Engineering properties of some Montana soil series
by William Pius Volk

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Soil Science
Montana State University

Abstract:
The purpose of this study was to determine the use of National Cooperative Soil Surveys by highway departments, assign highway soil test data to mapping units, evaluate the estimated engineering ratings in the soil survey and inspect the relationship between engineering classes of Unified and AASHO and the family level of soil classifi- ation.

A questionnaire with 98% return revealed 82% of highway departments use the soil survey in varying degrees. Nine departments have produced literature to interpret soil survey maps for departmental needs.

Highway engineering data for 900 sites were precisely located on soil maps of the National Cooperative Soil Survey and assigned to mapping units. These soil tests would ordinarily cost about $55,000.

An additional 406 samples of 62 soil series were compiled from files, manuscripts and published soil surveys. Engineering data include gradation, liquid limit, plasticity index, depth, optimum moisture, maximum density, AASHO and Unified soil engineering classifications.

This study compares soil survey data with highway department data, and documents the reliability of soil surveys as a source of estimated engineering characteristics.

A comparison of soil engineering classes with soil family classification based upon 745 samples indicated that generally reliable predictions of engineering ratings at the major group level can be made when only the soil families are known.

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Signature William P. Volk

Date May 24, 1974

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by

WILLIAM PIUS VOLK

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree

of

MASTER OF SCIENCE

in

Soil Science

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Bozeman, Montana

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Deserving recognition in the Montana Highway Department is Mr. Joe Armstrong, Chief Geologist, for his interest and generous use of files and maps; those deserving special recognition in the Soil Conservation Service are Mr. Jack Rogers, Mr. Shelby Brownfield and Mr. Bobby Richardson for their interest and encouragement.

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To my family, I owe a debt of gratitude difficult to repay. My wife, Karilynn, was confidante, secretary and typist. Without her talents and understanding this thesis could not have been completed. To Amy, who had an absentee father, my love.

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ABSTRACT

The purpose of this study was to determine the use of National Cooperative Soil Surveys by highway departments, assign highway soil test data to mapping units, evaluate the estimated engineering ratings in the soil survey and inspect the relationship between engineering classes of Unified and AASHO and the family level of soil classification.

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INTRODUCTION

As Montana's population increases and the use of land shifts from agriculture and forest land to commerce, industry and housing, great interest has developed in land use planning. Meanwhile, the wealth of natural resource information has also been growing, but those who desire this information for planning have sometimes been thwarted because the data were not in a form compatible with their needs. For some, the data were too general; for others too detailed, and mostly the information was collected for other purposes. New laws, environmental impact statements, planning interests and a general desire to use resources according to their natural capabilities have increased the demand for readily available information about soil physical properties.

The pedologic system of soil classification and the resultant soil survey enable accurate identification of soils, and facilitate boundary delineation of a particular soil wherever it occurs (Soil Survey Staff, 1973). It is therefore possible through soil surveys to transfer knowledge previously obtained about a soil to other areas where that soil occurs.

The soil survey, as published by the Soil Conservation Service (SCS) has become the document used by diverse agencies and disciplines to obtain soil associated data for uses other than those agriculturally oriented. Due to the lack of resources to do replicated engineering tests on all 700 soil series in Montana, many ratings are systematically predicted. These predictions are based upon a limited number of laboratory tests.

Detailed soil investigations for highway construction have traditionally been conducted by making borings at intervals throughout a proposed route. These data, once determined and used on a project, could not be directly related to other projects in distant or adjacent geographic areas, or to others needing soil engineering data. When these data are correlated with pedologic soil map units, the value is enhanced. Substantial savings in drilling and testing can be realized (see South Dakota in Appendix III). Few state highway departments have adopted a pedologic soil survey approach to soil investigations and fewer have correlated soil engineering data with pedologic soil classification.

The study reported here represents the most complete thesaurus of soil series engineering data available for reference in Montana.

The purposes of this study were to:

1. Determine use of the pedologic soil survey by highway departments of the United States and Puerto Rico.

2. Determine if highway engineering data from soil borings can be applied to soil surveys in Montana.

3. Investigate the relationship between engineering ratings and the family level of soil classifications.

4. Evaluate the assigned SCS predicted engineering ratings in soil surveys.

5. Demonstrate products now obtainable from this extensive work.

REVIEW OF LITERATURE

The literature on engineering applications of soil survey information is extensive. References to soils as engineering materials vary from a mere suggestion that perhaps "the condition (corrugation of roads) is attributed to the peculiar soil" (Mather, 1963), to theses investigating the direct application of pedology to engineering (Haas, 1954; Keyser, 1961; Schori, 1971). Several texts include aspects of engineering treatment of soils (Abbet, 1956; Hewes and Oglesby, 1954; Woods, 1960).

Many investigators describe uses of soil surveys in engineering techniques (Elder, 1966; Rutka, 1961). Odel, et al, (1960) obtained multiple correlation coefficients of 0.959, 0.887 and 0.938 in a wide range of soils between liquid limit, plastic limit and plasticity index and three soil properties (% organic C, % clay, and % montmorillonite in clay).

The Portland Cement Association's soil primer (PCA, 1962) "was prepared to furnish highway engineers with basic information on soil with regard to its influence on the design construction, and performance of concrete, soil cement and other types of pavement surfaces" and "to reduce the substance of the most important treatises on soil science as related to pavements" and "to reduce this material to the simplest and most useful terms".

Publications by the Highway Research Board and the American Society of Testing Materials are major sources of information.

The importance of soil maps to scientists and engineers is illustrated in a highway engineering handbook by McAlpin and Hoffman, 1960.

> Soil science has provided an orderly procedure of classifying and indexing soil profiles throughout the world; and the identification of the in-place soil profile, which is the basis of this procedure, is founded on scientific observations that relate the full geologic history of an area to the natural environmental characteristics that have been responsible for the development of the current soil profile characteristics. Truly, this is a great scientific contribution, and its usefulness extends far beyond the field of agriculture...
>
> The scientific development of the pedologist in regard to the identification and classification of soils might still be buried in technical publications and usable by only a few specialists had not this knowledge been summed up graphically and presented in the form of soil survey maps. Such maps and the companion reports that give the soil description provide a rapid and accurate means of identifying the soil at a particular location, its areal extent, and its relationship to the other soils of the area.

The state highway departments of Missouri, Nebraska, and Wisconsin have prepared soils manuals to interpret pedologic soil survey mapping units for highway construction purposes (see Appendix III). The Michigan State Highway Department has prepared a Field Manual of Soil Engineering that specifies engineering properties by soil type (see Appendix III).

South Dakota Department of Highways and the Soil Conservation Service have cooperated to computerize a vast amount of soil data for highway testing and design (see Appendix III). This joint venture has resulted in both agencies producing better products and realizing substantial savings of taxpayer funds.

Cities and county road departments, with limited resources for soil drilling and testing, and private construction firms, would find soil series assigned engineering data helpful in planning and decision processes.

While this subject has been extensively discussed by many, very few have made a significant amount of data available for use by other agencies, engineers or scientists.

SYSTEMS OF SOIL CLASSIFICATION

Pedology

Pedology, or soil science, is defined as "the science dealing with soils as a natural resource on the surface of the earth including soil formation, classification, mapping, and determining the physical, chemical, biological and fertility properties of soils per se; and these properties in relation to their management and use." Soil science is based on the testimony that a soil's structure, form and properties are determined and controlled by five factors acting in combination. These factors are: (1) parent material, (2) climate, (3) relief, (4) biota, and (5) age.

Early soil classification systems have undergone changes and refinements. Soil scientists in the United States have, during the last decade, developed a more precise system of soil classification for making and interpreting soil surveys (Soil Taxonomy, Soil Survey Staff, 1973).

Engineering Classification

The engineering classification systems are based on laboratory analysis of disturbed soil samples for: (1) gradation analysis, (2) liquid limit and (3) plastic limit and other tests which are not of immediate concern to this study (Table 1, page 7).

Table 1: Standard Engineering Soil Tests

Standard Tests	Designation*	
	AASHO	ASTM
a. Sieve Analysis of Fine and Coarse Aggregates	T27	C136
b. Mechanical Analysis of Soils	T88	D422
c. Liquid Limit of Soils	T89	D423
d. Plastic Limit of Soils	T90	D424
e. Calculating the Plasticity Index	T90	D424

* AASHO: American Association of State Highway Officials

ASTM: American Society for Testing Materials

Mechanical Analysis

Gradation of samples is evaluated by determining the percentage of sample material which passes through sieves numbered 4, 10, 40 and 200. This conforms to the requirements of standard specifications (AASHO Designation: M 92). A comparison of the grain size limits in three classification systems is presented in Table 2, page 9.

Liquid Limit

The liquid limit (LL) of a soil is that water % by weight at which the soil passes from a plastic to a liquid state (AASHO Designation: T 89-60).

Plastic Limit

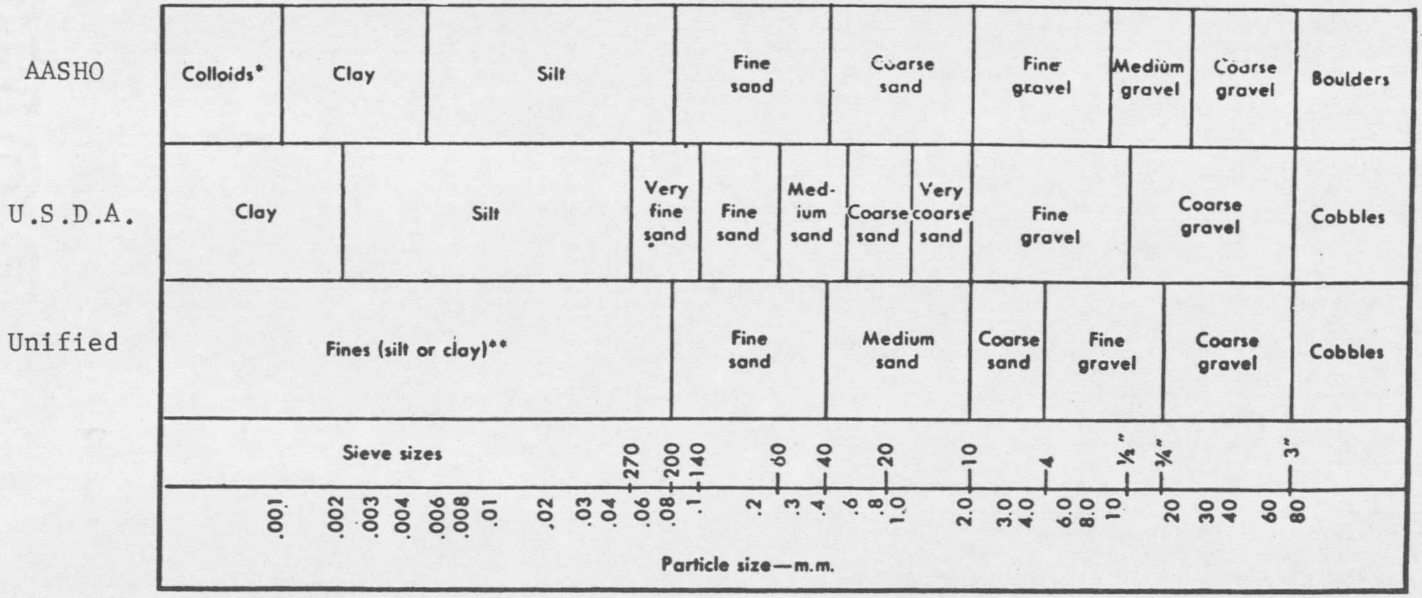
The plastic limit (PL) of a soil is the lowest water % by weight at which the soil remains plastic (AASHO Designation: T 90-61).

Plasticity Index

The plasticity index (PI) of a soil is the difference in water % between its LL and its PL (AASHO Designation: T 90-61).

The two systems most commonly used in classifying samples of soils for engineering are: (1) the Unified system used by engineers in SCS, Department of Defense, Bureau of Reclamation and others; and (2) the

Table 2 . A COMPARISON OF GRAIN-SIZE LIMITS IN THE 3 CLASSIFICATION SYSTEMS.



*Colloids included in clay fraction in test reports.

**The L.L. and P.I. of "Silt" plot below the "A" line on the plasticity chart, Table 4 and the L.L. and P.I. for "Clay" plot above the "A" line.

system adopted by the American Association of State Highway Officials (AASHO).

In the Unified system soils are classified according to particle-size distribution, plasticity, liquid limit and organic matter content.

Soil classes are coded to designate 15 groups of soils. The components and corresponding symbol are: Gravels -- G, Sand -- S, Silt -- M, Clay -- C, Organic -- O, Peat -- Pt. The gradation symbols are: poorly graded -- P, well graded -- W. The liquid limit symbols are: high liquid limit -- H (>50), low liquid limit -- L (<50). There are eight classes of coarse-grained soils, identified as GW, GP, GM, GC, SW, SP, SC; six classes of fine-grained soils, identified as ML, MH, CL, CH and OH; and one class of highly organic soil, identified as Pt (Table 3, page 11). The suffix d is used when the liquid limit (LL) is 25 or less and the plasticity index (PI) is 5 or less; the suffix u is used otherwise. Typical symbols for soils in this group are GMd and SMu.

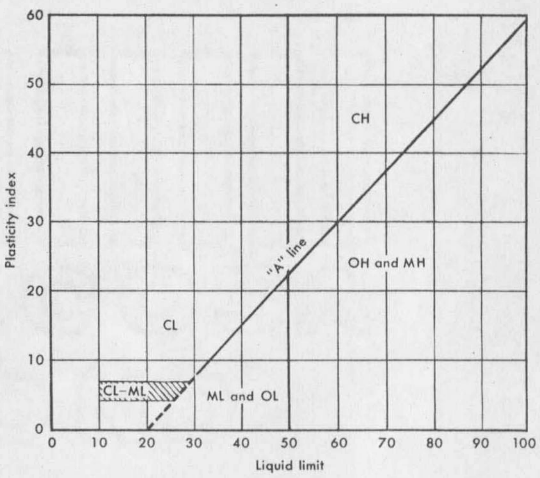
Soils on the borderline between two classes are designated by symbols for both classes, for example, ML-CL.

The plasticity-compressibility characteristics are evaluated by plotting the liquid limit (LL) on a standard plasticity chart (Table 4, page 12). The position of the plotted points yields information from which its behavior as a construction material is predicted.

The AASHO system is used in classifying soils according to those properties that affect use in highway construction and maintenance. In

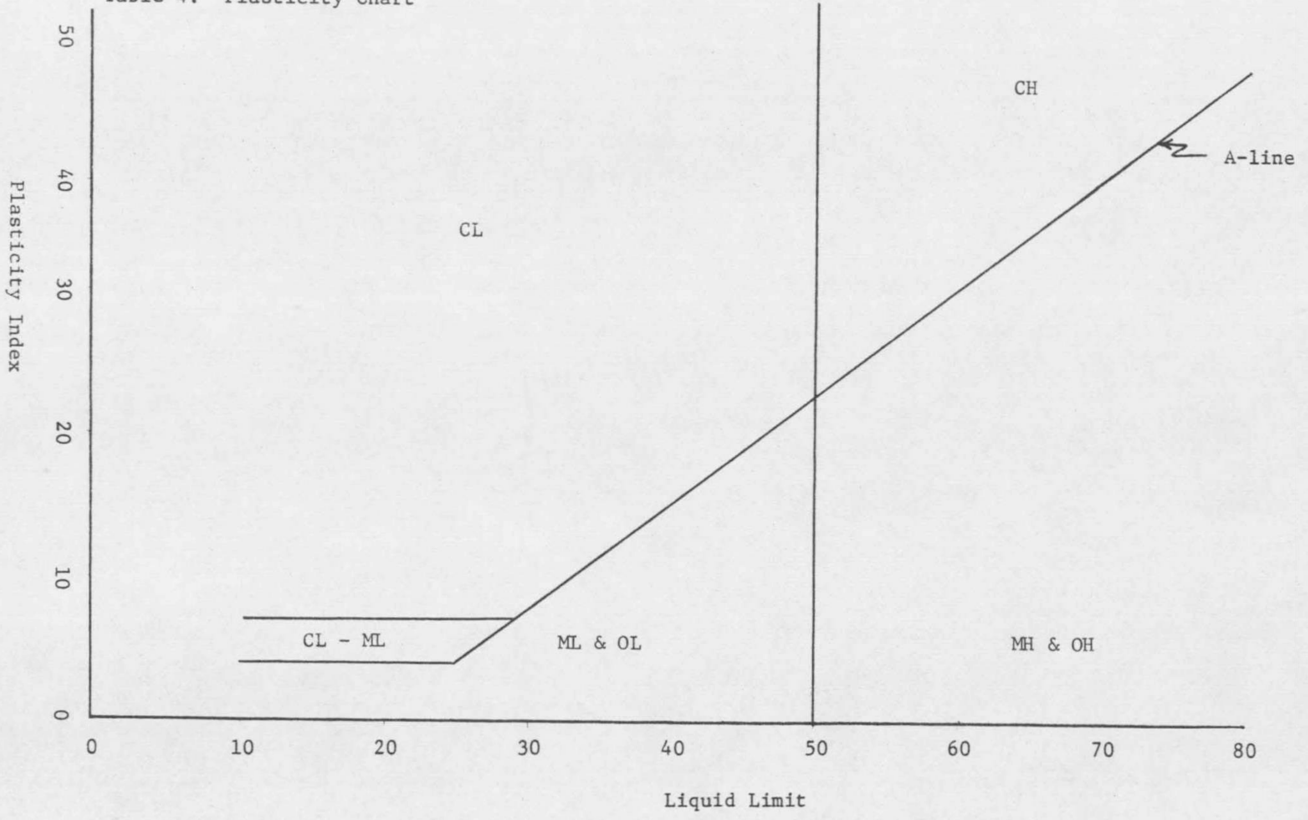
Table 3. Unified Soil Classification System

Major divisions			Group symbols	Typical names	Laboratory classification criteria		
Coarse-grained soils (More than half of material is larger than No. 200 sieve size)	Gravels (More than half of coarse fraction is larger than No. 4 sieve size)	Clean gravels (Little or no fines)	GW	Well-graded gravels, gravel-sand mixtures, little or no fines	Determine percentages of sand and gravel from grain-size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size), coarse-grained soils are classified as follows: Less than 5 per cent .... GW, GP, SW, SP; More than 12 per cent .... GM, GC, SM, SC; 5 to 12 per cent .... *Borderline* cases requiring dual symbols**	$C_u = \frac{D_{60}}{D_{10}}$ greater than 4; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3	
			GP	Poorly graded gravels, gravel-sand mixtures, little or no fines		Not meeting all gradation requirements for GW	
		Gravels with fines (Appreciable amount of fines)	GM* d / u	Silty gravels, gravel-sand-silt mixtures		Atterburg limits below "A" line or P.I. less than 4	Above "A" line with P.I. between 4 and 7 are *borderline* cases requiring use of dual symbols
			GC	Clayey gravels, gravel-sand-clay mixtures		Atterburg limits above "A" line with P.I. greater than 7	
	Sands (More than half of coarse fraction is smaller than No. 4 sieve size)	Clean sands (Little or no fines)	SW	Well-graded sands, gravelly sands, little or no fines		$C_u = \frac{D_{60}}{D_{10}}$ greater than 6; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3	
			SP	Poorly graded sands, gravelly sands, little or no fines		Not meeting all gradation requirements for SW	
		Sands with fines (Appreciable amount of fines)	SM* d / u	Silty sands, sand-silt mixtures		Atterburg limits below "A" line or P.I. less than 4	Limits plotting in hatched zone with P.I. between 4 and 7 are *borderline* cases requiring use of dual symbols.
			SC	Clayey sands, sand-clay mixtures		Atterburg limits above "A" line with P.I. greater than 7	
Fine-grained soils (More than half of material is smaller than No. 200 sieve)	Silts and clays (Liquid limit less than 50)		ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands, or clayey silts with slight plasticity	Plasticity Chart (see below)		
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays			
			OL	Organic silts and organic silty clays of low plasticity			
	Silts and clays (Liquid limit greater than 50)		MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts			
			CH	Inorganic clays of high plasticity, fat clays			
			OH	Organic clays of medium to high plasticity, organic silts			
	Highly organic soils		Pt	Peat and other highly organic soils			



Plasticity Chart

Table 4. Plasticity Chart



this system, a soil is placed in one of seven basic groups ranging from A-1 through A-7 on the basis of grain-size distribution, liquid limit, plasticity index, and one class of highly organic soil, identified as A-8. In group A-1 are gravelly soils of high bearing strength, the best soils for subgrade (foundation).

At the other extreme, in group A-7, are clay soils that have low strength when wet and are the poorest mineral soils for subgrade. There are three major groups with six subgroups of coarse granular materials identified as A-1, A-2, A-3 with subgroups A-1-a, A-1-b and A-2-4, A-2-5, A-2-6, A-2-7. The four groups of fine-textured soils are A-4, A-5, A-6 and A-7 with two subgroups A-7-5 and A-7-6 (Table 5, page 14). As an additional refinement, the engineering value of a soil material can be indicated by a group index number. Group index values range from 0 for the best material to 20 or more for the poorest (Table 5-1, page 15).

Table 5. AASHO Classification of Soils and Soil-Aggregate Mixtures (With Suggested Subgroups).

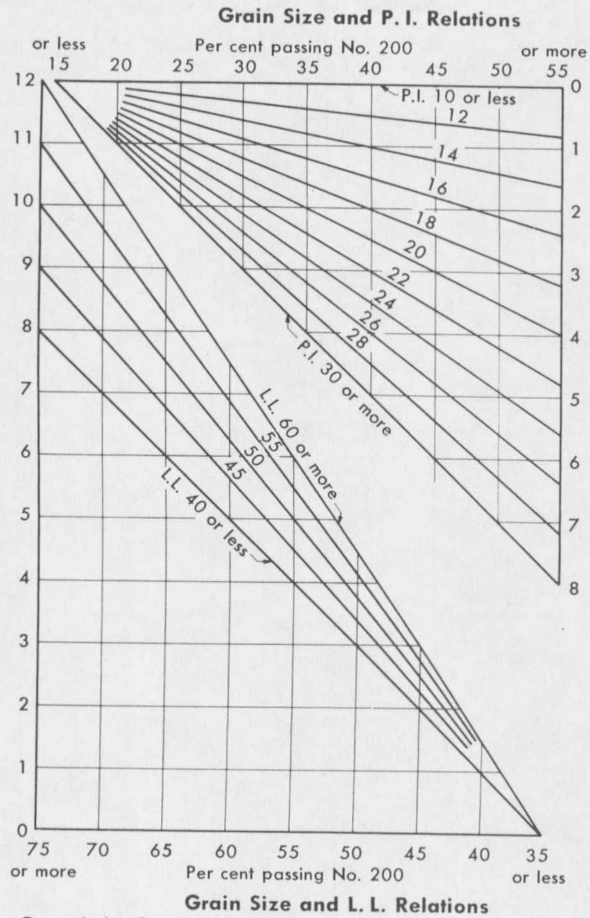
General classification	Granular materials (35 per cent or less of total sample passing No. 200)							Silt-clay materials (More than 35 per cent of total sample passing No. 200)			
Group classification	A-1		A-3	A-2				A-4	A-5	A-6	A-7
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5, A-7-6
Sieve analysis, per cent passing:											
No. 10	50 max.										
No. 40	30 max.	50 max.	51 min.								
No. 200	15 max.	25 max.	10 max.	35 max.	35 max.	35 max.	35 max.	36 min.	36 min.	36 min.	36 min.
Characteristics of fraction passing No. 40:											
Liquid limit				40 max.	41 min.	40 max.	41 min.	40 max.	41 min.	40 max.	41 min.
Plasticity index	6 max.		NP	10 max.	10 max.	11 min.	11 min.	10 max.	10 max.	11 min.	11 min.*
Group Index**	0		0	0		4 max.		8 max.	12 max.	16 max.	20 max.

Classification procedure: With required test data available, proceed from left to right on chart; correct group will be found by process of elimination. The first group from the left into which the test data will fit is the correct classification.

*P.I. of A-7-5 subgroup is equal to or less than L.L. minus 30. P.I. of A-7-6 subgroup is greater than L.L. minus 30

**See group index formula Table 5-1 for method of calculation. Group index should be shown in parentheses after group symbol as: A-2-6(3), A-4(5), A-6(12), A-7-5(17), etc.

Table 5-1. Group Index Charts



Group Index Equals Sum of Readings on Both Vertical Scales

METHODS

Questionnaire

Prior to any field work a preliminary survey was conducted to determine the "state of the art" of pedologic soil survey use among the 50 state highway departments and Puerto Rico.

A questionnaire with two parts was sent to an appropriate person or office in a state highway department. Survey questions were selected to obtain information concerning history, extent and appraisal of the pedologic soil survey as related to highway construction.

Additionally, questions concerning cost reductions related to drilling and contract specifications for highway construction from soil survey use were determined.

Study Site Selection Criteria

Sites for pedologic map correlation were selected on the basis of three major criteria. First, the study areas were to be along highway alignments where recent engineering soil surveys had been conducted by either the State of Montana, Department of Highways or by consultants under contract to the State of Montana, Department of Highways. This was to ensure that the latest engineering soil survey methods and recent soil test data would be available for comparison with the pedologic soil survey. Second, the study areas were chosen to include different kinds of soils as well as differing complexities of their occurrence. Third, to include several types of parent material and clay mineralogy as an aid to future studies.

Locations

The study areas were associated with projects from Interstate 94 in Yellowstone Co. (I-94-1), Treasure Co. (I-94-2), and Wibaux Co. (I-94-7); Interstate 90 in Gallatin Co. (I-90-6), Yellowstone Co. (I-90-8), and Big Horn Co. (I-90-9). Additionally, data were obtained from primary and secondary projects in Gallatin Co. (F-20(1)) and (S-182(2)), Big Horn Co. (F-212(13)), Flathead Co. (S-157(3)), and Lake Co. (F-93).

Plotting Sample Site Locations on Pedologic Soil Maps

Once it was determined that project plans (Figure 1, page 19) and sufficient soil boring data (Table 6, page 20) were available to justify plotting the project on the standard SCS soil survey, the highway routes were drawn on the soil map sheets. Criteria used to accurately plot the sample site locations included the following:

1. section and township lines
2. section and quarter corners
3. rivers
4. creeks
5. coulees
6. other highways and county roads

7. angles of approach
8. irrigation canals
9. topography
10. railroads
11. cities and towns
12. cemeteries

Highway Data Acquisition

Information from the questionnaire indicated that Montana was one of 46 states whose highway departments saved project plans (Figure 1, page 19) and associated soil boring data (Tables 6 and 7, pages 20 and 21). Further, the data were stored in the State of Montana Department of Highways geology section in the Cogswell Building, Helena, Montana, and in the district office Bozeman, Montana. Additionally, some data correlated with soils from Flathead and Lake Counties were obtained from Mr. C. B. Seago, Soil Scientist for that area, and are listed as those without identifying project numbers in Appendix I.

Soil boring data and project plans are identified by project number(s) such as I-90-9 (17) 483 Toluca East (Figure 1, page 19). Centerline station numbers locate sample sites on the project plans (Figure 2, page 22).

A specific number occurs only once in a project unless it is modified because, (1) the site is located left or right of the centerline,

STATE OF MONTANA
STATE HIGHWAY COMMISSION

PLAN AND PROFILE OF PROPOSED
FEDERAL AID PROJECT NO. I-90-9
I-IG-90 —9 (8) 483 P.E
(17) 483 CONST. U-1
(15) 483 R/W

TOLUCA - EAST
BIG HORN COUNTY

LENGTH 6.234 MILES

SCALES
HORIZONTAL: 1 Inch= 100 Feet
VERTICAL: 1 Inch= 10 Feet
CROSS SECTIONS--HOR. & VERT.: 1 Inch= 10 Feet
REDUCTION PRINTS ½ ORIGINAL SCALE

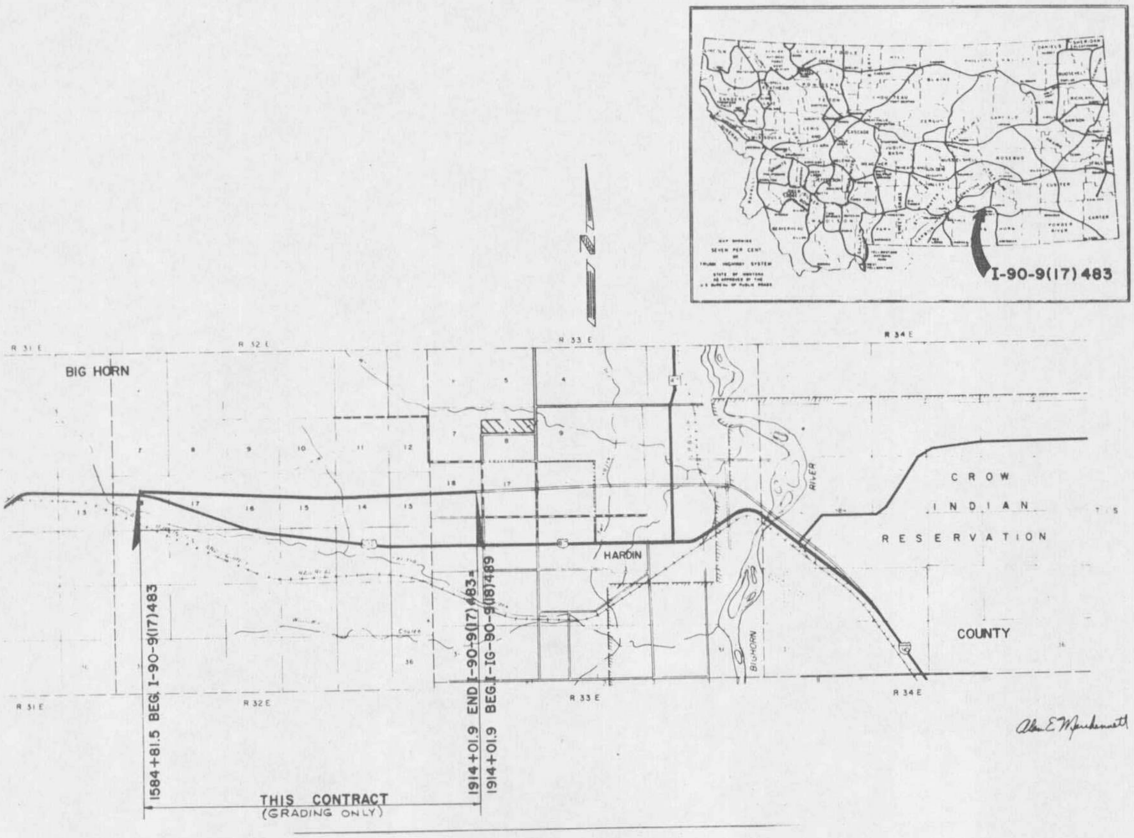


Figure 1. Cover of a typical project plan, with identifying project numbers and geographic location.

Table 6. Typical page of soil boring engineering data from a project report.

FOUNDATION & MATERIALS CONSULTANTS, INC.
839 Front St., Helena, Montana
Laboratory Test Summary Form S 1-72
Soil Classification

Client VTN, Inc.
Project Lodge Grass So.
Project No. 5315-01-01
Location

Page 1 of 6
By M
Approved
Date 10-20-71

Station or Hole #	Depth Ft. From	Depth Ft. To	Type Sample	Nat W %	Dry Dens. PCF	G.	Atterberg Limits LL	PL	PI	Grain Size Cum. % Passing 4	10	40	200	Laboratory Compaction Max DD	Opt W	Soil Class.	Comments
C-1	3^5	5°	SS	12			44	15	29	100	100	100	88			A-7-6(15)	
17+00	8^5	10°	SS	9			NP	NP	NP	100	100	99	48			A-4(2)	
Med ℄	10°	12°	ST	13	108.0		25	16	9							A-4	
C-2	0	3°	Aug	24			59	17	42	99	98	97	90			A-7-6(20)	S.L.= 12%
21+60	3^5	5°	SS	18	108.8		53	16	37	100	100	99	96	114.5	17.9	A-7-6(19)	
Med ℄																	
C-3	3^5	5°	SS	20			47	20	27	100	100	100	96	101.2	20.7	A-7-6(16)	
45+00	8^5	10°	SS	20	75.8		47	18	29	100	100	100	95			A-7-6(17)	
Med ℄																	
C-3 A	0	3°	Aug.	25			51	25	26	100	100	100	95			A-7-6(17)	
52+25	8^5	10°	SS	23	101.7		58	27	31	100	100	100	85			A-7-6(19)	
Med ℄																	
C-4	0	3°	Aug	17			32	19	13	99	98	97	58	115.0	17.0	A-6(6)	SL=20%
78+00	3^5	5°	SS	9	95.0		46	25	21	93	92	91	81	107.5	19.6	A-7-6(14)	SL= 16%
WB ℄	8^5	10°	SS	14	111.2		48	29	21	100	99	98	86	105.5	21.0	A-7-6(14)	
C-5	0	3°	Aug	18			48	22	26	100	100	99	91	108.8	18.9	A-7-6(16)	
125+50	3^5	3^8	SS	10	116.2	2.81	39	18	21	100	100	100	100			A-6(12)	
EB ℄																	
C-6	0	3°	Aug	16			46	21	25	100	100	99	88	113.3	16.5	A-7-6(15)	SL= 14%
159+20	3^5	5°	SS	14	112.4		37	23	14	100	100	100	98	115.0	14.8	A-6(10)	
Med ℄																	
C-7	0	3°	Aug	27			27	20	7	100	100	100	65			A-4(6)	
231+50	3^5	5°	SS	6													
EB ℄	8^5	9°	SS	10	88.4	2.62	NP	NP	NP	100	100	94	33	114.0	14.4	A-2-4(0)	

Table 7. Representative Drill Hole Log.

Foundations & Materials Consultants, Inc. 910 Helena Avenue, Helena, Montana Standard Drill Hole Log Surface Information Form DH65	Core Barrel Size NX Type HW Barrel Length 10'	Date Begin 1-15-71 Page 1 Date End 1-15-71 Of 1
Client V.T.N., Inc. Project Lodge Grass South I-90-9 (13) 528 Project No. 5315-01-01 Location Description Drill Hole No. C-1	Ground Water Observations: Depth None Time, Date 1-16-71 Depth ___ Time, Date ___ Depth ___ Time, Date ___	Casing Size NX Hammer Weight 350# Hammer Fall 30"
	Description of Drilling Method AUGER	Split Spoon OD 2" ID 1.375 Hammer Weight 140# Hammer Fall 30" Shelby Tube OD 2.88" ID 2.65"
		Driller J.S. Helper W.F. Engr. R.S.
Line MED ℄ Station 17+00 Offset 0' Ground Elev.	W/C: W-Wet, M-Moist, D-Dry, CB-Core Barrel, ST-Shelby Tube, SS-Split Spoon Aug.-Auger Sample, WB-Wash Boring, Sample ▮ Topsoil ≋ Peat	

Depth Below Ground Surf.	Casing Blows Per Foot	Sample Number Type of Sample		Split Spoon Blows Per 6" Drive 6"	12"	18"	Log	W/C	Color	Core Recovery Per Cent	Pressure While Sampling	Description of Material Sampled or Drilled	General Comments on Drilling
1		AUG	1									Moist dk br silty CLAY, some	EASY DRILLING
2												grass roots	SOFT MATERIAL
3													
4												Dry lt br SILT, trace fine SAND	
5		SS	1	11	14	14						Dry br silty CLAY, strong earthy	
6												odor, numerous root holes	
7													
8													
9												Damp lt br clayey SILT trace co. SAND	
10		SS	2	4	5	4						Damp br silty SAND	
11													
12		ST	1								550 #		
13													
14												END DRILLING 8^{5}	
15												END HOLE 12^{0}	
16													
17													
18													
19													
20													

UNIFIED SOIL CLASSIFICATION SYSTEM

DIV	SYM	NAME	DIV	SYM	NAME	DIV	SYM	NAME	DIV	SYM	NAME
50% > #4	GW	Well Graded Gravels Little Or No Fines	50% < #4 50% > #200	SW	Well Graded Sands Little Or No Fines	50% < #200 LL < 50	ML	Inorganic Silts & Fine Sands Of Low Plasticity	50% < #200 LL > 50	MH	Inorganic And Micaceous Silts - Elastic Silts
	GP	Poorly Graded Gravels Little Or No Fines		SP	Poorly Graded Sands Little Or No Fines		CL	Inorganic Clay - Low To Medium Plasticity		CH	Inorganic Clay Of High Plasticity
	GM	Silty Gravels & Gravel-Sand-Silt Mixtures		SM	Silty Sands & Sand-Silt Mixtures		OL	Organic Silt Or Clay Of Low Plasticity		OH	Organic Silts & Clays Of High Plasticity
	GC	Clayey Gravels & Gravel-Sand-Clay Mixtures		SC	Clayey Sands & Sand-Clay Mixtures						

ROCK CLASS.

SYM	NAME
	INTRUSIVE
	EXTRUSIVE
	SEDIMENTARY
	METAMORPHIC

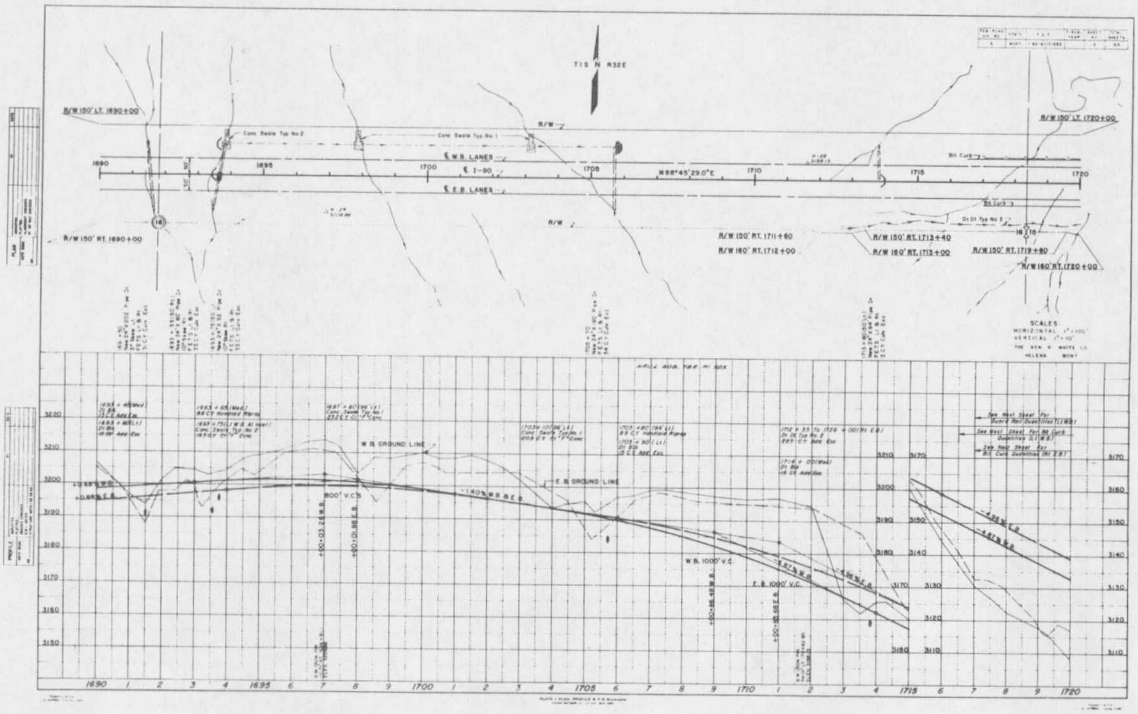


Figure 2. A typical interior page of project plans-aerial view (top half) depicts physiographic location; profile view (bottom half) presents landscape surface.

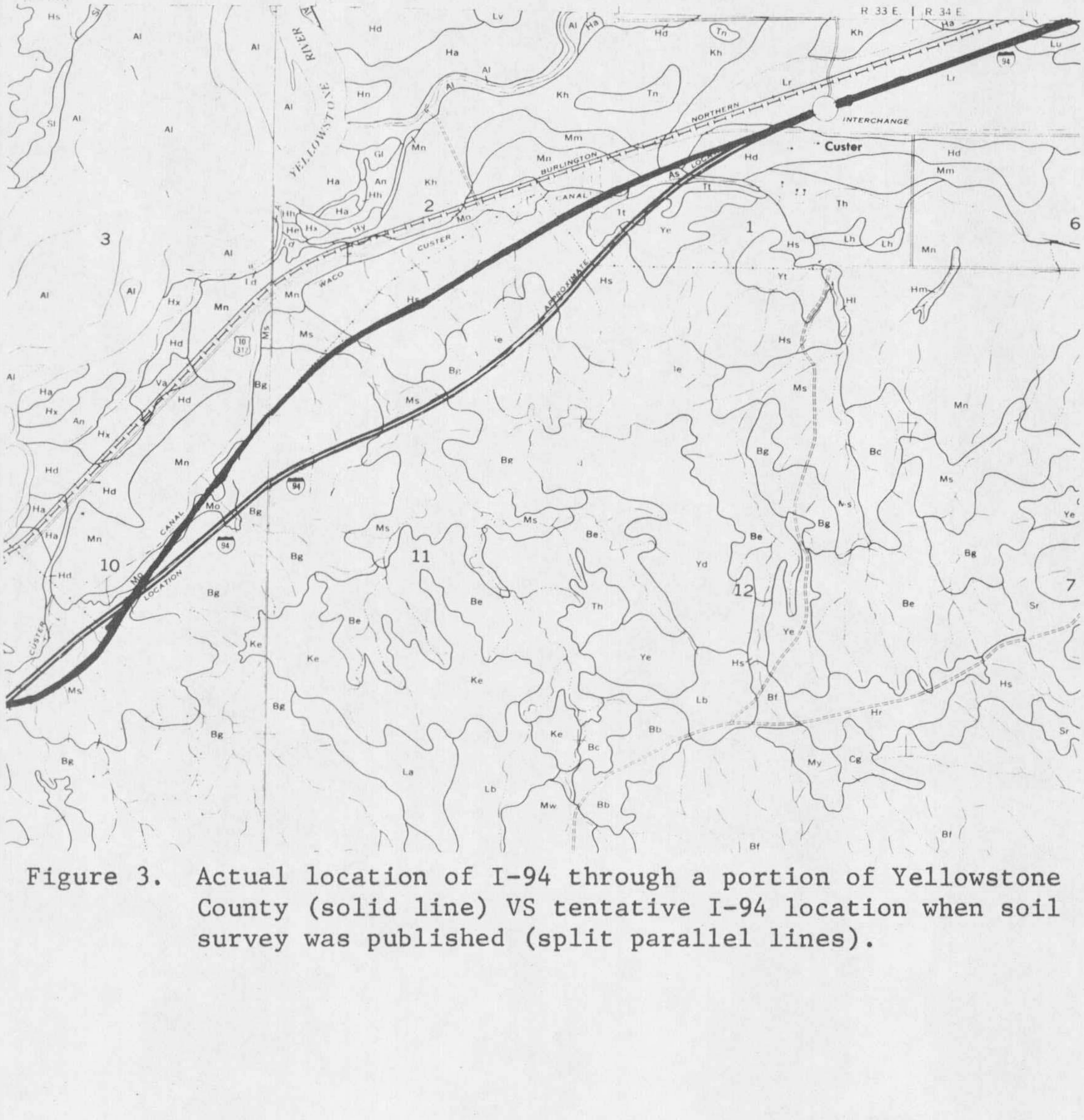


Figure 3. Actual location of I-94 through a portion of Yellowstone County (solid line) VS tentative I-94 location when soil survey was published (split parallel lines).

(2) a correction equation on the project plan alters the normal sequence of station numbers.

The first step in assigning highway engineering soil boring data to SCS mapping units was to tabulate the data. These data included project number and name, station number, depth, gradation analysis, liquid limit, plasticity index and AASHO rating (see Appendix I, Table 1).

A soil boring site from a project accurately routed on a soil map Figure 3, page 23) was given the soil map symbol corresponding to the delineated soil area in which it occurs. If a soil boring should occur on or near a line delineating contrasting soils, referral is made to the gradation analysis (Table 6, page 20) the soil drill hole log (Table 7, page 21) with its physical narrative description of the soil. This information, when compared to the SCS soil profile description will facilitate assigning the proper soil map symbol. Additional comparison of the SCS soil surveys physiographic description with the profile in the project plans (Figure 2, page 22) further strengthened a map symbol designation.

After individual soil boring sites were assigned a map symbol, the data from similar soils were compiled under one map unit name. These data are presented in Appendix I, Table 1.

Since the Montana highway department does not use the Unified system of soil classification, that rating was not obtained from the methods described earlier. The Unified ratings were determined by myself using procedures outlined in MS-10, Soils Manual of the Asphalt Institute, 1969. These ratings were assigned without the benefit of a gradation curve to separate, for example, poorly and well-graded gravels. This situation resulted in some dual ratings.

The CL category was divided into two subgroups, CL-1 and CL-2, with the PI being equal to or greater than 15 for the CL-2 subgroup.

Soil Survey Data Acquisition

Additional soil engineering data were obtained from the files of the state S.C.S. office in Bozeman; the published soil surveys; and prepared manuscripts of counties in Montana, North Dakota and South Dakota. Engineering tests on Montana benchmark soils were conducted by myself using MS-10, Soils Manual of the Asphalt Institute, 1969. These data are compiled aplphabetically in Appendix I, Table 2.

S.C.S. Predicted Engineering Ratings vs.
Engineering Ratings from this Project

This comparison used data from Yellowstone, Flathead and Treasure Counties, Montana (see Table 9, page 41).

The soil(s) in each mapping unit were identified, and its assigned rating and areal composition (%) were recorded. These values were compared with the soil sampling and rating done by the Montana Department of Highways.

The evaluation of the mapping unit was expressed as the maximum difference in composition between soil survey and highway data. Only map units sampled at least seven times by the highway department were included in this evaluation.

Engineering Test Data from Montana Soil Series vs. Soil Family Classes

Engineering test data from Montana soil series (Appendix I, Table 2) were assembled according to taxonomic soil family classification. Engineering ratings by numerical dominance were assigned to those soil families included in the data.

If a soil had several horizons all of which had the same engineering ratings, e.g., Pierre clay, it was considered one sample from one soil. If a soil had several horizons with different engineering rating, all of the ratings were recorded.

Assigning Engineering Ratings to Soils in Map Units

Engineering data presented by map units (Appendix I, Table 1) are difficult to interpret when several soils and numerous samples are in a map unit. The data were assigned to specific soils using the methods illustrated in the following example (see Heldt silty clay loam, Table 8):

1. The Heldt silty clay loam unit (Hlb, Hlc) in Big Horn County (Appendix I, Table 1) is a complex of three soils; Heldt silty clay loam, Lohmiller silty clay loam and McRae loam. The highway tests indicate two major groups (A-6, A-7).

2. The "Guide for Interpreting Engineering Uses of Soils", (U.S.D.A., S.C.S., 1971), indicates that silty clay loams are rated at A-7 unless the clay per cent is less than 30. If the clay per cent is less than 30, it is rated A-6.

3. LL vs. PI data from Appendix II for silty clay loams indicate a predominant LL and PI range of 32 - 50 and 12 - 23 respectively. These characteristics, when referred to the AASHO Classification Table (Context Table 5), indicate either A-6 or A-7.

4. Soil family ratings from Table 10 indicate that soils of the fine montmorillonitic families fall in the A-7 and A-6 ratings of AASHO.

5. A homogenous map unit, Heldt silty clay (Hle) (Appendix I, Table 1) indicates A-7-6(16-20), with per cent soil passing the No. 200 sieve, 96 or greater, further indicating that Heldt is an A-7-6.

6. Referring to engineering test data for Montana soil series (Appendix I, Table 2) we find that two of the three soils, Lohmiller and McRae, have been identified by soil scientists and laboratory tested for engineering ratings. The McRae series is rated A-4. No ratings of A-4 are represented in the highway data, eliminating the McRae soil. Lohmiller series, identified and rated by the same procedures, is rated A-6(9-11). This rating is further substantiated by the following published properties: average LL of 34, average PI of 14, No. 200 sieve analysis of 81, and average clay per cent of 30.

On the basis of the six steps illustrated above, it was concluded that Lohmiller silty clay loam is rated A-6(8-13) and Heldt silty clay loam is rated A-7-6(14-20) in map units H1b and H1c.