COMPUTERIZED SOIL TEST DATA FOR HIGHWAY DESIGN

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Sample sites of 22,404 highway engineering soil test samples, representing more than 20 years of highway soil testing throughout South Dakota, were precisely located on soil maps of the National Cooperative Soil Survey, and the test data for each sample site were identified by soil series name. Mapping was sufficiently accurate and most soil series were sufficiently unique to encompass a relatively narrow range of values for any engineering characteristic. The engineering test data include gradation, liquid limit, plasticity index, maximum density, and optimum moisture. The data were placed on computer tape, and a statistical program was written to compute minimum, maximum, mean, and standard deviation of test data, Unified Soil Classification System, old and new AASHO Soil Classification Systems, and mean and maximum California bearing ratio for each horizon of each soil series. Both the unprocessed and the statistical data have been sorted and printed out in several forms for maximum usefulness. The correlated data enable engineers to use pedological soil survey maps to accurately predict the engineering characteristics of soils along proposed highway routes, assist engineers in planning a much abbreviated and economical yet more effective drilling and testing program, indicate specific locations of possible sources of granular and select borrow materials, make possible the compilation of large-scale engineering soil maps or profiles based on any engineering characteristic, aid in route selection, right-of-way appraisal, and location of selected soil series, and give soil scientists and engineers reliable characterizations of soil series based on statistically significant sample size.

•DURING the course of designing and constructing highways, the South Dakota Department of Highways has obtained thousands of soil samples along highway routes during the past quarter century. These samples have all been tested to determine their engineering characteristics. This vast collection of soil information was of very little use after design and construction of the projects on which the samples were taken because the data could not be extended beyond the immediate area of sampling due to a lack of any type of engineering soil mapping.

In some cases, a soil testing program was conducted on new routes that closely parallel old routes even though they were tested originally. Figure 1 shows I-90, which in many places is within ½ mile of the federal-aid routes it replaces over most of its 414-mile length across South Dakota. Soil samples taken along much of the old route could not readily be used in the design of the new route because the areal extent of the various soils was not known. As a result, a new soil exploration and testing program was conducted on much of the new route. It was at this time that the study discussed in this report was started. Its main goal was to find a way of using the large amount of past soil testing experience on new highway locations.

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The U.S. Department of Agriculture's Soil Conservation Service (SCS) in South Dakota has, during the normal course of its work, accumulated a sizable store of published and unpublished soil maps and soil classification information. In 1965 it was decided that an attempt would be made to determine the soil series represented by each highway soil sample based on the type of soil mapped at each sample site. If found to be statistically reliable, this would provide a means of extending the engineering soil data over the entire area mapped by the SCS. Preliminary work indicated that mapping was sufficiently accurate, and most soil series were sufficiently unique to encompass a relatively narrow range of values for any given engineering characteristic.

This paper presents a discussion of the method and results of correlating soil series names with 22,404 engineering soil samples and developing a statistical program to present the data in a useful form.

RECORDING SOIL TEST DATA

The first step in correlating engineering soil test data with SCS taxonomic units was the orderly tabulation of the engineering data. A coding sheet was used to record the engineering data and the project and location data for each sample site. These data included project number, stationing, offset, depth, gradation, liquid limit, plasticity index, maximum density, optimum moisture, and color of each soil sample. This information was then placed on computer-punched cards.

To avoid lengthy checking of the soil classification data as recorded on the original soil data sheets, a computer program was written and each soil sample classified in accordance with AASHO, Unified, and highway textural classification systems. The computer was also programmed to detect obvious errors in recording data and keypunch errors, such as checking to see that the liquid limit value for each sample was larger than the plasticity index and that the percentage passing each sieve was greater than or equal to the percentage passing the next smaller sieve size.

Sample location information, engineering characteristics data, and classifications of each sample were then printed out by the computer. With this printout and a map of each highway project, the exact location from which each soil sample was obtained could be determined. With this information in hand, the SCS started a correlation and identification procedure. This procedure usually did not involve field inspection but was carried on in the office using test information, location of samples, and soil survey maps to properly identify the soils concerned. Each soil series was assigned a code number that was placed on the data sheet for each sample. In addition to soil series identification, the horizon designation was also determined. The depth of engineering soil samples often spanned more than one horizon, but the horizon thought to be best represented by the sample depth and test data was selected. Horizon designations were limited to A, B, C, 2C, and R.

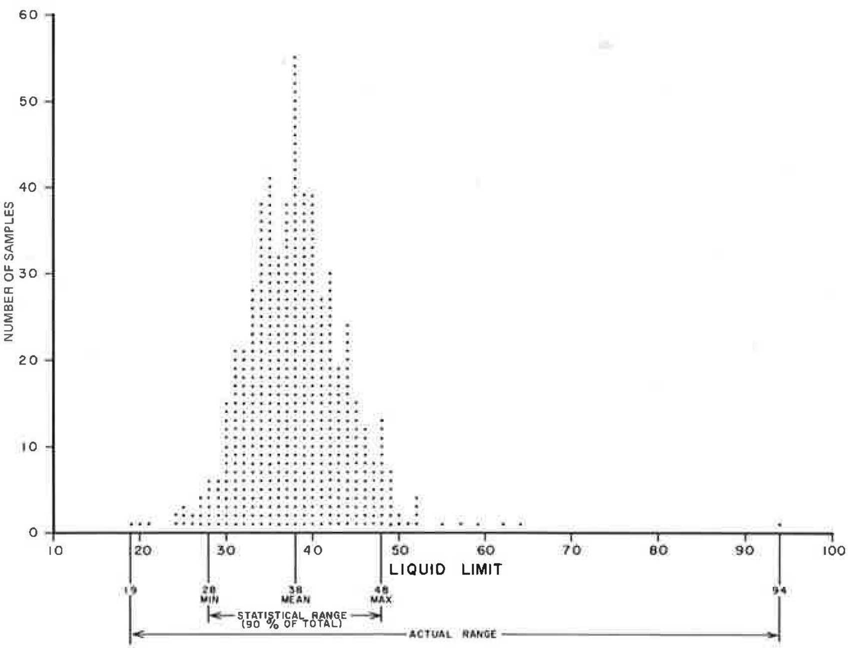
Following the correlation of engineering data with the soil types, the next step was to print out the correlated data.

ANALYSIS OF DATA

Upon completion of the correlation portion of this study 22,404 individual soil samples had been processed. This was still a prodigious volume of soil information that, to be useful, had to be reduced to a concentrated yet meaningful form. Figure 2 shows the distribution of the liquid limit values of the 561 samples of the Houdek series, C-horizon. The actual range of these values was from 19 to 94. This range includes several samples that obviously are not within the concept of the Houdek series, C-horizon. Through statistical analysis it was found that 90 percent of the soil can be expected to fall within the range of 28 to 48, using the standard deviation of 6.2 with a mean of 38. This limited range better portrays the actual variation expected in the C-horizon of areas mapped as the Houdek series. The maximum and minimum values shown in Figure 3 for all engineering characteristics are statistically derived to include 90 percent of the range centered about the mean, with the extreme upper and lower 5 percent excluded. The soils at these extremes are assumed to be inclusions of other soils that would not be called Houdek if they occurred as areas large enough to be

Figure 1. Old and new highway routes across South Dakota.

Figure 2. Sample distribution curve for Houdek series, C-horizon.



mapped separately. This results, for instance, in 95 percent of liquid limits for each soil or horizon falling below the maximum values shown. These data were then calculated for all horizons of all series by use of a computer program. Figure 3 is an example of the computer output from this program. This printout includes some additional information that the computer was programmed to provide. The new AASHO Soil Classification System was added showing the revised group index numbers. Also added were the California bearing ratio (CBR) values as determined from the liquid limit as calculated by the South Dakota Department of Highways. Figure 4 shows the relation of liquid limit values and CBR values as used in highway design procedures in South Dakota.

The soil data have been printed out in the following forms:

1. The results of the statistical program are machine-sorted (a) statewide by series as shown in Figure 3 (this is the primary end product), (b) by counties (in order of series within each county), and (c) by series (sorted by counties in which each series occurs); and
2. The individual sample data are machine-sorted (a) statewide by project and stationing, (b) by county (in order of series and horizons within each county), (c) statewide by soil series and horizon (in order of increasing liquid limit within each series and horizon), and (d) by AASHO Soil Classification System.

Printouts of programs for any of the statistical or individual sample data sorts are available from the South Dakota Department of Highways.

USES OF CORRELATED SOIL DATA BY THE SOUTH DAKOTA DEPARTMENT OF HIGHWAYS

Highway Design

With the correlation of engineering properties of soil with the soil maps produced by the SCS, engineers have a means of extending their knowledge of a soil from the immediate area in which it was sampled to the entire area over which the soil is found. The agriculture industry has been extending its knowledge of soil in this manner for years. In the past, the lack of engineering soil maps and the lack of correlation of engineering soil properties with existing soil maps have prevented engineers from applying their knowledge of soil over broad areas of the state. Where soil maps are published, an engineer must only locate a proposed highway route on the maps, scale the distance to each soil contact boundary, and look up the engineering characteristics of each soil to determine the soil properties along the proposed route. In areas where published maps are not available, an engineer may obtain soil mapping information from the appropriate SCS office. In areas that have not been mapped, SCS can rapidly map a strip of land along and adjacent to a proposed route. Soil maps are thus available or can be obtained for any area within the state with a minimum of effort.

On some projects where time does not permit a detailed field drilling and sampling program, the engineer has found it necessary and expedient to design directly from the computer data using soil survey maps. In South Dakota the standard method of determining the strength of soil requires using the average liquid limit from a group of samples sorted by similar characteristics and test results, determining the CBR from the curve shown in Figure 4, and proceeding with a CBR design method. By using the average liquid limit, 50 percent of the highways constructed on this soil are theoretically underdesigned. However, by using the maximum value as shown in Figure 3, 95 percent of the highways constructed on a given soil series will be properly designed. For most soils this increase will add approximately 1 in. of thickness. The estimated CBR values are computed by using both the mean liquid limit and the maximum liquid limit.

Soil Investigations and Drilling Programs

In South Dakota it was standard practice for many years to drill every 300 to 500 ft and sample every 1,200 to 1,500 ft on every project. By using soil maps and computerized data, the engineer now plans a much reduced yet more effective soil drilling and sampling program by concentrating his efforts in excavation and borrow areas, in areas where engineering soil data are meager, on soil types where the range of values of engineering properties is extraordinarily wide, or where problem areas appear. With this system, field drilling, sampling, and testing have been reduced substantially. Drilling on the average project now takes about 2½ to 3 days against about 10 days previously.

Materials Inventory

By using a different sorting of the data from the computer, the soils are grouped according to the AASHO Soil Classification System. In other words, all A-1-a soils are grouped together. This allows people involved in materials inventory studies to determine where valuable construction materials have been found throughout the state along existing highway routes.

Engineering Soil Maps

When the engineering properties of each soil are known, it is possible to prepare engineering soil maps by setting up class interval limits for any engineering property and assigning a color or pattern to each class interval. This can be done for any scale or intensity of mapping but is probably most useful when used on large-scale generalized county or state maps. A state engineering soil map has been prepared for South Dakota using mean liquid limits in five class intervals. The base map used is entitled Soil Associations of South Dakota. To date, the South Dakota Department of Highways has hand-colored copies for its own use, but the map has not been published.

Although not directly related to this project, it seems appropriate to mention that the SCS also furnishes other information about soils that is useful to engineers. In addition to published soil surveys, such information can be obtained from soil interpretation sheets that are being prepared to supplement soil series descriptions. The information of most interest to the highway engineer is the ratings of shrink-swell potential, potential frost action, and corrosivity to uncoated steel and concrete. State soil maps are being prepared for the corrosivity factors.

Other Engineering Uses

Other applications of computerized soil data include favorable route selection, aid to right-of-way appraisal, aid in locating various types of soils for use in the soil mechanics classes of engineering schools, and planning roadside improvement projects and rest areas.

USES OF CORRELATED SOIL DATA BY SCS

A statistical printout of the data for each county allows a comparison of engineering properties of soils from one county to another. The data given in Table 1 indicate that the Houdek series in Davison County is slightly less clayey than in other counties in which the soil occurs. Also the Kyle series in Fall River County is markedly less clayey than the Kyle soils from other counties. This information may indicate the necessity for establishing a new series, reviewing the concept of the Kyle soil in Fall River County, or classifying the soil in a different series.

The data give a more reliable characterization of a soil type than the usual one or two modal samples because of the statistical significance of the larger sample size.

PROJECT COST AND BENEFITS

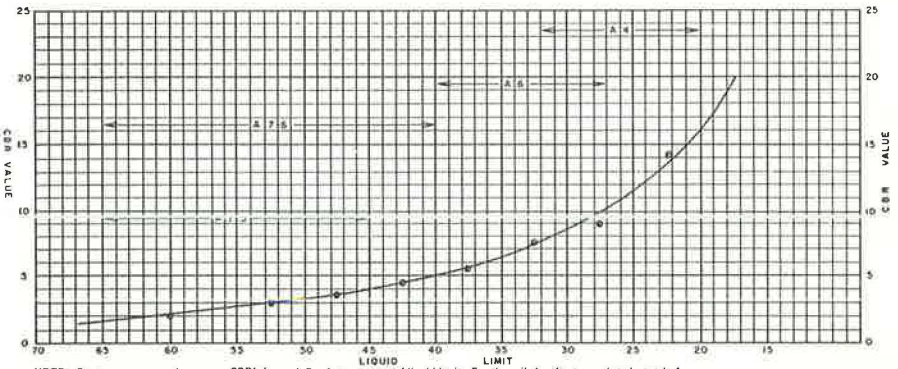
Total project cost to the South Dakota Department of Highways was $54,000, including data collection and coding, punching cards, preparing printouts and maps for series identification of SCS, tape updating, programming, and producing final printouts of data in several forms. Time spent by the SCS in locating and identifying soil samples is not included in this figure.

Figure 3. Computer printout of statistically processed soil data.

SERIES 363.0 HOUDEK

HORIZON		A	B	C	2C	R
NO OF SAMPLE		183	420	561	10	0
NO. 3/8	MIN	99	99	98	94	0
	MAX	100	100	100	100	0
	MEAN	100	100	100	99	0
	STANDARD DEV.	0.5	0.8	1.0	2.8	0.0
NO. 10	MIN	94	93	91	88	0
	MAX	100	100	100	100	0
	MEAN	98	97	96	97	0
	STANDARD DEV.	2.8	2.7	3.2	5.4	0.0
NO. 40	MIN	85	85	81	76	0
	MAX	100	99	98	100	0
	MEAN	93	92	90	92	0
	STANDARD DEV.	4.6	4.3	5.3	9.5	0.0
NO. 200	MIN	55	57	52	55	0
	MAX	87	85	94	100	0
	MEAN	71	71	68	80	0
	STANDARD DEV.	9.6	8.6	9.7	15.4	0.0
NO. 5MIC	MIN	15	20	20	24	0
	MAX	37	45	44	78	0
	MEAN	26	32	32	50	0
	STANDARD DEV.	6.8	7.4	7.3	16.6	0.0
LIQUID LIMIT	MIN	29	31	28	33	0
	MAX	47	49	48	79	0
	MEAN	38	40	38	56	0
	STANDARD DEV.	5.2	5.6	6.2	14.0	0.0
PLASTIC INDEX	MIN	9	12	11	14	0
	MAX	22	28	29	56	0
	MEAN	15	20	19	35	0
	STANDARD DEV.	4.0	4.9	5.3	13.0	0.0
NO OF DENSITY SAMPLE		39	152	250	5	0
MAXIMUM DENSITY	MIN	87	96	101	98	0
	MAX	110	114	117	108	0
	MEAN	98	104	108	103	0
	STANDARD DEV.	7.0	5.4	4.7	3.1	0.0
OPTIMUM MOISTURE	MIN	16	15	14	17	0
	MAX	28	23	21	23	0
	MEAN	21	19	17	20	0
	STANDARD DEV.	3.7	2.6	2.1	1.6	0.0
UNIFIED CLASS		MLCL	CL	CL	CH	
OLD AASHO		A6(9)	A6(11)	A6(11)	A76(19)	(0)
NEW AASHO		A6(10)	A6(13)	A6(12)	A76(29)	(0)
ESTIMATED CBR MEAN		6	5	6	3	0
ESTIMATED CBR MAX.		3	3	4	1	0

Figure 4. California bearing ratio—liquid limit curve.



NOTE: Points on curve are the average CBR's for each 5 point increment of liquid limit. For the soil classification as listed a total of 138 CBR tests were used to develop the curve. CBR and liquid limit relationship is not applicable to granular soils (the A1, A2, and A3 and subgroups of these classifications).

Table 1. Mean liquid limit variation among counties.

Houdek Series			Kyle Series		
	Horizon			Horizon	
County	B	C	County	B	C
Aurora	43	42	Butte	65	65
Beadle	39	37	Custer	63	60
Bon Homme	40	37	Fall River[a]	52	55
Brule	44	46	Haakon	70	73
Davison[a]	34	34	Jackson	67	72
Douglas	39	39	Lawrence	70	—
Hand	40	40	Meade	68	59
Hanson	38	37	Pennington	64	64
Hutchinson	40	38	Average	66	68
Jerauld	38	35			
McCook	45	43			
Miner	43	43			
Sanborn	38	36			
Spink	43	38			
Turner	40	42			
Yankton	43	36			
Average	40	38			

[a]Mean liquid limit indicates that review of mapping concepts to improve uniformity within a series may be necessary.

Although this project was conceived and carried out intermittently over a period of about 8 years, it is estimated that the total activity, if uninterrupted, could be completed in about 1 year.

A cost analysis indicates that the previous average annual soil survey cost was approximately $68,000; it now averages about $23,000, an annual saving of $45,000.

FUTURE STUDIES

It is anticipated that these data can be made more useful to highway engineers in several ways. An attempt will be made to relate highway performance and highway design to soil series and to soil-moisture relations. In several instances this possibility has appeared promising.

For example, contacts between soils or geologic materials of contrasting textures are often a problem, such as a mantle of windblown silt overlying clay shale or glacial till, a fairly common condition in South Dakota. In this situation, inadequate internal drainage of the underlying layer causes a concentration of moisture in the vicinity of the contact, which in turn can result in distortions and breakups of surfacing due to shrink-swell differentials, frost damage from ice lens buildup, and reduced subgrade strength at high-moisture contents. This is particularly evident where contacts occur on a hillside.

A related problem that has been noted is the high degree of variability of soil textures, which can and often does occur over relatively short distances, particularly where local relief is greater than about 6 percent combined with horizontal contacts within a few feet of the surface. Again, this results in heaving and breakups caused by differences in moisture-holding capacities and permeability rates among soil materials of contrasting textures from one location or level to another. One way of minimizing such differences is by undercutting and compacting the undercut soil or replacing with select soil of uniform texture.

Another problem on soils known to be underlain by clay shales of the Pierre formation is deep-seated bed movements and seeps caused by entry of water into subsurface fractures, faults, and bentonite seams, resulting in sliding or swelling when wet. No satisfactory remedy has been found for this type of movement.

In general, highway distress is seen to be related primarily to swelling, loss of soil strength, and frost heaving due to entry and retention of local drainage moisture in soil materials relatively high in silt and clay. There is obviously considerable variation in the degree to which different soil series contribute to these problems.

Relations of this type will be studied, and, as causes of distress become better understood, relief measures will be incorporated in the design process wherever possible.