a bituminous pavement of known life and behavior at 17 different locations in the above mentioned states. These four sacks were marked Sample A, Sample B, Sample C, and Sample D. Thus after samples had been taken at the 17 different locations there were 17-A samples: 17-B samples; 17-C samples; and 17-D samples. Finally the 17 sacks of A samples were carried by the writer to the Texas Laboratory at Austin, Texas; the 17-B sacks of samples were carried to the Oklahoma laboratory at Oklahoma City, Oklahoma, and the 17-C sacks of samples were carried to the Louisiana laboratory at Baton Rouge, Louisiana. The 17-D sacks of samples were reserved in storage by the writer to be utilized at a later date in case any sample happened to get lost, or any check tests became necessary.

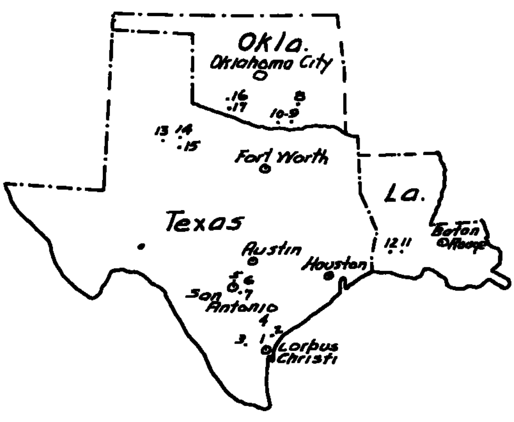

Figure 1. Base Course Material Research approximate locations where the 17 samples were taken.

The 17-A base course material samples were prepared for the disturbed soil indicator tests in the Texas laboratory at Austin, Texas, by the WET method of AASHO designation T-146-49 which is similar to method T.H.D. 53. The 17-B base course materials were prepared for the disturbed soil indicator tests in the Oklahoma laboratory at Oklahoma City, Oklahoma, by the DRY method or AASHO designation T-87-49. The 17-C samples were also prepared for the indicator tests in the Louisiana laboratory at Baton Rouge, Louisiana, by the DRY method AASHO designation T-87-49.

The laboratory procedure for preparing the base course material samples for the simple indicator soil tests by the DRY method (AASHO Designation T-87-49) is as follows:

Preparation of Test Samples

4(a) The base course sample as received from the field in the laboratory is dried thoroughly in air or by use of drying apparatus such that the temperature of the sample will not exceed 140F. After drying the aggregations are thoroughly broken up in a mortar with a rubber-covered pestle or suitable mechanical device in such a way as to avoid reducing the natural size of individual particles. Thereafter a representative test sample of the amount required to perform the tests is obtained by the method of quartering.

TABLE 2

Sample No.	Percent Passing -10 Lab. A	B	C	-40 Lab. A	B	C	-200 Lab. A	B	C	-0.05 Lab. A	B	C	-0.005 Lab. A	B	C	-0.001 Lab. A	B	C
1	40	44	33	26	29	20	15	18	12	13	15	10	8	7	6	5	2	0
2	33	41	33	19	26	21	10	15	11	9	12	9	6	5	6	3	1	1
3	64	71	68	46	56	53	31	42	32	28	41	28	9	10	8	3	1	0
4	54	63	48	40	46	41	30	31	29	27	31	26	9	11	8	3	4	0
5	36	34	14	31	29	12	21	20	8	21	18	7	11	9	2	4	3	0
6	48	47	32	41	41	28	35	35	23	32	34	20	10	12	7	3	2	0
7	41	42	31	29	31	22	15	16	10	13	15	9	11	7	4	2	1	0
8	40	38	35	27	22	24	14	16	12	13	13	10	6	5	4	1	1	1
9	44	42	39	25	30	22	13	17	10	11	13	9	4	4	3	1	1	1
10	71	72	62	36	46	36	26	24	22	22	24	20	12	11	11	4	1	0
11	42	52	34	26	35	21	12	15	8	11	12	6	5	5	2	2	1	1
12	67	62	58	52	52	46	23	21	16	19	18	13	12	8	8	9	5	3
13	91	91	70	88	82	64	42	45	29	35	39	23	22	19	10	8	6	3
14	63	70	53	55	66	48	26	34	18	22	29	16	13	13	6	4	2	2
15	63	59	47	54	56	43	29	40	22	26	31	18	11	10	5	2	1	2
16	61	58	60	21	26	26	11	14	10	9	11	8	6	4	4	2	2	1
17	72	52	69	34	30	36	14	13	11	12	11	8	5	3	4	2	1	0

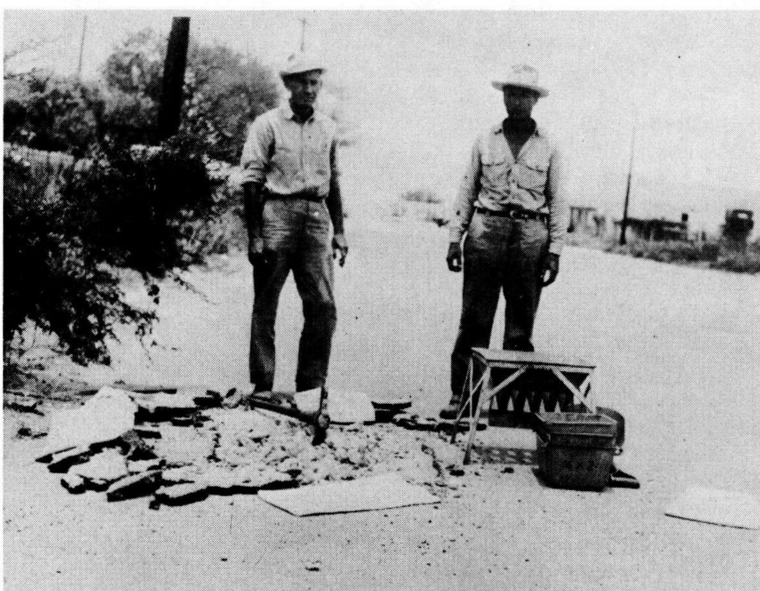

Figure 2.

4(b) The portion of the air-dried sample selected for purpose of mechanical analysis and physical tests is weighed and the weight recorded as the weight of the total sample uncorrected for hygroscopic moisture. The test sample is then separated into two portions by means of a 10 mesh sieve. The fraction retained on the No. 10 sieve is then ground in a mortar with a rubber-covered pestle or suitable mechanical device until the aggregations of soil particles are broken up into separate grains. The ground soil is then separated into two fractions by means of the No. 10 sieve.

4(c) The fraction retained on the No. 10 sieve after the second sieving is then set aside for use in the mechanical analysis of the coarse material.

5. The fractions passing the No. 10 sieve in both the sieving operations described

in section 4(b) is thoroughly mixed and by the method of quartering or the use of a sampler, a portion weighing approximately 115 grams for sandy soils, and approximately 65 grams for silt and clay soil, is selected for the mechanical analysis.

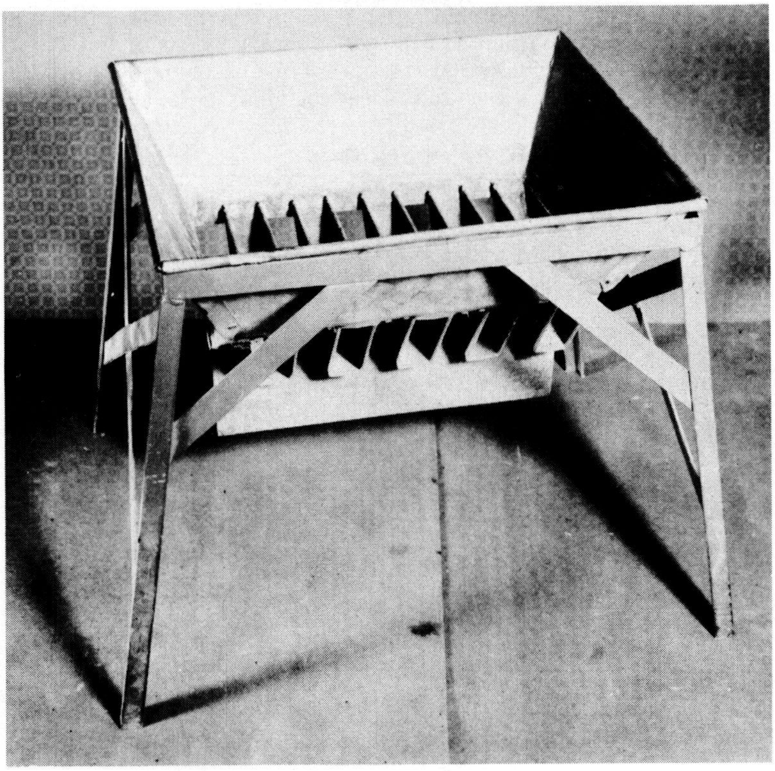

Figure 3.

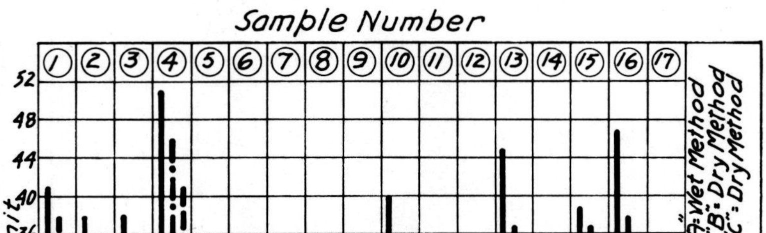

Figure 4.

Test Sample for Soil Constants

6. The remaining portion of the material passing the No. 10 sieve is then separated

into two parts by means of a No. 40 sieve. The fraction retained on the No. 40 sieve is then ground in a mortar with a rubber covered pestle or suitable mechanical device in such a manner as to break up the aggregation of soil particles without fracturing the individual grains. If the sample contains brittle fragments such as large flakes of mica, fragments of sea shells, etc., the grinding operation is done carefully and with just enough pressure to free the fragments from adhering particles of finer material. The ground soil is then separated into two fractions by means of the No. 40 sieve and the material retained on the No. 40 sieve and is reground as before. When repeated grind-

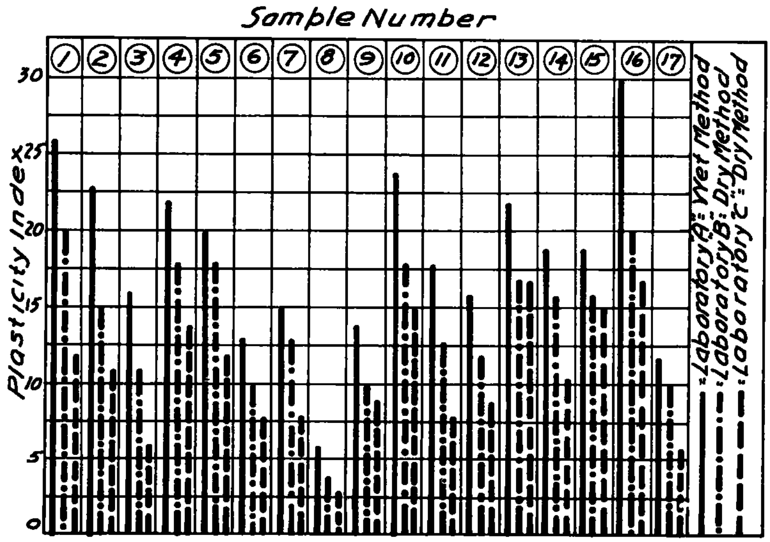

Figure 5.

TABLE 3

Sample Number	Liquid Limit: Maximum Difference	Liquid Limit: Minimum Difference	Plasticity Index: Maximum Difference	Plasticity Index: Minimum Difference	Ratio -200/-40 Lab A	Ratio Lab B	Ratio Lab C	0.05 to 0.005 Silt Lab. A	Silt Lab. B	Silt Lab. C	0.005 to 0 001 Clay Lab. A	Clay Lab. B	Clay Lab. C	bass 0.001 Colloids Lab A	Colloids Lab B	Colloids Lab C	Clay plus Colloids Lab A	Clay plus Colloids Lab B	Clay plus Colloids Lab C
1	11	3	14	6	58%	62%	60%	5	8	4	3	5	6	5	2	0	8	7	6
2	9	5	12	8	53	58	52	3	7	3	3	4	5	3	1	1	6	5	6
3	7	2	10	5	67	75	60	19	31	20	6	9	8	3	1	0	9	10	8
4	10	5	8	4	75	67	71	18	20	18	6	7	8	3	4	0	9	11	8
5	6	2	2	2	68	69	67	10	9	5	7	6	2	4	3	0	11	9	2
6	5	3	3	3	85	85	82	23	22	13	7	10	7	3	2	0	10	12	7
7	5	1	2	2	52	52	45	2	8	5	9	6	4	2	1	0	11	7	4
8	4	2	2	2	52	73	50	7	8	6	5	4	3	1	1	1	6	5	4
9	7	4	4	4	52	57	45	7	9	6	3	3	2	1	1	1	4	4	3
10	8	4	6	6	72	52	61	10	13	9	8	10	11	4	1	0	12	11	11
11	12	5	5	5	46	43	38	6	7	4	3	4	1	2	1	1	5	5	2
12	9	3	12	4	44	40	35	7	10	5	3	3	5	9	5	3	12	8	8
13	11	8	5	5	48	55	45	13	20	13	14	13	7	8	6	3	22	19	10
14	8	3	3	3	47	52	38	9	16	10	9	11	4	4	2	2	13	13	6
15	6	2	3	3	54	71	51	15	21	13	9	9	3	2	1	2	11	10	5
16	14	9	10	10	52	54	38	3	7	4	4	2	3	2	2	1	6	4	4
17	8	3	2	2	41	43	31	7	8	4	3	2	4	2	1	0	5	3	4

ings produce only a small quantity of soil passing the No. 40 sieve, the material retained on the No. 40 sieve is discarded. The several fractions passing the No. 40 sieve obtained from the grinding and sieving operations above described are then thoroughly mixed together and set aside for use in the determination of the disturbed soil constants.

The laboratory procedure for preparing the base course material samples for the simple indicator soil tests by the WET method (AASHO Designation T-146-49 or Texas Highway Department T.H.D. No. 53) is as follows:

SEPARATION OF SOIL BINDER FROM AGGREGATE

6. Weigh the air-dried sample and record the weight on the soil work card. Screen out all material that will easily pass 40 mesh sieve and save and identify the portion passing.

7. Immerse the retained portion from step 6 in a pan of clear water until all the binder material has slacked down or disintegrated, which may require from 2 to 24 hours. If the sample is immersed for only a few hours, extreme care should be taken to see that no lumps containing soil binder remain in the aggregate.

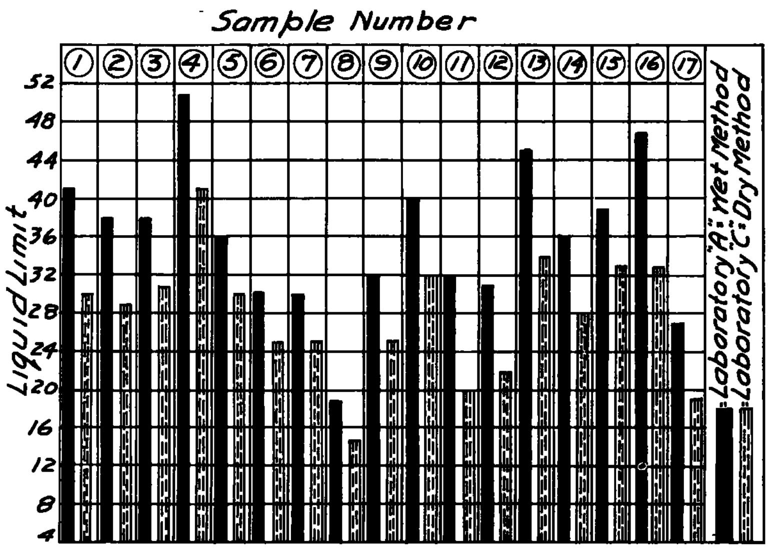

Figure 6.

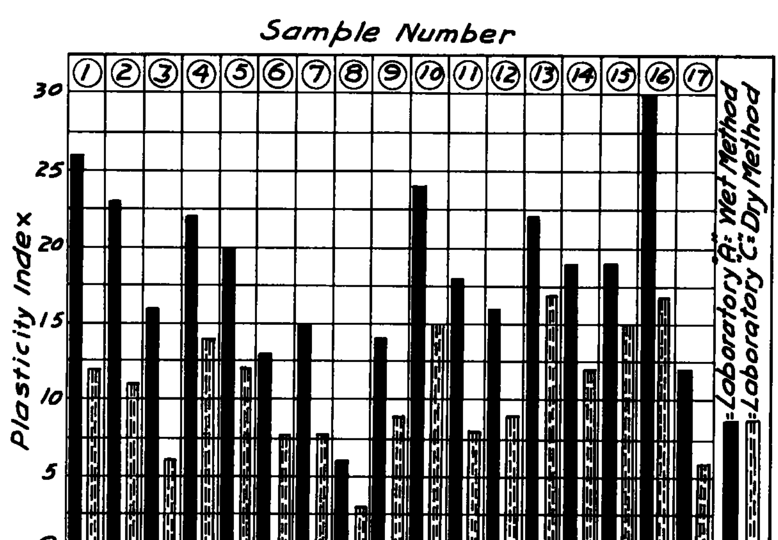

Figure 7.

8. The slacked material is then washed over a 40-mesh sieve. The empty 40-mesh sieve is set in the bottom of a milk pan and the surplus water from the sample poured into it. Enough additional water is added until the level of the water reaches a point approximately $\frac{1}{2}$ inch above the mesh in the sieve. Approximately one pound of the slacked material is placed in the water on the sieve and stirred by hand at the same

TABLE 4

Sample No.	L.L.	P.I.	F.M.E.	S.L.	L.S.	S.R.	Base Type	Class
1A	41	26	26	18	10.3	1.76	Shell	A-6
2A	38	23	23	20	8.4	1.73	Shell	A-6
3A	38	16	31	25	6.1	1.60	Caliche	A-4-7
4A	51	22	36	29	8.9	1.50	Caliche	A-7
5A	36	20	22	17	10.9	1.90	Gravel	A-6
6A	30	13	20	17	6.8	1.82	Gravel	A-2
7A	30	15	21	15	8.0	1.90	Gravel	A-2
8A	19	6	15	13	3.7	1.97	Cr. Rock	A-2
9A	32	14	21	17	7.4	1.81	Cr. Limest.	A-2
10A	40	24	21	15	11.8	1.86	Gravel	A-6
11A	32	18	18	15	8.5	1.84	Gravel	A-6-2
12A	31	16	20	18	7.0	1.80	Gravel	A-2-6
13A	45	22	26	16	13.1	1.81	Caliche	A-7
14A	36	19	24	17	9.2	1.77	Caliche	A-6-2
15A	39	19	26	19	9.2	1.73	Caliche	A-6-2
16A	47	30	25	16	14.1	1.87	Gravel	A-6
17A	27	12	18	15	6.4	1.88	Gravel	A-2

	Percent Retained on															
	Round Opening in inches					Square Mesh Screen Sieve Numbers						Grain Diam. in mm.				
Sample No.	1½	1	¾	½	¼	10	20	40	60	100	200	0.05	.005	.001	Soil Binder	Sp. Grav.
1A	1	8	14	25	46	60	70	74	76	78	85	87	92	95	26	2.67
2A	7	14	22	40	52	67	77	81	82	83	90	91	94	97	19	2.66
3A	0	9	14	17	25	36	47	54	59	63	69	72	91	97	46	2.61
4A	0	6	11	16	31	46	57	60	62	65	70	73	91	97	40	2.62
5A	0	13	22	36	54	64	68	69	71	75	79	79	89	96	31	2.68
6A	1	11	19	30	44	52	56	59	61	62	65	67	90	97	41	2.67
7A	3	11	18	30	47	59	65	71	77	81	85	87	89	98	29	2.69
8A	6	17	25	35	49	60	67	73	78	82	86	87	94	99	27	2.68
9A	0	8	15	25	39	56	67	75	79	83	87	89	96	99	25	2.68
10A	0	0	3	5	11	29	52	64	68	71	74	78	88	96	36	2.61
11A	0	3	10	25	46	58	64	74	81	85	88	89	95	98	26	2.62
12A	0	2	10	19	28	33	35	48	57	69	77	81	88	91	52	2.66
13A	0	0	0	3	6	9	11	12	19	37	58	65	78	92	88	2.65
14A	9	14	17	21	29	37	42	43	49	59	74	78	87	96	55	2.67
15A	6	8	11	15	26	37	43	46	50	57	71	74	89	98	54	2.65
16A	3	21	28	32	39	51	71	79	84	87	89	91	94	98	21	2.72
17A	0	0	6	9	17	28	48	66	76	82	86	88	95	98	34	2.70

time the sieve is agitated up and down. If the material retained on the 40-mesh sieve contains lumps that have not slacked or disintegrated, but which can be crumpled or mashed between the thumb and finger so as to pass through the 40-mesh sieve, such lumps shall be broken and washed through the sieve to the binder pan. The reason for slacking or breaking all such lumps is that it is assumed that any such soft material in lumps will be broken down to binder size particles during the process of construction. When all the soil binder appears to have passed through the sieve, the sieve then is held above the soil and water in the pan and the material retained on the sieve is washed by pouring a small amount of clean water over it and letting the water run into the pan.

9. The material retained on the sieve is poured into another clean pan and another batch of the material with slacked binder placed on the 40-mesh sieve and washed as before. After the total sample has been washed, the pan containing all the soil binder

in the water is set aside and not disturbed for several hours, until all the soil binder has settled to the bottom of the pan and the water above the soil binder has become clear. All the clear water that is possible is then decanted or siphoned off the soil binder.

10. Dry the material retained on the 40-mesh sieve and dry-screen over the 40-mesh sieve, being careful to crumble or mash between the thumb and finger any soft material contained so that it will be included in the soil binder portion. It is necessary to dry-screen the washed retained material, even though it may not contain soft lumps, because there will be coarse-grained particles go through the 40-mesh screen which did not pass when covered with a film of water.

11. Combine all dry material passing the 40-mesh sieve and weigh.

12. Weigh the material retained on the 40-mesh sieve and record as "Wt. Retained on No. 40 Sieve."

TABLE 5

Sample No.	L. L.	P. I.	F. M. E.	S. L.	Vol. Change	S. R.	Base Type	Class
1-B	38	20	29	20	8.5	1.70	Shell	A-2-6(2)
2-B	33	15	29	21	13.0	1.67	Shell	A-2-6(1)
3-B	36	11	30	26	6.6	1.57	Caliche	A-6(2)
4-B	46	18	41	28	20.5	1.52	Caliche	A-2-7(2)
5-B	34	18	31	15	29.0	1.87	Gravel	A-2-6(1)
6-B	27	10	24	18	10.4	1.79	Gravel	A-2-4(0)
7-B	29	13	26	15	20.0	1.89	Gravel	A-2-6(1)
8-B	17	4	15	15	1.5	1.93	Cr. Rock	A-2-(0)
9-B	28	10	24	18	12.4	1.80	Cr. Limest.	A-2-4(0)
10-B	36	18	31	15	30.3	1.87	Gravel	A-2-6(2)
11-B	27	13	25	16	16.4	1.84	Gravel	A-2-6(1)
12-B	28	12	28	17	20.3	1.83	Gravel	A-2-6(1)
13-B	37	17	33	17	28.1	1.79	Caliche	A-6(5)
14-B	33	16	29	19	18.6	1.74	Caliche	A-2-6(2)
15-B	37	16	34	20	24.6	1.72	Caliche	A-6(4)
16-B	38	20	31	15	30.2	1.89	Gravel	A-2-6(1)
17-B	24	10	20	16	8.1	1.89	Gravel	A-2-4(0)

Percent Retained on

Sample No.	Square Opening in inches					Square Mesh Screen Sieve Numbers						Grain Diam. in mm.			Soil Binder	Sp. Grav.
	1½	1	¾	½	# 4	10	20	40	60	100	200	.05	.005	.001		
1-B	0	4	7	14	39	56	-	71	-	-	82	85	93	98	29	-
2-B	0	5	8	15	41	59	-	74	-	-	85	88	95	99	26	-
3-B	0	4	5	9	20	29	-	44	-	-	58	59	90	99	56	-
4-B	0	0	4	9	26	37	-	54	-	-	69	69	89	96	46	-
5-B	0	9	14	28	57	66	-	71	-	-	80	82	91	97	29	-
6-B	2	9	14	25	45	53	-	59	-	-	65	66	88	98	41	-
7-B	0	7	14	26	49	58	-	69	-	-	84	85	93	99	31	-
8-B	6	13	18	32	52	62	-	78	-	-	84	87	95	99	22	-
9-B	0	8	17	28	46	58	-	70	-	-	83	87	96	99	30	-
10-B	0	0	3	5	13	28	-	54	-	-	76	76	89	99	46	-
11-B	0	3	5	15	40	48	-	65	-	-	85	88	95	99	35	-
12-B	0	7	10	21	34	38	-	48	-	-	79	82	92	95	52	-
13-B	0	0	1	3	7	9	-	18	-	-	55	61	81	94	82	-
14-B	6	10	15	19	26	30	-	34	-	-	66	71	87	98	66	-
15-B	0	0	8	14	32	41	-	44	-	-	60	69	90	99	56	-
16-B	0	3	25	33	42	53	-	74	-	-	86	89	96	98	26	-
17-B	0	0	6	16	32	48	-	70	-	-	87	89	97	99	30	-

TABLE 6

Sample No.	L. L.	P. I.	F. M. E.	S. L.	L. S.	S. R.	Base Type	Class
1-C	30	12	22	15	-	1.76	Shell	A-2
2-C	29	11	22	17	-	1.71	Shell	A-2
3-C	31	6	27	19	-	1.63	Caliche	A-2
4-C	41	14	30	23	-	1.54	Caliche	A-2-7
5-C	30	12	21	11	-	1.91	Gravel	A-2
6-C	25	8	18	15	-	1.80	Gravel	A-2
7-C	25	8	19	12	-	1.89	Gravel	A-2
8-C	15	3	13	10	-	1.94	Cr. Rock	A-2
9-C	25	9	17	16	-	1.81	Cr. Limest.	A-2
10-C	32	15	19	12	-	1.83	Gravel	A-2
11-C	20	8	13	13	-	1.84	Gravel	A-2
12-C	22	9	14	14	-	1.82	Gravel	A-2
13-C	34	17	19	14	-	1.81	Caliche	A-2-4
14-C	28	12	18	15	-	1.76	Caliche	A-2
15-C	33	15	20	17	-	1.71	Caliche	A-2
16-C	33	17	19	13	-	1.90	Gravel	A-2-4
17-C	19	6	15	13	-	1.89	Gravel	A-2

Percent Retained on

Sample No.	Square Opening in inches					Square Mesh Screen Sieve Numbers						Grain Diam. in mm.			Soil Binder	Sp. Grav.
	1½	1	¾	½	# 4	10	20	40	60	100	200	.05	.005	.001		
1-C	4	12	-	32	56	67	-	80	-	85	88	90	94	100	20	2.67
2-C	3	12	-	34	56	67	-	79	-	85	89	91	94	99	21	2.66
3-C	2	5	-	13	24	32	-	47	-	60	68	73	92	100	53	2.61
4-C	1	4	-	18	40	52	-	59	-	66	71	74	92	100	41	2.62
5-C	2	16	-	44	76	86	-	88	-	90	92	93	98	100	12	2.68
6-C	3	16	-	40	62	68	-	72	-	74	77	80	93	100	28	2.67
7-C	2	10	-	32	59	69	-	78	-	86	90	91	96	100	22	2.69
8-C	4	16	-	38	58	65	-	76	-	84	88	90	96	99	24	2.68
9-C	2	12	-	31	51	61	-	78	-	86	89	91	97	99	22	2.68
10-C	0	2	-	8	22	38	-	64	-	74	78	80	89	100	36	2.61
11-C	1	4	-	24	58	66	-	79	-	88	92	94	98	99	21	2.62
12-C	0	4	-	22	38	42	-	54	-	75	84	87	92	97	46	2.66
13-C	3	5	-	8	17	30	-	36	-	58	71	77	90	97	64	2.65
14-C	4	15	-	29	42	47	-	52	-	72	82	84	94	98	48	2.67
15-C	2	6	-	20	46	53	-	57	-	68	78	82	95	98	43	2.65
16-C	0	13	-	30	42	50	-	74	-	86	90	92	96	99	26	2.72
17-C	0	2	-	10	21	31	-	64	-	82	89	92	96	100	36	2.70

13. Add the weights obtained in steps 11 and 12 for the "Wt. of Total Sample." This weight is used in the calculations, but should check reasonably close to the original weight (step 8) so as to be sure that all the sample is obtained.

$$\text{Calculate, \% Soil Binder} = \frac{\text{Wt. Passing No. 40 Sieve}}{\text{Wt. of Total Sample}} \times 100$$

14. The material retained on the 40-mesh sieve is preserved for screen analysis, specific gravity, or any other test required.

PREPARATION OF SOIL BINDER

15. The soil binder portion will contain numerous lumps of soil particles, but none of the soil particles are larger than 40 mesh. Place the 40-mesh sieve on the 8½ inch

milk pan, and dry-screen out all of the material that will easily pass the screen.

16. If a pulverizer is available, the material retained (step 15) can be passed through the pulverizer with the jaw opening set slightly wider than 40-mesh in size.

If the pulverizer is not available, a portion of the material retained (step 15) shall be placed in the mortar and ground with the stone pestle until a majority of the lumps appears to be smaller than 40-mesh in size. This material is then placed on the 40-mesh sieve and the portion that will pass the sieve added to the portion passing from step number 15. Another portion of the retained material from step number 15 is placed in the mortar and the above operation repeated.

17. When the retained portion has been reduced down to approximately 100 or 150 grams, it is placed in the mortar and ground with the rubber covered pestle. This is to prevent the breaking up of any particles which might be larger than 40-mesh in size, and to separate the soil binder from these particles.

18. After all of the soil binder has been "prepared" to pass the 40-mesh sieve, it should be combined and stirred thoroughly to produce a uniform homogeneous mixture of all particles. This mixing can be expedited by screening the soil binder through a larger screen such as the ¼ inch screen.

DISCUSSION OF THE LABORATORY TEST RESULTS

The soil constants and the complete mechanical analysis including the hydrometer analysis of the seventeen "A" Base Course samples tested in the Texas Laboratory at Austin, Texas by the WET method of preparation for test are outlined in Table 4. Within the limits of the human equation all of the seventeen "A" samples were prepared for test strictly in accordance with specifications AASHO T-146-49 which is similar to T.H.D. No. 53.

The soil constants and the complete mechanical analysis including the hydrometer analysis of the seventeen "B" Base Course samples tested in the Oklahoma Laboratory at Oklahoma City, Okla. by the DRY method of preparation for test are outlined in Table 5. Within the limits of the human equation all of the seventeen "B" samples were prepared for test strictly in accordance with specifications AASHO Designation T-87-49.

The soil constants and the complete mechanical analysis including the hydrometer analysis of the seventeen "C" Base Course samples tested in the Louisiana Laboratory at Baton Rouge, La. by the DRY method of preparation for test are outlined in Table 6. Within the limits of the human equation all of the seventeen "C" samples were prepared for test strictly in accordance with specifications AASHO Designation T-87-49.

The variations that were obtained in the Liquid Limit of the seventeen base course samples between Laboratory A(Texas), WET method, and Laboratory B (Oklahoma), DRY method, and Laboratory C (Louisiana,) DRY method, are illustrated graphically in Figure 4.

The variations that were obtained in the Plasticity Index of the seventeen Base Course samples between Laboratory A (Texas) WET method, and Laboratory B (Oklahoma) DRY method, and Laboratory C (Louisiana) DRY method, are illustrated graphically in Figure 5.

The main, as well as the initial objective of this research study was to obtain the maximum possible difference in the soil constants. Inspection of Figures 4 and 5 indicate that the maximum difference in the Liquid Limit and the Plasticity Index test exists in all seventeen samples between the results of Laboratory A (Texas) WET method, and Laboratory C (Louisiana) DRY method. The results of Laboratory B (Oklahoma) DRY method are in all instances intermediate between these two. To show this maximum variation more clearly Figures 6 and 7 were introduced into this report.

The maximum variations in the Liquid Limit Test of the seventeen base course samples between the WET method of base course sample preparation of the Texas Laboratory (17-A samples), and the DRY method of base course sample preparation of the Louisiana Laboratory (17-C samples) are graphically outlined in Figure 6.

The maximum variations in the Plasticity Index Test of the 17 base course samples between the WET method of base course sample preparation of the Texas Laboratory (17-A samples) and the DRY method of base course sample preparation of the Louisiana

Louisiana Laboratory (17-C samples) are graphically outlined on Figure 7.

Table 2 summarizes mechanical analysis, including the hydrometer analysis of the percent passing the number 10, 40, 200 sieves and the 0.05, 0.005, and 0.001 mm of Laboratory A, WET method, and laboratory B, DRY method, and Laboratory C, DRY method of each of the seventeen samples.

Table 3 outlines numerically the maximum difference in each of the seventeen samples of the Liquid Limit and the Plasticity Index between the WET and the DRY method of sample preparation. This numerical maximum was obtained by subtracting the Liquid Limits and the Plasticity Indexes of Laboratory C from those of Laboratory A.

A minimum numerical difference in the Liquid Limits and Plasticity Indexes of the seventeen base course samples is also outlined in Column 2 and Column 4 of Table 3. This minimum difference was obtained by subtracting the Liquid Limits and the Plasticity Indexes of Laboratory B from Laboratory A. It will be seen from this numerical summary in Table 3 that the maximum difference in the Liquid Limit varies from 4 to 14; the maximum difference in the Plasticity Index varies from 3 to 14. Also the minimum difference in the Liquid Limit varies from 1 to 8; and the minimum difference in the Plasticity Index varies from 2 to 10.

Table 3 also outlines the ratio of the Minus 200 mesh sieve to the minus 40 sieve of each of the seventeen samples for all three laboratories namely Laboratory A, Laboratory B, and Laboratory C.

CONCLUSIONS

Wide differences are obtained in the disturbed soil constants of base course material samples prepared for test by the WET method (AASHO Designation T-146-49 or T.H.D. No. 53) over the DRY method (AASHO Designation T-87-49.) At this time the exact reason for this is obscure. It may possibly be due to the more active quality of the increased percentage of very fine intimate surface colloidal material that is obtained by the WET Method of sample preparation.

This research study also discloses that minor variations may arise in the soil constants of base course materials prepared for test by two different soil laboratories under the DRY Method specifications (AASHO Designation T-87-49). The exact reason for this at this time is also obscure. It may possibly be due to the variation in the intensity of effort and the difference in length of time that a sample is pounded in the pestle between operators in the two laboratories.

Rubber-Balloon Apparatus for Measuring Densities of Soils in Place

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Determinations of in-place densities of soils are commonly accomplished in engineering practice by augering or digging a hole, weighing and determining the moisture content of the soil from the hole, and measuring the volume of the hole. The volume may be measured by the oil method, by the sand-cone method, or by using a rubber-balloon apparatus. The rubber-balloon method has been demonstrated to be accurate and is now widely accepted.

Various kinds of commercially available apparatus have been designed especially for measurements of densities of subgrades, bases, and compacted earth fills. These are limited to use on fairly level surfaces. Work in Iowa on natural soils showed a need for an apparatus which could be used either on level, sloping, or vertical faces. With such an apparatus, measurements could be made in roadcuts, in quarry faces, in borrow pits, in basement excavations, and in other like places deep in the soil section. Additional requirements for the design of the apparatus were that it be rugged enough to withstand rough field usage and light and compact enough for use by a man suspended from a rope over a roadcut or quarry wall. A new rubber-balloon apparatus was developed to meet these requirements. As a result of 2 years of use of the new apparatus in the United States and Alaska, various modifications and improvements have been made.

The paper describes the apparatus and presents representative test data.

● DURING the past several years, soils investigations by the Iowa Engineering Experiment Station have included in-place density measurements at a large number of locations in and out of the state. It was often desired to extend these measurements to depths of tens of feet in the soil materials and quarries and roadcuts became almost a necessary convenience. However, the common existing disturbed methods of density measurement, the oil, the sand-cone, and the rubber balloon methods (1, 2, 3, 4), are all adapted to measurements on a level surface. On a vertical face or a steeply sloping face, this required an undesirable amount of hand excavation; therefore a new apparatus was designed. The desirable features in the new apparatus were that it be equally adapted for use on level, sloping, or vertical faces and that it be light and handy enough to be operated by one person hanging on a rope swing.

A modified rubber-balloon apparatus was designed and constructed to meet these requirements. During the trial and development period of two years, many modifications have been made, and some rather unique features have been incorporated. The apparatus has been used and tried in various soils in the United States and Alaska. It is now used by the experiment station for all field density tests, including those on level surfaces.

DESCRIPTION

Figure 1 shows the Iowa balloon apparatus in use. The apparatus consists essentially of a folding template and a small balloon holder, the holder being connected by a ⅜-inch plastic hose to a 3-foot cylinder graduated in 0.001 cubic foot increments. The testing operation is as follows:

A smooth face is cut on the soil. The sample bag is put in place on the template and the template is pushed against the smoothed face, where it is held by pins projecting from the back of the template into the soil. With the hole in the template as a guide, a hole 4 inches in diameter and 4 to 6 inches deep is cut in the soil. On steep faces, all soil falls in the sample bag, and the bag can be removed and weighed immediately. On level or near level surfaces, the excavated soil is pushed away from the hole in the template; the balloon holder is fitted into this hole, and the volume of the excavation is measured.

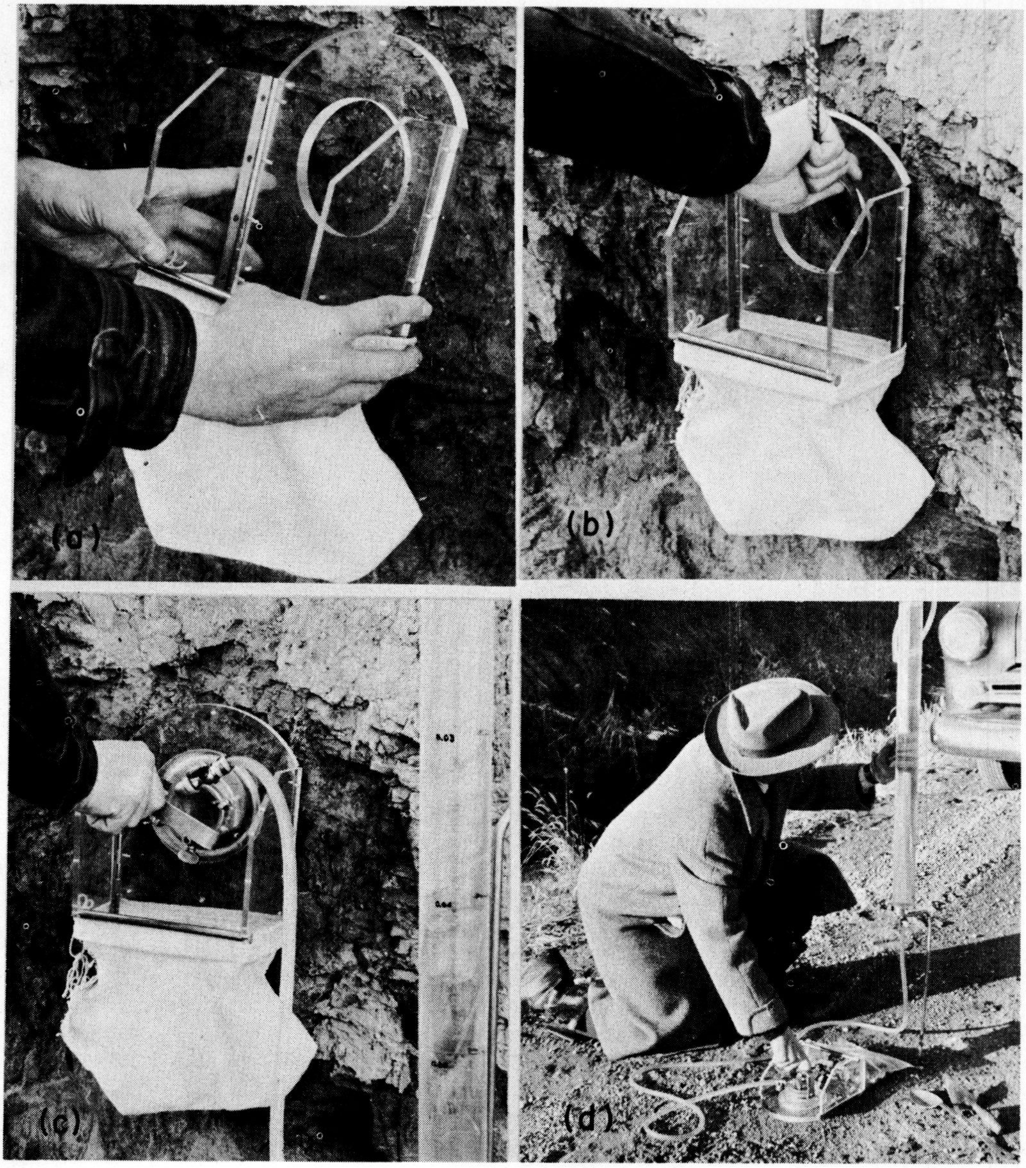


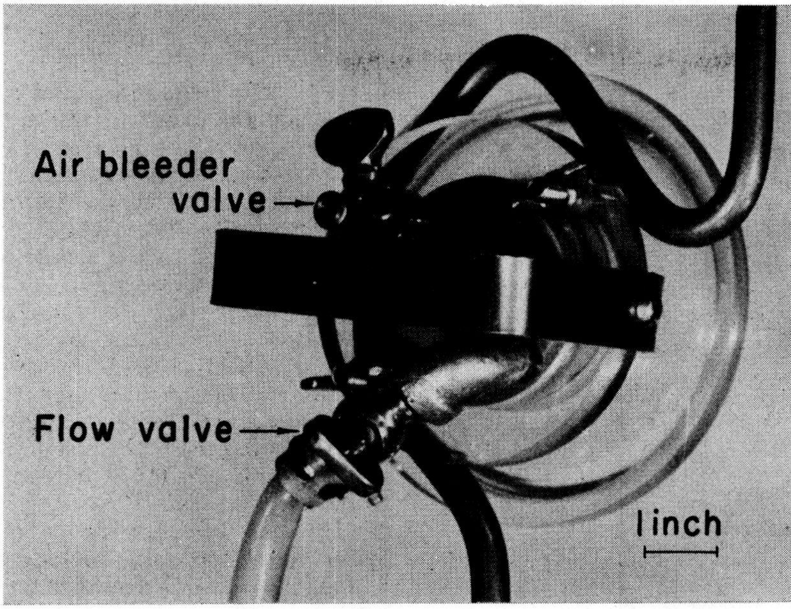
Figure 1. The Iowa field density apparatus in use. (a) The assembled template and sample bag are applied to a prepared flat surface. Pins hold the template in place (b) A hole is excavated through the template, and the soil falls into the sample bag.(c) The balloon holder fits into the template. It is held there while water pressure is applied from the calibrated cylinder (right). Volume readings are made from the water level in the cylinder. (d) Density measurements may also be made on a level surface. Here a plastic sample bag is used; the bag may be sealed for weight and moisture determinations in the laboratory.

One of the flow valves is turned off, the balloon is removed from the hole, and the sample bag is then removed and weighed. A moisture determination sample is taken from soil in the sample bag. Zero measurements are required for volume, the weight of the moisture can, and the weight of the sample bag. (A detailed procedure is given in Appendix A.)

UNIQUE FEATURES AND ADVANTAGES

Other features incorporated into the apparatus and believed to be advantageous are:

1. The graduated cylinder, balloon holder and template are all constructed of plexiglass—easy to see through but hard to break. Breaks can be repaired with common



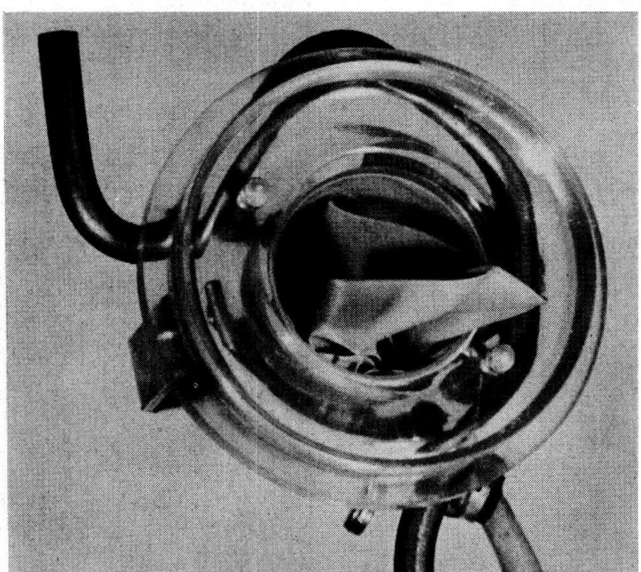


Figure 2. The balloon holder clipped into the steel cylinder support for carrying. In the lower photograph may be seen the concave rounded bottom of the balloon holder designed to minimize balloon breakage. The balloon is drawn inside of the holder as for a rapid zero reading.

household cements, most of which have a solvent effect on the plastic.

2. The balloon holder is concave and rounded on the bottom, minimizing balloon breakage (see Figure 2).

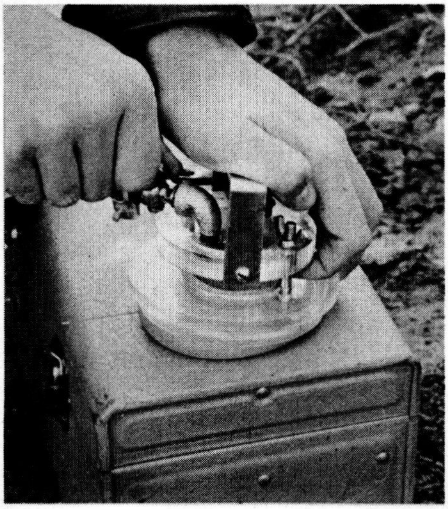


Figure 3. (a) For a rapid zero check, pressure is applied to draw the balloon up into the holder. A flow valve is turned, and the graduated cylinder is held vertically while the water level is read. (b) Normal method for making a zero reading. The rapid zero reading is calibrated to this reading.

3. Water flow is obtained by changing the head, so pumps or suction devices are unnecessary. For example, after running a test a flow valve is turned off, and the water is returned from the balloon to the cylinder by removing the balloon from the hole and holding it higher than the cylinder. The flow valves are opened, and the water flows back into the graduated cylinder.

4. A rapid check of the zero reading to determine effects of temperature changes during the day can be made by raising the balloon holder so that the water drains into the cylinder (see Figure 3a). The balloon is thus drawn up tightly inside of the balloon holder, giving a base point for a zero reading (see Figure 2). This reading must be calibrated to the normal zero reading obtained by inflating the balloon with the holder against a flat surface (see Figure 3b).

5. To secure complete inflation of the balloon inside the hole, pressure is applied by locating the cylinder above the balloon holder. If necessary, additional pressure can be applied by blowing into a hose connected to the top of the cylinder.

6. The apparatus uses ordinary toy balloons with the necks cut off. Balloons are replaced by dismantling the balloon holder with two thumb nuts. The balloon itself forms the gasket.

7. The apparatus clips together into a balanced unit which can be lowered on a rope or carried in one hand (see Figure 4).

Figure 4. Apparatus assembled for carrying. The balloon holder and loose hose fasten onto the graduated cylinder support, and (right) the folding template fits into the sample bag for carrying.

PRECAUTIONS AND DISADVANTAGES

1. Due to leaks or balloon changes, air may get into the balloon holder. To remove the air water is run into the balloon, the holder air valve is opened, and the air is forced out by squeezing the balloon. The valve is then closed.

2. Reasonable care must be taken

during the test to prevent kinks in the hose. If there are no kinks, the plastic hose holds its shape well and does not expand appreciably with the pressures used, and the volume reading is not changed by moving the hose.

3. The sample bag must be shaken out and re-weighed prior to every test.

4. The mouth of the sample bag may stretch so that it does not fit the template tightly. To correct this, the drawstring is drawn shorter and tied.

5. The steel rod holding the graduated cylinder is forced into the ground in order to support the cylinder. (A foot rest is provided.)

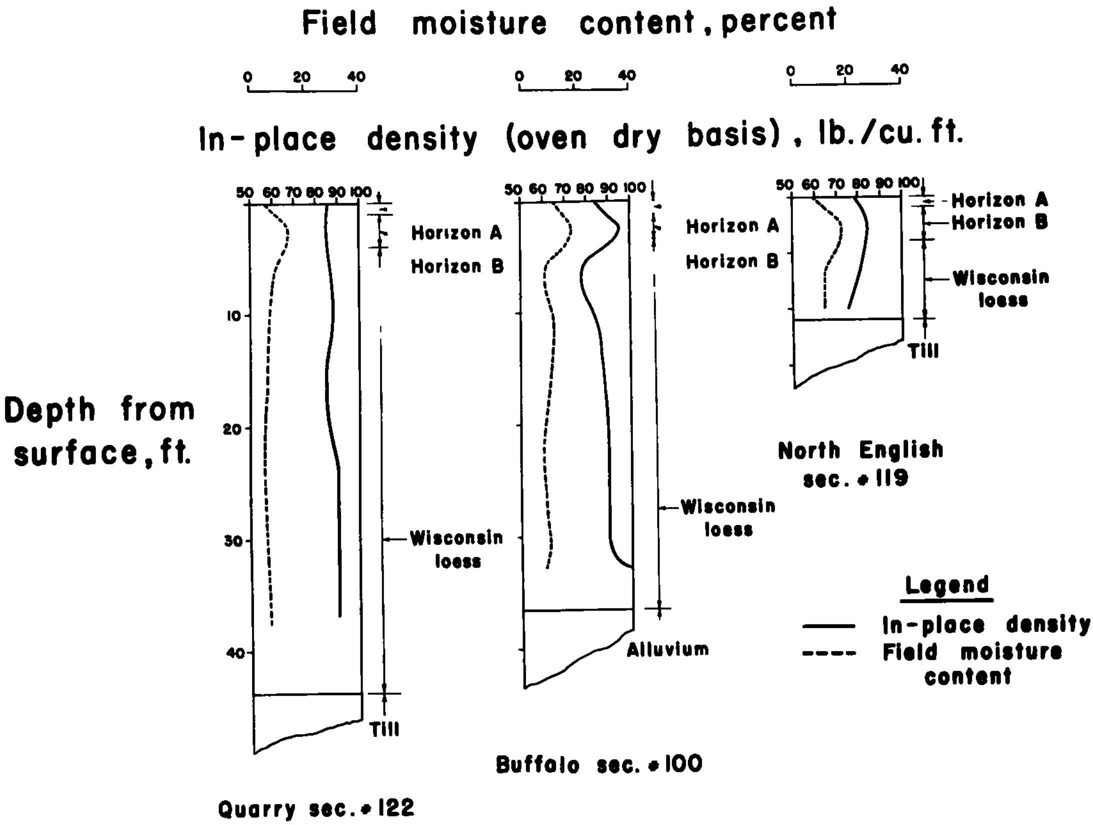


Figure 5. Depth field density relationships obtained with the Iowa apparatus. Measurements were made in roadcuts and quarries.

6. The overall length of the apparatus is about five feet, and care must be used to prevent breakage in transportation.

7. The calibrated cylinder is two inches in internal diameter and has a capacity of 0.06 cubic foot. Therefore the maximum depth for a four inch hole in the soil is about $7\frac{1}{2}$ inches. If desired, a larger cylinder could be used, but this size was found to be satisfactory for most soils, and superior from the standpoint of portability.

Note 1: Tests are now being conducted with disposable polyethylene plastic sample bags. Since the plastic is waterproof, the bags can be sealed and returned to the laboratory for weighing and moisture content determinations. This would eliminate the need for transporting a rather delicate weighing mechanism into the field. The plastic bags will cost about ten cents apiece, and should be reusable several times.

APPLICATIONS OF THE APPARATUS

The new balloon apparatus, in addition to being used for ordinary borrow or compaction operations, may be used to determine densities through deep sections in soils. An example of the data obtained is presented in Figure 5. These data show that the in-place

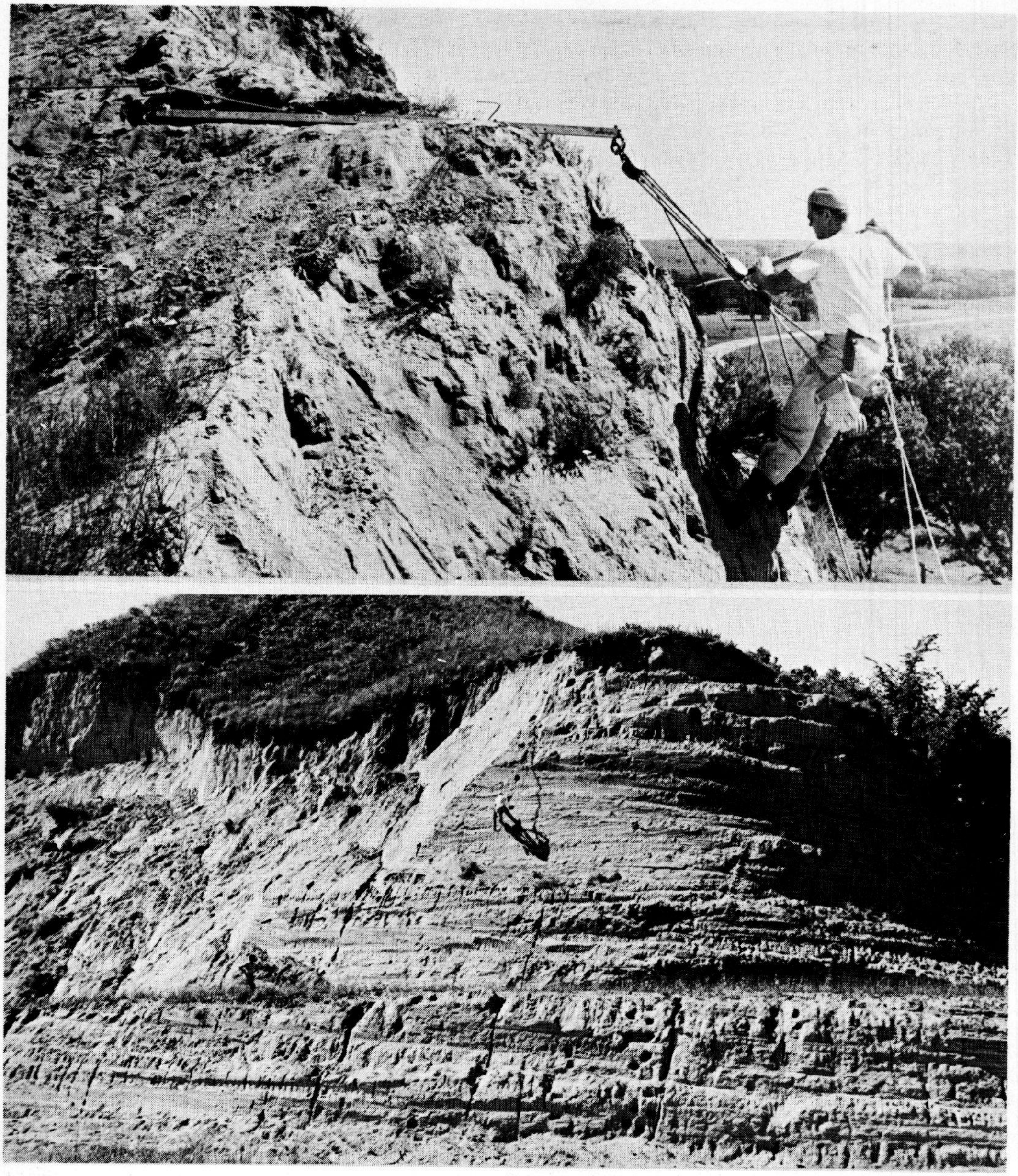


Figure 6. (a) A block-and-tackle apparatus for sampling and testing soils in deep cuts. A corkscrew-type soil anchor is used at the back of the two-piece aluminum beam. (b) Field densities on a deep cut.

density of loess gradually increases with increasing depth, probably due to the weight of the overlying material. Quite often there is also a large increase in loess density near the basal contact, probably due to mixing with the underlying material and to puddling by the water table.

Incidental to the development of the density apparatus, a rope swing was used in sampling and testing high, steep faces. The apparatus, pictured in Figure 6, consists of a board seat suspended by a 3/8-inch or 1/2-inch rope on a 3-to-1 block and tackle with the double block at the top. The top block is suspended from an eye at the end of a 6-foot collapsible aluminum beam. The beam was fabricated from 2-inch angles, and has a bearing plate $1\frac{1}{2}$ feet back from the outer end. The other end is fastened to a cork-screw-type soil anchor. A safety rope is a convenient accessory in case of emergency.

ACKNOWLEDGEMENT

The subject matter of this paper was obtained as part of the research being done under Project 283-S of the Iowa Engineering Experiment Station of Iowa State College. This project, entitled "The Loess and Glacial Till Materials of Iowa; An Investigation of Their Physical and Chemical Properties and Techniques for Processing Them to Increase Their All-Weather Stability for Road Construction", is being carried on under contract with the Iowa State Highway Commission and under the sponsorship of the Iowa Highway Research Board. The project is supported by funds supplied by the commission and the Bureau of Public Roads.

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Appendix A

Suggested Procedure for Use of Iowa Density Apparatus

APPARATUS

1. Iowa density apparatus, including calibrated cylinder, rubber balloon holder, template and sample bag.
2. Digging tools. A heavy kitchen spoon, hunting knife, chisel, prospector's pick, small pointed trowel, and a small flat shovel will be useful.
3. Tin cans with press tops for moisture tests. Four or eight ounce cans are satisfactory.
4. A balance of 3,000 gram capacity, accurate to 0.1 gram in the lower range.
5. A stove or oven for drying samples. The alcohol burning procedure is an alternative method for drying[5].

TESTING

1. Prior to testing, an average zero volume reading is obtained by inflating the balloon with the holder pressed against a flat surface (see Figure 3b). The zero reading will ordinarily change only because of leaks or large temperature changes, but it should be checked occasionally. The check can be made by either repeating the zeroing operation or more conveniently by deflating the balloon so that it is drawn tightly back into the balloon holder. This is done by opening the flow valves and raising the holder four or five feet above the cylinder (see Figure 3a). The zero thus obtained must be corrected by adding to it the volume of the balloon holder. This volume can be determined by following the above procedure at the time of the initial zeroing and comparing the two zero readings.
2. The sample bag is shaken out and weighed prior to each test. To remove loose soil, the sample bag can be turned inside out, shaken and used that way in the next test.
3. The soil is shaved and smoothed off to a flat surface at the site of the test. The

area should be about a foot square and may be inclined. A shallow groove is scraped across the lower part of the area to make room for the seam of the sample bag.

4. The cylinder support is pushed into the ground near the test site to hold the cylinder vertical. The balloon holder is unclipped and set aside ready for use.

5. The folding template is removed from the sample bag and enough pins installed to hold it to the soil. Unless the soil is loose, three of the short pins, two at the top, will usually suffice.

6. The sample bag is placed on the folding template and the template braced open.

7. The assembled template is pushed against the soil face (see Figure 1a); the pins will be pushed into the soil and hold the template there. If the template does not fit solidly, it should be removed and the soil face trimmed. The plexiglass allows one to see irregular contacts.

8. The test hole is dug through the hole in the template, and the excavated soil placed in the sample bag or on the template (see Figure 1b). The hole should be smooth and approximately four to six inches deep.

9. (a) On steep slopes all excavated soil falls into the sample bag, and the bag can be removed and weighed immediately. (b) On level or near level surfaces the bag is left in place the soil is pushed away from the hole in the template, and the balloon holder installed (see Figure 1d). The flow valves are opened; the balloon fills with water and expands into the test hole. The balloon holder must be held down with a hand, knee or foot. Additional water pressure can be applied by either raising the cylinder or blowing in the cylinder air hose. As more pressure is applied, it should be noted if there is any increase in the reading. An increase would indicate that the balloon does not yet completely fill the hole, and the higher pressures are necessary. Caution must be used lest the balloon holder be lifted off the template. A 6-foot water head obtained by raising the cylinder will exert about 2.5 psi. pressure in the balloon, and the balloon holder must then be held down with a force of about 30 pounds.

10. When the balloon is inflated to a maximum inside the hole, one of the flow valves is turned off, and the balloon and holder are lifted from the hole and set aside. The volume can be read and recorded immediately or after the sample sack has been removed and weighed. If the operator is working alone, the latter procedure is advisable to reduce evaporation from the soil sample.

11. The template is lifted and the soil is brushed into the sample bag, which is then removed and weighed. A moisture can is filled with soil from the middle of the sample bag and the weight of the filled can is recorded. The soil in the can is later dried in an oven or by the alcohol burning method and the moisture content calculated.

12. The volume reading is estimated to 0.0001 cubic foot. The flow valves are opened and the balloon held above the cylinder so that the water flows back into the cylinder. The operation can be speeded up by squeezing the balloon.

13. All valves are closed and the apparatus either folded up or made ready for another test. Calculations of moisture content and dry density are illustrated in Appendix B.

SPECIAL PROCEDURES

14. Removing air from the system. This is seldom necessary unless there are leaks. The flow valves are opened and some water is allowed to run into the balloon. A flow valve is shut, the air valve on the balloon holder is opened, and the air is forced out by squeezing the balloon. It is necessary to re-zero after this operation.

15. Replacing a broken balloon. As much water as can be saved is run back into the cylinder, and more water added if necessary. Then the flow valves are closed and the balloon holder is disassembled by removing the two wing nuts. A new balloon is installed smoothly over the end of the holder tube and the holder reassembled. Air is removed (procedure 14), and the apparatus re-zeroed.

Ordinary round toy balloons are satisfactory for the test, although large sizes may be preferable. The neck is cut from the balloon at a point where it is somewhat smaller than the tube of the balloon holder.

16. Filling or adding water to the apparatus. If a water tap and small hose are available, water can be introduced at either the cylinder air valve or the balloon holder air valve.

In either case all valves are opened and the apparatus arranged to allow air to escape.

If no hose or water pressure is available, the cylinder can be filled by removing the balloon and pouring water into the upturned balloon holder. The flow valves and the cylinder air valve must be open. The balloon is then replaced (Procedure 15), the air removed, and the apparatus re-zeroed.

Appendix B

SAMPLE DATA AND CALCULATION SHEET

Location:	F1A-1, Fairbanks, Alaska.
Material:	Very dry, buff-colored friable silt.
Compaction:	None.
Depth of Test:	2'7" to 2'11" (vertical roadcut)
Hole:	Final reading 0.0336 cu. ft.
	Zero reading 0.0171 cu. ft.
	Hole Volume 0.0165 cu. ft.

Moisture Content:

Wt. can + moist soil	149.8 gm.	Wt. can + dry soil	144.3 gm.
Wt. can + dry soil	144.3 gm.	Wt. can	30.0 gm.
Wt. moisture	5.5 gm.	Wt. dry soil	114.3 gm.

$$\text{Moisture Content} = \frac{5.5}{114.3}(100) = 4.8\%$$

Density:

Wt. sack + moist soil	729.5 gm.
Wt. sack	40.6 gm.
Wt. moist soil	688.9 gm.

$$\text{Wt. dry soil} = \frac{688.9}{100 + 4.8}(100) = 657 \text{ gm.} = 1.45 \text{ lb.}$$

$$\text{Dry density} = \frac{1.45 \text{ lb.}}{0.0165 \text{ cu. ft.}} = 87.9 \text{ pct.}$$

Discussion

M.D. MORRIS, Eastern Representative, Soiltest, Inc.—Early in the abstract and later in the text, the authors state that . . . "the rubber balloon method has been demonstrated to be accurate . . .", it would be interesting to see some comparative results of a series of tests run simultaneously with this method, and say, with the sand cone method.

It would be of further interest to see some notes on comparative times per test on the series suggested above.

Although it incorporates the disadvantage of being opaque, the template, flaps and bag holder might be made of aluminum to reduce the weight and breakage factors. One always does not have the necessary repair cements with him in the field. Also, as the working surface of the template becomes scratched from use it too loses its transparent feature.

For operating in hard surfaces or on roads the spike end stand might be augmented by a sliding tripod stand of the same type used to support portable motion-picture screens.

The top hook might have welded to it a right angle spike to push into sideslopes to stable the apparatus while working suspended down vertical faces.

It is still not entirely clear how the apparatus is "zeroed-in" and how the level is maintained during tests on vertical faces while suspended to various elevations.

Granting that the space between the 0.001 readings will be lessened, it might prove economical, space, mobile and weight wise to use a shorter fluid reservoir of a larger diameter.

It would be of interest to know something of the balloon mortality rate considering rough spots not always removed from inside the hole or burrs on the template edges.

With this apparatus it is always necessary to carry an extra supply of water. Also, in very hot climates it might become necessary to make involved corrections to accommodate for temperature changes.

The observations regarding the expendable plastic bags could very well be most useful in many other phases of taking field samples for laboratory testing as well as density testing.

Neutron and Gamma-Ray Methods for Measuring Moisture Content and Density to Control Field Compaction

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Several publications have described in detail the use of radioactive materials to determine the moisture content and density of soils in place. So far, most of the work has been confined to laboratory studies involving the development of instruments, and some small-scale experiments in the field. The results of these studies indicate that the method may develop into a useful tool for the practicing engineer.

One application of the nuclear method would be for control of compacted fills. The purpose of this investigation is to determine whether or not such an application is practical. It is planned to conduct tests with the nuclear equipment on various soils commonly used for fills and compare the results obtained by the nuclear method with those obtained through the use of the current field tests for moisture content and density. The material presented in this paper represents a small portion of the data it is planned to collect. The results of field tests upon a sandy loam only are given.

A brief description of the principles underlying the nuclear procedure is given to aid the reader in understanding the field procedures which are described in detail.

The effect of placing access tubes into the soil in different ways upon the results obtained by the nuclear method are included in the report, since these results served as the starting point for the development of a field procedure to check moisture content and density in a compacted fill. Four methods of placement were tried. Driving the access tubes yielded results which were the closest to the results obtained by the ordinary method of sampling.

The results of moisture and density tests at a site in Millbrae, California where several thousand yards of sandy loam are being placed each day are tabulated for comparison between the method now in use and the nuclear procedure.

It was found that the results obtained by the use of calibration curves developed on the job compared more favorably with the results obtained by the ordinary method of field sampling than did the results obtained by the use of calibration curves developed in the laboratory. When using calibration curves developed in the field the deviation between the nuclear procedure and the ordinary sampling method was slightly less than one percent water content in terms of dry weight and slightly less than three lb. per cu. ft. dry density. On the other hand the deviation between the two procedures was nearly 1½ percent water content in terms of dry weight and over 5 lb. per cu. ft. dry density when using laboratory calibration curves. A discussion of the personnel, equipment, and time required for each procedure is also included.

Finally, conclusions concerning the placement of access tubes for the nuclear procedure, and the use of the nuclear procedure for the control of compacted fills are set forth and discussed.

● THE determination of moisture content and density of soils by the use of radio-active materials has been adequately described in detail in a number of publications. Most of the work reported heretofore has concerned laboratory development of instruments and some small-scale experiments in the field. This work has indicated that the method has promise and may develop into a useful tool for the engineer wherever a knowledge

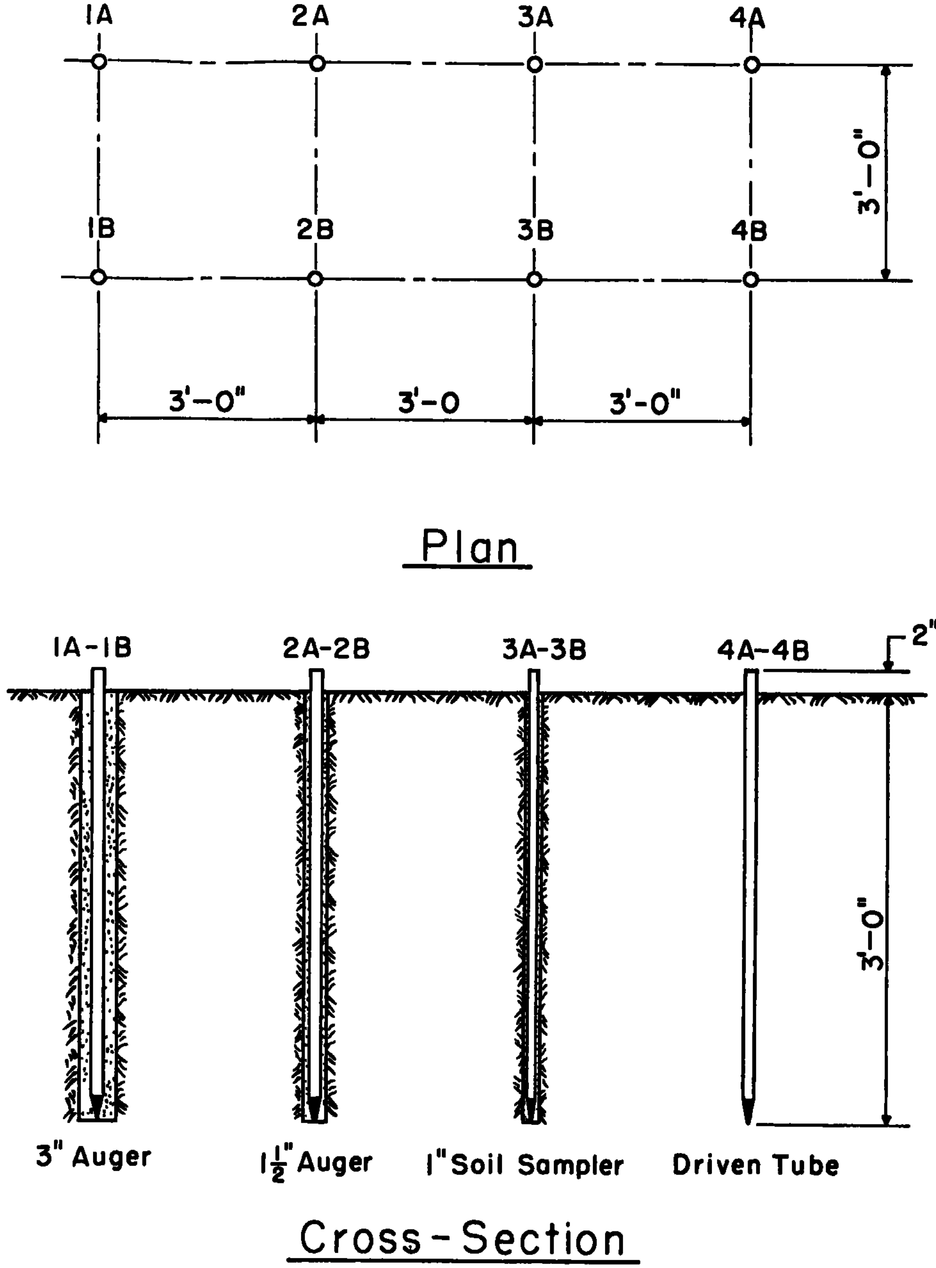

Figure 1. Arrangement and cross-section of access tubes in place.

of changing conditions in moisture content or density of soils is desired.

One application where the nuclear method might be used to advantage is in the control of density and moisture content of earth-fills during construction. The method requires no sampling, is more rapid than the procedures now in use, and requires no more personnel.

The purpose of the work reported here is to determine whether the nuclear method can be used to control soil compaction during construction. It is planned to conduct tests with the nuclear equipment on a variety of soils and compare the results with the results obtained by the use of current procedures for determining density and moisture content.

The material presented in this paper represents the results of field tests on only one type of soil, namely sandy loam.

In addition to the data on field compaction there are included some data as to how the placing of access tubes affects moisture and density determination by the nuclear procedure.

PHYSICAL BASES OF THE NUCLEAR METHOD

Readers interested in the theory of the nuclear method are referred to previously published work, especially to references 1,2,3,8, herein. A few fundamentals are, however, reviewed here because they bear on the interpretation of the procedures followed in this study and the results obtained.

TABLE 1

PLACEMENT OF ACCESS TUBES--
COMPARISON OF MOISTURE CONTENT
NUCLEAR METHOD VS. OVEN DRYING

Boring No	Difference in Moisture Content-Percent of Dry Weight			
	Maximum	Minimum	Average	Average for Method of Placement
1A	4 73	0.86	2 90	2.09
1B	3 08	0 07	1 29	
2A	1 37	0 03	0 69	1 68
2B	6 64	0 58	2 66	
3A	2.24	0.84	1.51	1.30
3B	2.08	0.27	1.09	
4A	1 48	0.09	0.54	0.57
4B	1 55	0 20	0 60	

Samples for oven-drying obtained with one-inch sampler

Water Content Determination

If a source of "fast" neutrons is placed in a soil, neutrons will scatter in a random manner from the source through the soil. These neutrons are particles of matter having a mass approximately equal to that of a hydrogen atom, high kinetic energy, and no change. As they move through the soil, they collide with atoms in the soil and rebound as objects do in an elastic collision. The neutrons lose some of their energy in these collisions. Since the hydrogen atom is the one atom in most soils with a mass nearly equal to that of the neutron, the neutrons which are scattered will lose more energy in collisions with hydrogen atoms (atomic wt. 1.008) than they will in collision with other atoms commonly found in soils (oxygen, atomic wt. 16,000). Some of the neutrons will return to the vicinity of the source after many collisions at a much lower energy level. If a counter capable of recording these "slow" neutrons is in close proximity the source of radiation, a count may be obtained which will reflect the quantity of hydrogen atoms in the soil. Fortunately, the principal source of hydrogen atoms in a soil is water, and therefore, such a count may be used to indicate the amount of water in the soil surrounding the source of "fast" neutrons.

Density Determination

If a source of gamma radiation is placed in a soil, gamma rays will be emitted from the source into the surrounding soil. These rays will be scattered by the electrons in the soil and lose energy in the process. Some of the scattered rays will return to a detector near the source and can be counted. The number of gamma rays counted will depend upon the average length of their path to the detector and their energy when they reach the detector. By properly shielding the gamma ray detector from the source of gamma radiation and placing the detector a specific distance from the source, an experimental curve may be drawn which will reflect the density of most common soils in terms of gamma rays counted during a time interval. For the common types of soil in which the engineer is interested, a low count of gamma rays will indicate high density; and a high count, low density. As the density of a soil increases, the electron density increases proportionally, and causes greater scattering and energy loss of the gamma rays. Thus the chance that gamma rays will be scattered back to the detector with great enough energy to be counted becomes smaller, and so the count rate drops.

TABLE 2

PLACEMENT OF ACCESS TUBES--
COMPARISON OF MOISTURE CONTENT,
NUCLEAR METHOD VS OVEN DRYING

Method of Placement	Percent of Nuclear Measurements Within Indicated Percent of Dry Weight Determined by Oven Drying		
	5	3	1½
1 (A & B)	100	70	40
2 (A & B)	90	80	60
3 (A & B)	100	100	70
4 (A & B)	100	100	90

APPARATUS USED IN STUDY

The principal items of equipment used in this investigation were two probes containing radioactive sources; an electronic instrument capable of recording the pulses from the detectors in the probes caused by radiation; an electric timer; and access tubes. In the field measurements, a gasoline generator provided current which was fed through a voltage regulator and a variable resistance in order to reproduce the 60-cycle, 115-volt current normally available in the laboratory. A continuous check upon the current cycle was obtained by means of a Frahm Frequency Meter.

TABLE 3

COMPARISON OF NUCLEAR MEASUREMENTS OBTAINED BY USE OF CALIBRATION CURVES DEVELOPED IN THE FIELD WITH MEASUREMENTS MADE BY EXTRACTING SAMPLES

	Deviation Between the Two Procedures			
	Water Content		Density	
	lb per cu ft	% of Dry Wt	Wet lb./cu ft.	Dry lb /cu ft
Maximum	2 70	3 20	6 30	7 80
Minimum	0 00	0 00	0 20	0 00
Average	1 08	0 97	3 18	2 80
	41% of measurements were within 0 5 lb	41% of measurements were within 0 5 %	50% of measurements were within 3 0 lb	64% of measurements were within 3.0 lb

Moisture Probe

This probe, which was similar to that used by the Civil Aeronautics, Administration, consisted of a thin-walled brass cylinder with an outside diameter of approximately 1 inch and a length of 7 inches. The neutron source, which in this study was a $Po^{210}Be$ (half-life 140 days), was held in a brass cap fastened to the end of the probe. A short lead plug separated the source from the Geiger-Mueller tube which was enclosed in a thin silver foil 3 mils thick. "Slow" neutrons returning to the probe react with the silver foil to form isotopes of silver. These isotopes decay very rapidly and emit, as one of the products of this decay, gamma rays which are counted by the Geiger tube. Details of this probe are shown in References 6 and 7.

Density Probe

This probe is the same as that used by the Civil Aeronautics Administration. The density probe is about 6 inches longer than the Moisture Probe although it is approximately the same diameter. The source, which was Co^{60} (half-life 5.3 years), is held in an aluminum probe. A much greater amount of lead is needed to shield the Geiger tube detector from gamma radiation directly from the source. This accounts for the greater over-all length of the probe. Details of this probe are shown in References 6 and 7.

Access Tubes

The access tubes were fabricated from aluminum. The inside diameter of the tube was approximately one inch and the wall of the tube was $\frac{1}{32}$ in. thick.

Auxiliary Equipment

The recording unit used with the probes was a Model 2000 manufactured by the Berkley Scientific Company. This unit electronically records counts from 0 to 999 and has a mechanical counter which records from 1,000 to 100,000,000. The unit has a regulated high-voltage supply ranging from 0 to 2,500 volts, read on a scale with 50 volt increments.

A timer was connected to the recording unit so that at the end of a preset time, (200 seconds in this study) the counting was stopped automatically. A photograph of the scaler and timer are shown in Reference 6.

A spherical container of aluminum in which was inserted a lead sphere surrounded by paraffine was used to house the moisture probe during transit to and from the job. The container also served as a standard for checking the equipment in the field.

TABLE 4

COMPARISON OF NUCLEAR MEASUREMENTS OBTAINED BY USE OF CALIBRATION CURVES DEVELOPED IN THE LABORATORY WITH MEASUREMENTS MADE BY EXTRACTING SAMPLES

	Deviation Between the Two Procedures			
	Water Content		Density	
	lb per cu. ft	% of Dry Wt	Wet lb./cu ft	Dry lb /cu. ft.
Maximum	3 50	2 70	13 00	12 70
Minimum	0 00	0 00	0 30	0 20
Average	±1 44	±1 09	± 6 75	± 5 63
	10% of measurements were within 0 5 lb	25% of measurements were within 0 5 %	20% of measurements were within 3 0 lb	28% of measurements were within 3.0 lb

FIELD PROCEDURES USED IN STUDY

Description of Test Sites

Prior to initiating the tests on control of compaction in the field, some exploratory

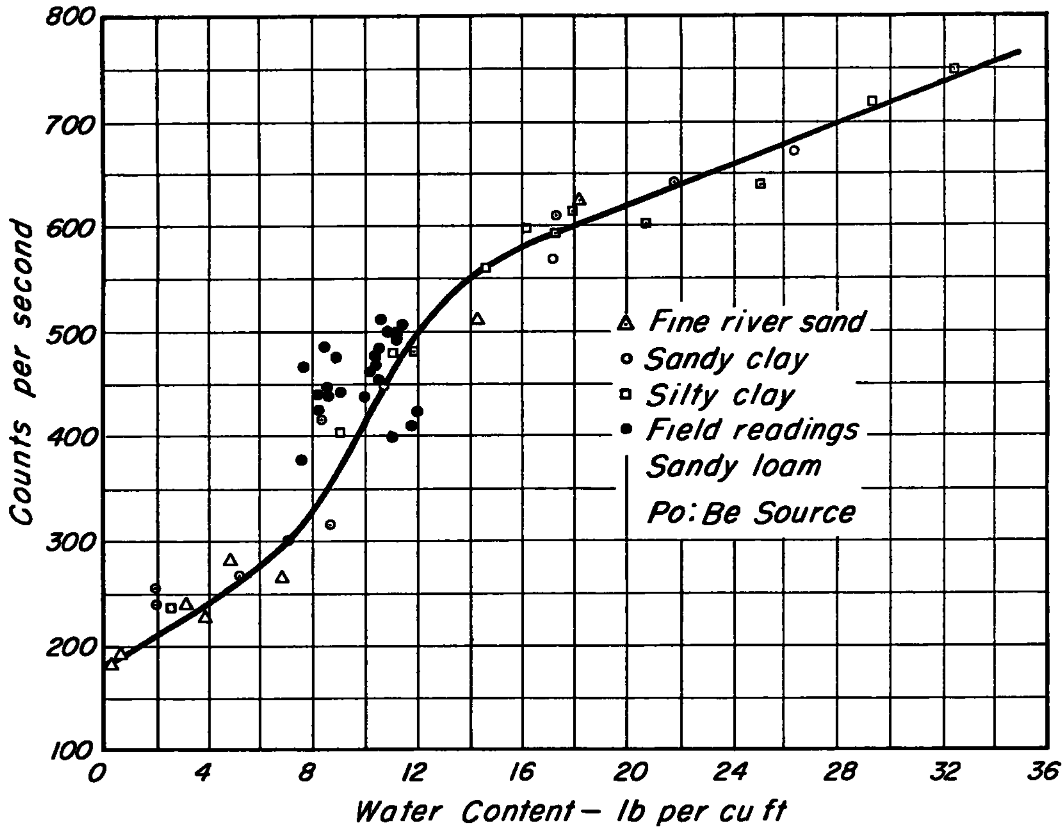

Figure 2. Water content, results of readings in the field superimposed on calibration chart developed in the laboratory.

tests to determine the effect of placement of access tubes on the results obtained by the nuclear procedure were conducted. These tests were carried out at the Engineering Field Station of the University of California in Richmond, California, and in Orinda, California, at the intersection of State Highway 24 and the San Pablo-Moraga Highway. At the Engineering Field Station, the tests were conducted at two different locations, while in Orinda, only one location was utilized. At Richmond, the upper 1½ ft. of soil consisted of loam while the underlying stratum was sandy clay. At Orinda the material consisted of a mixture of sandy clay and black shale.

For the control of field compaction a sandy loam fill being constructed in connection with the development of the Mills Estate near Millbrae, California was utilized.

Placement of Access Tubes.

For the exploratory tests at Richmond and Orinda four methods of placing access tubes were investigated. These methods were as follows: (1) A hole was made with a 3-in. soil auger, the soil removed being placed in a covered pan. When the hole had been drilled to a depth of 3 ft. the soil was returned to the hole, and rodded with the access tube to avoid large voids. The access tube was then driven into the center of the hole. This method of placement is referred to as 1A and 1B in Tables 1 and 2. (2) The same as in Case 1, except that a 1½-in. soil auger was used to bore the hole. This method of placement is referred to as 2A and 2B in Tables 1 and 2. (3) The access tube was driven into a hole made by a 1-in. soil sampler after the soil removed from the hole by the sample had been replaced loosely. This method of placement is referred to as 3A and 3B in Tables 1 and 2. (4) The access tube was driven directly into the ground. This method of placement is referred to as 4A and 4B, in Tables 1 and 2.

A sketch of the access tubes in place is shown in Figure 1. It was felt that this arrangement of access tubes would keep the test holes close enough so that similar conditions of moisture and density could be expected, and yet far enough apart so that the readings at a particular hole would not be influenced by the close proximity of the other access tubes.

In the tests at Millbrae the access tubes were driven directly into the ground, since, as will be seen later in this report, this method proved to give the best results.

Depths at Which Nuclear Measurements Were Made

In the case of the exploratory tests at Orinda and Richmond the access tubes were driven approximately 3 ft. into the soil (see Fig. 1) and readings taken at a depth of 2 ft. from the surface.

In the tests at Millbrae the access tubes were driven 14 in. into the soil and readings taken 12 in. below the surface of the ground. Since the principal objective at the Millbrae site was to control compaction it was desirable to obtain a reading as close to the surface of the soil as possible since the contractor was placing the fill in layers approximately 8 in. thick.

Procurement of Soil Samples for Moisture and Density Determination for Comparison with Nuclear Method

At Orinda and Richmond, soil samples for moisture content determination by oven drying were obtained at a depth of 2 ft. by means of a 1-in. soil sampler. Except for the access tubes which were driven directly into the ground these samples were taken in the identical location as the tubes. In the case of the driven tubes the samples were taken about a foot away. No density determinations by sampling were made at these two sites.

At Millbrae, AASHO Test Procedure T 147-49 utilizing sand was used to determine the density and moisture content of the fill. The test holes were about 6 in. in diameter

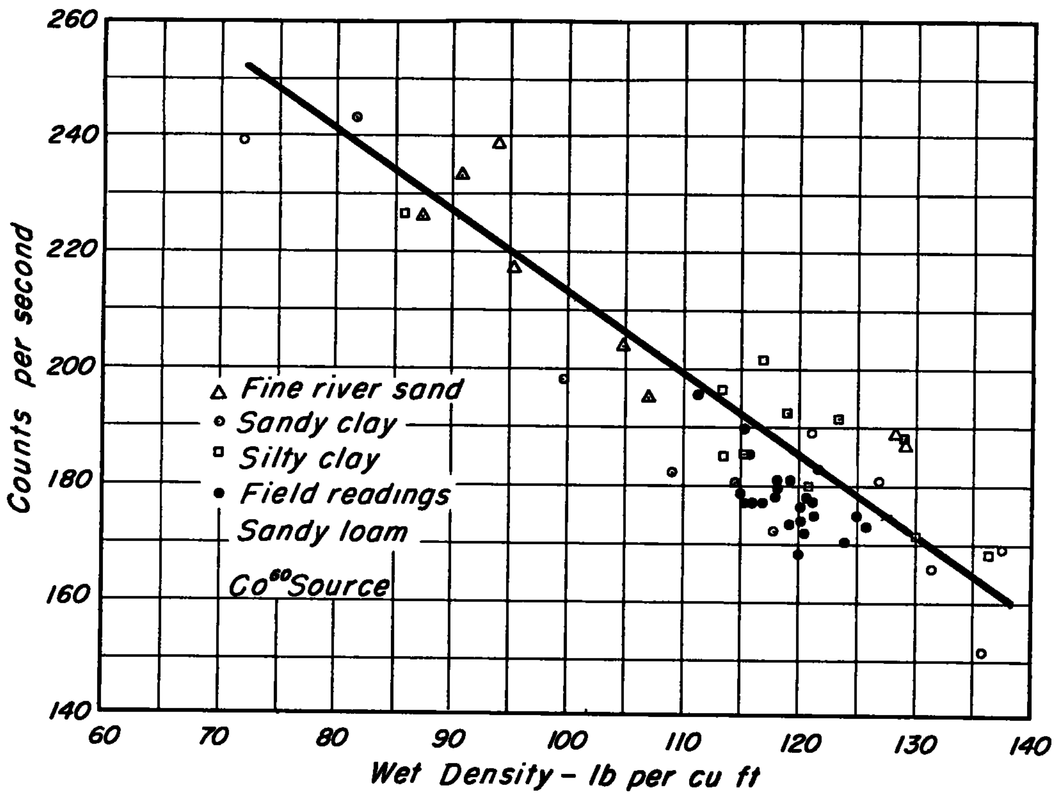

Figure 3. Wet density, results of readings in the field superimposed on calibration chart developed in the laboratory.

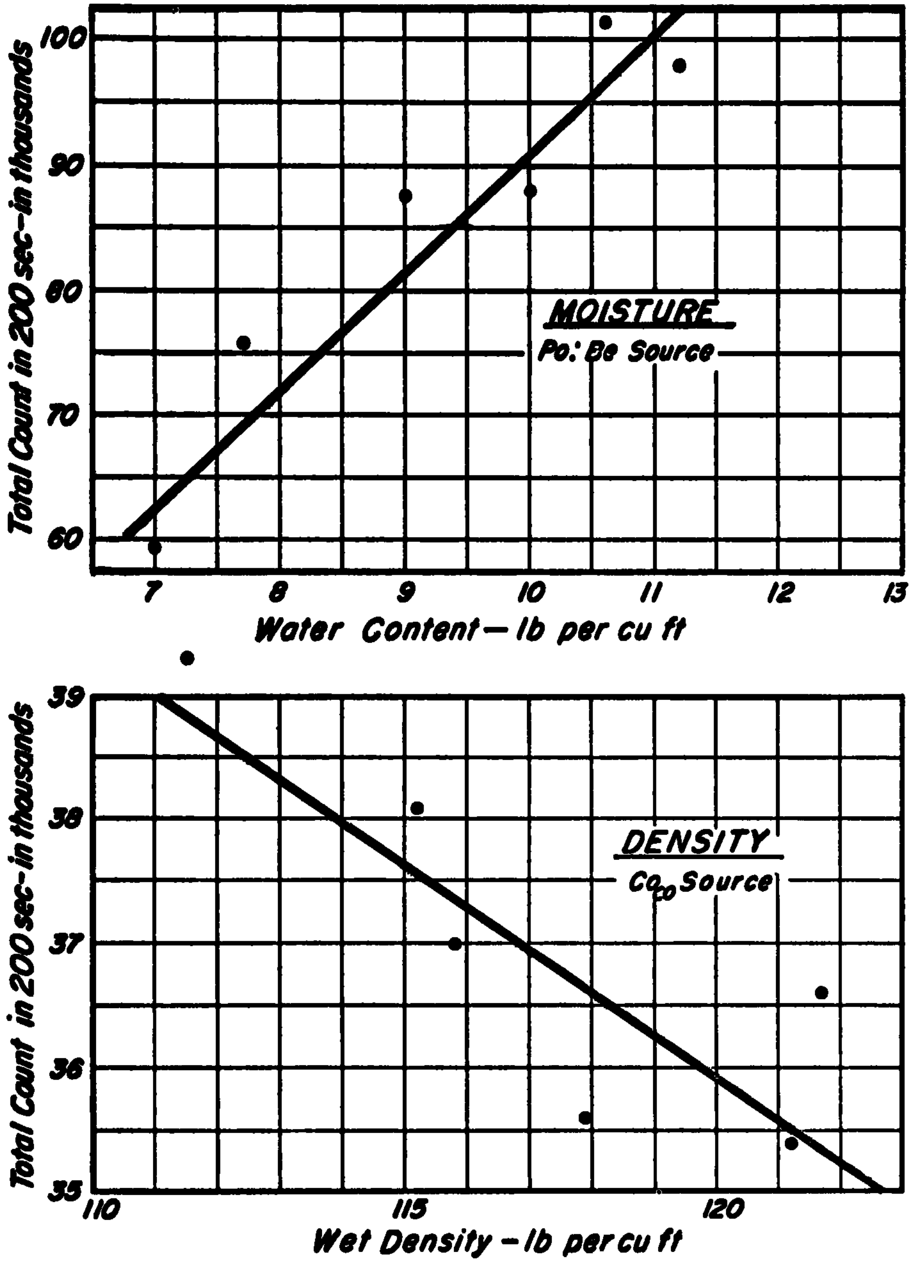

Figure 4. Mills estate, field calibration curves, nuclear procedure.

and the depth likewise was about 6 in. below the prepared surface. The prepared surface was about 2 in. below the surface of the ground. This was done to eliminate the loose material near the surface from being included in the test.

Procedure for Use of Nuclear Apparatus in the Field

Upon arrival at a test location, the gasoline generator was started and the recording apparatus set up near the test holes. A period of about 20 minutes was allowed for the tubes in the scaler to warm up. Then the moisture probe was attached by means of a cable to the recording unit and the probe lowered into the access tubes to the desired depth below the surface of the ground. A period of five minutes was allowed for the moisture probe to come to equilibrium at the level a reading was desired and then the count in a period of 200 seconds was recorded. Generally, two and no more than three counting periods were sufficient to obtain readings within one percent of each other. The average of the counts was used as the final count at a particular access tube, for the determination of water content.

After the moisture determinations were completed, the density probe was attached to the scaler and the probe again placed in the access tubes. A 200-second period was also used for the density determination and the average of two or three consecutive readings within one percent of each other taken as the density count. No time is necessary for the density probe to come to equilibrium and counting can be started at once.

In order to avoid waiting several minutes for the moisture probe to come into equilibrium at each access tube, the following procedure was used. When the moisture content determination at one access tube was completed, the probe was immediately taken to the next access tube and allowed to remain in the tube while the density measurements were being made at the first tube.

Before beginning each day's field tests and at the end of the day, the moisture probe was taken into the laboratory and lowered into an access tube placed in the center of a barrel of water. This access tube was identical with those used in the field tests. The counts obtained in the barrel were used to calculate a correction factor which could be applied to all the readings for moisture content obtained in the field on that day. This factor includes the decay of the source and any changes in the sensitivity of the electronic equipment. Similarly, a correction factor for density readings was determined. These correction factors, in effect, transposed the readings for Moisture Content and Density back to a reference date. It was necessary to do this since the calibration curves on Figures 2 and 3 are also based on the same reference date. The count obtained in the sphere was used to establish a ratio in count between the water and the sphere. In the field, every so often counts were obtained in the sphere to ascertain whether the equipment was in proper working condition. If the counts in the sphere were, at any time, different materially from the initial reading in the laboratory, this would indicate that the equipment was not performing properly.

Determination of Moisture Content and Density by the Nuclear Procedure

For the tests at Richmond and Orinda the moisture content (in pounds per cubic foot of soil) and wet densities (in pounds per cubic foot) were established by the use of calibration charts developed previously in the laboratory (Figures 2 and 3).

For the tests at Millbrae field calibration charts for moisture and density shown on Figure 4 were developed. On the first day of the tests the counts corresponding to the moisture contents and densities determined by the ordinary sampling procedure were plotted against the counts obtained by the nuclear procedure and curves drawn. Thereafter these field calibration charts were used to determine the moisture contents and densities at Millbrae.

ANALYSIS OF RESULTS

Comparison of Water Content Measurements by Various Methods of Placing Access Tubes

The effect of various methods of placing access tubes upon water content determinations by the nuclear procedure can be shown by comparing the nuclear measurements with the water contents found by oven drying soil samples. In Table 1 there are tabulated the differences in water content between the nuclear and oven-drying procedures for each method of placement. The data indicate that driving the access tubes directly into the ground (Boring 4A, 4B) yields the least difference between the two procedures (in terms of percent of dry weight), while the use of a 3-in. soil auger (Boring 1A, 1B) yields the greatest difference. The other two methods fall in between these two extremes. It will also be noted that placing the access tube into the hole made by a 1-in. soil sampler yields results that are slightly closer to oven drying moisture contents than placing the tube in a hole made by a $1\frac{1}{2}$-in. soil auger.

Another way of indicating the effect of access tube placement on nuclear moisture measurements is to indicate for each method of placement the proportion of the nuclear measurements which differ no more than specified amounts (5, 3, 1½ percent) of the water contents determined by sampling. This comparison is shown in Table 2. It will be noted that almost all of the nuclear measurements, regardless of the method of placement differed not more than 5 percent (dry weight) with the measurements made by oven drying soil samples. On the other hand, only 40 percent of the measurements made using the 3-in. auger (1A, 1B) were within 1½ percent water content determined by oven drying, while for the driven tubes (4A, 4B) 90 percent of the measurements were within 1½ percent.

Effect Upon Wet Density of Method of Placing Access Tubes

In the exploratory tests at Richmond and Orinda densities were not measured by sampling, nevertheless a few observations concerning density measurements by the nuclear procedure are worthy of mention. The following was observed: (1) the wet densities in the 3-in. auger hole were lower than for any other method of placement; (2) the wet densities in the 1½-in. auger hole were slightly less on the average than those for the driven tube and for the tube placed in the hole bored by the 1-inch soil sampler; and (3) the wet densities obtained in the access tubes driven directly into the ground were not significantly different from the wet densities in the access tubes placed in holes bored by the 1-inch soil sampler.

Results of Tests on Field Compaction

A total of 26 measurements of moisture and density were made at the Millbrae site. These measurements are tabulated in Table 4A. The nuclear moistures and densities obtained by the use of calibration curves developed in the field (Figure 4) are compared with the measurements made by the sand method (AASHO Test Method T147-49) in Table 3. The data in this table indicate the amount of deviation between the two methods. The average difference for moisture is approximately one percent (in terms of dry weight) and for dry density it is approximately three lb. pcf.

It has been the thinking that calibration charts developed in the laboratory could be used for field measurements provided the same types of radioactive sources and access tubes were used for the field measurements. In Table 4 the nuclear moistures and densities obtained by the use of calibration curves previously developed in the laboratory (Figs. 2 and 3) are compared with the moisture and densities obtained by the ordinary procedure of sampling.

It will be noted that the difference in moisture content between the two procedures is a little greater than in the case where a field calibration chart was used; for density the average differences between the two procedures is considerably greater, indicating that for this particular soil, greater accuracy was obtained by the use of calibration curves developed in the field than in the laboratory. Graphically, these differences are shown by plotting on the laboratory calibration charts (Figs. 2 and 3), for a particular test position, the counts obtained in the field by the nuclear procedure against the corresponding moisture and density obtained by the usual sampling procedure. An examination of Figures 2 and 3 indicates that, for a particular moisture content the count in the field is higher than the count shown by the laboratory calibration chart. This means that in most cases, if the laboratory chart were used for the field readings, the moisture contents determined by the nuclear procedure would be higher than the moisture contents determined by sampling. On the other hand, for a particular wet density the count is lower than shown by the laboratory calibration chart. If the laboratory chart were used for the field readings most of the wet densities determined by the nuclear procedure would be higher than the corresponding densities determined.

Manpower and Time Required for Field Compaction Tests

It was found that on the average 20 minutes were required to make one moisture and one density determination by the nuclear procedure. In an eight-hour work day about 16 moisture and density measurements can be made with the nuclear equipment. A certain amount of time is required for moving from one test position to another, driving access tubes, and checking the performance of the equipment by obtaining counts in the sphere.

With the nuclear equipment the construction work is always under observation of the inspector. With the ordinary procedure of sampling the inspector must do his work in a field laboratory usually located away from the actual construction operations.

Discussion

It is believed that a number of factors entered into the observed differences between the results obtained with the nuclear procedure and those obtained by the ordinary method. One such factor is related to the volumes of soil measured by the two procedures. The nuclear procedure measures moisture content and density in a soil by a process of integration over the volume of a bulb of soil with the radioactive source as the centroid of the bulb. The effective radius of the bulb varies but is generally from 15 to 18 inches and decreases as moisture content and density increase. In contrast to this method, the sampling procedure uses the volume of soil taken from a hole 6 inches in diameter and approximately 6 inches deep. The moisture content determination is made by using a portion of this soil (generally from 100 to 150 grams) as a representative sample.

In the studies conducted by the Civil Aeronautics Administration, the moisture contents and densities were plotted against count-ratios rather than total counts or counts per second. The count-ratio is the ratio of the count in the soil to the count in a so-called standard material such as water (for moisture) and concrete (for density). The advantage of the count-ratio is that any variation in counts due to decay of the source and to performance of scaler and probe are automatically taken care of. On the other hand the count-ratio requires that every time a reading is made in the soil, a reading must also be made in the standard material. This increases the time necessary to make an individual measurement. It has been observed that the counts in the standard materials vary to some extent even in an 8-hour period. It was therefore thought to be pertinent to study the magnitude of these variations in order to ascertain whether there would be a large advantage gained in obtaining counts in the standard each time a measurement in the soil was made.

Readings were made in the field and in the laboratory over periods of several hours to observe the magnitude of these variations. The standard used for this purpose was the sphere filled with paraffine. With the equipment and sources used in this study the count in the standard remained relatively steady (within 1.5 percent) in an 8-hour work day. However, it is advisable to keep the power source and the electronic counter continously in operation in order to minimize the variations in the count in the standards. Therefore, the best procedure to follow would be to take the readings in the standard in the field immediately before starting to work and on several occasions during the working day. The counter and power generator should remain in operation at all times, even during the lunch hour.

The final factor which may have entered into the observed variations between the two methods is the "dead time" of the Geiger tube used in the nuclear apparatus. It is known that in the particular model of tube used in these studies there is a "dead time" of 100 micro-seconds. This means that if two gamma rays arrive at the tube within 100 micro-seconds of each other the tube will only count one of them. This occurrence leads to loss of counts and introduces errors into the results in a random manner. However, for practical purposes, if the count rate is high, the error may be considered negligible in comparison to the other factors which influence the results.

It was found in this study that the results obtained using a calibration curve developed in the field for the particular soil investigated were superior to those obtained using a previously developed laboratory curve. From a practical standpoint, the results obtained using the laboratory curve were not close enough to the results obtained by the ordinary method to allow accurate control of filling operations. Up to now it appears that in using the nuclear method for compaction control it is better to rely on calibration curves developed in the field than on those developed in the laboratory.

A few final observations may be made regarding the field equipment used in this study. Since this investigation was in the nature of a pilot study, no attempt was made to construct equipment which would serve for a long period of time in the field. Laboratory equipment was merely adapted to field conditions. The equipment proved to be cumbersome and unwieldy at times, but stood up remarkably well under the rough conditions encountered in the field. However, it was the concensus of those engaged in this study that in applying the nuclear procedure to the control of a compacted fill over a long period of time, modifications would have to be made in the equipment and its arrangement. The scaler, timer, and voltage stabilizer, as well as the frequency meter should be contained in one unit which is provided with a dust cover. This unit should be mounted on shock absorbers. It would also be desirable to replace the gasoline generator with a vibrator pack similar to that used with the Army Signal Corps ANGRC 9 radio. Such changes in the apparatus would definitely improve the speed and ease, and reduce the cost, of taking nuclear readings under field conditions.

CONCLUSIONS

Placement of Access Tubes

1. In this investigation driving the access tube directly into the ground yielded results which were the closest to the results obtained by sampling.
2. The results obtained by placing the access tubes in a 1-in. diameter hole were very similar to the results obtained by driving the tubes.

Field Compaction

The following conclusions are related only to the soil so far investigated:

1. The nuclear procedure can be used for the control of field compaction provided the depth at which measurements are made is not less than 8 in.
2. Calibration curves developed on the job yielded results in closer agreement with the moisture and density measurements by sampling than did the use of calibration curves developed in the laboratory. This was particularly true for density.
3. The moisture contents by the nuclear procedure were in fairly close agreement with the sampling procedure; the average of all measurements by the two procedures being within one percent (dry weight) of each other.
4. The densities obtained by the nuclear procedure did not compare as favorably with the densities by sampling as did the moisture contents; the average of all measurements by the two procedures (using field calibration charts for the nuclear procedure) being about three lb. apart.

ACKNOWLEDGMENT

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Simplified Methods of Testing Soil-Cement Mixtures

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Ten years ago, standard laboratory testing procedures for soil-cement mixtures were adopted by both ASTM and AASHO, incorporating the best information and experience available. These procedures have proved satisfactory for establishing control factors for soil-cement construction. Thousands of miles of soil-cement paving for roads and streets, as well as for many airports, parking areas, and similar projects, have been constructed on the basis of these control factors. Dependability of the standardized tests is attested to by the outstanding performance of these projects.

Invaluable as they are, the standard tests are time consuming and require considerable effort and material. By applying the information and experience gained from testing hundreds of soils in the ensuing 10 years, the Portland Cement Association has been able to modify and shorten the test methods gradually. Some steps have been eliminated altogether. The basic concept of providing hardened soil-cement strong and durable enough to withstand the stresses resulting from wetting and drying and freezing and thawing has been retained. Use of the shortened test procedure has resulted in considerable savings of time, manpower and materials.

This paper discusses in detail the modifications that have been made. For example, cement contents are expressed in relation to weight of soil, rather than on a volume basis. Only one moisture-density test is made. Total material is used, except that material larger than ¾-in. is replaced by an equal amount of No. 4 to ¾-in. material. A total of only four test specimens, instead of twelve, are required for the wet-dry and freeze-thaw tests. Volume and moisture change specimens are eliminated.

For most sandy soils, test work can be reduced even further. Only a moisture-density test, a silt and clay content determination and 7-day compressive strengths are required. This short-cut procedure utilizes charts based on a correlation of data obtained from previous ASTM-AASHO tests on more than 2,000 soils.

For emergency construction and for small projects where detailed testing is not feasible, or where facilities are not available, a simple procedure involving molding and inspection of specimens to establish safe construction control factors is given.

The value of identifying soils occurring on soil-cement projects by soil series name as identified by the United States Department of Agriculture is stressed as a means of further reducing laboratory testing.

●LABORATORY and field experience during the past 20 years have shown conclusively that soils can be hardened adequately by the addition of relatively small quantities of portland cement to produce a strong, durable material suitable as a low-cost paving. One of the key factors accounting for successful application of soil-cement to the paving field is careful predetermination of engineering control factors in the laboratory and their application throughout construction. Adherence to this principle has accounted for the uniform high quality of thousands of miles of soil-cement pavement.

Although soils are complex chemically, they react in specific ways or patterns when combined with portland cement and water. The manner in which a given soil reacts with various amounts of cement is determined by simple laboratory tests made on mixtures of cement with the soil. The amount of laboratory testing required for a given project depends on the requirements of the constructing agency, the number of soil types encountered, the size of the job, and similar factors.

On major projects, for example, detailed tests generally are required and the minimum cement content that can be used safely is determined for each significant soil type on the job. State highway department and many other laboratories are well equipped to run complete detailed tests. The cost of laboratory tests for major projects is small in comparison with the total cost of the project.

On smaller projects, particularly where testing facilities and manpower are limited,

Figure 1. Soil-cement road after 18 years of service proves the dependability of the test procedures.

it is sometimes considered advantageous to conduct only sufficient laboratory tests to determine a safe, but not necessarily minimum, cement factor which can be used for construction.

For emergency construction and for small projects, where laboratory testing facilities are not available or detailed testing is not feasible or practical, a quick and simple test procedure involving molding and inspection of specimens has been used successfully. It provides a safe cement factor, but one which may be appreciably higher than the minimum for adequate hardness.

In some areas, special test methods and criteria have been developed specifically for local conditions. For the particular soils and climate involved these locally developed test methods also have proved satisfactory.

In all cases the tests are performed to determine three fundamental requirements for quality soil-cement: (1) How much portland cement is needed to harden the soil adequately? (2) How much water should be added? (3) To what density must the soil-cement be compacted?

Detailed test methods for determining these control factors were approved by the American Society for Testing Materials[1] and American Association of State Highway Officials 10 years ago:

"Method of Test for Moisture-Density Relations of Soil-Cement Mixtures", ASTM Designation: D558-44; AASHO Standard T-134-45.

"Method of Wetting-and-Drying Test of Compacted Soil-Cement Mixtures", ASTM Designation; D559-44; AASHO Standard T-135-45.

"Method of Freezing and Thawing Test of Compacted Soil-Cement Mixtures", ASTM Designation: A560-44; AASHO Standard T-136-45.

The outstanding service record of soil-cement paving for roads and streets, as well as for many airports, parking areas, and similar projects which were built using control factors obtained by these test methods prove their dependability. But invaluable as they are, they require considerable time and work in laboratory calculations and manipulations. The Portland Cement Association has modified the procedures on the basis of the information and experience gained from testing hundreds of soils during the

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[1] Reprints available free in the United States and Canada upon request to the Portland Cement Association, or for a nominal charge from headquarters, American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pennsylvania.

past 10 years since adoption of the standards. In addition, by correlating test data obtained in the testing of over 2,000 sandy soils, a special short-cut testing procedure was evolved for determining cement factors for sandy soils.[2] As a result, substantial savings in both time and manpower for laboratory testing have been possible.

This paper gives a general discussion of the ASTM-AASHO test methods as modified by the Portland Cement Association. This is followed by a general discussion of the special short-cut testing procedures for sandy soils. A discussion of test methods used for emergency construction, and for small projects is given. The value of identifying the soils occurring on a project by soil series name as identified by the United States Department of Agriculture is stressed as a further means of reducing testing requirements. The interrelation of these test methods is shown graphically in the flow diagram (Figure 2).

MODIFIED TEST METHODS

The three ASTM-AASHO test methods listed above determine the fundamental control factors for quality soil-cement. The moisture-density test establishes the proper density and the optimum moisture content while the wet-dry and freeze-thaw tests are used to determine the minimum cement content for durability. The discussion which follows describes the ASTM-AASHO test methods as modified and used by the Portland Cement Association.

Moisture-Density Test

The moisture-density test is used to determine the moisture content (optimum moisture) and density (corresponding maximum density) for molding laboratory test specimens. The test is also used in the field to determine the quantity of water to be added and the density to which soil-cement should be compacted during construction.

In the standard procedure, the optimum moisture content and maximum density are determined on the portion of the soil passing a No. 4 sieve. This procedure makes no provision for soils containing material retained on the No. 4 sieve, even though it is desirable to determine the maximum density and optimum moisture of the total mixture so that test specimens will represent the material to be used during construction as nearly as possible.

In the previous practice, the optimum moisture and maximum density of the total mixture was computed from data obtained from the minus No. 4 fraction by taking into account the amount, specific gravity and absorbtion of the plus No. 4 material. The computations were made on the assumption that the addition of plus No. 4 material in-

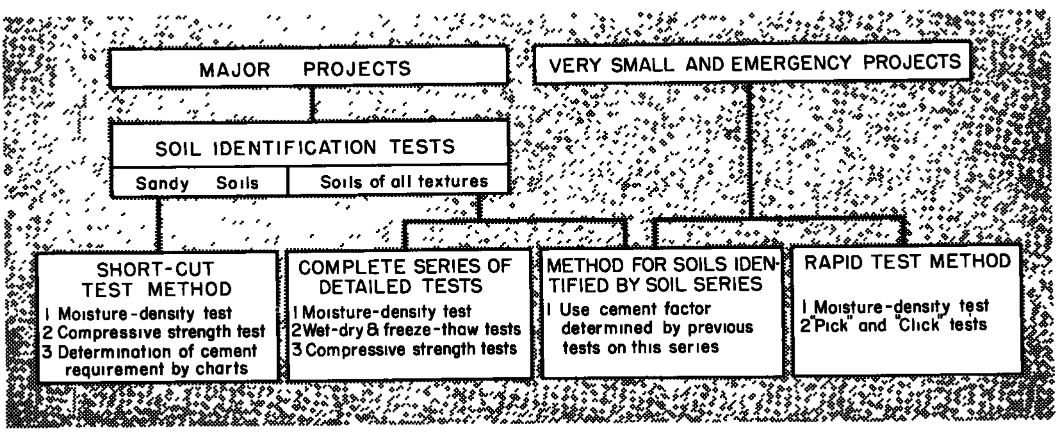

Figure 2. Interrelation of methods of testing soil-cement mixtures.

[2] Soil-Cement Test Data Correlation Affords Method of Quickly Determining Cement Factors for Sandy Soils" presented by J. A. Leadabrand and L. T. Norling at 32nd Annual Meeting of the Highway Research Board, January 1953.

creases the density of the mixture by displacing the minus No. 4 soil in equal volume. No allowance was made for possible increase in void space, although it is obvious that it should be taken into account. But this is difficult to do accurately, since the void space depends on the amount, size, and shape of plus No. 4 particles.

Experience has shown that when the above procedure is followed the densities obtained in preparing laboratory test specimens using calculated optimum moisture content may be considerably less than the theoretical maximum density. The difference increases as the amount of plus No. 4 material is increased. In some cases, using soils having about 40 percent of plus No. 4 material, actual densities have been as much as 10 pcf. below the calculated theoretical density, apparently due to voids not accounted for in the calculations.

The Portland Cement Association, therefore, has modified the ASTM-AASHO moisture density procedure for soils containing plus No. 4 material as follows:

1. The soil sample used in the test has the same plus No. 4 content as the original soil material. However, ¾-inch material is the maximum size used. Should there be material larger than ¾ inch in the original soil, it is replaced by an equivalent weight of No. 4 to ¾-inch-size material. A maximum size of ¾ inch was selected because a 4-inch-diameter mold is used. This also is the maximum size material used in preparing soil-cement specimens for wet-dry and freeze-thaw testing.

2. A 750-grain moisture sample is taken. This larger size moisture sample is necessary in order to obtain a representative moisture content.

3. When performing the test using fragile soil materials that tend to crush or break down under the weight of the compaction rammer, a separate batch of soil-cement is used for determining each point on the moisture-density curve.

Wet-Dry and Freeze-Thaw Tests

Most soil-cement mixtures have sufficient stability to carry traffic immediately after being compacted to maximum density at optimum moisture content. As the cement hydrates the stability of soil-cement is increased tremendously. The ASTM-AASHO wet-dry and the freeze-thaw tests were developed to determine the resistance of hardened soil-cement to repeated moisture and temperature variations and to alternate freezing and thawing.

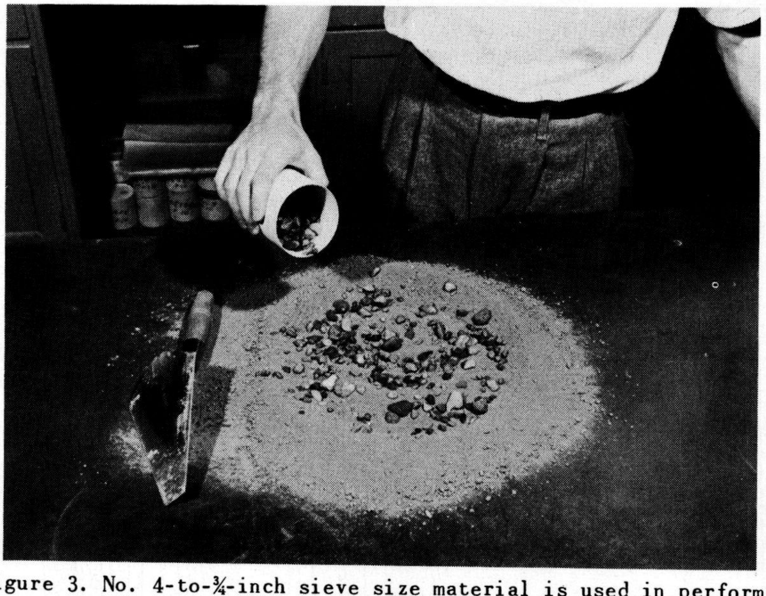

Figure 3. No. 4-to-¾-inch sieve size material is used in performing the moisture-density test.

Data obtained from the tests permit selection of the minimum cement content required for durability.

The standard ASTM-AASHO wet-dry and freeze-thaw test procedures have been modified and shortened to some extent by the Portland Cement Association for use in its Soil-Cement Laboratory. These modifications materially reduce the number of test specimens required, reduce the amount of daily routine handling of specimens and result in a more practical procedure. Successful construction and excellent performance of many projects built using cement factors obtained from these modified tests prove their adequacy.

The modifications follow:

1. Volume and moisture change specimens (referred to in the ASTM standard as No. 1 specimens) are considered unnecessary and are not molded since experience has shown that the brushing test is more critical. Generally this will mean a saving of six test specimens since they usually were prepared at three cement contents for both wet-dry and freeze-thaw tests.

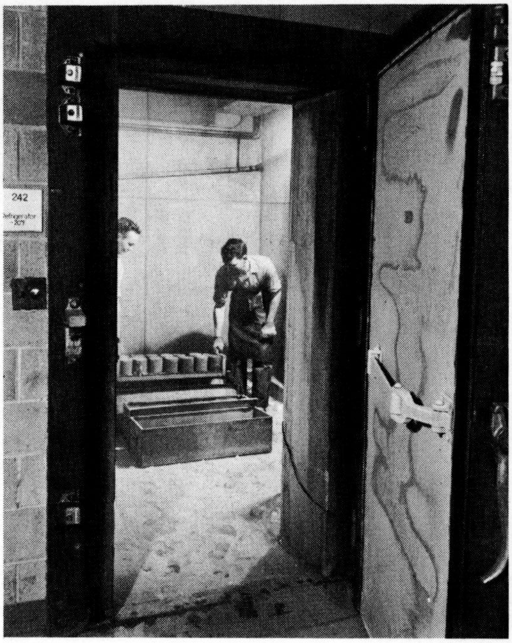

Figure 4. First portion of freeze-thaw test cycle consists of 24 hours' freezing at temperature not warmer than -10 F.

2. Freeze-thaw specimens to be subjected to brushing are molded usually at three cement contents with a two percentage point range between specimens. However, only one wet-dry specimen at the median cement content is molded. Experience has also shown that the soil-cement losses incurred during the tests are almost always higher for the freeze-thaw specimens than for comparable wet-dry specimens. Exceptions sometimes occur in the case of soils with high silt and clay content and coarse grained "one size" sands. Because of such soils, one wet-dry specimen generally is molded.

3. The time schedule of the freezing and thawing test has been changed slightly for practical reasons. Freezing and thawing time has been increased, thereby reducing the time for brushing and handling specimens. This reduction is possible mainly because of the elimination of the volume and moisture change specimens. The time schedule used is: 24 hours of freezing, 23 hours of thawing, 1 hour brushing and handling specimens, or 48 hours total time for one cycle.

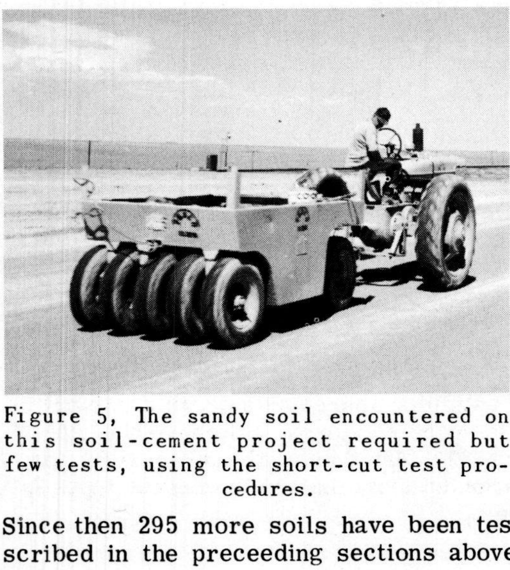
Figure 5, The sandy soil encountered on this soil-cement project required but few tests, using the short-cut test procedures.

SHORT-CUT TESTING PROCEDURES FOR SANDY SOILS

One of the most significant reductions in the amount of work in testing soil-cement mixtures was made possible by development of a special short-cut testing procedure for sandy soils. This procedure was presented in a paper "Soil-Cement Test Data Correlation Affords Method of Quickly Determining Cement Factors for Sandy Soils" by the authors at the Thirty-Second Annual Meeting of the Highway Research Board, January 1953. The procedure is based on correlations of data obtained from the standard ASTM-AASHO and supplementary tests on 2,229 sandy soil-cement mixtures. Since then 295 more soils have been tested using both the modified procedures described in the preceeding sections above and the short-cut method. This comparison of data further confirmed the validity of the short-cut procedures.

As explained in the original paper referred to above, the short-cut testing procedures do not involve new tests or additional laboratory equipment. Instead, data and charts developed from previous tests of similar soils are utilized to eliminate the need for some tests and greatly reduce the amount of work required. The only laboratory tests required are a grain size analysis, a moisture-density test and compressive strength tests. Relatively small soil samples are needed and all tests can be completed in one day, except for results of 7-day compressive strength tests.

While this procedure does not always indicate the minimum cement factor that can be used, it provides a safe cement factor generally close to that indicated by standard ASTM-AASHO wet-dry and freeze-thaw tests. The procedure is finding wide application by engineers and builders and may, in time, largely replace the standard tests as experience in its use is gained and the relationships are checked. Possibly the charts and procedures may be modified to conform to local conditions if needed.

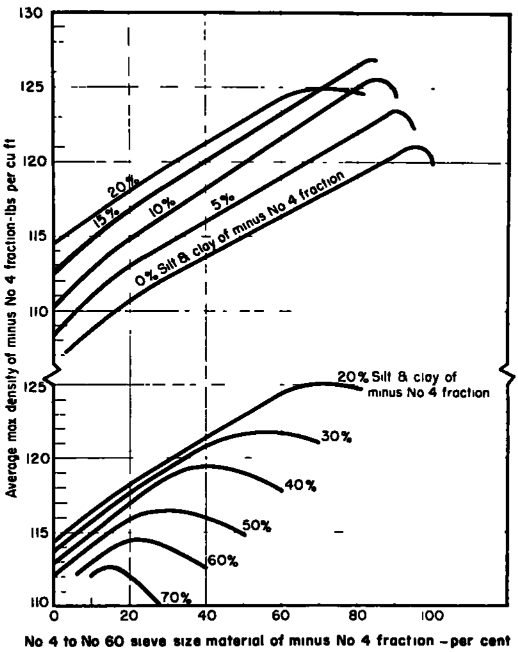

Figure 6. Average maximum densities of the minus No. 4 fraction of soil-cement mixtures.

As originally prepared, the charts for the short-cut procedure were based on cement contents calculated on a volume basis. In the following discussion the accompanying charts show cement contents by weight of soil. The maximum densities shown were obtained by using the minus No. 4 fraction of the soil. Charts based on the maximum density obtained by tests using the total mixture instead of the minus No. 4 fraction are being developed.

The nomenclature of textural classification used in the following discussion has been revised to conform with the revised system now in use by the U.S. Department of Agriculture.

The short-cut testing procedures that follow involve: (1) determining the texture of the soil to permit its placement in either Group I or II; (2) running a moisture-density test on a mixture of portland cement and the minus No. 4 fraction of the soil; (3) determining the indicated portland cement requirement by the use of charts; and (4) verifying the indicated cement requirement by compressive strength tests.

Preliminary Steps

1. Make a grain-size analysis of the soil.
2. If the soil contains less than 20 percent material smaller than 0.005 mm. and less than 50 percent smaller than 0.05 mm., the short-cut procedure can be used and the soil is placed in either Group I or II as follows:

Group I. Less than 20 percent smaller than 0.05 mm. and less than 25 percent gravel larger than No. 10 sieve or 20 to 50 percent smaller than 0.05 mm.

Group II. Less than 20 percent smaller than 0.05 mm. and more than 25 percent gravel larger than No. 10 sieve.

Dark gray to black sandy soils, obviously containing appreciable organic impurities together with miscellaneous granular materials such as cinders, caliche, chat, chert marl, red dog, scoria, shale, slag, etc., should be tested using the full modified procedures as described previously until information on local materials of these types is sufficient to permit use of short-cut procedures.

Group I Soils

Step 1: Determine by test the maximum density and optimum moisture content for a mixture of the minus-No. 4 soil and portland cement. The cement content by weight to use can be obtained from Figure 8 by using the combined silt and clay content (smaller than 0.05 mm.) of the minus-No. 4 fraction of the soil[3] and an estimated density obtained from Figure 6.

Step 2: Using the maximum density obtained by test in Step 1, determine from Figure 8 the indicated cement factor by weight of the minus-No. 4 soil.

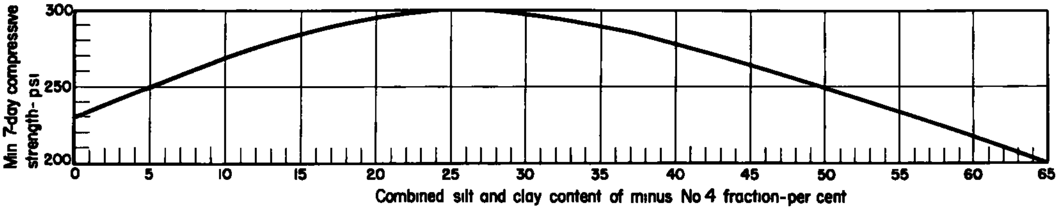

Figure 7. Minimum 7-day compressive strengths required for Group I soils at the indicated cement content obtained from Figure 8.

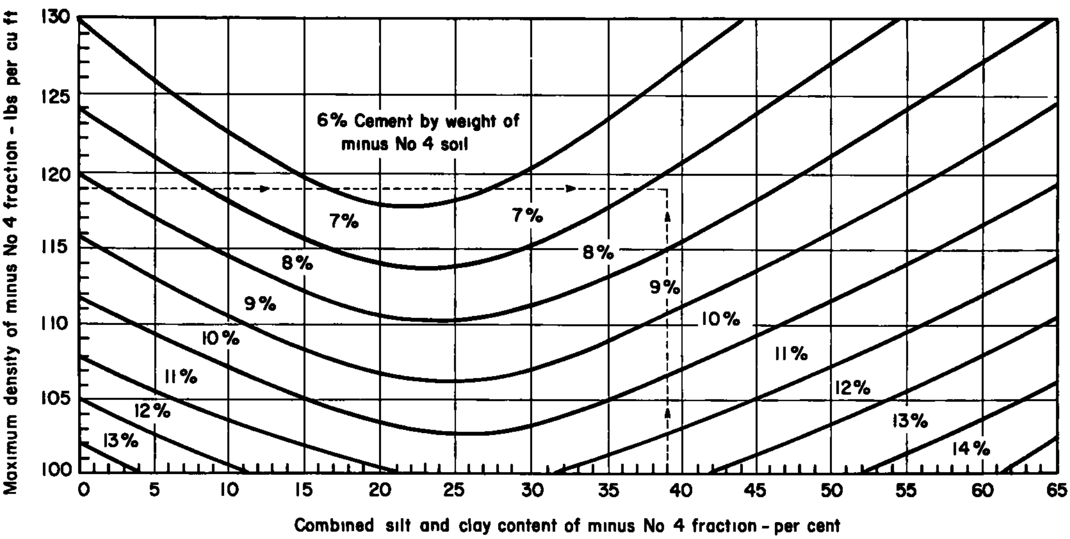

Figure 8. Indicated cement content by weight of minus No.4 fraction of Group I soils.

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[3] The percentage of combined silt and clay is usually given in relation to the total soil mixture for identification and classification purposes. If the soil contains material retained on the No. 4 sieve, it is necessary to convert this figure to the percent based on the minus No. 4 fraction. Likewise, this is true of the amount of material between the No. 4 and 60 sieves. The conversions may be made using the following formulas:

$$\% \text{ (No. 4 to No. 60 sieve size) of No. 4 fraction} = \frac{\% \text{ (No. 4 to No. 60 sieve size) of total}}{100 - \% \text{ plus No. 4}} \times 100$$

$$\% \text{ (silt + clay) of No. 4 fraction} = \frac{\% \text{ (silt + clay) of total}}{100 - \% \text{ plus No. 4}} \times 100$$

Step 3: (A) Mold three compressive-strength specimens[4] at maximum density and optimum moisture using minus No. 4 soil and the cement factor obtained in Step 2. (B) Determine the average compressive strength of the specimens after 7 days of moist-room curing.

Step 4: (A) On Figure 7 plot the average compressive strength value obtained in Step 3. If this value falls above the curve shown, the indicated cement factor by weight of the minus No. 4 soil obtained in Step 2 is adequate. If the original soil sample contained material retained on the No. 4 sieve, it is necessary to convert this cement factor based on the minus No. 4 soil to the cement factor based on the total soil. This is quickly done as follows: cement content by weight of total soil = cement content by weight of minus No. 4 soil x $\frac{(100 - \%\text{ plus No. 4})}{100}$. This cement content by weight usually is then converted[5] to a volume basis for field construction by using Figure 9. (B) If the average strength value falls below the curve of Figure 7, the indicated cement factor obtained in

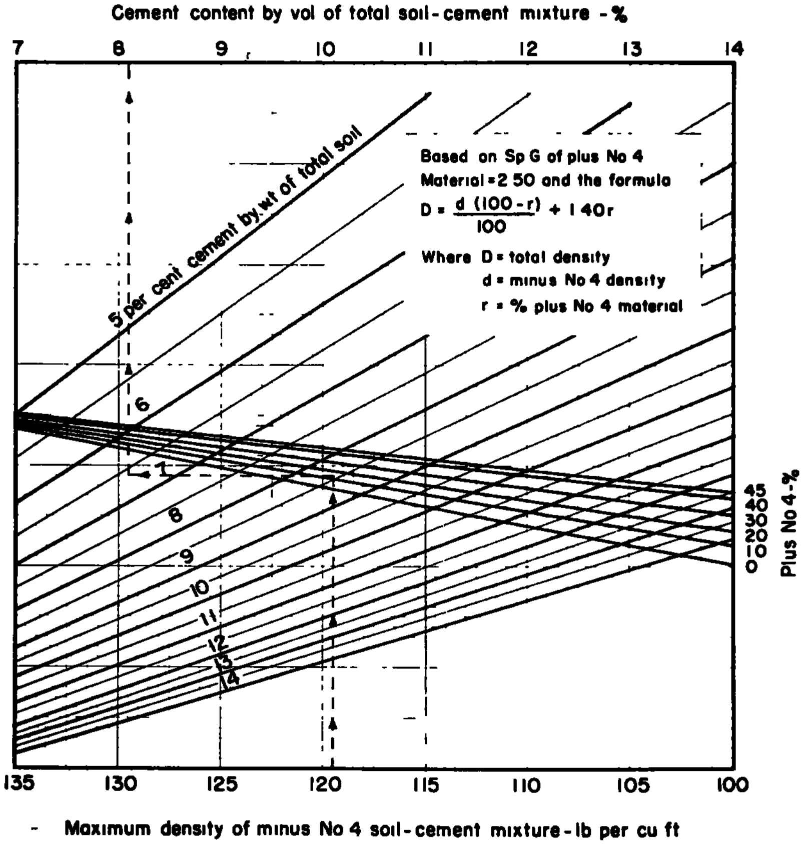

Figure 9. Relation of cement content by weight of total soil to cement content by volume of total compacted soil-cement mixture.

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[4] 2-in. diameter by 2-in. high specimens or 4-in. diameter by 4.6-in. high specimens may be molded using minus No. 4 soil-cement material. The 2-in. specimens shall be submerged in water one hour before testing and the 4-in. specimens four hours.

[5] The formula, $D = \frac{d(100 - r)}{100} + 1.40\ r$, used to develop Figure 9 is based on formula given in "Laboratory Compaction Tests of Coarse-Graded Paving and Embankment Materials", Highway Research Board Proceedings of the Thirty-Second Annual Meeting, 1953.

Step 2 is probably too low. Additional testing following the modified ASTM-AASHO test procedures is needed to establish the cement requirement for the soil. Generally, however, only two freeze-thaw specimens will be needed; one at the cement content by weight indicated as adequate in Step 4(A) based on the total soil and one at a cement content two percentage points higher.

Group II Soils

Seven percent cement by volume, based on the total mixture, is automatically the indicated cement factor for these soils for soil-cement construction.[6]

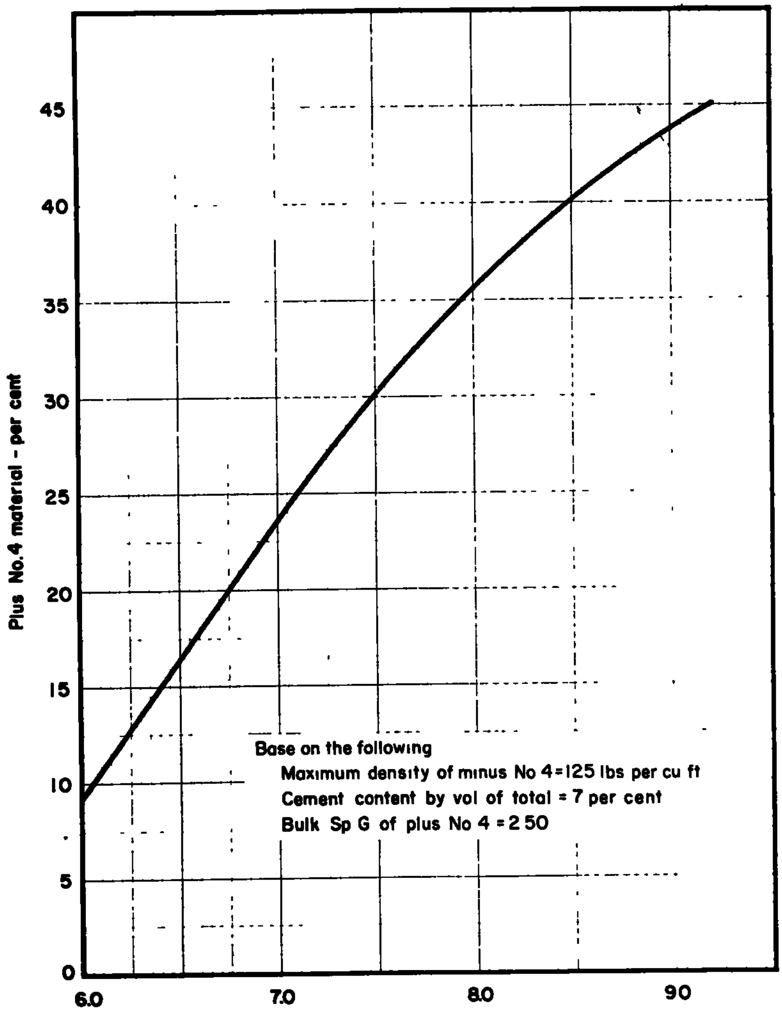

Figure 10. Cement content by weight of minus No. 4 soil for moisture-density test of Group II soils.

[6] Seven percent of portland cement by volume was the minimum recommended for these soils. It is quite probable that tests with lower cement contents would have shown adequate hardening in some cases with less cement. In past years the recommendation of a minimum of 7 percent cement was considered necessary to insure quality construction. More recently considerable soil-cement has been satisfactorily constructed with cement factors well below 7 percent. Modern construction equipment plus job know-how has made quality construction easier.

Step 1: Determine by test the maximum density and optimum moisture content for a mixture of the minus No. 4 soil and portland cement. The cement content by weight of minus No. 4 soil to be used in the test can be determined from Figure 10 by using the percentage of plus No. 4 material in the original soil sample.

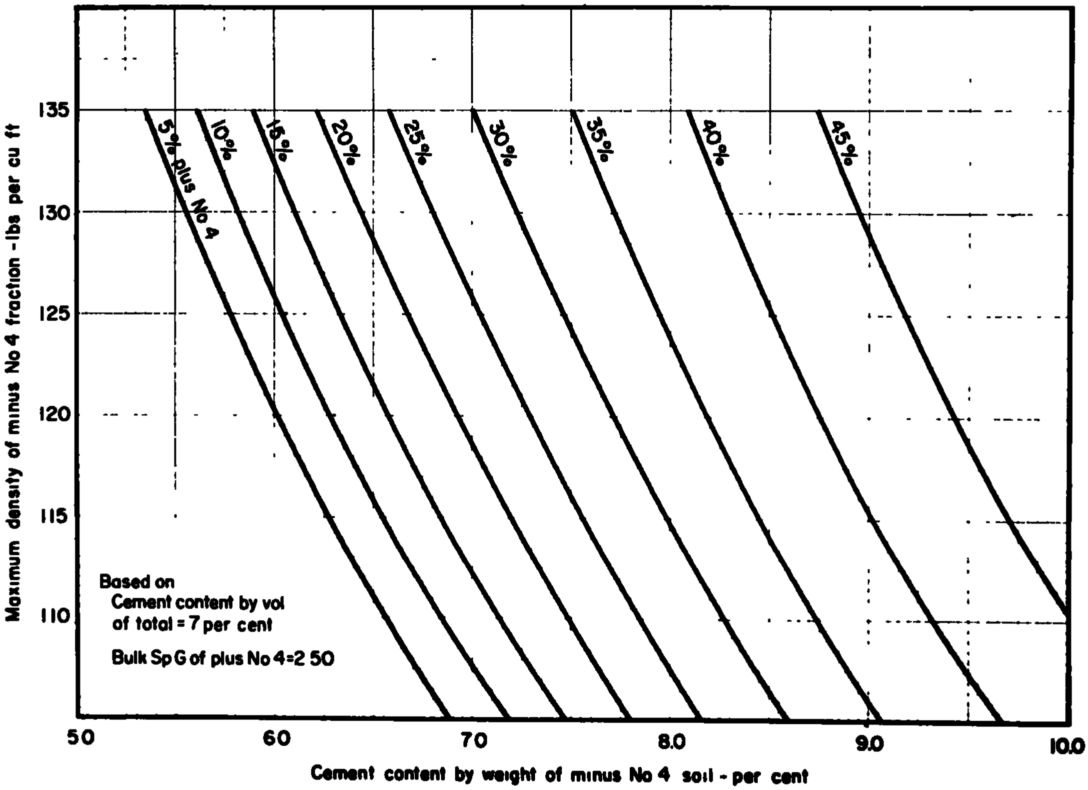

Figure 11. Cement content by weight of minus No. 4 soil for compressive strength specimens of Group II soils.

Step 2: (A) Mold compressive strength specimens[7] in triplicate at maximum density and optimum moisture using minus No. 4 soil and the cement content obtained from Figure 11 by using the maximum density obtained in Step 1 and the percentage of plus No. 4 material. (B) Determine the average compressive strength of the specimens after 7-day's moist room curing.

Step 3: (A) On Figure 12 plot the average compressive strength value obtained in Step 2. If this value falls above the line shown, 7 percent cement by volume of the total soil-cement mixture is adequate for soil-cement construction. If the point falls well above the line it is likely that less than 7 percent cement would be satisfactory. This could be checked by conducting modified standard tests at lower cement contents. (B) If the average strength falls below the line of Figure 12, 7 percent cement by volume of the total mixture is probably not adequate. In this case it is necessary to conduct the modified ASTM-AASHO tests. Generally, however, only two freeze-thaw specimens will be adequate; one at 7 percent cement and one at 9 percent.

Rapid Test Procedure. A rapid method of testing soil-cement has been used successfully for emergency construction and for very-small projects where more complete test-

[7] Two-inch-diameter by 2-inch-height specimens or 4-inch-diameter by 4.6-inch-height specimens may be molded using minus No. 4 soil-cement material. The 2-inch specimens shall be submerged in water for an hour before testing and the 4-inch specimens for four hours.

ing is not feasible or practical.[8] It involves molding and inspecting visually several specimens covering a wide range of cement contents, for example: 10, 14 and 18 percent. After at least a day or two of hardening while kept moist the specimens are inspected by "picking" using a sharp-pointed instrument and by sharply "clicking" each specimen against a hard object such as concrete to determine the relative hardness. If a specimen cannot be penetrated more than 1/8 to 1/4 inch by "picking" and produces a clear or solid tone upon "clicking," an adequate cement factor is indicated.

Even an inexperienced person can soon differentiate between satisfactorily and unsatisfactorily hardened specimens and will be able to select a cement content adequate to harden the soil.

Tests on Soils Identified by Soil Series. A most helpful tool for the engineer in reducing soil-cement test work is the Department of Agriculture soil classification system[9]. In this classification system, soils are subdivided into groups called soil series. Soils of a certain series have similar characteristics of subsoil (B horizon), parent material (C horizon), climate, age and vegetation. Large areas may be covered by soils of the same series. It is important to identify soils by series name in soil-cement work because it has been found that soils of the same series and horizon require the same amount of cement for adequate hardening. Once the cement requirement of a given soil series and horizon has been determined by laboratory tests, no further tests for that particular soil series are needed regardless of where it is encountered. Thus by identifying the soil series, testing can be sharply reduced or eliminated altogether for large areas. An increasing number of engineers are making use of this system of classification to reduce their soil-cement testing work.[10]

As a further aid along this line, the Portland Cement Association has underway a project to determine the cement requirements of the major soil series occurring in various areas of the United States. This involves obtaining representative samples of each horizon of each of the significant series in the area under study and determining the required cement content in the laboratory. When these soil series are encountered

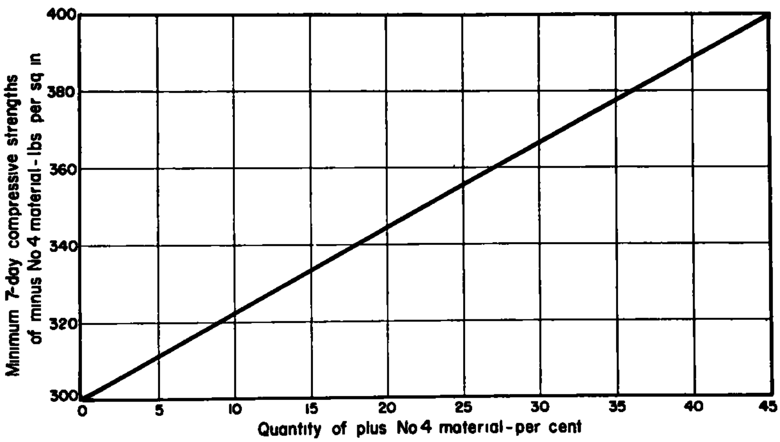

Figure 12. Minimum 7-day compressive strengths required for Group II soils at cement contents equivalent to 7 percent by volume of total mixture.

[8] Details of this are given in "Suggestions for Emergency Soil-Cement Testing and Construction" available free in the United States and Canada upon request to the Portland Cement Association.

[9] The Department of Agriculture soil classification system is described in PCA Soil Primer published by the Portland Cement Association, available free in the United States and Canada.

[10] "The Use of Agricultural Soil Maps in Making Soil Surveys" by L. D. Hicks, Chief Soils Engineer, North Carolina State Highway Commission Engineering Use of Agricultural Soil Maps. Highway Research Board Bulletin No. 22, October 1949, p. 108.

and accurately identified on future soil-cement projects, detailed testing will not be required.

Soil surveys have been made over a large portion of the United States and maps have been prepared by the Department of Agriculture. County maps are available to the public and can be viewed or obtained from the U.S. Department of Agriculture, County Extension Agents, colleges, universities, libraries, etc.

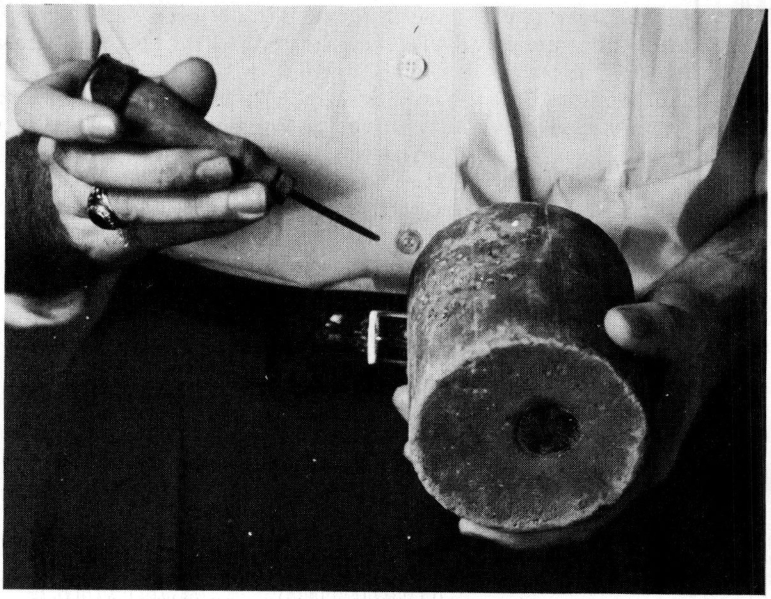

Figure 13. The "pick" test.

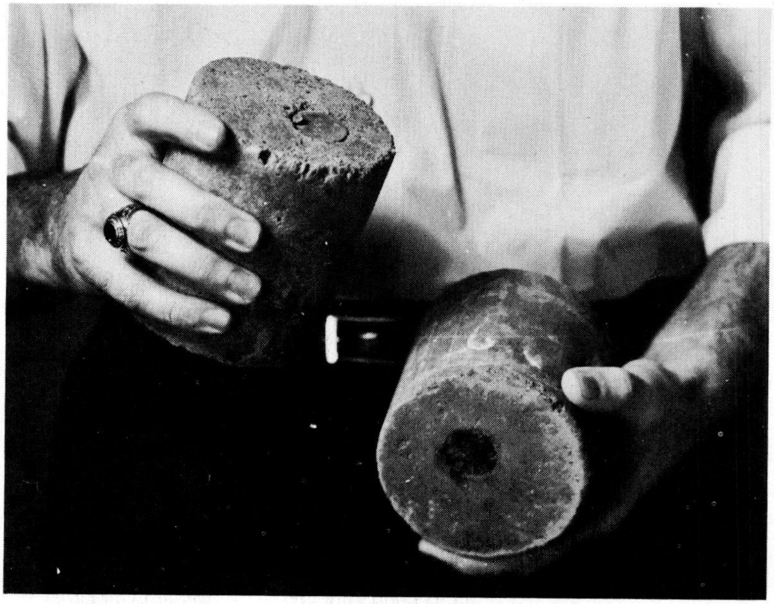

Figure 14. The "click" test.

The highway Research Board reports the status of soil mapping by the Department of Agriculture and other agencies periodically through publications sponsored by the Committee of Soil Surveying and Mapping. These periodic publications list the soil surveys completed and the new ones underway since the preceding publication was published. They keep the highway engineer abreast of the latest information on soil surveys and mapping.

The use of grain size and physical test constant test[11] are also helpful in identifying and classifying soils. These data can be used to good advantage in conjunction with the soil series identification system. They also provide additional information to permit the construction engineer to identify the various soil types on the project which were tested in the laboratory.

SUMMARY

Simplified methods of testing soil-cement to establish cement contents and other construction control factors as required for large and small jobs have been developed in the Portland Cement Association laboratories.

On major projects, when the very minimum cement factor for adequate hardening is required, modified ASTM-AASHO test procedures may be used. Use of the modified tests affords a considerable saving of time and manpower.

The modified procedures include:

1. Cement contents are expressed on a weight basis rather than by volume.
2. The moisture-density test has been modified to include plus No. 4 material. Material larger than ¾ inch however is replaced by an equal amount of No. 4-to-¾-inch material.
3. When moisture-density tests are made on materials that tend to crush or break down under blows of the compaction rammer, a separate batch of soil-cement is used for each trial.
4. Only four specimens instead of twelve are required for the wet-dry and freeze-thaw tests, since volume and moisture change specimens are not molded and only one wet-dry specimen is made.
5. The time schedule of freezing and thawing has been changed slightly to make it more accurately reflect the time actually required to handle specimens.

In addition to the modified ASTM-AASHO tests a special short-cut procedure has been evolved for determining the cement requirements of sandy soils. This procedure does not necessarily give the minimum factor that can be used.

For emergency construction and small projects where testing facilities are not available or detailed testing is not feasible, a rapid method of testing involving molding and visual inspection of specimens can be used. This method provides cement factors that are adequare but sometimes appreciably above the minimum that could be used if more detailed tests were made.

The identification of soils by the U.S. Department of Agriculture soil classification system is most helpful for reducing testing work. Soils for the same series and horizon require the same cement factor. Since many soil series cover large areas, the need for conducting soil-cement tests can be sharply reduced once the cement requirement of each horizon of a definite soil series has been determined. Up-to-date information on soil surveys and availability of soil maps is provided by the Highway Research Board's Committee on Soil Surveying and Mapping.

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[11] The soil tests, such as grain size analysis and physical test constants, which are commonly used to identify and classify soils are described in "PCA Soil Primer" published by the Portland Cement Association, available free in the United States and Canada.

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