USE OF SOIL SURVEYS FOR PLANNING AND DESIGNING LOW VOLUME ROADS

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A method was developed to use soil surveys made under the guidelines of the National Cooperative Soil Survey to aid highway engineers in designing the most economical routes and pavement structures for low volume roads. The support value of a subgrade soil is needed in the pavement design process, but this value is not normally readily available without extensive field sampling and testing. Using detailed soil maps, a correlation was developed between the soil series shown on the maps and the California Bearing Ratio (CBR) values for those same soils. Data on soil samples and borings obtained by the Soil Conservation Service (SCS) were compared to similar data obtained by Indiana State Highway Commission engineers in order to develop estimated CBR values for 275 different soils in Indiana. The SCS soil maps and the correlation of the soil series names to estimated CBR values allow an engineer to quickly determine the value of the subgrade soil support for any desired routing of a low volume road. In addition, the SCS maps and CBR values can be used together by the engineer to determine preliminary thickness design calculations for the various routes chosen.

Four primary factors must be considered when a highway engineer begins a pavement design analysis. These factors include: (a) Traffic--the number as well as the type and weight of the vehicles; (b) Subgrade soil strength--the ability of the soil to adequately support the overlying pavement layers; (c) Material characteristics--the type and quality (relative strength) of the layers used in the pavement structure; and (d) Environmental variables--climate conditions and drainage requirements.

The goal of every highway engineer should be to design a roadway that will adequately carry, at the lowest possible cost, the traffic volumes using the pavement. This minimum cost criterion must include both initial construction costs and long-term maintenance costs.

This paper describes the use of soil surveys to determine the relative values of subgrade soil strength for a particular stretch of highway pavement. The soil survey can be used during several steps in the design process to reduce the cost of designing and constructing a roadway. The survey information can be utilized during the preliminary route selection phase to determine the choice of highway location which crosses the best subgrade soil conditions and bypasses the poorest soil areas. It can also be employed during the preliminary thickness design phase to determine the estimated structural number of the pavement cross section. Finally, it can be utilized by the contractor during the construction phase to indicate the existence of suitable borrow pits and potential problem soil areas.

Evaluating Subgrade Soil Strength

CBR Method

One of several methods available for estimating the relative strength of a subgrade soil for road construction purposes is the California Bearing Ratio (CBR) test. This method is primarily a penetration test that measures the shearing resistance of a soil (1). The procedure is fully described in ASTM D 1883 and AASHTO T 193 (2,3).

CBR tests can be conducted on in-place, undisturbed field soil samples. Such tests, however, evaluate the relative strength of the soil only at the field moisture and density conditions existing at the time of the test. Most CBR investigations, therefore, are conducted on remolded laboratory soil specimens. The laboratory procedure determines the relative strength of the soil after it has been soaked in water for 96 hours.

The lab CBR value depends on three primary factors: the soil density, the moisture content of the soil when the test specimen is prepared, and the moisture content of the soil after soaking. Since density and moisture content greatly affect the strength of the soil, the initial moisture and density values of the laboratory prepared specimen should be similar to those obtained by construction equipment in the field.

Soil Maps

Another way to estimate the CBR value of a soil is by using the detailed soil surveys published by the United States Department of Agriculture (USDA), Soil Conservation Service (SCS). For this method, a correlation is needed between the soil series names on the soil maps and the CBR value of that soil determined from a laboratory test. Such a correlation study was completed recently for 275 different soils in Indiana.

Soil Surveys

The Soil Conservation Service is an agency of the USDA charged by Congress with responsibility for soil and water conservation and proper land use (4). All soil survey work, including soil interpretations, is done by the SCS in cooperation with state agricultural experiment stations and other governmental agencies under the guidelines of the National Cooperative Soil Survey. In Indiana, the SCS works with the Purdue University Agricultural Experiment Station in making soil surveys. From the very beginning of soil surveys in 1899, they have been beneficial to land users who desire knowledge about the soils' physical and chemical properties shown in Tables 1 and 2 (5) as well as their location and extent shown in Figure 1 (6, map 11).

Soil

Soil is a natural, three-dimensional body at the earth's surface that is capable of supporting plants and has properties resulting from the integrated effect of climate and living matter acting on earthy parent material, as conditioned by relief over periods of time (7). Soils have distinct horizons or layers, as shown in Figure 2 (1, p. 19). The horizons or layers, which are approximately parallel to the surface, have distinct characteristics produced by the soil-forming processes.

An organic layer of fresh and decaying plant residue is at the surface of most mineral soils. Below this organic layer is the A horizon, formed or forming at or near the surface. It is an accumulation of humified organic matter mixed with mineral matter. The A2 horizon is mainly a residual concentration of sand and silt, which is high in resistant minerals content as a result of the loss of silicate clay, iron, aluminum, or a combination of these.

The B horizon is a layer of change between the overlying A and underlying C horizon. The B horizon is characterized by (a) the accumulation of clay, sesqui-oxides, humus, or a combination of these; and/or (b) a prismatic or blocky structure; and/or (c) redder or browner colors than those in the A horizon. The combined A and B horizons are generally called the solum, or true soil. If a soil lacks a B horizon, the A horizon is the solum.

The C horizon, excluding indurated bedrock, is little affected by soil-forming processes and does not have the same properties as the A or B horizon. The material of the C horizon may be either similar or dissimilar to that from which the solum is presumed to have formed. The R layer is consolidated rock. It commonly underlies the C horizon, but can be directly beneath either the B or A horizon.

The depth or thickness of an individual soil horizon varies within defined limits for each particular soil. Some soils, however, form in two materials. The properties of the top part of the B horizon soil can be different from the properties of the bottom part of the same horizon; each part of the soil can then have a different CBR value.

Making a Soil Survey

Soil surveys are conducted in the field by soil scientists who walk the area mapping soil landscapes (8). They take many soil samples in order to determine the soil profiles. The profiles are compared with those in other soil survey areas. The soils are then classified according to their individual properties, conforming to a uniform, nationwide procedure (7).

Soils that have similar soil profiles make up a soil series. Except for different textures in the surface layer, all soils of one soil series have major horizons that are the same in thickness, arrangement, and other characteristics. Each soil series is named for a town or geographic feature near the place where a soil of that series was first observed and mapped. All the soils in the United States having the same series name, such as Crosby or Plainfield, are essentially alike in those characteristics that affect their behavior in the undisturbed landscape.

Soils of a particular series, however, can differ in the texture of the A horizon as well as the slope or some other characteristic that affects the use of the land (9). The name of a soil phase indicates a feature that affects land use and management. For example, Crosby silt loam, 2 to 6 percent slopes, is one of several phases within the Crosby soil series.

When conducting a soil survey, the soil scientists gather soil samples for laboratory testing. Some of the data collected during the laboratory part of the investigation are shown in Tables 1 and 2 (5). Among the data available for use by highway design engineers are the Unified and AASHTO soil classifications, sieve analysis, Atterberg limits, permeability, soil reaction, shrink-swell potential, depth of the water table, depth to bedrock, and frost heave potential.

After determining the extent or area of a particular soil, the soil scientist delineates the boundaries of each soil on aerial photographs. Essentially all soil maps in the United States are drawn at a scale between 1:15840 to 1:24000 (10.16 cm or 4 inches to 6.70 cm or 2.64 inches per mile). The larger scale allows contrasting soil areas as small as 0.81 to 1.21 hectares (2 or 3 acres) to be drawn on the aerial photographs. Packets of different soils smaller in size than this, however, are not shown on the soil maps. The properties of the soils in the small, unmapped areas may be more or less favorable than the soil delineated on the map.

Detailed soil surveys have been completed for about 60 percent of the United States and approximately 65 percent of Indiana. In areas not yet surveyed, local SCS personnel are available to assist highway design engineers determine the type of soil in a particular location.

Correlation of CBR Values

ISHC Data

In conjunction with the construction of the interstate highway system across the state, the Indiana State Highway Commission (ISHC), Division of Materials and Tests, has collected many soil samples from the various soils found along the routes. Sometimes these soil specimens were taken along several possible route centerline locations in order to determine which route encountered the best soil conditions. The only way to judge field conditions was to take field soil samples, Once a particular route had been selected for a project, additional soil samples were taken to determine the type of subgroup soil along the proposed roadway. These samples were usually taken at predetermined intervals along the centerline, in some cases without regard to actual field conditions. Pockets of poor soil were thus sometimes missed during the field sampling, only to be "discovered" during construction.

A small number of collected soil samples were used to determine the CBR value of some of the soils found along the route. These values were used by ISHC design engineers to determine the required pavement thickness for individual paving projects. If several soils with different CBR numbers were determined within one project limit, generally the lowest value was used for design purposes, and all the pavement for the total length of the section was set at the same thickness. This procedure led to very conservative and costly design practices when better soil conditions (higher CBR numbers) were encountered over a significant distance within a particular project.

Data Correlation

For both preliminary route selection and preliminary pavement thickness design analysis, SCS soil survey data and soil maps can be used to estimate the CBR values of the soils along a particular roadway route. A way was needed, however, to correlate the data in the SCS soil surveys with actual laboratory CBR values for the same soils.

Several joint meetings were held between ISHC personnel, SCS soil scientists, and other interested engineers to determine if such a soil correlation could be obtained. Many hours were spent in review of ISHC information to determine exactly what data were available for each individual CBR test number, particularly (a) the exact location in the field where the sample was taken, and (b) other soil sample characteristics, such as Atterberg limits, field moisture content, field density, soil sieve analysis, and soil classification.

The SCS soil maps were then used to identify the field location when the actual soil samples had been taken. This location correlation required several months of extensive cross checking between ISHC project plans, field soil sampling notes, and the SCS soil maps. In addition, SCS personnel went back to every field site (over 162 in number), examined and classified the soil where the ISHC sample had been taken, and compared the data obtained to the ISHC CBR test information.

Some obvious errors were discovered--the CBR value for a given test site might be 3 while the soil maps would indicate an A-4 or ML soil, with an estimated CBR value of 6 to 10. Usually, however, the laboratory CBR values agreed well with the expected CBR value for a particular individual soil series name.

Considerable scatter was found in some of the data. Table 3 shows 18 actual laboratory CBR values obtained on Crosby soils from highway projects in 9 different Indiana counties across the central part of the State. The values range from a low of 2.2 to a high of 4.7. The average laboratory CBR value for this soil series is 3.60, with a standard deviation for the 18 values of 0.62. For this particular soil, an estimated CBR value of 3.0 was selected as the design value. Approximately 84 percent of all laboratory CBR test values are equal to or greater than the chosen design CBR value.

Of the 275 soils in Indiana, sufficient data (at least 8 samples of each soil) were available on about 58 primary soils to determine estimated CBR values in a manner similar to that described above for the Crosby soil series. Due to the variability of the CBR values obtained for each soil, however, and because of a very limited number of samples available for some particular soil series, a statistically based analysis could not be completed. As more data is gathered from future correlation work between ISHC soil tests and SCS soil maps, a revised and updated listing of estimated CBR values will be published for Indiana. Once the CBR numbers for the major soils were calculated, the values for the remaining soils were assigned according to similar soil properties. Nine CBR classes were used to group the 275 Indiana soils for pavement design purposes. The CBR values selected were 2 through 8, 10, and 15. A tenth CBR class CBR=0, was used to indicate those soils which are peats or mucks and are completely unsuitable as foundation soils for highways.

Table 4 shows a correlation of the estimated CBR values determined for Indiana soils with both the Unified and AASHTO soil classification systems (10). Each group of AASHTO soils is shown in the first column, with the most probable comparable Unified system soil in the second column. The typical CBR number range for each soil classification is listed in the third column, followed by the most probable soaked CBR value within the range.

Table 5 lists the estimated CBR values for Indiana soils. Some of the soils listed have been formed in two different parent materials. These soils, marked with an asterisk, can have two different values of soaked soil strength; thus the two given CBR values--the first for the upper part and the second for the lower part of the B horizon.

Words of Caution

The information shown in Tables 4 and 5 must be used with caution. The CBR values listed are valid only for Indiana soils. In addition, the estimated CBR numbers have been determined based on a limited amount of laboratory testing. No soil has only one CBR number. Depending on the density and moisture content of the soil, its CBR value can vary significantly. The numbers listed, therefore, are the most probable values expected for a particular soil.

The CBR values given for use with the soil survey maps are those for the B horizon. For road building purposes, the A horizon soil should be stripped and removed before a pavement structure is constructed on the B horizon material. In relatively flat terrain, the roadway subgrade is normally built entirely on the B horizon soil. In rolling countryside, however, roadway cut sections more than five feet deep may be encountered. Thus the C horizon soil may be used as the subgrade soil foundation. The information contained on the soil maps for this horizon is less reliable than that for other soil horizons near the surface.

The information contained on the soil survey maps should be used only for preliminary highway design purposes. It can be used to determine probable roadway route centerline soils. It can also be utilized for preliminary thickness design calculations without a detailed analysis of the subgrade soil. It must be emphasized, however, that field soil samples should be obtained, tested, and analyzed before a final pavement structural section is selected.

Summary

The subgrade soil CBR data developed for Indiana soils using SCS soil maps and laboratory CBR tests can be established for other areas through cooperation between the Soil Conservation Service (SCS) and the state highway department. It will take some effort and patience to collect and correlate the necessary information. Applied together, the CBR data and soil surveys can be used effectively during the route selection phase, preliminary pavement thickness design phase, and construction phase of a highway project.

References

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Table 1. Morphological[a] and estimated soil properties of Crosby soils.

ESTIMATED SOIL PROPERTIES

DEPTH (IN.)	USDA TEXTURE	UNIFIED	AASHTO	FRACT >3 IN (PCT)	PERCENT OF MATERIAL LESS THAN 3" PASSING SIEVE NO. 4	10	40	200	LIQUID LIMIT	PLASTICITY INDEX
0-11	SIL, L	CL, CL-ML	A-4, A-6	0	100	95-100	80-100	50-90	22-34	6-15
11-30	CL, SICL	CL, CH	A-6, A-7	0-3	92-99	89-97	78-93	64-76	37-55	17-31
30-60	L, CL, SL	CL, ML, CL-ML	A-4, A-6	0-3	88-94	83-89	74-87	50-64	17-30	2-14

DEPTH (IN.)	CLAY (PCT <2MM)	MOIST BULK DENSITY (G/CM3)	PERMEABILITY (IN/HR)	AVAILABLE WATER CAPACITY (IN/IN)	SOIL REACTION (PH)	SALINITY (MMHOS/CM)	SHRINK-SWELL POTENTIAL	EROSION FACTORS K	EROSION FACTORS T	WIND ERODIBILITY GROUP	ORGANIC MATTER (PCT)	CORROSIVITY STEEL	CORROSIVITY CONCRETE
0-11	11-22	1.50-1.70	0.6-2.0	0.20-0.24	5.1-6.5	-	LOW	.43	3	5	1-3	HIGH	MODERATE
11-30	35-45	1.50-1.70	0.06-0.2	0.15-0.20	5.1-7.3	-	MODERATE	.43					
30-60	15-26	1.70-2.00	0.06-0.6	0.05-0.19	7.9-8.4	-	LOW	.43					

FLOODING FREQUENCY	FLOODING DURATION	FLOODING MONTHS	HIGH WATER TABLE DEPTH (FT)	HIGH WATER TABLE KIND	HIGH WATER TABLE MONTHS	CEMENTED PAN DEPTH (IN)	CEMENTED PAN HARDNESS	BEDROCK DEPTH (IN)	BEDROCK HARDNESS	SUBSIDENCE INIT. (IN)	SUBSIDENCE TOTAL (IN)	HYD GRP	POTENT'L FROST ACTION
NONE			1.0-3.0	APPARENT	JAN-APR	-		>60		-		C	HIGH

[a]The Crosby series consists of deep, somewhat poorly drained soils formed in loess and the underlying glacial till on moraines and till plains. Typically these soils have dark grayish brown silt loam surface layers 22.9 centimeters (9 inches) thick and mottled light brownish gray silt loam subsurface layers 5.1 centimeters (2 inches) thick. The subsoil is mottled yellowish brown clay loam in upper 48.3 centimeters (19 inches) and yellowish brown and grayish brown loam in lower 15.2 centimeters (6 inches). The underlying material is brown loam. Slopes range from 0 to 6 percent.

Table 2. Morphological[a] and estimated soil properties of Plainfield soils.

ESTIMATED SOIL PROPERTIES

DEPTH (IN.)	USDA TEXTURE	UNIFIED	AASHTO	FRACT >3 IN (PCT)	PERCENT OF MATERIAL LESS THAN 3" PASSING SIEVE NO. 4	10	40	200	LIQUID LIMIT	PLASTICITY INDEX
0-8	LS, LFS	SM	A-2, A-4	0	100	100	55-95	15-40	-	NP
0-8	S, FS	SP-SM, SM	A-3, A-2	0	100	100	50-95	5-35	-	NP
8-60	S	SP	A-3, A-1, A-2	0	75-100	75-100	45-70	1-4	-	NP

DEPTH (IN.)	CLAY (PCT <2MM)	MOIST BULK DENSITY (G/CM3)	PERMEABILITY (IN/HR)	AVAILABLE WATER CAPACITY (IN/IN)	SOIL REACTION (PH)	SALINITY (MMHOS/CM)	SHRINK-SWELL POTENTIAL	EROSION FACTORS K	EROSION FACTORS T	WIND ERODIBILITY GROUP	ORGANIC MATTER (PCT)	CORROSIVITY STEEL	CORROSIVITY CONCRETE
0-8	5-15	1.35-1.65	2.0-6.0	0.10-0.12	4.5-7.3	-	LOW	.17	5	2	<1	LOW	HIGH
0-8	4-9	1.35-1.65	6.0-20	0.07-0.09	4.5-7.3	-	LOW	.17	5	1	<1		
8-60	1-4	1.50-1.65	6.0-20	0.05-0.07	4.5-6.0	-	LOW	.17					

FLOODING FREQUENCY	FLOODING DURATION	FLOODING MONTHS	HIGH WATER TABLE DEPTH (FT)	HIGH WATER TABLE KIND	HIGH WATER TABLE MONTHS	CEMENTED PAN DEPTH (IN)	CEMENTED PAN HARDNESS	BEDROCK DEPTH (IN)	BEDROCK HARDNESS	SUBSIDENCE INIT. (IN)	SUBSIDENCE TOTAL (IN)	HYD GRP	POTENT'L FROST ACTION
NONE			>6.0			-		>60		-		A	LOW

[a]The Plainfield consists of excessively drained soils formed in sandy drift on outwash plains, stream terraces and glaciated uplands. The surface layer is brown loamy sand 20.3 centimeters (8 inches) thick. The subsoil is dark yellowish-brown sand 30.5 centimeters (12 inches) thick. The substratum is light yellowish-brown, yellowish-brown and strong-brown sand.

Table 3. CBR values for Crosby soils.

County Sampled	Lab CBR Value
Bartholomew	4.4
Boone	3.6, 4.0
Hancock	3.1, 2.2
Henry	3.0, 3.9
Madison	4.7, 3.8
Marion	4.0, 3.5
Montgomery	3.0, 3.0
Tippecanoe	3.9, 3.2, 4.6
Wayne	3.3, 3.6

Table 4. Comparable soil groups.

AASHTO Group	Unified Group	Usual CBR Range	Most Probable CBR
A-1-a	GW,GP	20+	25
A-1-b	SW,SP,GM,SM	15-20	15
A-3	SP	8-12	10
A-2	GM,SM,GC,SC	8-12	10
A-4	ML	6-10	7-8
A-6	CL	4-7	5-6
A-7-5	MH	3-6	4
A-7-6	CH,CL	2-5	3

Table 5. Estimated California Bearing Ratio (CBR) alues for Indiana soils.

Soil Name	Estimated CBR	Soil Name	Estimated CBR	Soil Name	Estimated CBR
Ade	10	Crosier	4	Huntington	4
Adrian	0	Cuba	5	Huntsville	5
Alford	5				
Algiers	5	Dana	5	Iona	5
Alida	7	Darroch	6	Ipava	3
Allensville	6	Del Ray	3	Iva	4
Allison	5	Dickinson	8		
Alvin	8	Door	6	Jasper	6
Armiesburg	5	Dowagiac	6	Johnsburg(a)	4
Aubbeenaubbee	4	Dubois(a)	4	Jennings	5
Ava	4	Dunning	3	Jules	5
Avonburg(a)	5				
Ayr*	7-4	Eden(b)	3	Kalamazoo	6
Ayrshire	6	Edwards	0	Kerston	0
		Edenton(b)	3	Kings	2
Bartle(a)	5	Eel	6	Kokomo	3
Baxter	2	Elkinsville	5		
Beasley	3	Elliott	4	Landes	7
Bedford*(a)	5-2	Elston	8	Lawrence*(a)	5-2
Belmore	8	Evansville	3	Lenawee	3
Berks(b)	4			Lindside	4
Birds	5	Fabius	10	Linkville	4
Bloomfield	10	Fairmount(c)	3	Longlois	6
Blount	3	Fincastle	5	Lorenzo	10
Bonnie	4	Flanagan	3	Lowell	3
Bono	2	Foresman	6	Lucas	3
Boonesboro(b)	6	Fox	6	Lydick	6
Boyer	10	Frederick	2	Lyles	5
Brady	7	Fulton	2		
Brems	15			Mahalasville	3
Bronson	8	Genesee	6	Manlove	5
Brookston	3	Gessie	6	Markham	4
Burgin	3	Gilford	5	Markland	3
Burnside	8	Gilpin(b)	4	Martinsville	6
		Ginat(a)	4	Martisco	0
Camden	5	Glenhall	6	Massie	8
Carlisle	0	Granby	8	Matherton	6
Casco	10	Grayford	5	Maumee	8
Catlin	5	Guthrie*(a)	4-2	McGary	3
Celina	4			Medway	6
Chalmers	3	Hagerstown	2	Mellott	5
Chelsea	15	Hanna	7	Mermill*	4-2
Cincinnati(a)	5	Haskins*	5-3	Metamora	4
Clarence	3	Haubstadt(a)	4	Metea*	7-4
Clermont	4	Haymond	6	Miami	4
Colyer(c)	4	Hennepin	6	Milford	3
Conover	4	Henshaw	4	Millsdale(b)	3
Conrad	0	Hickory	4	Milton(c)	4
Corwin	4	High Gap(b)	4	Monitor	5
Cory	4	Hillsdale	7	Montgomery	2
Corydon(c)	2	Homer	6	Montmorenci	4
Coupee	8	Hoopeston	7	Morley	4
Crane	5	Hosmer(a)	5	Morocco	10
Crider*	5-2	Houghton	0	Muren	5
Crosby	3	Hoytville	2	Muskingum(b)	4

Soil Name	Estimated CBR	Soil Name	Estimated CBR	Soil Name	Estimated CBR
Mussey	10	Rensselaer	4	Toronto	5
		Riddles	4	Tracy	7
Nappanee	3	Rimer*	5-3	Trappist(b)	4
Negley	7	Robinson	3	Treaty	3
Newark	4	Rockcastle(b)	3	Troxel	5
Newton	8	Rodman	15	Tyner	15
Nicholson(a)	4	Romney	3		
Nineveh	6	Ross	6	Uniontown	4
Nolin	5	Rossmoyne(a)	5		
		Runnymede	4	Vigo	4
Oakville	15	Rush	5	Vincennes	4
Ockley	6	Russell	5	Volinia	6
Octagon	4	Ryker	5		
Odell	4			Wallkill	0
Ormas	10	Saranac	2	Wakeland	6
Oshtemo	8	Saugatuck	8	Wanatah	5
Otwell(a)	4	Sciotoville(a)	6	Warners	0
Owosso*	5-4	Sebewa	4	Warsaw	6
		Seward*	5-3	Wasepi	10
Palms	0	Shadeland*(b)	6-4	Washtenaw	3
Parke	6	Shipshe	10	Watseka	10
Parr	4	Shoals	6	Wauseon*	4-2
Pate	3	Sidell	5	Wawasee	5
Patton	3	Sleeth	5	Wea	6
Pekin(a)	5	Sloan	5	Weikert(c)	4
Peoga	4	Sparta	15	Weinbach(a)	5
Petrolia	3	St. Clair	3	Weiss	10
Pewamo	3	Starks	5	Wellston	4
Pike	5	Steff	5	Westland	4
Pinhook	5	Stendal	5	Wheeling	6
Plainfield	15	Stonelick	7	Whitaker	6
Plano	5	Stoy(a)	5	Whitson	3
Pope	7	Strole	2	Wilbur	6
Princeton	6	Sunbury	3	Willette	0
Proctor	5	Switzerland	3	Wingate	5
		Swygert	3	Woodmere	4
Quinn	5	Sylvan	5	Woolper	3
				Wooten	10
Ragsdale	3	Taggart	5	Wynn(b)	5
Rahm	3	Tama	5		
Randolph(b)	4	Tawas	0	Xenia	5
Rarden(b)	3	Tedrow	10		
Raub	5	Tilsit(a)	4	Zanesville(a)	4
Rawson*	5-3	Tippecanoe	6	Zipp	2
Reesville	4	Toledo	2		

[a]Soils that have a fragipan or compact, impervious layer at a depth of 18 to 32 inches below the top of the soils.
[b]Soils that have bedrock at a depth of 20 to 40 inches below the surface of the soil.
[c]Soils that have bedrock at a depth of less than 20 inches below the surface of the soil.

Figure 1. A soil survey delineating Crosby (CrA) and Brookston (Br) soils.

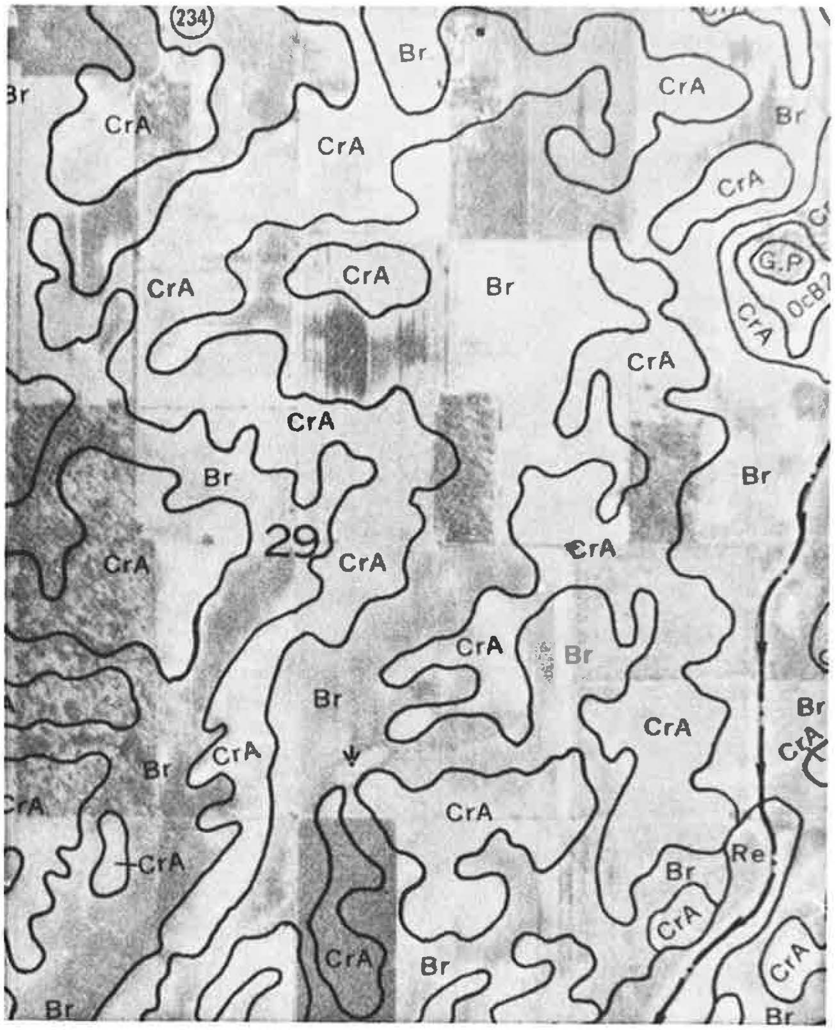

Figure 2. Major soil horizons. No one soil profile would contain all horizons listed, but most soils have some kinds of A, B, or C horizons.