CHARACTERISTICS AND USES OF LOESS IN HIGHWAY CONSTRUCTION.

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ABSTRACT. Some of the properties of loess which are important in highway construction are described and discussed. Special physical tests of "soils," which include loess, and which have been standardized by engineers, permit identification of their types and their expected performance as building material. Disturbances of soils due to exposure in cuts and to various subsequent engineering operations have important effect on their properties. There are also some regional variations in loess properties in different sections of Nebraska, which are indicated by a series of tests. Performance of loess in subgrades, as binder in stabilized base courses and filler in bituminous surfacing are described.

THE knowledge of methods of classification of soil as developed by soil scientists or pedologists has been used more and more during the past twenty years, and now, it has been found almost indispensable in highway soil surveys. Highway engineers today generally agree that soil studies are a very essential part of the engineering required in highway design and construction.

Although soil is one of the oldest and most complex of the construction materials, the engineer knows the least about its physical and mechanical properties. He has considerable knowledge of most of the principal materials of construction, can usually find accurate and extensive physical data concerning them, and, generally, can predict with confidence how these materials will perform in a given structure. However, he cannot find corresponding data concerning soils, nor can he predict with certainty how a soil will perform in various structures.

SOIL SURVEYS AND TESTS USED IN HIGHWAY DESIGN.

The Nebraska Department of Roads and Irrigation is charged with the responsibility for the construction and maintenance of the highways of the State. During the early activities of the Department in the construction of low-cost roads, systematic soil studies were inaugurated, in an endeavor to gather general and specific information concerning the characteristics of soil which are related to highway construction. A progress report, Bulletin No. 6 of the Nebraska State-Wide Highway Planning Survey, was the first publication concerning these soil studies.

The general procedures followed by the Department of Roads and Irrigation in conducting soil surveys and performing the identification tests are described in the Methods of Tests of the American Association of State Highway Officials (A.A.S.H.O.) and in Bulletin No. 6 by the Highway Planning Survey. These surveys entail the field identification of soils, sampling, location of areas which carry surface and underground water, and observations of road subgrade conditions and of soil conditions adjacent to highways.

The most important uses of the soil survey in the design of grades and surfacing are to determine: (A) The requirements for compaction of embankments. (B) The necessity of subsurface drainage and its extent. (C) The location and extent of undesirable subgrade soils. (D) The most suitable types of surfacing. (E) The thickness of the surfacing required. (F) The location of acceptable local material deposits for surfacing and bases. Other uses of the soil survey are in landscaping, erosion control, and in foundation engineering.

SOIL TESTS.

Many soil terms and identification tests are common to the soil scientist and the engineer. Many of these tests have been standardized by engineers through organizations such as the American Association of State Highway Officials and the American Society for Testing Materials, and standard procedures for these tests are found in the publications of these organizations.(1) These procedures differ from those used by soil scientists so much that comparable results may not be obtained when the same soils are tested by the two groups. Some of these are Mechanical Analysis, Atterburg Constants, Centrifuge Moisture Equivalent and Shrinkage Tests. Other tests made by the highway engineer and similarly used in the evaluation of soils are the Tri-Axial Compression Test, Shear Test, California Bearing Value Test, Consolidation Test and the Compaction Test.

EFFECTS OF SOIL DISTURBANCE.

The construction of highways affects the natural soil body and the structure of the soil by creation of a number of disturbances, though these sometimes are not apparent. These disturbances create additional problems to those already encountered in nature. Some of these are as follows. The disturbed and recompacted soil often has a much lower shear strength than the undisturbed soil. The construction of a high embankment causes considerable consolidation of the undisturbed natural soil under the embankment. The construction of impermeable and semi-permeable pavement on subgrades and the densification of the soil in cuts and embankments interferes with the normal evaporation and creates seasonal transient water tables. Snow removal operations on bituminous surfaced or black-top roads leave snow on the shoulders. This causes differential temperature conditions in the soil under the shoulders and under the surfacing. The melting snow results in saturation of the road bed and potential frost damage. Drainage problems are often created by intercepting permeable layers of soil which rest on less permeable layers. Deep excavations made for bridge abutments and piers create settlement problems.

MAJOR MANTLE AND BEDROCK AREAS IN NEBRASKA.

From the point of view of the highway engineer the existing division of Nebraska into seven major areas of mantle and bedrock formations is suitable. When working in these areas he will know, to a varying degree of accuracy, the probable type of material which would be encountered in highway construction. These seven regions are Bottomlands, Sand Hills, Glacial Drift Areas, Loess Uplands and Terraces, Clay and Shale Areas, the Mixed Area and Tableland Areas on Sandstone.

The Sand Hills and The Loess Uplands present the most uniform soil conditions of any of the regions as far as the highway engineer is concerned. These two areas include a total of approximately 50,000 of the 77,000 square miles in Nebraska. The Loess Uplands comprise approximately 30,000 square miles, and the loess is quite a common material used in the construction of highways.

EXTENT AND VARIATION OF LOESS.

In general, throughout the Loess Uplands and Terraces, excavations made in hills during highway construction do not penetrate through the Peorian Loess blanket. On the flat uplands the Loveland Loess is seldom exposed. The glacial drift area, located in the eastern part of the state, has been covered with loess deposits but erosion has removed much of them leaving in some places only loess-capped hills. Highway excavations in southeastern Nebraska frequently cut through the loess caps on hills and expose bedrock and glacial deposits. These abrupt changes present different problems than those encountered in the loess in the Loess Uplands and Terraces. The loess is also often mixed with glacial materials during grading operations.

The physical characteristics of the material in the loess blanket are quite uniform. However, there is a tendency toward higher clay content, higher plasticity index, and lower sand content as the distance from the sand-hill area increases. The loess in the bluffs along the Missouri River may be an exception. These tendencies are based on studies of soil profiles encountered in highway planning surveys, which were made both before and after publication of Bulletin No. 6.

The Loess underlying soils of twelve series in twenty-four counties in Nebraska were included in the study of the variation of physical properties of the loess. Four arbitrary zones were established, with an increasing distance from the geographic center of the Nebraska Sand Hills. Figure 1 shows the location of the zones, the limits of which are somewhat generalized.

Table I shows the average of tests of the Loess underlying each soil series in each county which was included in the study. The average tests of loess were obtained for each county, and all county means were then averaged for each zone. The average test values for a county which is cut by a zone line were used in the mean zone values for the zone in which the greater area of the county is included. The mean zone values for per cent sand, per cent silt, per cent clay, and the plasticity index are shown in Figure 2.

The test values used in the construction of this chart are comparative and not absolute. If an attempt is made to correlate these values with test values from other methods of test some differences may be found. In the tests shown on this chart the silt is generally lower and the clay content is generally higher than in tests performed by other organizations. This may be due to degradation of the sample during mechanical dispersion.

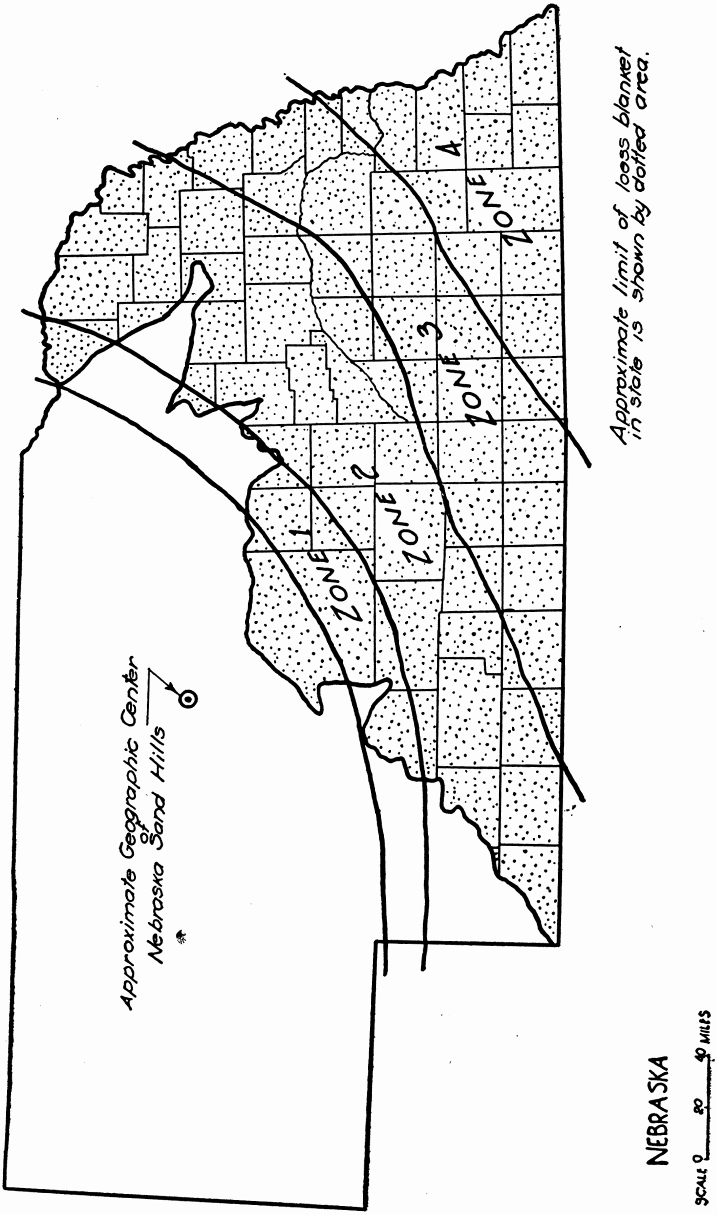

Fig. 1. Location of zones used in determining variation of loess in state of Nebraska.

TABLE I.

Physical Properties of Peorian Loess Underlying Various Soil Series in Certain Counties in Nebraska.

		Mechanical Analysis															Liquid Limit			Plasticity Index			Source and No.
		% Retained on No. 200 Sieve			Sand			Silt			Clay			Colloids									
Soil Series	County	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	of Tests
Butler	Nuckolls	2	1	0	14	13	12	59	58	56	30	29	28	15	14	13	38	37	36	13	12	11	3 L
Butler	Clay		0		13	10	7	63	55	51	38	35	28				40	38	33	18	16	13	4 F
Butler	Butler	2	1	0	15	14	13	63	58	53	33	28	23		19*		36	35	34	11	10	9	1 L, 1 F
Crete-Grundy	Clay	4	2	0	13	10	6	66	60	55	38	30	23				40	36	32	16	14	11	24 F
Crete-Grundy	Nuckolls	4	2	0	17	13	10	65	60	55	32	27	22	16	12	9	40	35	30	16	13	11	5 L, 8 F
Crete-Grundy	Thayer	4	2	0	12	9	8	67	63	58	30	28	25	16	14	12	40	35	30	15	10	5	2 L, 2 F
Crete-Grundy	Polk	4	2	0	16	11	6	67	52	59	30	27	25				39	35	34	15	9	8	1 L, 9 F
Crete-Grundy	Fillmore	4	2	0	8	16	0	66	57	50	41	35	28		15*		46	40	36	18	12	9	3 L, 58 F
Crete-Grundy	Kearney	4	2	0	17	15	13	65	60	55	30	26	22				37	35	33	13	12	11	2 L
Crete-Grundy	Gage	4	2	0	20	11	5	64	57	44	38	32	24		16*		45	38	30	22	16	11	3 L, 10 F
Fillmore	Clay	2	1	0	12	11	10	55	54	53	36	35	34				38	37	35	17	15	14	2 F
Hall-Bearden†	Platte	17	9	2	23	15	12	64	58	50	35	27	18				38	34	29	12	8	3	17 F
Hall-Bearden	Webster	11	4	1	32	21	16	69	58	48	26	21	20	12	10	8	34	31	26	12	9	6	4 L
Hall-Bearden	Furnas		1			17			59			24			12			33			11		1 L
Hall-Bearden	Valley & Garfield	10	4	1	33	23	16	67	61	51	23	16	11		10*		31	29	25	6	4	1	2 L, 8 F
Hall-Bearden	York	2	1	0	14	11	8	57	55	53	35	34	33		18*		42	40	36	18	15	13	1 L, 2 F
Hall-Bearden	Harlan	17	9	2	31	33	17	58	52	38	31	25	20				32	27	24	11	9	7	5 F
Hall-Bearden	Harlan	16	11	9	21	17	12	62	55	45	36	29	23		14*		37	32	26	16	12	8	2 L, 8 F
Hall-Bearden	Gage	2	1	0	12	11	10	56	53	51	39	36	32	20	18	16	47	44	42	20	17	15	2 L
Hastings	Clay	3	1	0	16	11	5	67	59	56	35	30	26		13*		43	34	30	16	13	10	2 L, 13 F
Hastings	Saline	3	2	1	13	12	10	62	59	58	31	29	25				39	37	35	17	15	11	6 L
Hastings	Gage	2	1	0	11	10	9	58	57	56	34	33	32	17	16	15	43	42	41	18	17	16	2 L
Hastings	Webster	2	1	0	16	15	14	66	65	64	21	20	19	11	10	9	35	34	33	10	9	8	2 L

TABLE I (Continued).

Physical Properties of Peorian Loess Underlying Various Soil Series in Certain Counties in Nebraska.

		Mechanical Analysis															Liquid Limit			Plasticity Index			Source and No. of Tests
		% Retained on No. 200 Sieve			Sand			Silt			Clay			Colloids									
Soil Series	County	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	
Hastings	Thayer	9	2	1	34	14	10	65	59	46	32	27	20	16	12	9	42	38	29	16	13	8	8 L
Hastings	York	3	1	0	16	10	6	65	58	46	40	32	17		14*		46	39	33	18	14	10	5 L, 31 F
Hastings	Platte	2	1	0	18	15	14	60	55	48	37	30	25	20	14	11	44	40	36	20	17	12	5 L
Holdrege	Nuckolls	2	1	0	17	13	10	66	59	48	38	28	23				46	36	30	21	15	10	4 L, 9 F
Holdrege	Phelps	5	3	1	23	20	18	60	55	50	31	25	18	17	11	8	37	33	30	15	10	5	7 L
Holdrege	Webster	11	7	1	36	22	13	65	55	40	26	23	20	14	12	10	39	32	28	12	10	8	4 L
Keith	Hitchcock	10	6	2	29	26	20	56	54	51	30	20	16				32	30	28	11	10	8	1 L, 6 F
Knox	Butler		7			26			58			16						29			5		1 F
Marshall	Boone	4	3	2	14	12	10	71	66	62	26	22	19				34	33	31	13	11	9	8 F
Marshall	Madison	2	1	0	16	15	13	65	59	51	36	26	20	21	13	7	44	37	33	20	14	11	6 L
Marshall	Burt & Thurston	4	2	0	14	10	7	67	64	59	29	26	24	18	12	9	38	36	34	15	12	9	11 L
Moody	Dixon & Cedar	2	1	0	19	15	13	63	59	53	34	26	22	18	13	8	37	33	28	14	10	6	6 L
Nuckolls	Nuckolls	9	1	0	27	22	16	55	49	46	37	29	22				41	31	25	19	14	7	1 L, 9 F
Nuckolls	Gage	17	15	14	34	26	20	49	45	42	34	29	24	14	13	12	38	32	29	15	12	10	4 L
Nuckolls	Clay	32	20	4	41	30	15	48	39	30	37	31	27				38	33	29	19	14	10	3 F
Scott	Fillmore	2	1	0	11	7	5	65	55	46	49	38	27				52	42	37	24	15	10	10 F
Scott	York	2	1	0	14	12	9	57	52	44	44	36	30				41	39	33	19	15	7	1 L, 4 F
Maximum Values		32	20	14	41	33	20	71	66	64	49	38	34	20	19	16	52	44	41	24	17	16	
Average Values		6	3	1	20	16	11	62	57	51	34	28	24	16	14	10	39	35	32	16	12	9	
Minimum Values		0	0	0	8	7	0	48	39	30	21	16	11	11	10	7	31	29	24	6	4	1	

* One test only.
† Listed on soil map as "Sandy Loam."

L. = Lincoln Laboratory.
F. = Field Laboratory.

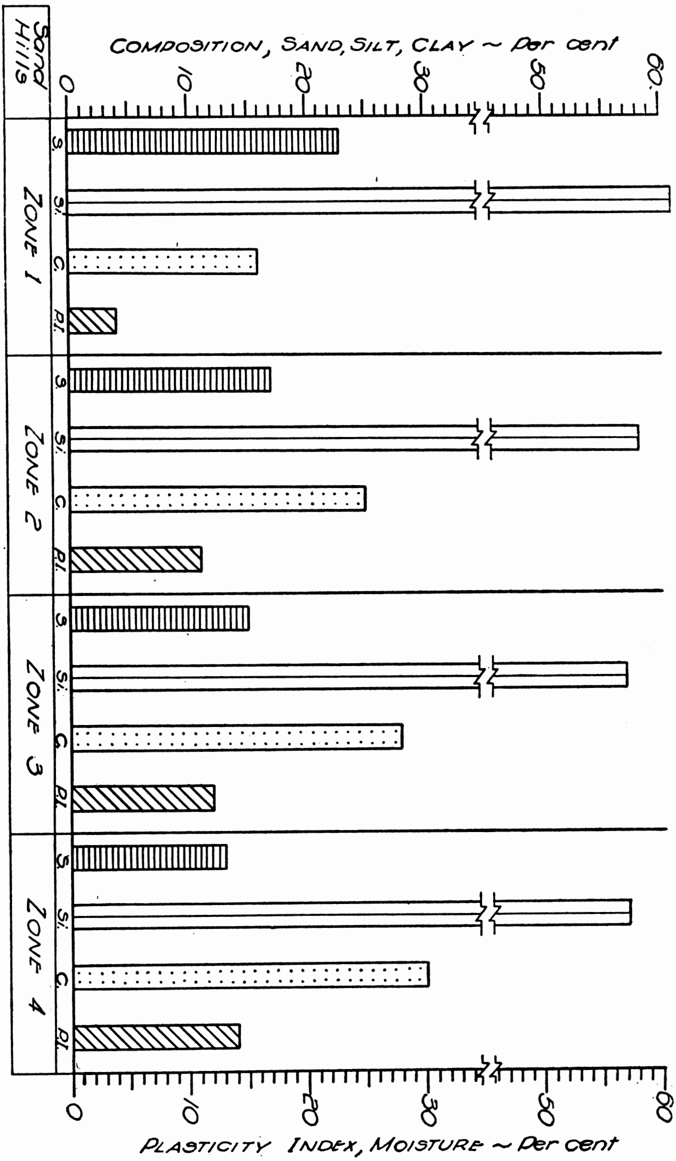

Fig. 2. Variation of sand, silt, clay and plasticity index of loess with respect to distance from geographic center of sand hills in state of Nebraska.

CHARACTERISTICS OF LOESS IN SUBGRADES OR EMBANKMENTS.

The greatest quantity of loess utilized in highway construction is used in the construction of subgrades. The average loess is considered a fair to poor subgrade material in most locations. It is classified by the Public Roads Administration's system as an A-4 subgrade soil. It absorbs water readily and softens to such an extent that it becomes unstable. It has a high rate of capillarity, especially when the silt content is quite high; and when the loess has access to water, detrimental frost heaving may occur during severe winters. This heaving causes differential vertical displacement of the surfacing which results in a rough and sometimes dangerous riding surface. Subsequent thawing results in a soft and unstable area of the subgrade which may be the cause of failure of the surfacing under normal traffic loads.

When the clay content of the loess is near the maximum and the silt near the minimum it is a more suitable subgrade material. The higher clay content reduces the rate of water intake, produces more cohesion under similar water contents and decreases the elastic characteristics. The higher clay content also maintains a more uniform water content during wet and dry cycles.

In the eastern part of Nebraska where the highway excavation frequently cuts through or nearly through the loess, many highway grades result in a soil profile containing a shallow layer of Peorian Loess which rests on Loveland Loess or glacial clay. When these latter materials have a higher clay content or a higher density than the overlying Peorian Loess they perform as an impervious horizon and prevent or retard the downward percolation of surface water. Thus a potential source of capillary water is created which may later cause detrimental frost heaving.

One of the outstanding characteristics of the loess is its ability to stand practically vertical in highway cuts and drainage channels. When the sides of a cut are sloped during construction operations the subsequent erosion of the cut slopes presents maintenance problems.

CHARACTERISTICS AS SOIL BINDER.

Soil Binder is a term describing the material which supplies the cohesion to blended mixtures known as stabilized soil base course mixtures. These mixtures are composed of soil, fine sand, and graded sand-gravel aggregate. Loess is often used as soil binder. The aggregations of particles can be easily pulverized so that the preparation of the loess in base course construction is relatively simple. Loess which contains a high per cent of clay produces better soil binder than does loess which contains a lower per cent of clay.

The function of the soil binder is to produce cohesion and embedding properties in the stabilized soil mixture so that it can be compacted to a high density which does not change with changing water contents. The Public Roads Administration has published considerable data on the selection and use of soil binders.(2)

CHARACTERISTICS AS MINERAL FILLER.

Mineral filler is a term which describes the finely divided material passing the No. 200 sieve and which is used as a stiffening agent in the asphaltic material incorporated in bituminous surfacing mixtures. Filler material is considered as that material which furnishes the preponderance of particle sizes passing the No. 200 sieve. Commercial mineral filler is pulverized by grinding. Limestone dust and Portland Cement are the major commercial mineral fillers.

Loess and numerous soils are used as mineral filler in highway surfacing construction in Nebraska instead of commercial mineral filler due to their low cost and availability. The loess, which is selected for use as mineral filler, should have a high per cent of silt and a low per cent of clay in order that it will be easy to pulverize and not form clods or aggregations if it should become wet after pulverization.

The bitumen absorption of the mineral filler is a characteristic which affects the economy of its use. The absorption of the loess is the lowest of any filler except pulverized silica. Detailed descriptions of the standard tests and of special tests of filler as well as test values of many fillers including loess are reported in the proceedings of the Association of Asphalt Paving Technologists.(3)

Although the loess is the most uniform of natural construction materials there is sufficient variation in its characteristics in most profiles that it can be used for two dissimilar purposes in highway construction, that is, either as soil binder or as mineral filler, in addition to its use in subgrades and embankments.

DISCUSSION.

PATE: Size-particle distribution indicates that there is essentially an axis or focal point in the sandhills, which would suggest this as the point of origin for the loess.

BOLLEN: When making a comparison of this type, using a limited number of samples, we could not change county distribution any. When comparisons are made in different districts we get some results which appear to have certain tendencies but they seem to disappear after a greater number of comparisons are made.

PATE: The heavy soil material in the southeastern part of the state is apparently of loess origin and is farthest from the sandhills.

SCHULTZ referred to J. C. Mahr's thesis on calcium carbonate or lime content of loess which confirmed what Bollen said.

STOUT: If these data seem to indicate that much of our loess comes from sandhills source, perhaps some of this information would suggest that at least a part of our loess is from that source area rather than from a glacial source area. I wonder what percentage comes from the sandhills. I suspect that as we get toward the margins of these areas, one will find local source areas becoming more important. The sandhills are perhaps one major source area of the loess.

BOLLEN: The bluffs along the Missouri River were excepted because they appeared to be quite different. Knowledge from other tests seem to indicate that this loess is somewhat different from the rest of the loess in the state.

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