HIGHWAY RESEARCH BOARD

Bulletin 148

Soil Series Cement Requirements

National Academy of Sciences—

National Research Council

publication 440

HIGHWAY RESEARCH BOARD

Officers and Members of the Executive Committee

1957

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2101 Constitution Avenue Washington 25, D. C.

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PRESENTED AT THE
Thirty-Fifth Annual Meeting
January 17–20, 1956

1957
Washington, D. C.

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Soil Series as a Basis for Determining Cement Requirements for Soil-Cement Construction

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One of the most important tools of the soils engineer is a good method of identifying soils. This permits proper classification and comparison of soils for engineering purposes. Proper identification makes classification work simpler whenever the same soils are encountered on future projects. An excellent soil identification method is the pedalogical system developed by the U. S. Department of Agriculture. This method provided the basis for the project described in this paper.

It has been known for some time that soils of the same series and horizon, as identified by the Department of Agriculture's system require the same cement factor for soil-cement construction. Once the cement factors for a given soil series are established it is unnecessary to conduct tests for soil-cement construction involving the same series no matter where it is encountered. Since it is not uncommon for some soil series to cover large areas, sometimes hundreds of square miles, the importance of this relationship is obvious.

First, this paper reviews briefly the Department of Agriculture's identification system. It then describes the results of a project to determine cement requirements for soil-cement construction for 43 major soil series occurring in several Great Plains states, the eastern half of Washington and the northern part of Idaho. Department of Agriculture soil maps showing the location and extent of the soil series were used to determine sampling locations. In several cases samples of the same series were taken at 3 or 4 widely separated areas. Both soil and soil-cement tests were made on the samples.

Included in the paper are maps showing the areas sampled and tables listing the cement requirements for soil-cement construction for the 43 soil series.

The physical properties of the soil samples taken from widely separated areas but representing the same horizon of a specific soil series were generally similar, reflecting the accuracy of the U. S. Department of Agriculture soil maps. The cement requirements of the duplicate samples were consistently the same. These results prove the usefulness of the pedalogical system of soil identification in soil-cement work.

IT is important that soils be properly identified before being classified for engineering purposes (1). Proper identification, for example, permits a common ground for comparison of the various engineering classifications, thereby facilitating interpretation of test data. It also simplifies future work when the same soils are encountered on other projects.

A method of soil identification that is growing in use as a basis for making engineering soil classifications is that devised by the U. S. Department of Agriculture. It has been used by agricultural scientists for many years. The value of this identification system in soil-cement construction lies in the fact that cement factors can be established for each horizon of a given soil series and no further soil-cement tests are then needed on future work involving the same series. Thus by proper soil identification, much test work can be eliminated.

Many engineers engaged in soil-cement work have made routine use of the Department

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of Agriculture identification system for systemizing their work. To add further to the information developed by these individuals and to simplify future soil-cement test work, the Portland Cement Association recently started field and laboratory work to determine the cement requirements of the major soil series in several areas. This report covers the tests made on 43 major soil series occurring in several Great Plains states and in the eastern half of Washington and the northern part of Idaho. Typical samples were taken from the profiles of the major soil series under study. In several cases samples of the same series were takenfrom three or four widely separated points to check and further verify that the cement requirement for a given horizon of a specific soil series is constant.

This paper presents: (1) a brief description of the U. S. Department of Agriculture soil identification system; (2) a description of the areas studied; (3) the sampling procedure used; (4) a description of the laboratory tests made; (5) the tests' results including cement factors for soil-cement construction for 43 soil series; and (6) a summary.

Inasmuch as the Department of Agriculture soil identification system is the basis of this project a brief description of the method follows.

THE DEPARTMENT OF AGRICULTURE SOIL IDENTIFICATION SYSTEM[1]

As a result of early studies by agricultural soil scientists in Russia and later in the United States, it was observed that certain soils could be grouped together as similar irrespective of their parent material. It was recognized that soils having the same parent material in different parts of the country were entirely different, whereas soils in the same climatic zone having different parent materials were similar. It was also observed that each soil was characterized by a distinct series of layers, the morphology of which depended upon the environment in which the soil was formed. These layers of soil have been designated as horizons and make up what is referred to as the soil profile.

These observations led to the development of the Department of Agriculture system of identifying soils. This system recognizes such factors as parent material, age, topography, climate and biologic activity (plant and animal life), all of which influence the type of soil formed and its physical and chemical properties.

Three Main Orders

In this classification system, the soils of the United States are divided into three main divisions or orders: zonal, intrazonal and azonal depending upon the amount of profile development.[2]

The zonal soils are mature soils characterized by well differentiated horizons and profiles that differ noticeably according to the climatic zone in which they occur. They are found in areas where the land is well drained but not too steep. Intrazonal soils are those having well developed characteristics resulting from some influential local factor of relief or parent rock and are usually local in occurrence. Bog and peat soils are typical examples of intrazonal soils. Azonal soils are relatively young and reflect to a minimum degree the effects of environment. They do not have the profile development, arrangement and structures usually developed by the soil forming processes. Alluvial soils of flood plains and sands along large lakes are examples of azonal soils.

Great Soil Groups

The three main orders are then subdivided into suborders and then further subdivided into great soil groups on the basis of the combined effect of climate, vegetation and to-

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[1] The Department of Agriculture soil identification system is described in detail in U. S. Department of Agriculture Yearbook of Agriculture 1938, Soils and Men. It is also summarized in PCA Soil Primer published by the Portland Cement Association, available free only in the United States and Canada.

[2] These three divisions of the top order replace the two categories (Pedalfers and Pedacals) previously used by the Department of Agriculture. See James Thorp and Guy D. Smith, "Higher Categories of Soil Classification: Order, Suborder and Great Soils Groups," Soil Science, Vol 67, January to June, 1949, p. 117.

pography. For example, the great soil group Chernozems belong to the suborder developed under grass vegetation in temperate subhumid areas. Laterites belong to the suborder developed in areas of abundant rainfall and high temperature.

Soil Series

Soils within each great soil group are divided further into soil series and soil type. Similar soils within a great soil group having uniform development (the same age, climate, vegetation and relief) and similar parent material are given a soil series designation. All soil profiles of a certain soil series therefore are similar in all respects with the exception of some variation in the texture of the topsoil or A horizon. The soil series were originally named after some town, county, stream or other local feature where the soil series was first identified. This method of naming series, however, is not necessarily used at present as it may in some cases interfere with the present system of the Department of Agriculture of correlating series over wide areas.

Soil Type

As already mentioned, the texture of the surface soil or A horizon may vary slightly within the same soil series. The soil series is therefore subdivided into the final classification unit called the soil type. The soil type recognizes the texture of the surface soil and is made up of the soil series name, plus the textural classification of the topsoil or A horizon.

Availability of Soil Maps

A large portion of the United States has been surveyed and mapped by the Soil Survey Division, Department of Agriculture. At the completion of a soil survey, usually covering an area of one county, a soil map is made and a report written describing the soil types occurring in the county. These 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.

The Highway Research Board reports the status of soil mapping by the Department

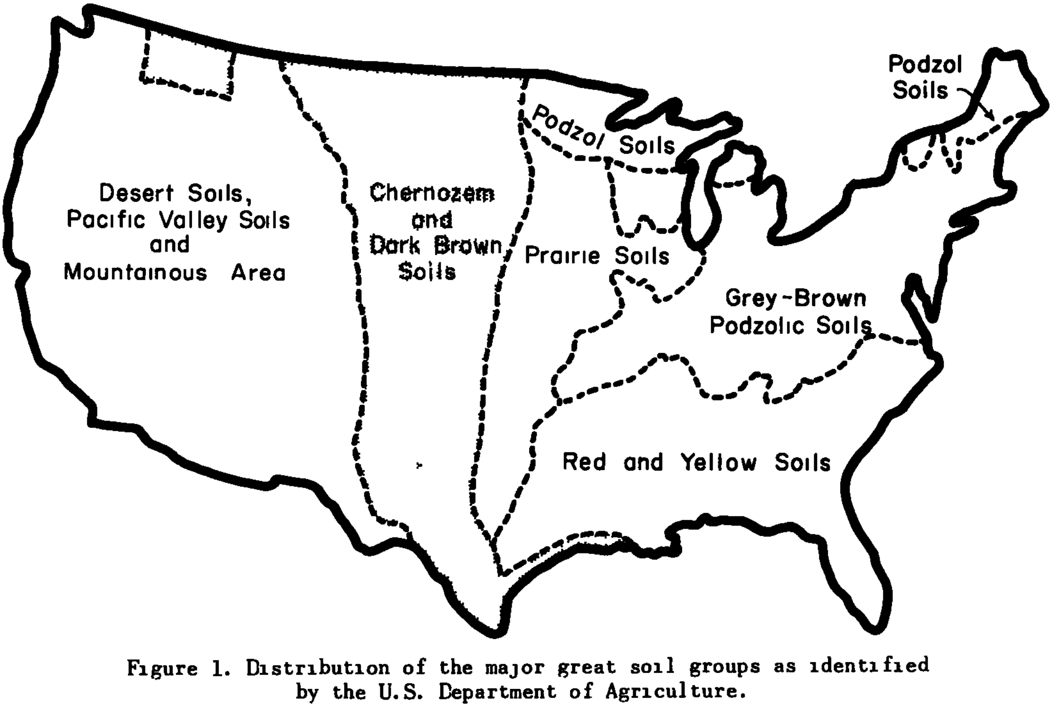

Figure 1. Distribution of the major great soil groups as identified by the U.S. Department of Agriculture.

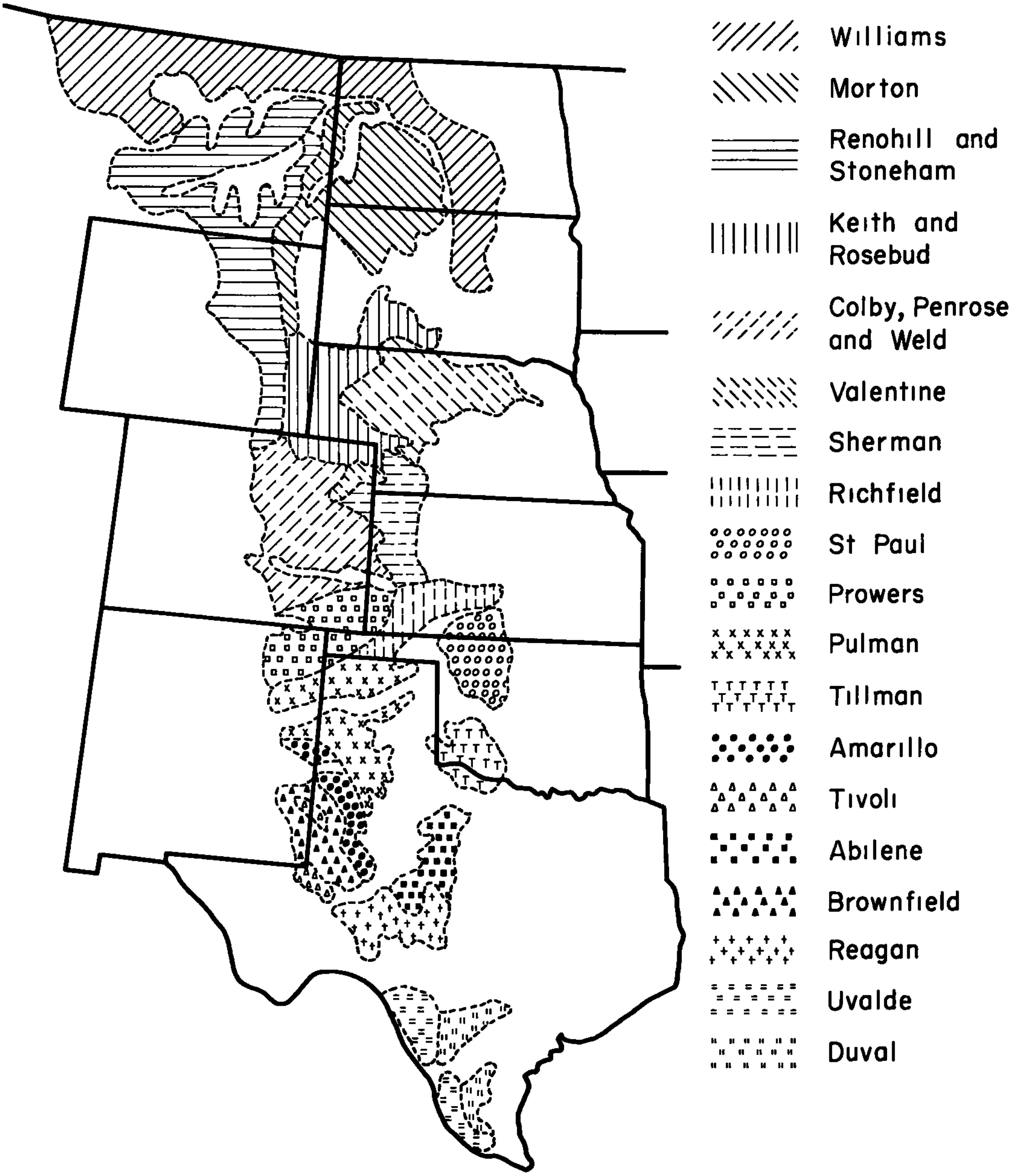

Figure 2. Approximate area where the 23 major soil series studied in the Great Plains area are found.

of Agriculture and other agencies periodically through publications sponsored by the Committee of Soil Surveying and Mapping (2, 3, 4, 5, 6). These publications list the soil surveys completed and the new ones underway since the preceding publication was published. Bulletin No. 22, "Engineering Use of Agricultural Soil Maps," also gives an accuracy rating of the soil maps available.

Application to Soil-Cement Testing

The use of the Department of Agriculture soil identification system is most helpful in soil-cement testing and construction work. For instance, the cement requirement of a given horizon of a specific soil series will be found the same regardless of where it is sampled. As indicated further on in this report some soil series cover large areas, hundreds of square miles in some cases. Once the cement requirement has been determined no further soil-cement tests for the particular soil horizon of that series are needed, even when it is encountered on another project located many miles from the original point of sampling. Thus by identifying soils by series and horizon, the need for conducting soil-cement tests can be eliminated for large areas. An increasing number of engineers are adopting this system of identification to simplify their soil-cement work (7).

TABLE 1

LOCATION IN WHICH SOIL SERIES OCCUR AS MAJOR SERIES

Soil Series	Location[a]
Athena	Asotin, Columbia, Garfield, Walla Walla, Whitman
Burke	Grant, Lincoln
Douglas	Douglas
Ephrata	Benton, Franklin, Grant Walla Walla, Yakima
Hesseltine	Adams, Lincoln, Spokane, Whitman
Marble	Ferry, Lincoln, Spokane, Stevens
Mission	Ferry, Pend Oreille, Spokane, Stevens
Nez Perce	Lewis County, Washington, and Clear Water and Nez Perce Counties, Idaho
Othello	Grant
Palouse	Columbia, Garfield, Lincoln, Spokane, Walla Walla, Whitman
Quincy	Benton, Chelan, Douglas, Franklin, Grant, Kittitas, Okanogan, Walla Walla, Yakima
Ritzville	Adams, Asotin, Benton, Columbia, Douglas, Franklin, Garfield, Grant, Kittitas, Klickitat, Lincoln, Okanogan, Walla Walla, Whitman, Yakima
Sagemoor	Adams, Benton, Franklin, Grant, Kittitas, Klickitat, Okanogan, Walla Walla, Yakima
Southwick	Northern Idaho
Springdale	Ferry, Lincoln, Spokane, Stevens, Pend Oreille
Timmerman	Benton, Franklin, Grant
Touhey	Douglas, Okanogan
Waits	Ferry, Pend Oreille, Spokane, Stevens
Walla Walla	Columbia, Garfield, Walla Walla, Whitman
Typical Basalt	Eastern Washington

[a] Counties listed are in the state of Washington unless noted otherwise

AREAS STUDIED

Soil samples of major soil series in nine states of the Great Plains area, the eastern half of the state of Washington and the northern part of Idaho (see shaded areas in Figure 1) were obtained and tested.

The Great Plains Area

The Great Plains area included portions of nine states ranging from North Dakota on the north, Texas on the south, the Rocky Mountains on the west and an approximate line running from the center of North Dakota to the tip of Texas on the east. Twenty-three major series of the area covering approximately 60 million acres were studied. Figure 2 shows the approximate areas where each of these series are found.

Washington and Idaho Areas

Twenty soil series covering the eastern half of Washington and the northern part of Idaho were studied. The counties in which these soils occur as major series are given in Table 1.

SAMPLING PROCEDURE

Each sampling location was prepared by digging a pit to permit an inspection of the soil profile. Samples of each horizon were then taken from the face of the pit starting with the A horizon. Seventy-five-pound samples were taken from each horizon of the profile for all series. In the case of the Great Plains area, additional 25-lb check samples were taken of each series at two or three other points located several miles apart.

LABORATORY TEST PROCEDURES

Each sample was prepared for testing by screening through a 3-in., ¾-in. and No. 4 sieve and the gradation determined by AASHO Designation T88-54. The soils were classified texturally using the U. S. Department of Agriculture definitions and specifications for texture. The maximum density and optimum moisture content of each soil mixed with cement were then determined.[3]

To determine the cement requirements of the soils representing the Great Plains area, soil-cement tests were first made on each horizon of one of the four profiles from each series. These tests involved the molding of test specimens and subjecting them to wetting-and-drying and freezing-and-thawing tests.[3] The criteria commonly used to determine cement requirements for soil-cement road, street and airport construction were used as a basis to determine whether or not specimens were of satisfactory hardness at the conclusion of tests.

After the cement requirement for each horizon of each soil series from the Great Plains area had been determined on the 75-lb samples as outlined above, check tests were made on the 25-lb check samples. In most cases, only two test specimens were molded for each check sample, each containing the cement content determined as adequate by test on the first sample. One specimen was subjected to the wet-dry test, the other to the freeze-thaw test and the results compared with those obtained on the first sample.

Compressive strength tests were also made on each sample at the required cement content. The test specimens were 2 in. in diameter and 2 in. high and were broken in compression at age 2, 7 and 28 days. They were cured by storing at room temperature in an atmosphere of high humidity and then soaked in water for one hour before breaking. A rate of load application of 20 psi per second was used.

The cement requirements of the soils from the eastern half of Washington and the northern part of Idaho were determined using the same procedures as given above except that samples representing only one profile of each series were tested.

TEST RESULTS

Test results are given in Table 2 for the major soil series in the Great Plains area and similar data for the Washington and Idaho areas are given in Table 13. Detailed discussions of the test data follow.

The textural classifications used in the tables and the discussion are those of the U. S. Department of Agriculture. The following abbreviations are used:

CS	coarse sand	VFSL	very fine sandy loam
S	sand	L	loam
FS	fine sand	SiL	silt loam
VFS	very fine sand	Si	silt
LCS	loamy coarse sand	SCL	sandy clay loam
LS	loamy sand	CL	clay loam
LFS	loamy fine sand	SiCL	silty clay loam
LVFS	loamy very fine sand	SC	sandy clay
CSL	coarse sandy loam	C	clay
SL	sandy loam	SiC	silty clay
FSL	fine sandy loam		

The Great Plains Area

Table 2 lists test results for the samples from the Great Plains area. The data given for each horizon of each of the series are average values (based on four samples in most cases) and include the cement requirements for soil-cement construction.

A detailed discussion of the test data for samples representing four of the 23 soil series is given below.

Sherman Silt Loam. The Sherman soil series is found in Kansas, Nebraska and eastern Colorado. It includes Chestnut soils developed in silty and calcareous loess on up-

[3] Details of the test procedures used are described in Soil-Cement Laboratory Handbook, available free only in the United States and Canada from the Portland Cement Association and are modifications of the following AASHO test methods:

Moisture-Density Test	- AASHO Designation T134-45
Wetting-and-Drying Test	- AASHO Designation T135-45
Freezing-and-Thawing Test	- AASHO Designation T136-45

TABLE 2

TEST RESULTS ON MAJOR SOIL SERIES IN THE GREAT PLAINS AREA[a]

Soil Series	Horizon	Color (moist)	Gradation: % Passing No 4 Sieve	No 10 Sieve	No 40 Sieve	No 200 Sieve	Gradation: % Smaller than 0.05 mm	0.005 mm	0.002 mm	USDA textural class	Maximum density pcf	Optimum moisture %	Required cement content % by vol	Compressive strength at recommended cem content - psi: 7 day	28 day
Abilene	A	Gr br	100	100	98	76	68	39	27	CL	103.0	19.7	12	508	585
	B	Dk gr br to br	100	100	98	76	69	46	39	CL	101.1	21.2	12	543	744
	C	Lt br	100	99	96	77	72	52	45	C	106.7	17.6	13	525	787
Amarillo	A	Br	100	100	98	46	33	16	13	VFSL	116.2	12.0	8	368	575
	B	Red br to yel rd	100	100	99	58	46	27	25	SCL	110.2	13.0	8	411	571
	C	Pink	100	100	98	52	39	24	22	SCL	114.4	12.9	8	482	685
Brownfield	A	Br to lt red br	100	100	99	21	9	3	3	FS	117.9	9.8	8	181	247
	B	Red	100	100	99	38	29	20	20	FSL	115.5	13.6	8	355	470
	C	Yel red	100	100	99	34	26	19	19	FSL	115.2	12.8	8	382	530
Colby	A	Gr br to pale br	100	100	100	76	60	24	19	L	106.9	17.6	12	519	675
	C	V pale br	100	100	100	70	56	27	22	L	110.4	15.6	12	516	666
Duval	A	Red br	100	100	100	44	30	13	12	VFSL	112.7	12.4	8	324	397
	B_1	Red	100	100	99	51	38	19	17	VFSL	113.5	14.2	8	372	552
	B_2	Red	100	99	98	54	42	22	21	SCL	111.8	15.0	8	438	496
	C	Yel to red yel	100	100	98	51	37	13	12	VFSL	110.2	14.8	8	337	608
Keith	A	Dk gr br	100	100	100	85	76	32	18	SiL	100.3	19.3	11	430	568
	B	Dk gr br to gr br	100	100	100	86	77	35	22	SiL	102.7	17.9	11	580	693
	C	V lt gr br	100	100	100	84	75	27	13	SiL	103.1	18.0	11	590	772
Morton	A	V dk br	100	100	99	75	69	32	18	SiL	97.5	21.4	14	477	496
	B	Dk br	100	100	100	73	66	35	27	CL	102.6	19.8	13	434	480
	C	Br	100	100	98	66	61	35	28	CL	105.3	18.6	13	496	781
	D	Yel br	100	100	97	29	22	15	14	FSL	112.2	11.4	11	508	684
Penrose	A	Gr br	100	97	91	70	58	23	20	L	103.8	17.2	10	331	398
	B	Lt gr br	100	96	91	74	67	32	25	L	106.4	17.8	7	370	458
	C	V lt gr br	100	96	91	76	66	34	29	CL	109.5	16.3	7	366	462
Powers	A	Br	100	99	96	80	71	24	16	SiL	104.8	17.2	10	354	437
	B	Br	100	100	99	89	82	34	24	SiL	104.5	18.0	9	314	448
	C	Pale br	100	99	98	88	82	28	18	SiL	107.2	16.9	8	387	509
Pullman	A	Gr br	100	100	99	83	77	38	26	SiL	103.0	18.4	12	337	469
	B	Br	100	100	100	90	86	52	42	SiC	97.3	23.3	12	471	609
	C	Br	100	100	100	91	85	51	42	SiC	100.0	21.0	12	508	612
	D	Red yel	100	100	100	86	81	44	36	CL	101.2	20.2	12	592	828
Reagan	A	Pale br	100	100	97	68	60	31	22	L	105.9	16.9	11	558	695
	B	V pale br	100	99	98	77	68	40	32	CL	105.1	18.2	10	608	855
	C	Pink white	99	98	92	68	63	42	38	CL	109.8	16.0	9	463	656
Renohill	A	Lt br gr	100	100	99	84	77	46	30	CL	102.4	19.6	15	412	440
	B	Yel br	100	100	100	84	77	43	35	CL	103.9	18.5	14	462	653
	C	Yel gr	100	100	99	82	75	44	35	CL	105.9	17.2	14	501	705
Richfield	A	Dk br	100	100	99	80	71	28	18	SiL	103.6	17.8	10	335	428
	B_1	Dk br to br	100	100	99	83	76	41	39	CL	100.7	21.1	12	434	516
	B_2	Lt gr br	100	100	99	95	91	48	34	SiCL	98.2	23.0	12	480	667
	C	Br to lt br	100	100	99	94	88	43	31	SiCL	97.7	22.0	12	568	924
Rosebud	A	Dk gr br	100	100	94	70	59	19	12	L	104.5	17.5	10	464	546
	B	Gr br	100	100	95	74	65	28	22	SiL	102.2	18.8	11	383	478
	C	Lt yel br	100	99	90	56	47	20	16	FSL	110.8	16.3	10	399	562
St Paul	A	Red br to dk red br	100	100	99	82	72	24	14	SiL	107.4	15.2	10	337	418
	B_1	Dk red br	100	99	98	75	64	28	18	L	109.8	16.0	10	395	453
	B_2	Red br	100	99	93	63	54	26	19	L	113.1	14.3	10	484	614
	C	Br red	100	100	98	76	65	30	22	L	110.5	15.9	10	383	506
Sherman	A	Dk gr	100	100	100	94	83	31	17	SiL	99.8	19.7	13	631	785
	B	Med dk gr	100	100	100	96	86	34	20	SiL	100.1	20.8	12	635	814
	C	Gr	100	100	100	95	85	31	16	SiL	99.2	21.3	10	621	829
Stoneham	A	Br to gr br	100	100	98	46	26	7	6	VFSL	108.1	14.8	10	400	511
	B	Br	100	100	98	56	36	10	7	VFSL	108.5	15.3	10	528	645
	C	Lt br	100	100	98	45	31	7	6	FSL	108.5	15.2	9	420	575
Tillman	A	Red br	100	100	99	90	83	34	21	SiL	105.2	17.2	12	397	468
	B	Red br	100	100	99	94	90	48	38	SiCL	103.9	18.4	13	411	484
	C	Lt red br	100	100	99	94	90	43	32	SiCL	108.1	17.3	12	466	543
Tivoli	A	Lt gr br	100	100	96	8	0	0	0	FS	111.4	10.4	10	191	228
	C	Lt yel	100	100	96	9	2	1	1	FS	110.9	10.6	10	204	275
Uvalde	A	Gr br	100	100	98	85	77	39	35	CL	99.9	21.0	10	481	589
	B	Pale to v pale br	100	100	99	88	80	45	42	C	100.0	21.1	11	533	638
	C	V pale br	100	100	99	88	82	47	44	C	103.8	19.9	10	571	729
Valentine	A	Dk gr br	100	100	96	12	4	1	1	FS	114.1	10.0	10	301	447
	B	Gr br	100	100	96	12	1	1	0	FS	113.3	10.3	11	410	582
	C	Lt gr br	100	100	97	12	1	1	0	FS	113.6	10.0	11	354	531
Weld	A	Gr br	100	100	99	80	66	24	20	L	105.6	16.6	12	587	670
	B	Br	100	100	99	87	79	36	29	CL	102.0	19.2	13	510	696
	C	Lt yel br	100	100	99	89	79	28	22	SiL	103.0	19.5	13	479	646
Williams	A	V dk br to dk br	99	98	91	63	56	16	6	SiL	98.0	21.3	16	460	526
	B	Dk gr br	100	99	94	66	60	24	17	L	104.0	18.2	16	563	660
	C	Yel br	100	99	94	68	63	30	22	L	108.0	17.2	11	441	507

[a] Average of data for three or four samples

lands. The series is quite deep and is a combination of two soil profiles, one on top of the other. The top profile developed and combined with the A horizon of the bottom profile to form one profile with a deep A horizon. This series covers approximately 190,000 acres.

Samples of the soil profile were taken at the following locations in Kansas:

Soil No. 111 to 113 - Sec 1 T8S R35W

TABLE 3

GRADATION OF SHERMAN SILT LOAM

Soil No.	Horizon	Depth below ground surface, in.	Color of moist soil	Gradation, % of total soil VCS	CS	MS	FS	VFS	Si	C	U.S.D.A. textural classification
111	A	1 to 26	Dark grey	0	0	0	1	15	69	15	silt loam
114	A	1 to 26	Dark grey	0	0	1	1	13	66	19	silt loam
117	A	1 to 26	Dark grey	0	0	1	2	17	67	13	silt loam
120	A	1 to 24	Dark grey	0	0	1	2	15	60	22	silt loam
112	B	26 to 40	Med dk grey	0	0	0	1	16	68	15	silt loam
115	B	26 to 48	Med dk grey	0	0	0	1	12	64	23	silt loam
118	B	26 to 48	Med dk grey	0	0	0	1	13	66	20	silt loam
121	B	24 to 36	Med dk grey	0	0	0	1	12	63	24	silt loam
113	C	40 -	Grey	0	0	0	1	9	74	16	silt loam
119	C	48 to 60	Grey	0	0	1	1	16	68	14	silt loam
122	C	36 to 50	Grey	0	0	0	2	14	65	19	silt loam

Soil No. 114 and 115 - Sec 14 T7S R35W
Soil No. 117 to 119 - Sec 14 T7S R36W
Soil No. 120 to 122 - Sec 9 T8S R36W

The gradations are tabulated in Table 3 and the range in gradation is shown in Figure 3. Results of soil-cement tests are given in Table 4.

The A horizon is dark grey brown and has a crumb to prismatic structure. All four samples are similar in gradation, being classified texturally as silt loams. Maximum densities ranged from 96 to 101 pcf, three of them being 101, and optimum moisture contents ranged from 18.4 to 21.5 percent. Thirteen percent cement by volume provides adequate hardening for all four samples.

The B horizon is dark grey brown. These four samples are also classified texturally as silt loams. Maximum densities ranged from 99 to 101 pcf and optimum moisture contents ranged from 20.0 to 21.7. Twelve percent cement by volume is adequate for all four samples.

The C horizon is grey brown. The three samples are quite similar and are classified texturally as silt loams. Maximum densities ranged from 98 to 100 pcf and optimum moisture contents ranged from 21.0 to 21.5 percent. Ten percent cement by volume is adequate for all three samples.

As shown in Tables 3 and 4, the profile of the Sherman silt loam was quite similar at the four locations sampled. The cement requirement of each horizon at all four locations was identical.

Also of interest is the similarity in physical properties of the A, B and C horizon materials. The gradation curves shown in Figure 3, for example, are almost identical. It should be noted, however, that the cement requirements of the profile decrease with depth, ranging from 13 percent by volume for the A horizon to 10 percent for the C horizon. Because of the similar physical properties, this difference in cement requirement must be due to differences in chemical properties of each horizon. This change in chemical properties with change in horizon is par-

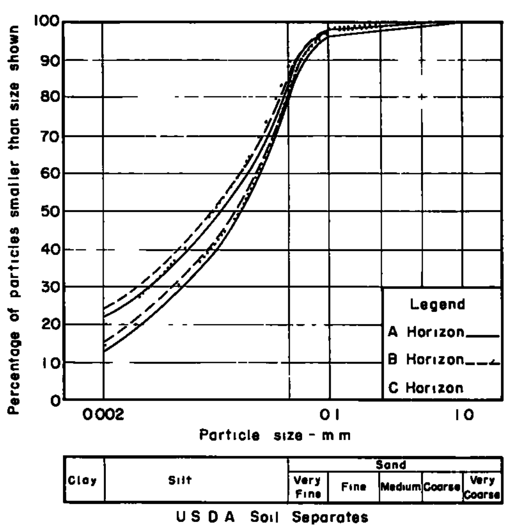

Figure 3. Range in gradation of Sherman silt loam.

TABLE 4

SOIL-CEMENT TEST RESULTS ON SHERMAN SILT LOAM

Soil No.	Horizon	Maximum density pcf	Optimum moisture content %	Soil-cement loss during freeze-thaw test cement content % by vol				Recom-mended cement content % by vol	Compressive strength at recommended cement content, psi	
				10	11	12	13		7 day	28 day
111	A	101.2	18.4			8		13	668	859
114	A	100.8	19.0				5	13	735	890
117	A	101.0	20.0				6	13	579	642
120	A	96.2	21.5				3	13	541	750
112	B	100.5	21.7	15		3		12	547	820
115	B	99.0	21.4		11			12	691	855
118	B	100.8	20.0		9			12	735	906
121	B	100.0	20.0		8			12	567	674
113	C	99.6	21.5	4		3		10	534	788
119	C	98.2	21.5	6				10	738	890
122	C	99.7	21.0	7				10	592	808

tially evident in the change in color and organic content as given in Table 5. This is an excellent example of the importance of the chemical property of a soil in soil-cement and emphasizes the value of an identification system that recognizes the factors that influence this property, such as parent material, age, topography, climate, vegetation.

Keith Silt Loam. The Keith soil series is found in southwestern Nebraska and adjacent parts of Colorado and Kansas. It includes normal soils of the loess-mantled level uplands and has a low-lying horizon of lime and a deeply developed profile. This series covers approximately 5,100,000 acres.

Samples of the soil profile were taken at the following locations in Nebraska:

Soil No. 66 to 68 - Sec 22 T14N R41W
Soil No. 69 to 71 - Sec 32 T15N R41W
Soil No. 72 to 74 - Sec 17 T14N R40W

TABLE 5

COLOR AND ORGANIC CONTENT OF SHERMAN SILT LOAM

Horizon	Color	Organic content ppm[a]
A	dark grey	2700
B	med dark grey	800
C	grey	400

[a] Average of four samples.

TABLE 6

GRADATION OF KEITH SILT LOAM

Soil No.	Horizon	Depth below ground surface, in.	Color of moist soil	Gradation, % of total soil							U.S.D.A. textural classification
				VCS	CS	MS	FS	VFS	Si	C	
66	A	1 to 8	Dk gr br	0	0	0	3	16	62	19	silt loam
69	A	1 to 6	Dk gr br	0	0	0	4	19	60	17	silt loam
72	A	1 to 8	Dk gr br	0	0	1	8	21	51	19	silt loam
67	B	8 to 20	Gr br	0	0	0	4	14	58	24	silt loam
70	B	6 to 18	Gr br	0	0	0	6	25	49	20	loam
73	B	8 to 24	Gr br	0	0	0	8	22	48	22	loam
68	C	20 to 48	Vlt gr br	0	0	0	4	18	68	10	silt loam
71	C	18 to 48	Vlt gr br	0	0	0	6	18	57	19	silt loam
74	C	24 to 48	Vlt gr br	0	0	0	10	18	62	10	silt loam

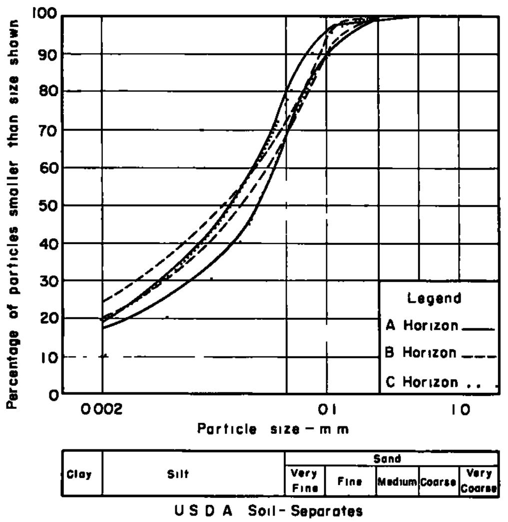

Figure 4. Range in gradation of Keith silt loam.

The gradations are tabulated in Table 6 and the range in gradation is shown in Figure 4. Results of soil-cement tests are given in Table 7.

The A horizon is dark grey brown. The three samples are very similar in gradation, all being classified as silt loams. Maximum densities were also quite consistent, ranging from 99 to 102 pcf. Optimum moisture contents ranged from 18.5 to 20.3 percent. Eleven percent cement by volume was adequate for all three samples. Compressive strengths at 11 percent cement were excellent.

The B horizon is light grey brown. The texture of the three samples was quite consistent, ranging from loams to silt loam. Maximum densities ranged from 102 to 106 pcf and optimum moisture contents ranged from 15.8 to 20.5. Eleven percent cement by volume was adequate for all three samples. Compressive strengths at this cement content were excellent.

The C horizon is very light grey brown. The three samples were similar in gradation, all being classified as silt loams. Maximum densities and optimum moisture contents were quite consistent, ranging from 102 to 104 pcf and from 17.7 to 18.3 percent, respectively. Eleven percent cement by volume was adequate for all three samples and compressive strengths at this cement content were excellent.

The profile of the Keith silt loam was very similar in physical properties at the three locations sampled and cement requirements were constant.

The A, B and C horizon materials were also similar and showed little change with depth. In addition, each required the same cement content indicating that the chemical properties of each horizon are similar.

Weld Loam. The Weld soil series is found in Colorado, Kansas, Nebraska and Wyoming. The soils were developed on uplands from silty loess or loess-like deposits which probably were blown from the soft shale and sandstone materials in the region and to some extent from old river flood plains. This series covers approximately 4,800,000 acres.

TABLE 7

SOIL-CEMENT RESULTS ON KEITH SILT LOAM

Soil No.	Horizon	Maximum density pcf	Optimum moisture content %	Soil-cement loss during freeze-thaw test cement content % by vol				Recommended cement content % by vol	Compressive strength at recommended cement content, psi	
				10	11	12	14		7 day	28 day
66	A	99.6	20.3	8		4	4	11	525	649
69	A	102.1	19.0		4			11	395	480
72	A	99.2	18.5		7			11	369	-
67	B	101.5	20.5	9		5	4	11	439	579
70	B	100.7	17.3		8			11	643	845
73	B	105.8	15.8		7			11	598	655
68	C	103.9	18.3	8		6	5	11	509	916
71	C	103.4	18.1		5			11	550	629
74	C	102.0	17.7		7			11	611	770

TABLE 8

GRADATION OF WELD LOAM

Soil No.	Horizon	Depth below ground surface, in.	Color of moist soil	Gradation, % of total soil VCS	CS	MS	FS	VFS	Si	C	U.S.D.A. textural classification
87	A	1 to 8	Br	0	0	1	9	15	43	32	clay loam
90	A	1 to 8	Gr br	0	0	1	10	30	43	16	loam
93	A	1 to 6	Gr	0	0	3	10	18	54	15	silt loam
96	A	1 to 9	Gr br	0	1	2	13	22	47	15	loam
88	B	8 to 18	Br	0	0	1	5	14	46	34	clay loam
91	B	8 to 18	Br	0	0	1	5	15	49	30	clay loam
94	B	6 to 18	Br	0	0	4	7	13	54	22	silt loam
97	B	9 to 18	Gr br	0	0	1	6	13	51	29	clay loam
89	C	18 to 48	Lt br	0	0	0	5	11	54	30	silty clay loam
92	C	18 to 48	Lt br	0	0	1	4	18	49	28	clay loam
95	C	18 to 48	Lt br	0	0	1	6	16	61	16	silt loam
98	C	18 to 48	Lt br	0	0	1	6	14	65	14	silt loam

Samples of the soil profile were taken at the following locations in Colorado:

Soil No. 87 to 89 - Sec 5 T5N R67W
Soil No. 90 to 92 - Sec 25 T5N R67W
Soil No. 93 to 95 - Sec 12 T2N R52W
Soil No. 96 to 98 - Sec 33 T3N R52W

The gradations are given in Table 8 and the range in gradation is shown in Figure 5. Results of soil-cement tests are given in Table 9.

The A horizon is grey brown and has a crumb structure. The four samples ranged in texture from loams to clay loam. Maximum densities ranged from 102 to 112 pcf, with loam soils having the higher densities. Although there was considerable variation in physical properties, 12 percent cement was adequate for all four samples. Compressive strengths at 12 percent cement were excellent.

The B horizon is brown and has a prismatic structure. The texture of the four samples ranged from silt loam to clay loams. Maximum densities ranged from 97 to 106 pcf and optimum moisture contents ranged from 17.5 to 21.8. Thirteen percent cement by volume was adequate for all samples. Compressive strengths at 13 percent cement were excellent.

The C horizon is light yellowish brown and has a cloddy structure. The texture of the four samples ranged from silt loams to silty clay loams. Maximum densities ranged from 98 to 107 pcf and optimum moisture contents ranged from 18.0 to 23.0. Thirteen percent by volume was adequate for all four samples even though they varied considerably in physical properties. Compressive strengths at 13 percent cement were excellent.

The profile of the Weld loam showed appreciable variation in physical properties at the four locations sampled, indicating some variation in the area mapped as Weld loam. The variation is not considered as excessive, however, and is probably within the accuracy of any prac-

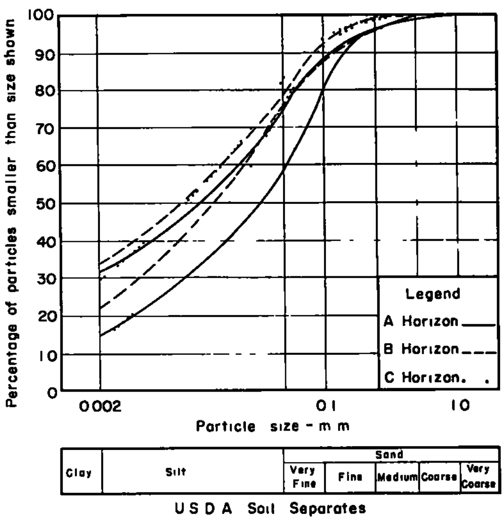

Figure 5. Range in gradation of Weld loam.

TABLE 9

SOIL-CEMENT TEST RESULTS ON WELD LOAM

Soil No.	Horizon	Maximum density pcf	Optimum moisture content %	Soil-cement loss during freeze-thaw test cement content % by vol				Recom-mended cement content % by vol	Compressive strength at recommended cement content, psi	
				10	12	13	14		7 day	28 day
87	A	102.6	19.0		4			12	439	525
90	A	111.5	13.0		6		3	12	672	-
93	A	101.5	17.5		10			12	675	850
96	A	106.6	16.7		6			12	563	634
88	B	105.5	18.4			7		13	573	691
91	B	106.0	17.5		8		6	13	462	770
94	B	100.0	19.0			3		13	592	739
97	B	96.7	21.8			7		13	414	586
89	C	106.9	18.5			5		13	506	636
92	C	104.5	18.0	11	8		3	13	455	636
95	C	102.0	18.5			5		13	573	834
98	C	98.4	23.0			4		13	382	480

tical system of soil mapping and identification. The chemical properties of each horizon at the four locations, however, are apparently quite consistent. This is evident by the constant cement requirement of the four samples of each horizon (Table 9) and by the similar color and organic content as given in Table 10. The variation in physical properties at the four locations is apparently not significant enough to cause a change in cement requirement and is overshadowed by the apparent consistency in chemical properties.

Valentine Sand. The Valentine soil series is found in Colorado, Nebraska and North Dakota under a rather sparse grassy vegetation and level terrain. The soils are developed from wind-blown materials composed largely or entirely of sand. In most virgin areas enough organic and fine material have accumulated in the surface layers to darken them some. This series covers approximately 7,000,000 acres.

Samples of the soil profile were taken at the following locations in Wyoming and Nebraska:

Soil No. 51 to 53 - Sec 10 T26N R65W
Soil No. 54 to 56 - Sec 7 T24N R60W
Soil No. 57 to 58 - Sec 7 T15N R38W
Soil No. 60 to 62 - Sec 5 T15N R38W

The gradations are given in Table 11 and the range in gradation is shown in Figure 6. Results of soil-cement tests are given in Table 12.

The A horizon is dark grey brown. All four samples were quite similar in physical properties, ranging in texture from sand to fine sands. Maximum densities ranged from 110 to 117 pcf and optimum moisture contents ranged from 9.5 to 10.7 percent. Ten percent cement by volume was adequate for all four samples.

The B horizon is grey brown. The texture ranged from sand to fine sand and the maximum densities ranged from 112 to 116

TABLE 10

COLOR AND ORGANIC CONTENT OF WELD LOAM

Soil No.	Horizon	Color	Organic content ppm
87	A	brown	800
90	A	grey-brown	-
93	A	grey	900
96	A	grey-brown	1100
88	B	brown	300
91	B	brown	-
94	B	brown	300
97	B	grey-brown	200
89	C	light brown	100
92	C	light brown	-
95	C	light brown	200
98	C	light brown	325

TABLE 11

GRADATION OF VALENTINE SAND

Soil No.	Horizon	Depth below ground surface, in.	Color of moist soil	Gradation, % of total soil VCS	CS	MS	FS	VFS	Si	C	U.S.D.A. textural classification
51	A	1 to 5	Dk gr br	1	5	29	41	16	8	0	sand
54	A	1 to 5	Dk gr br	0	0	8	72	20	0	0	fine sand
57	A	1 to 8	Dk gr br	0	0	25	53	22	0	0	fine sand
60	A	1 to 4	Dk gr br	0	0	25	51	14	6	4	fine sand
52	B	5 to 15	Gr br	2	5	33	42	18	0	0	sand
55	B	5 to 20	Gr br	0	0	10	53	37	0	0	fine sand
61	B	4 to 10	Gr br	0	0	23	47	29	1	0	fine sand
53	C	15 to 48	Lt gr br	0	0	25	51	22	2	0	fine sand
56	C	20 -	Lt gr br	0	0	10	48	42	0	0	fine sand
58	C	8 to 48	Lt gr br	0	0	21	56	23	0	0	fine sand
62	C	10 to 48	Lt gr br	0	2	24	53	21	0	0	fine sand

pcf. Optimum moisture contents were similar, ranging from 10.0 to 10.4 percent. Soil-cement losses were also similar and 11 percent by volume was adequate for all three samples.

The C horizon is light grey brown. The textures of the four samples were similar, all being classified as fine sands. Maximum densities ranged from 110 to 117 pcf and optimum moisture contents ranged from 9.7 to 10.4. Eleven percent cement by volume was adequate for all four samples.

The profile of the Valentine sand soil type was similar in physical properties at the four locations sampled.

As the Valentine soils are sandy soils, the "short-cut test procedure" as developed by the Portland Cement Association can be used to determine cement requirements (8, 9). The data for the eleven Valentine sands are plotted on the short-cut chart, Figure 7. Using this chart, cement contents of 10, 11, 11 and 9 percent, respectively, are indicated for the four A horizon soils which actually require 10 percent cement by AASHO test methods. The 7-day compressive strengths of the three soils plotted in the 10 and 11 percent band are satisfactory, thereby verifying that these cement contents are adequate. The 7-day compressive strength of the soil plotted in the 9 percent area, however, is below the minimum required, indicating that more than 9 percent is required for adequate hardness (actually 10 percent is required). Again using the short-cut chart, Figure 7, eleven percent cement is indicated for the B and C horizon soils. This is verified by the 7-day compressive strengths which are above the minimum required. This agrees exactly with the 11 percent cement requirement for those soils based on AASHO tests.

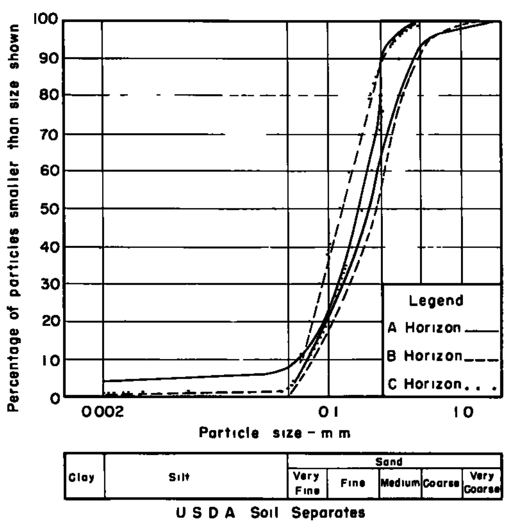

Figure 6. Range in gradation of Valentine sand.

<u>Remaining 19 Soil Series.</u> The test data for the remaining 19 soil series from the Great Plains area showed the same trends as the series described above. The physical properties of all samples representing a specific horizon and series generally were similar. Except for one soil series, the cement requirement of the

check samples were within one percentage point of the requirement of the original sample and in most cases were identical.

Detailed test data on these 19 soil series can be obtained by writing to the Portland Cement Association.

TABLE 12

SOIL-CEMENT TEST RESULTS ON VALENTINE SAND

Soil No.	Horizon	Maximum density pcf	Optimum moisture content %	Soil-cement loss during freeze-thaw test, cement content % by vol: 8	10	11	12	Recommended cement content % by vol	Compressive strength at recommended cement content, psi: 7 day	28 day
51	A	114.7	9.5		6			10	468	668
54	A	110.4	10.7		11			10	245	376
57	A	114.6	10.3	19	12		6	10	258	344
60	A	116.8	9.5		13			10	232	401
52	B	112.5	10.0			8		11	461	646
55	B	111.6	10.4			8		11	283	433
61	B	115.8	10.4			9		11	487	668
53	C	110.2	10.4			8		11	414	481
56	C	112.7	9.8			8		11	243	407
58	C	114.8	10.3	31	19		11	11	267	471
62	C	116.5	9.7			13		11	493	764

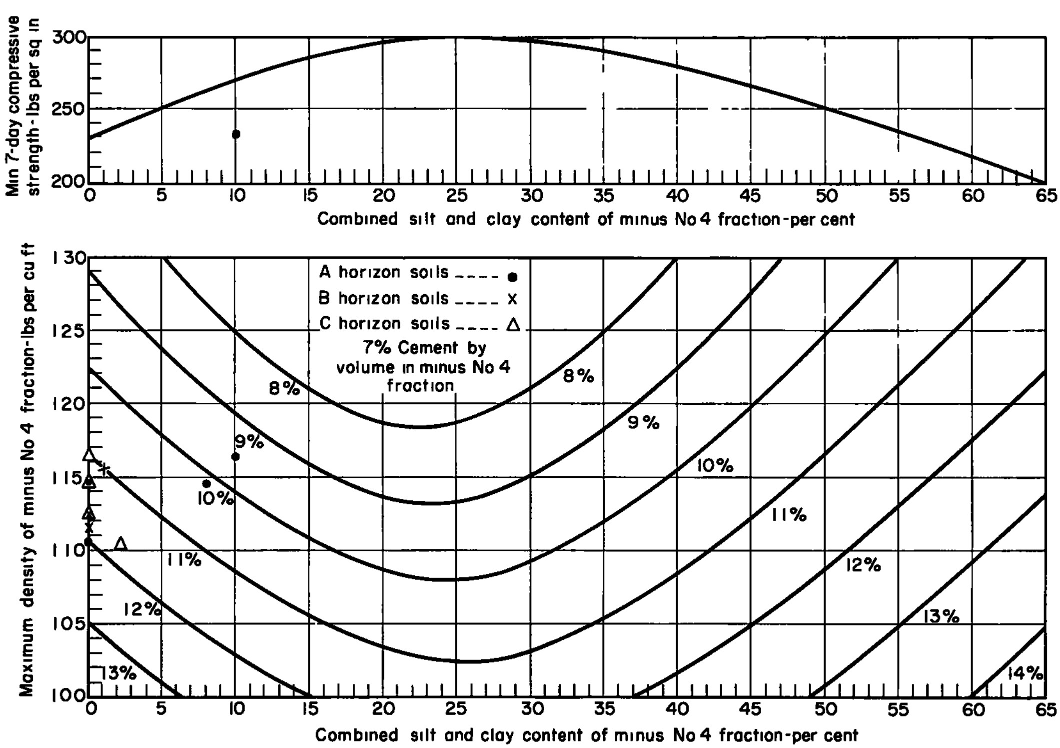

Figure 7. Application of short-cut testing procedure for Valentine sand.

TABLE 13

TEST RESULTS ON THE MAJOR SOIL SERIES IN THE EASTERN HALF OF WASHINGTON AND NORTHERN PART OF IDAHO

			Gradation													
			% Passing				% Smaller than			U S D A	AASHO	Maximum	Optimum	Required Cement	Compressive strength at recommended cement content - psi	
Soil Series	Horizon	Color (moist)	No 4	No 10	No 40	No 200	0 05 mm	0 005 mm	0 002 mm	Textural Class	Soil Class	Density pcf	Moisture %	Content % by vol	7 day	28 day
Athena	A	Br	100	100	99	96	88	21	13	SiL	A-4(8)	99 0	20.4	15	299	-
	B	Br	100	100	100	96	90	24	13	SiL	A-4(8)	98.0	19.4	15	357	-
	C	Yel br	100	100	99	96	85	23	15	SiL	A-6(10)	101 0	20.0	10	307	318
Burke	A	Lt br	100	100	98	62	25	3	2	LVFS	A-4(8)	93 7	20 0	10	197	363
	B_1	Lt gr br	87	82	78	61	49	6	2	SiL	A-4(5)	99 0	18 7	9	471	778
	B_2	Gr	48	36	33	24	20	2	1	G SiL	A-4(6)	112 5	14 2	7	310	-
Douglas	A	Br	100	100	87	57	48	13	7	FSL	A-4(4)	112 5	13 5	7	363	423
	B	Lt br	100	99	80	45	37	8	4	SL	A-4(2)	102 3	15 3	6	466	621
	C	Yel br	100	100	88	48	40	4	1	FSL	A-4(3)	104 5	15 5	6	627	745
Ephrata	A	Lt br	92	73	51	39	34	4	1	GCSL	A-4(1)	119 0	12 8	7	461	-
	B	Lt br	82	58	5	2	2	1	0	CS	A-1-b(0)	116 8	9 7	9	251	-
	C	Lt br	79	57	6	3	2	0	0	GCS	A-1-b(0)	121 5	9 5	9	173	-
Hasseltine	A	Br	67	60	52	42	38	11	7	G SiL	A-4(1)	113 0	15 7	8	325	-
	C	Lt br	61	55	49	39	35	8	3	G SiL	A-4(1)	113 0	15 4	7	438	-
Mission	A	Dk br	100	100	98	91	84	20	8	SiL	A-4(8)	94 0	22 5	14	323	493
	B	Lt br	100	100	99	91	87	25	10	SiL	A-4(8)	102 5	17 5	14	503	-
	C	Gr br	100	100	99	95	89	23	8	Si	A-4(8)	98 5	22 1	14	455	646
Marble	A	Lt br	100	100	70	16	13	4	2	S	A-2-4(0)	115 0	12 8	10	242	344
	C	Yel br	100	100	70	8	2	0	0	S	A-3(0)	117 0	11 4	6	251	388
Nez Perce	A	Dk br	100	100	98	92	88	27	12	SiL	A-5(8)	86.3	28 0	14	-	-
	B	Br	100	100	98	95	92	39	24	SiL	A-7-6(13)	100 0	20 5	12	312	337
	C	Red br	100	100	97	93	91	47	35	SiCL	A-7-6(16)	96 7	24.5	12	387	637
Othello	A	Lt gr br	100	100	99	68	46	3	2	VFSL	A-4(7)	92 5	20.9	10	166	306
	C	Lt gr br	100	100	98	72	58	5	2	SiL	A-4(7)	99 1	18 0	10	365	573
Palouse	A	Dk br	100	100	100	96	90	19	6	Si	A-4(8)	100 5	20.0	10	264	296
	B	Br	100	100	100	97	87	23	12	SiL	A-4(8)	105 0	18 3	8	515	713
	C	Yel br	100	100	98	96	89	21	9	SiL	A-4(8)	105 4	17 8	8	372	589
Quincy	A	Lt br	100	100	85	28	17	4	3	LS	A-2-4(0)	119.8	11 0	7	-	-
	B	Gr br	100	100	81	17	11	0	0	S	A-2-4(0)	116 2	11 7	7	280	546
	C	Gr	100	100	97	76	64	6	1	SiL	A-4(8)	100 0	21 0	11	421	789
Ritzville	A	Lt br	100	100	99	85	67	7	4	SiL	A-4(8)	100 5	18 0	10	644	1044
	C	Lt br	100	100	98	85	76	8	2	SiL	A-4(8)	99 0	19 7	10	627	770
Sagemoor	A	Lt gr br	100	100	98	72	60	15	4	SiL	A-4(8)	105 5	17 1	10	453	630
	B	Br gr	100	100	98	82	74	20	10	SiL	A-4(8)	103 5	19.0	10	480	672
	C	Br gr	100	100	100	91	82	11	4	SiL	A-4(8)	99 2	20 5	10	380	522
Southwick	A	Dk br	100	100	98	92	87	24	12	SiL	A-5(8)	89.1	27 0 over	20	168	181
	B	Br	100	100	98	93	90	30	17	SiL	A-7(12)	94 0	22 8	16	248	286
	C	Lt br	87	87	82	75	71	23	13	SiL	A-4(8)	103 5	19 0	12	245	344
Springdale	A	Lt br	57	46	29	23	20	6	2	GCSL	A-1-b(0)	126.0	9 8	7	292	-
	B	Pale yel	51	40	18	13	11	3	1	GLCS	A-1-a(0)	137 6	7 2	7	270	-
	C	Lt br	47	24	4	2	2	0	0	GCS	A-1-a(0)	127 0	7 0	7	215	-
Timmerman	A	Lt br	100	100	71	57	47	6	1	CSL	A-4(4)	114 7	12 7	8	363	780
	B	Br gr	100	100	17	12	11	4	0	CS	A-1-b(0)	129 0	10 8	7	449	554
	C	Gr	100	100	4	0	0	0	0	CS	A-1-b(0)	113 5	12 8	13	320	802
Touhey	A	Gr br	98	97	89	51	41	6	2	VFSL	A-4(3)	107 0	14 7	10	188	223
	B	Gr br	92	89	79	54	48	7	1	SiL	A-4(4)	115 0	12 5	10	312	522
	C	Lt br gr	74	69	61	45	38	8	1	G SiL	A-4(2)	125 1	10 0	10	301	-
Waite	A	Dk br	88	77	62	47	42	5	2	G Sil	A-5(2)	85 0	27 0 over	20	143	153
	B	Lt br	74	62	50	35	30	5	2	GFSL	A-2-4(0)	108 5	15 7	10	270	-
	C	Yel br	45	33	26	15	13	2	1	GSL	A-1-a(0)	129 7	9 1	5	410	-
Walla Walla	A	Lt br	100	100	98	91	82	22	9	SiL	A-4(8)	101 0	19 5	7	451	748
	B	Gr br	100	100	97	87	77	10	2	SiL	A-4(8)	96 8	20 8	9	591	955
	C	Lt gr br	100	100	97	87	78	10	2	SiL	A-4(8)	91 7	22 4	11	635	993
E Washington Basalt	C	Dk gr	53	36	19	12	10	2	1	GLCS	A-1-a(0)	127 6	9.3	7	216	-

Washington and Idaho Areas

Results of tests on the 20 series from eastern Washington and northern Idaho are given in Table 13. They are all excellent materials for soil-cement construction except for the A horizon for the Waits and Southwick series which require high cement factors due to organic material, and the C horizon of the Nez Perce series, a "tough" clay which would require special effort to pulverize during construction.

Of interest is the Walla Walla series which is developed from loessal materials and which has little textural or structural development. The maximum densities range from 101.0 pcf for the A horizon to 91.7 for the C horizon. Optimum moisture contents range from 19.5 to 22.4, respectively. These values would generally indicate that the soils would require rather high cement factors. The cement requirements for these soils, however, range from 7 percent by volume for the A horizon to 11 percent for the C horizon. Another similar example is the A horizon of the Othello series which is a fine sandy loam having a maximum density of 92.5 pcf and an optimum moisture content of 20.9 percent. This soil requires only 10 percent cement by volume.

It is also of interest to note that the Basalt material reacts very well with cement and requires 7 percent cement by volume. Basalts are found in large quantities in the southeastern part of Washington. The quality is variable due to variations in amount of weathering and additional testing would be required to determine definitely a blanket cement requirement for basalt materials.

SUMMARY

The test results on 43 major soil series from the Great Plains area and from eastern Washington and northern Idaho show them to be, in general, excellent materials for soil-cement construction. The A horizons of four series (Renohill, Williams, Southwick and Waits) required above average amounts of cement due to organic material.

In cases where a soil series was sampled at three or four different locations, the data showed marked similarity in physical properties. This reflects the accuracy of the Department of Agriculture soil maps. Where these check samples were taken, the cement requirements of each profile checked within one percentage point, except in the case of one series, and in most cases results were identical. This further verifies that the cement requirement of a specific soil series and horizon is the same regardless of where it is encountered and points up the value of the pedalogical method of soil identification in soil-cement work.

The importance of the chemical properties of a soil as related to soil-cement is illustrated. Changes in chemical properties of a soil with change in depth in the profile are reflected in changes in cement requirement. These changes in chemical properties outweigh changes in physical properties. This further shows the value of an identification system which recognizes the factors that influence this property such as parent material, age, topography, climate and vegetation.

The cement recommendations given for each of the 43 soil series can be used in construction when these soils are identified in the field. Department of Agriculture soil maps which are available through county extension agents, colleges, universities, libraries, etc, can be used to determine the soil series on any particular project.

It should be recognized that there are a number of soil series in the areas studied which are similar to those investigated. These other soil series would be similar due to similar climatic conditions, rainfall, etc, with some variation in topography, drainage and parent material. These associate soils probably require about the same cement content as the major series tested. A minimum of testing would be needed to establish the cement requirement of these associate soil series and would greatly expand and add to the value of the data presented in this paper.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to members of the staff of the Division of Soil Survey, U. S. Department of Agriculture, for their counsel and cooperation on this project. Their fieldforces also were most cooperative in the field identification and sampling work. Helpful suggestions of members of the Physical Research Laboratory, Bureau of Public Roads, is also appreciated.

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HRB.OR-39

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