SOILS BULLETIN

19

SOIL SURVEY INTERPRETATION FOR ENGINEERING PURPOSES

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

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INTRODUCTION

In most developing countries considerable benefits can be achieved through increased engineering interpretations of soils. For too long engineering aspects of uses of soils defined as pedological units have been neglected, chiefly because soil data were lacking and because more immediate pressures appeared to be evident to concentrate on uses of soils for increasing food production. At the present time, however, enough soil data are becoming available in most developing countries so that a start can be made for applying the soil profile descriptions, soil laboratory data and soil maps toward solution of soil engineering problems also. Programmes involving economic development, increasing productivity and improving environmental quality should be as much concerned with building better roads, improving waste disposal facilities and laying out pipeline routes and irrigation and drainage systems, as with the response of different soils to different fertilizer inputs. The purpose of this publication is to provide some guidelines that will assist workers in developing countries in improving use of their soil maps and data in helping to solve some of the engineering problems associated with economic development.

Pedological soil maps and data are being increasingly recognized as being valuable for engineering purposes and are being increasingly improved for engineering uses. Several authors (e.g., Olson, 1964; Orvedal, 1963) have pointed out relationships between pedology and engineering. Revisions in the Soil Survey Manual (Soil Survey Staff, 1951) for particle size and other determinations will make soil survey data of even more value for engineers. Criteria for the comprehensive Soil Taxonomy (Soil Survey Staff, 1970) are based to a considerable extent upon characteristics of soils important for engineering as well as agricultural uses. As Orvedal (1963) states:

> "Today, it is becoming increasingly recognized that many, perhaps most, properties which influence the behaviour of soils in construction also may be related to the production of plants, and, conversely, many, perhaps most, properties which influence the production of plants also may be related to the behaviour of soil in construction; and both are commonly related to soils as natural bodies. Engineers and soil scientists have, therefore, a growing common interest in soils."

In most developing countries procedures for making soil descriptions and maps approximate those outlined in the Soil Survey Manual (Soil Survey Staff, 1951; FAO, 1965). Soil laboratory determinations on pedological samples generally approximate those outlined in Soil Survey Investigations Report Number 1 (Soil Survey Staff, 1967). Observations from soil maps and descriptions valuable for engineering interpretations include those relating to slope, drainage, geology, stoniness, depth to bedrock, texture, consistence, reaction and structure. Laboratory analyses commonly run on pedological soil samples which are especially valuable to engineers include percent sand, percent silt, percent clay, percent and size of coarse fragments, mineralogy, percent organic matter, percent $CaCO_3$, bulk density, coefficient of linear extensibility, percent H_2O at 1/3 bar tension, percent H_2O at 15 bars tension, percent Na, etc.

Soil analyses that engineers need are outlined in many publications including PCA Soil Primer (PCA, 1962) and the Soils Manual for Design of Asphalt Pavement Structures (Asphalt Institute, 1964). Fortunately, many of the analyses required on soil samples by engineers can be approximated, estimated, adapted or transferred from the pedological descriptions and analyses. Some pedological soil tests, like the coefficient of linear extensibility (Soil Survey Staff, 1967), have been created by soil scientists especially to make their soil analyses more valuable for engineers to use. Recently an excellent guide has been published (Soil Survey Staff, 1971) to make ratings of pedologically-defined soils for various engineering uses.

One soil test, extremely important for engineering interpretations, that is not commonly run in pedological laboratories is the determination of plasticity index. Because this test is of such great value to engineers and because it is relatively easy and inexpensive to determine on soil samples, many laboratories in developing countries may wish to acquire the apparatus and train personnel to do the test. The equipment generally costs less than 100 dollars. The plasticity index is defined (PCA, 1962) as the numerical difference between liquid limit and plastic limit of a soil sample. The liquid limit is the moisture content at which a soil passes from a plastic to a liquid state. The plastic limit is the moisture content at which a soil sample changes from a semi-solid to a plastic state.

LIQUID LIMIT OF SOIL

The liquid limit of a soil is the percentage water content at which the soil passes from a plastic to a liquid state, as determined by a standard procedure (Asphalt Institute, 1964), requiring an evaporating dish, a spatula, a grooving tool, containers for weighing and drying soil samples, a balance sensitive to 0.1 gram, and a liquid limit device which will provide for standard shocks of one centimeter drop to be applied to a moistened soil sample in a brass cup (with the soil sample cut into 2 parts with the grooving tool) to force the two parts of the soil sample to join together.

For the liquid limit test, moisten with about 15-20 mililiters of water about 50 grams of soil that has been passed through a Number 40 (40 mesh per inch) sieve and put into an evaporating dish. Mix the wet soil to form a uniform mass of stiff consistence and place the soil in the bottom of the brass cup. Spread, squeeze and level the soil in the bottom of the brass cup with the spatula, being careful not to trap air bubbles in the soil. The soil should be at a depth of about one centimeter at its point of maximum thickness in the brass cup. The soil in the cup is then separated into two parts with the grooving tool. The cup containing the sample is lifted and dropped by turning the crank on the liquid limit device at a rate of two revolutions per second until the two sides of the soil sample come into contact at the bottom of the groove along a distance of about half an inch. The number of shocks required to close the groove is recorded.

A slice of soil is taken from the brass cup, approximately the width of the spatula and extending from edge to edge of the soil cake at right angles to the groove and including that portion of the groove in which the soil flowed together. This part of the soil mass is weighed, oven dried to a constant weight at 110°C., and weighed again. The loss in weight due to drying is recorded as the weight of water.

These operations are repeated for at least two additional portions of the soil sample to which sufficient water has been added to bring the soil to a more fluid condition. The object of this procedure is to obtain samples of such consistence that at least one determination will be made in each of the following ranges of shocks: 25-35, 20-30 and 15-25.

The water content of the soil is expressed in percentage calculated as follows:

Percentage moisture = (Weight of water/Weight of oven dried soil) x 100

A flow curve representing the relation between moisture content and corresponding number of shocks is plotted on semi-logarithmic graph paper with the moisture contents as abscissae on the arithmetical scale and the number of shocks as ordinates on the logarithmic scale. The flow curve should be a straight line drawn as nearly as possible through the three or more plotted points. The unit percentage moisture content corresponding to the intersection of the flow curve with the 25 shock ordinate is taken as the liquid limit of the soil.

PLASTIC LIMIT OF SOIL

The plastic limit of a soil is the lowest percentage water content at which the soil remains plastic, as determined by a standard procedure (Asphalt Institute, 1964), requiring an evaporating dish, a spatula, containers for weighing and drying soil samples, a balance sensitive to 0.1 gram, and a ground glass plate or piece of smooth unglazed paper on which to roll the soil sample.

For the plastic limit test, take about eight grams of moistened soil from the excess of the sample prepared for the liquid limit test. The soil mass should be at a moisture content to be plastic enough to be easily shaped into a ball without sticking to the fingers excessively when squeezed. The soil mass is shaped in the hand into an ellipsoidal-shaped mass. The soil mass is then rolled between the fingers and the ground-glass plate or the piece of paper lying on a smooth horizontal surface with just sufficient pressure to roll the mass into a thread of uniform diameter throughout its length. The rate of rolling is between 80 and 90 strokes per minute, counting a stroke as one complete motion of the hand forward and back to the starting position again.

When the diameter of the thread becomes 1/8 inch, break the thread into six or eight pieces. Squeeze the pieces together again between the thumbs and fingers of both hands into a uniform mass roughly ellipsoidal in shape and reroll. Continue this alternate rolling to a thread 1/8 inch in diameter, gathering together, kneading and rerolling until the thread crumbles under the pressure required for rolling and the soil can no longer be rolled into a thread.

Crumbling may occur when the thread has a diameter greater than 1/8 inch; this shall be considered a satisfactory end point for the plastic limit determination, provided the soil has been previously rolled into a thread 1/8 inch in diameter. The crumbling will manifest itself differently with the various kinds of soil. Some soils fall apart in numerous small aggregations of particles; others may form an outside tubular layer that starts splitting at both ends. The splitting may progress toward the middle and finally, the thread falls apart into many small platy parts. Fine textured clay soils require much pressure to deform the thread, particularly as they approach the plastic limit and then, finally, the thread may break into a series of barrel-shaped segments each about 1/4 to 3/8 inch in length.

The soil scientist making the test should not attempt to produce failure at exactly 1/8 inch diameter by allowing the thread to reach 1/8 inch, then reducing the rate of rolling or the hand pressure, or both, and continuing the rolling without further deformation until the thread falls apart. It is permissible, however, to reduce the total amount of deformation for slightly plastic soils by making the initial diameter of the ellipsoidal-shaped mass nearer to the required 1/8 inch final diameter.

When the plastic limit has been reached, gather the portions of the crumbled soil together, place in a container and weigh. Oven-dry the soil in the container to constant weight at 110°C and weigh again. Record the loss in weight as the loss of water.

Calculate the plastic limit, expressed as the water content in percentage of the weight of the oven dry soil, as follows:

Plastic limit = (Weight of water/Weight of oven dry soil) x 100

Report the plastic limit to the nearest whole number.

PLASTICITY INDEX OF SOIL

From the liquid limit and the plastic limit determined on a sample of soil, calculate the plasticity index as the difference between its liquid limit and its plastic limit, as follows:

Plasticity index = Liquid limit - Plastic limit

The difference calculated is reported as the plasticity index of a soil sample, except under the following conditions: (1) when the liquid limit or plastic limit cannot be determined, report the plasticity index as non-plastic, (2) when the soil is extremely sandy, the plastic limit test should be made before the liquid limit - if the plastic limit cannot be determined, report both the liquid limit and the plastic limit as non-plastic, and (3) when the plastic limit is equal to, or greater than, the liquid limit, report the plasticity index as non-plastic.

UNIFIED SOIL CLASSIFICATION SYSTEM

One of the most useful of the engineering soil classification systems employing the plasticity index is that developed initially by Dr. Arthur Casagrande of Harvard University, and tested extensively by the U.S. Army Corps of Engineers during World War II (PCA, 1962). The unified soil classification system has been revised and expanded after World War II, in cooperation with the U.S. Bureau of Reclamation, so that currently it applies to embankments and foundations as well as to roads and airfields.

The unified soil classification system identifies soils according to their textural and plasticity qualities and their grouping with respect to their performances as engineering construction materials. The soil classes are based on: (1) percentages of gravel, sand and fines (particles passing Number 200 sieve, with 200 mesh per inch), (2) shape of the particle size distribution curve and (3) plasticity and compressibility characteristics. Each soil sample is given a descriptive name and a letter symbol indicating its principal characteristics.

Four size fractions for soils are recognized for engineering uses in the unified soil classification system; cobbles, gravel, sand and fines (silt and clay). The limiting size boundaries and their comparisons with the USDA soil textures are given in Figure 1. Table 1 gives the percentage of soil material commonly passing specified engineering sieve sizes, for the different pedological soil texture classes. Where engineering test data are not available, Figure 1 and Table 1 will be useful in transferring pedological soil data into engineering terms.

In the unified soil classification system, soils are classified into (1) coarse grained, (2) fine grained and (3) highly organic categories. The coarse grained soils contain 50 percent or less material smaller than the Number 200 sieve and fine grained soils contain more than 50 percent material smaller than the Number 200 sieve. Highly organic soils can generally be identified visually and present no great problem in classification.

The coarse grained soils are subdivided into gravel (G) and sand (S). Gravel has the greater percentage of the coarse fraction (that portion retained on the Number 200 sieve) retained also on the Number 4 sieve (4 mesh per inch), and the sands have the greater portion passing the Number 4 sieve. The four secondary divisions of each group - GW, GP, GM and GC (gravel); SW, SP. SM and SC (sand) - depend on the amount and type of fines and the shape of the grain size distribution curve. Well graded materials (W) generally have grain size curves that are smooth and concave with no sizes lacking and no excess of material in any size range. Poorly graded materials (P) have excesses of materials in specific size ranges.

Representative soil descriptions for some of the secondary groups of soils in the unified soil classification system are given in Table 2. Figure 2 outlines the relationships of the liquid limit and the plasticity index in subdividing the finer textured soils. Fine grained soils are segregated into silt (M) and clay (C) depending on their liquid limit and plasticity index. Silts are those fine grained soils with a liquid limit and plasticity index that plot below the "A" line in Figure 2 and clays are those that plot above the "A" line. Organic clays do not fit into the graph in Figure 2 because their liquid limit and plasticity index plot below the "A" line. The silt and clay groups have secondary divisions based on whether the soils have a relatively low (L) or high (H) liquid limit. General relationships between the unified soil classification, USDA textures and some soil properties are listed in Table 3.

The highly organic soils, usually very compressible and with undesirable construction characteristics, are classified into one group designated by the symbol "Pt". This category includes peat, muck, humus and swamp soils.

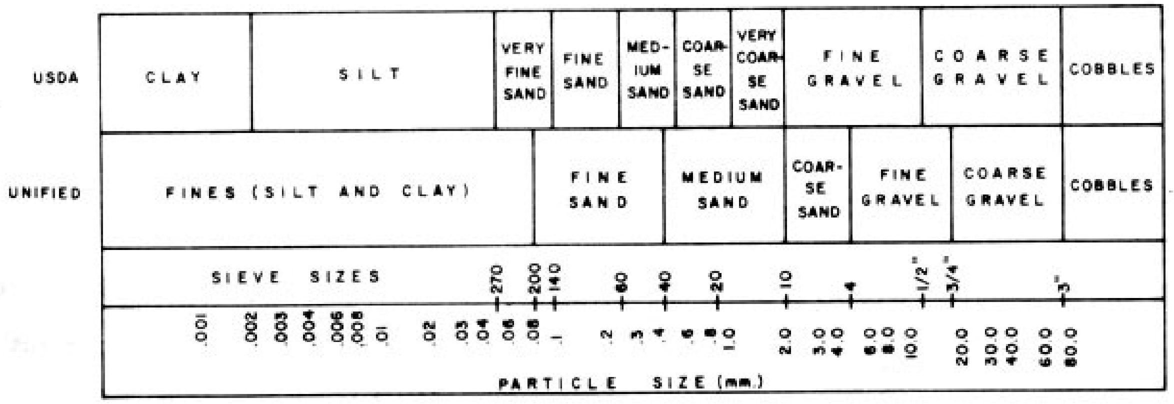

Figure 1. Comparison of particle sizes of soils in the USDA pedological and the unified engineering soil classification systems (adapted from PCA, 1962).

Table 1. Percentage of soil material of different textures commonly passing specified sieve sizes (to be used as a guide where engineering test data are not available; adapted from Soil Survey Staff, 1971).

USDA textural class	Percent passing sieves 1/	
	Number 40 (0.42 mm)	Number 200 (0.074 mm)
Clay	90 - 100	75 - 95
Silty clay	95 - 100	90 - 95
Silty clay loam	95 - 100	85 - 95
Clay loam	90 - 100	70 - 80
Loam	85 - 95	60 - 75
Silt loam	90 - 100	70 - 90
Silt	100	90 -100
Sandy clay	85 - 95	45 - 60
Sandy clay loam	80 - 90	35 - 55
Sandy loam	60 - 70	30 - 40
Fine sandy loam	70 - 85	40 - 55
Very fine sandy loam	85 - 95	50 - 65
Loamy very fine sand	90 - 95	40 - 60
Loamy sand	50 - 75	15 - 30
Fine sand	65 - 80	20 - 35
Sand	50 - 70	5 - 15
Very fine sand	75 - 90	35 - 55

1/ NOTE: To determine texture class, material larger than 2.00 mm is removed. Therefore, all material from textural class determination passes both No. 4 and No. 10 sieves. Above percentages, therefore, must be adjusted to include the percent of material coarser than 2.0 mm.

EXAMPLE: Gravelly loam texture with 20 percent, by weight, of soil material larger than 2.0 mm and 30 percent of tested material coarser than 0.074 mm. Then, 80 percent of total sample is less than 2.0 mm. Coarse soil material is 30 percent of 80 = 24 percent of total material + 20 percent. Fifty-five percent would pass No. 200 sieve (report would show 50 - 60 percent) and 80 percent would pass the No. 10 sieve (report would show 75 - 85 percent).

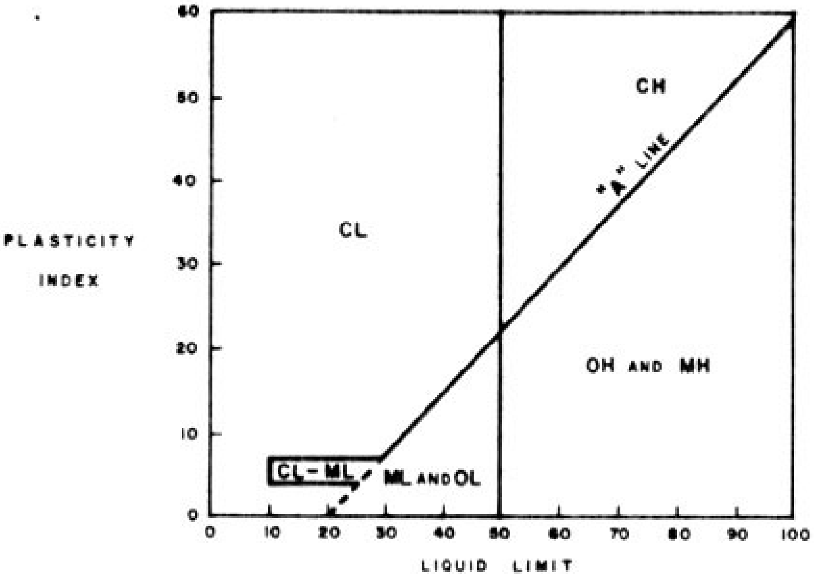

Figure 2. Groupings of soils in the unified soil classification system in the fine grained sizes, showing relationships between the categories and the liquid limit and plasticity index (adapted from PCA, 1962). See Table 2 for an explanation of the symbols.

Table 2. Typical names and group symbols of the unified soil classification system (adapted from PCA, 1962).

Group symbol	Typical names
GW	Well graded gravel, gravel and sand mixtures, little or no fines.
GP	Poorly graded gravel, gravel and sand mixtures, little or no fines.
GM	Silty gravel, gravel and sand and silt mixtures.
GC	Clayey gravel, gravel and sand and clay mixtures.
SW	Well graded sands, gravelly sands, little or no fines.
SP	Poorly graded sands, gravelly sands, little or no fines.
SM	Silty sands, sand and silt mixtures.
SC	Clayey sands, sand and clay mixtures.
ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands, or clayey silts with slight plasticity.
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.
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.
Pt	Peat and other highly organic soils.

Table 3. Soil ratings and properties for engineering uses (this table may be used as a guide in classifying soils for which no engineering test data are available; adapted from Soil Survey Staff, 1971).

USDA texture	Unified symbol	Soil properties
Clay, silty clay	CH	High shrink-swell clays
	MH	Mica, iron oxide, kaolinite clays
	CL	Low liquid limit, generally < 45% clay
Silty clay loam	CL	Low liquid limit, plastic
	ML-CL	Low liquid limit, moderately plastic
	CH	High liquid limit, high shrink-swell clays
	MH	High liquid limit, mica, iron oxide, kaolinitic
Clay loam	CL	Low liquid limit, plastic
	ML-CL	Low liquid limit, moderately plastic
	CH	High liquid limit, high shrink-swell clays
	MH	High liquid limit, mica, iron oxide, kaolinitic
Loam	ML-CL	Moderately plastic
	CL	Plastic
	ML	Low plasticity
Silt loam	ML-CL	Moderately plastic
	ML	Low plasticity
	CL	Plastic
Silt	ML	Low plasticity
Sandy clay	CL	Fines > 50%
	SC	Fines < 50%
Sandy clay loam	SC	Plastic, fines 36-50%
	SC	Plastic, fines < 35%
	CL	Plastic, fines > 50%
Sandy loam	SM	Low plasticity
	SC	Plastic
	SM-SC	Moderately plastic
Fine sandy loam	SM	Non-plastic, fines < 50%
	ML	Non-plastic, fines > 50%
	ML-CL	Moderately plastic, fines > 50%
	SM-SC	Moderately plastic, fines < 50%
Very fine sandy loam	ML-CL	Moderately plastic
	ML	Low plasticity
Loamy sand, loamy fine sand, loamy very fine sand	SM	Non-plastic, fines < 35%
	SM-SC	Moderately plastic, fines < 35%
	SM	Low plasticity, fines > 35%
	ML	Little or no plasticity
Sand, fine sand	SP-SM	Fines 5-10%
	SM	Fines > 10%
	SP	Fines < 5%
Very fine sand	SM	Low plasticity
	ML	Little or no plasticity
Coarse sand	SP or GW	Fines < 5%
	SP-SM	Fines 5-12%
	SM	Fines 13-25%
	SM	Fines > 25%
Gravel (50% passed Number 200 sieve, 50% of coarse passes Number 4 sieve)	GP or GW	Fines < 5%
	GM or GC	Fines 5-25%
	GM or GC	Fines 26-35%
	GM	Fines > 35%
	GC	Fines > 35%

RATINGS OF SOILS FOR DIFFERENT USES

On the basis of soil properties, mapped and described in the field and analyzed in the laboratory, and on the basis also of acquired experience in measurement and observation of performances of various soils when subjected to engineering loads or other engineering uses, soils may be rated into simple groupings which will help people to decide whether or not a given soil at a given location is likely to be good or poor for a specific use. In most cases, of course, especially for very expensive engineering structures, it is necessary also to conduct extensive on-site engineering tests and deep borings in addition to evaluation of the pedological soil data, before construction starts. Pedological soil data used for engineering purposes, however, can be extremely valuable to engineers in deciding where to make deeper borings, and many engineering construction sites can be tentatively accepted or rejected on the basic of pedological soil maps and data. The pedological information can also be used by engineers to determine the likely soil conditions that may need to be modified for construction, like leveling of sloping sites, draining wet soil areas, etc. The value of the pedological data to engineers, of course, is dependent upont the scale and detail of the soils maps and upon the quantity and quality of the pedological soil data available.

Soils generally can be grouped into about three categories to provide useful first approximations for engineering purposes, based on pedological information. Most soils can be rated good, moderate, or poor for most engineering uses; more refined groupings, of course, can be made where it is necessary and when more data are available. Sometimes it is useful to have categories of soils that are "unsuited" for a specific use; sometimes categories can be devised to show likely soil performance with respect to shrink-swell potential or corrosivity in terms like low, moderate and high. Most engineering performances of most soils, however, can be evaluated in soil groupings or terms like good, moderate, or poor.

Soils rated good for engineering constructions have properties favourable for the rated use. The degree of limitation is minor and can be overcome easily. Good performances and low maintenance costs can be expected.

Soils rated moderate for engineering constructions have properties moderately favourable for the rated use. This degree of limitation can be overcome or modified by special planning design, or maintenance. During some part of the year the performance of the structure or other planned use is somewhat less desirable than for soils rated good. Some soils rated moderate require treatment such as runoff control to reduce erosion, extra excavation, artificial drainage, extended sewage absorption fields, or some other modification of certain features through manipulation of the soil. For these soils, modification is needed from those construction plans for soils rated good. Modifications may include special foundations, extra reinforcement of structures, sump pumps, etc.

Soils rated poor for engineering constructions have one or more properties unfavourable for the rated use, such as steep slopes, bedrock near the soil surface, flooding hazard, high shrink-swell potential, a seasonally high water table, or low bearing strength. This degree of limitation generally requires major soil reclamation, special design, or intensive maintenance.Some of these soils can be improved by reducing or removing the soil feature that limits use, but in most situations it is difficult and costly to alter the soil or to design a structure so as to compensate for a severe degree of limitation.

AGGREGATE SOIL MATERIAL

For road construction and other engineering work in developing countries, soils as sources of aggregate material (sand and gravel) are extremely important. Aggregate material is generally used as a base for hard surfacing on roads, or as a surfacing on roads where asphalt or concrete is not applied. Aggregate material is commonly used as fill where natural soils are unsuitable for subgrade for roads or where natural soils may be unstable as a base for other engineering structures. Because aggregate soil materials are bulky and expensive to transport, soil maps can be very useful to engineers in finding local sources. Soils that are good to moderate sources need to have layers of sand or gravel that are at least one metre thick.

Good sources of sand and gravel are generally those soils rated SW, SP, GW, or GP in the unified soil classification system. These groups are shown for aggregate material in Table 4, and Table 2 gives brief descriptions of the character of these soil materials. Well graded (W) aggregate materials (Table 2) have particle size ranges with no sizes lacking and no excess of material in any size range; poorly graded (P) aggregate materials tend to have concentrations of particles in one narrow size range.

Soils with moderate suitability as sources of aggregate material for construction purposes (table 4) have silts mixed with the sand and gravel (Table 2). The silt, of course, is finer textured and provides a base that is much less stable for engineering support than are coarser textured materials. Silt deposits are commonly mixed between layers of sand and gravel in soil areas where geologic deposits were laid down by alternating periods of fast-flowing and slower-moving waters.

Poor sources of aggregate materials (Table 2) are those soils in which clays and silts predominate (Table 4). The fine textured soil materials also provide poor support for roads and foundations. Soils rated ML, CL, OL, MH, CH, OH and Pt are unsuitable as sources of aggregate material (table 2, table 4). All these materials provide relatively unstable support for roads and foundations. Probably the highly organic soils present the most problems of all when they are built upon.

Table 4. Ratings of soils as sources of aggregate material (sand and gravel) for construction purposes (rated according to the unified soil classification system; adapted from Soil Survey Staff, 1971).

Probable source		Improbable source	
Good	Moderate	Poor	Unsuited
SW	SW - SM	SM	all other groups in the unified soil classification system
SP	SP - SM	SW - SC	
		SP - SC	
GW	GP - GM	GM	
GP	GW - GM	GP - GC	
		GW - GC	

SECONDARY ROADS ON SOILS

In developing countries, roads are extremely important in almost all phases of national programmes for economic development. Good roads are absolutely essential in order to provide goods and services to populations in remote villages. Roads are essential also for administration purposes, for movement of agricultural products to larger cities, and for education and health programmes of rural and urban peoples. General ratings of soil properties for secondary roads are given in Table 5. The most important soil properties affecting road construction are slope, depth to bedrock, sub-grade materials, shrink-swell potential, susceptibility to frost action (in some areas), stoniness, rockiness, soil drainage and flooding.

For building and improving roads, engineers can use soil information in many ways. Soil maps can be used in locating optimum routes for new roads. Improvement of old roads can benefit from use of soil maps in locating local sources of fill and aggregate materials. Soils maps can indicate areas that might need drainage, or areas of unstable soils. Problems to be encountered like flooding and stoniness are also indicated by soil information. Where available soil information is not detailed enough, special soil maps and samplings could be made along the right-of-way of routes scheduled for road construction or road improvement.

Soil ratings for secondary roads in Table 5 are based on the assumptions that the roads consist of (1) underlying local soil material, whether cut or fill, called sub-grade; (2) the base material of gravel, crushed rock, lime-stabilized soil, or soil-cement-stabilized soil; and (3) the actual road surface is either flexible (asphalt), rigid (concrete), or gravel with binder in it. These roads are also graded to shed water, to assure all-weather travel opportunities and conventional drainage measures are provided. Except for the hard surfaces, the secondary roads are built mainly from the soil at hand; cuts and fills generally are limited to less than two metres in thickness. In the ratings in Table 5, of course, the most limiting single property of a soil determines the overall rating for that soil; thus a soil with 20 percent slope is rated poor for secondary roads even if all its other properties are good or moderate for road construction.

Table 5. Ratings of soils for secondary roads (adapted from Soil Survey Staff, 1971)

Item affecting use	Soil rating Good	 Moderate	 Poor
Slope	0 - 8%	8 - 15%	>15%
Depth to bedrock 1/	>100 cm	50 -100 cm	<50 cm
Unified soil group for sub-grade 2/	GW, GP, SW SP, GM, GC 3/ SM 3/, SC 3/	CL with plasticity index <15	CL with plasticity index >15, CH, MH 4/, OH, OL, Pt
Shrink-swell potential	Low	Moderate	High
Susceptibility to frost action 5/	Low	Moderate	High
Stoniness class 6/	0, 1 and 2	3	4 and 5
Rockiness class 6/	0	1	2,3,4 and 5
Soil drainage class 7/	Excessively drained, somewhat excessively drained, well drained and moderately well drained	Somewhat poorly drained	Poorly drained and very poorly drained
Flooding	None	Soils flooded less than once in 5 years	Soils flooded more than once in 5 years

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1/ If bedrock is soft enough so that it can be dug out with hand tools or light power equipment,(such as backhoes) reduce ratings of moderate and poor by one category.

2/ If engineering test data are not available, estimate the unified soil groups from pedological data and Figures 1-2 and table 1-3.

3/ Downgrade soil rating to moderate if content of fines is more than about 30%.

4/ Upgrade soil rating to moderate if MH is largely kaolinitic, friable and free of mica.

5/ Use this item only where frost penetrates below the paved or hardened surface layer and where moisture transportable by capillary movement is sufficient to form ice lenses at the freezing point.

6/ Class definitions are given on pages - 216-223 of the Soil Survey Manual (Soil Survey Staff, 1951).

7/ Class definitions are given on pages 169-172 of the Soil Survey Manual (Soil Survey Staff, 1951).

BUILDING FOUNDATIONS IN SOILS

Soil suitability for buildings is given in Table 6, considering each important soil property separately. These ratings are only first approximations, and do not eliminate the need for detailed on-site engineering borings before construction starts. The ratings are for constructions of buildings of fewer than three floors; if extensive excavations are done the column in Table 6 applying to basements should be used. The emphasis in rating soils for small buildings is on the soil properties that affect foundations, but also considered beyond the effects related exclusively to foundations are slope, susceptibility to flooding, seasonal wetness and other hydrologic conditions.

The soil properties influencing foundation support are those affecting bearing capacity and settlement under load and those affecting costs of excavation and construction. Properties affecting bearing strength and settlement of the natural soil are density, wetness, flooding, plasticity, texture and shrink-swell potential. Soil properties influencing the amount and ease of excavation are wetness, slope, depth to bedrock, stoniness, and rockiness. Also considered are soil properties, particularly depth to bedrock, that influence installation of utility lines like those for water supplies and sewage disposal (but not for septic tank seepage fields, for which soils are rated in a separate table). Interpretations for corrosion of steel and concrete in soils are also discussed separately, and are not considered in Table 6.

Table 6. Ratings of soils for buildings (adapted from Soil Survey Staff, 1971)[1]

Item affecting use	Soil rating [2]		
	Good	Moderate	Poor
Slope [3]	0 – 8%	8 – 15%	> 15%
Shrink-swell potential	Low	Moderate	High
Unified soil group	GW,GP,SW,SP GM, GC, SM, SC, CL with plasticity index < 15	ML, CL with plasticity index >15	CH, MH[4] OL, OH
Potential frost action [5]	Low	Moderate	High
Stoniness class [6]	0 and 1	2	3,4, & 5
Rockiness class [7]	0	1	2,3,4, and 5
Flooding	None	None	Rare, occasional or frequent
Depth to bedrock [7]	With basements	With basements	With basements
	> 150 cm	100 – 150 cm	< 100 cm
	Without basements	Without basements	Without basements
	> 100 cm	50 – 100 cm	< 50 cm

Table 6 (continued). Ratings of soils for buildings (adapted from Soil Survey Staff,[1] 1971).

Item affecting use	Soil rating[2]		
	Good	Moderate	Poor
Soil drainage class [8]	With basements Excessively drained some what excessively drained, well drained	With basements Moderately well drained	With basements Somewhat poorly drained, poorly drained, very poorly drained
	Without basements Excessively somewhat excessively drained, well drained, moderately well drained	Without basements Somewhat poorly drained	Without basements Poorly drained, very poorly drained
Seasonal water table (seasonally high for one month or more during the year)	With basements Below a depth of 150 cm	With basements Below a depth of 75 cm	With basements Above a depth of 75 cm
	Without basements Below a depth of 75 cm	Without basements Below a depth of 50 cm	Without basements Above a depth of 50 cm

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1/ If slope limits are reduced 50%, this table can be used for evaluating soil limitations for small industrial buildings or commercial centers with foundation requirements not exceeding those of ordinary three story dwellings.

2/ Some soils with moderate or poor ratings may be good sites from the standpoint of aesthetics but require more site preparation and maintenance.

3/ Reduce slope limits 50% for those soils susceptible to landslides.

4/ Upgrade to moderate if MH is largely kaolinitic, friable and free of mica.

5/ Use this item only when frost penetrates to assumed depth of footings and where the soil is moist during freezing weather.

6/ Class definitions are given on pages 216-223 of the Soil Survey Manual (Soil Survey Staff, 1951).

7/ If bedrock is soft enough so that it can be dug out with hand tools or light power equipment,(such as backhoes) reduce ratings of moderate and poor by one category.

8/ Class definitions are given on pages 169 - 172 of the Soil Survey Manual (Soil Survey Staff, 1951).

HUMAN WASTE DISPOSAL IN SOILS

Many of the health problems in developing countries are caused by inadequate disposal of human waste. Water supplies and food supplies may be contaminated with desease-producing organisms, due to lack of adequate waste disposal facilities. Soils can be excellent media for receiving and filtering human waste materials, if the volumes of the soils receiving the materials are not overloaded and if the properties of the soils are good or moderate for receiving sewage effluent. It must be pointed out that adequate waste disposal is as important to the health and well-being of populations in developing countries as is adequate food production; uses of soils for waste disposal should be as important in planning economic development programmes as plans for use of soils for farming.

Septic tank systems provide for solid settlement of human waste and digestion in an anaerobic tank, with the effluent (liquid) passing out of the tank into a seepage field where it is filtered through the soils. Designs for many different systems have been extensively tested, and are available in a number of publications (Olson, 1964). Criteria for rating soils for human waste disposal in Table 7 are based on the ability of the soils to filter effluent. Some important factors influencing the capacity of a soil to filter effluent are (1) design, load and maintenance of the engineering aspects of the disposal system, (2) permeability of the subsoil and substrata, (3) depth to consolidated rock or other impervious layers, (4) flooding, (5) seasonal and annual groundwater level and (6) slope.

Soils for sewage disposal, of course, should have relatively rapid permeability, but the effluent should not run through the soil so fast or in such large volumes that it contaminates the groundwater. Soils subject to more than rare flooding are rated poor, because floodwaters interfere with the proper functioning of the seepage field. Steep slopes cause mechanical problems for layout and construction of tile lines for effluent filtration and effluent seepage downslope may contaminate water supplies. Septic tank seepage fields properly installed and maintained in suitable soils can contribute a great deal toward improved health conditions in many parts of developing countries, especially where population densities are not too great.

Table 7. Ratings of soils for human waste disposal in septic tank seepage fields (adapted from Soil Survey Staff, 1971).

Item affecting use	Soil rating		
	Good	Moderate	Poor
Permeability class [1]	Rapid, [2] moderately rapid, and upper end of moderate	Lower end of moderate	Moderately slow [3] and slow
Hydraulic conductivity rate (Uhland core method)	> 2.5 cm/hr [2]	2.5 – 1.5 cm/hr	< 1.5 cm/hr
Percolation rate (Auger hole method; Olson, 1964)	Faster than 18 min/cm	18 – 24 min/cm	Slower than 24 min/cm
Depth to water table	> 180 cm	120 – 180 cm	< 120 cm
Flooding	None	Rare	Occasional or frequent
Slope	0 – 8%	8 – 15%	> 15%
Depth to hard rock [4], bedrock or other Impervious materials	> 180 cm	120 – 180 cm	< 120 cm
Stoniness class [5]	0 and 1	2	3,4 and 5
Rockiness class [5]	0	1	2,3,4 and 5

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[1] Class limits are the same as those suggested by the Work Planning Conference of the National Cooperative Soil Survey (Soil Survey Staff, 1971). The suitability ratings should be related to the permeability of soil layers at and below the depth of the installed tile lines of the seepage field.

[2] Special considerations should be given to places where pollution is a hazard to water supplies.

[3] In arid or semi-arid areas, soils with moderately slow permeability may have a rating of moderate.

[4] These depth ratings are based on the assumption that tile in the seepage field is at a depth of about 60 centimetres.

[5] Class definitions are given on pages 216–223 of the Soil Survey Manual (Soil Survey Staff, 1951).

TRANSPORTED PLANT MEDIUM (ARTIFICIAL SOIL)

In and around engineering constructions, it is frequently necessary to create new soils in which plants will grow, from transported or artificial soil materials. These engineering situations arise on road embankments, around buildings where natural soils have been scraped or buried, over pipelines, and in many other places. Ratings of soils in table 8 consider suitability of soil materials that have been moved, or that are still in place in the natural horizons of soils but are to be excavated and transported to other sites.

Soils rated good in Table 8 have good physical, chemical and biological characteristics favourable to establishment and growth of adapted plants; the soil is friable and easy to handle and spread. It is likely to be responsive to heavy fertilization. Soils rated poor in Table 8 have extreme sandy or clayey textures, firm consistence, shallowness to rock or gravel, stones, high salt concentrations, or occupy slopes or wet spots. Although not listed in Table 8, soils that contain toxic substances should obviously be rated poor for growing plants in these areas.

Table 8. Ratings of disturbed soils for growing plants (for topsoil that can be transported to gardens and other places; adapted from Soil Survey Staff, 1971).

Item affecting use	Soil rating		
	Good	Moderate	Poor
Moist consistence	Very friable, friable	Loose, firm	Very firm, extremely firm
Texture	fsl, vfsl, l, scl, sl, sc if 1:1 clay is dominant	cl, scl, sicl, sc if 2:1 clay is dominant; c and sic if 1:1 clay is dominant	s, ls, c, and sic if 2:1 clay is dominant
Thickness of material (generally uppermost part of profile)	>40 cm	20 - 40 cm	<20 cm
Coarse fragments (volume)	<3%	3 - 15%	>15%
Soluble salts (conductivity of saturation extract)	<4 mmhos/cm	4 - 8 mmhos/cm	>8 mmhos/cm
Stoniness class 1/	0	1	2,3,4 and 5
Slope	< 8%	8 - 15%	>15%
Soil drainge class 2/	Better drained than poorly drained	Better drained than poorly drained	Poorly drained, very poorly drained

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1/ Class definitions are given on pages 216-223 of the Soil Survey Manual (Soil Survey Staff, 1951).

2/ Class definitions are given on pages 169-172 of the Soil Survey Manual (Soil Survey Staff, 1951).

SHRINK - SWELL POTENTIAL OF SOILS

Shrink-swell behaviour is that quality of the soil that determines its volume change with change in moisture content. Building foundations, roads and other engineering structures may be severely damaged by the shrinking and swelling of soil. The volume change of soil is influenced by the amount of moisture change and the amount and the kind of clay. Knowledge of the kind and the distribution of clay helps in predicting the behaviour of a soil. Soil genesis is a critical factor in determining the kind of clay in a soil; shrink-swell potential of soils may vary greatly from place to place within relatively short distances.

One measure (Soil Survey Staff, 1967) of the shrink-swell behaviour of soils is the determination of the coefficient of linear extensibility (COLE). COLE is an estimate of the vertical component of swelling of a natural soil clod. COLE is defined as:

$$(Lm - Ld) / Ld$$

where Lm = Length of moist sample and Ld = Length of dry sample.

Shrink-swell interpretations of soils are relevant to structures including houses and other low buildings, streets and roads, and structures like lined irrigation canals and embankments. Five classes have been developed (Soil Survey Staff, 1971) to express shrink-swell behaviour, but in many cases only three classes are necessary. Soils with very low and low shrink-swell potential can be combined into a single low class ($<$0.03 COLE), moderate shrink-swell potential has a COLE range 0.03 - 0.06 and soils with high and very high shrink-swell behaviour can be combined in a high class with $>$0.06 COLE.

Where five classes of shrink-swell behaviour of soils are useful, the following distinctions can be made (1) soils with very low shrink-swell behaviour generally include soils that are loamy sand and sand and that contain any kind of clay mineral and sandy loam, loam, and silt loam that contain kaolinite or other low shrink-swell clay minerals (COLE$<$0,01); (2) soils with low shrink-swell behaviour generally include soils that are silt loam, silty clay loam, clay loam, silty clay, sandy clay, and clay that contains mainly kaolinite or other low shrink-swell clay minerals (COLE 0.01 - 0.03); (3) soils with moderate shrink-swell behaviour generally include soils that are silty clay, silty clay loam, clay loam, sandy clay loam, and clay containing mixed clay minerals that include some montmorillonite or other high shrink-swell minerals (COLE 0.03 - 0.06); (4) soils with high shrink-swell behaviour generally include soils that are clay loam, silty clay loam, silty clay, sandy clay, and clay that are made up of a large percentage of montmorillonite or other high shrink-swell clay minerals (COLE 0.06 - 0.09); and (5) soils with very high shrink-swell behaviour generally include soils that are clay, silty clay, and sandy clay that are made up mainly of montmorillonite or other high shrink-swell minerals (COLE $>$0.09).

EMBANKMENTS OF SOIL MATERIALS

Many engineering uses of soils are involved with placement and compaction of soil materials in embankments for holding back or confining water; these interpretations are particularly relevant in construction of dams, dikes, canals, and levees and may also apply in some situations to fill, terraces, and other structures. Table 9 lists some of the characteristics of different soil materials for compacted embankments, as described and classified in the unified soil classification system (Table 2). Among the properties commonly affecting evaluation of soils to be used in embankments are shear strength, compressibility, permeability of the compacted soil, susceptibility to piping, and compaction characteristics. Other properties of soils as source materials for embankment constructions include depth to bedrock, shrink-swell potential, content of gypsum or other salts, and percentage of coarse fragments.

The shear strength of a soil (Table 9) indicates the relative resistance of that soil to sliding when supporting a load. The highest resistance to sliding occurs in soils that are composed of clean gravel ($<$ 5% fines). Soil strength decreases as fines increase and is lowest in fine-grained organic soils (OL and OH). Landslide susceptibility of the base on which the embankments are placed is of course a primary consideration determining feasibility of the structure.

The compressibility of a soil (Table 9) pertains to the decrease in volume of the mass when supporting a load. Compressibility is lowest in coarse-grained soils having grains that are in contact; volume of the mass decreases very slightly when these soils support heavy loads. Compressibility increases as fines increase and is highest in fine-grained soils containing organic matter.

The permeability of compacted soil (Table 9) pertains to the rate at which water moves through soil after compaction. If a coarse-grained soil, after compaction, contains large continuous pores, the soil transmits water rapidly and is said to have high permeability. Because fine-grained soils contain very small discontinuous pores, a compacted fine-gravel soil transmits water very slowly and has low permeability.

Susceptibility to piping (Table 9) or internal erosion of a soil applies to the likelihood of removal of soil particles by water moving through the pores or cracks in the compacted soil mass. Highly susceptible soil materials are those that have large pores through which water moves rapidly, yet in which soil grains are fine enough and sufficiently lacking in coherence so that the individual grains move readily. The most susceptible materials are fine sands and non-plastic silts with a plasticity index of less than five. Although coarse sands and gravel also may transmit water rapidly, they consist of large individual grains that, themselves, resist internal movement. Also, other soil materials of low susceptibility to piping are fine-grained, cohesive, and highly plastic; they transmit water very slowly and, thus, resist piping or internal erosion.

Compaction characteristics (Table 9) indicate the relative response of soil to compactive effort. Where there is satisfactory moisture control and a soil can be compacted to a high degree with minimum effort, the compaction characteristics of that soil are evaluated as good. The degrees to which compactive effort and construction control must be increased are reflected in the evaluations of fair and poor in Table 9.

Table 9. Characteristics of different soil materials for compacted embankments (adapted from Soil Survey Staff, 1971).

Unified classification	Shear strength	Compressibility	Permeability of compacted soil	Susceptibility to piping	Compaction characteristics
GW	High	Low	High	Low	Good
GP	High	Low	High	Low	Good
GM	High to medium	Low	Medium to low	Medium to low	Fair to good
GC	Medium	Low to medium	Low	Medium to low	Good to fair
SW	High	Low	High	Medium	Good
SP	Medium	Low	High	Medium to high	Good
SM	Medium	Low to medium	Medium to low	Medium to high	Fair to good
SC	Medium to low	Low to medium	Low	Medium to low	Good to fair
ML	Medium to low	Medium	Medium to low	High	Fair to poor
CL	Medium to low	Medium	Low	Low to medium	Fair to good
MH	Low	High	Low to medium	Medium to low	Poor
CH	Medium to low	High	Low	Low	Fair to poor
OL 1/	Low	High	Low to medium	Medium to high	Fair to poor
OH 1/	Low	High	Low	Medium to low	Poor
Pt 2/	Unsuitable	Unsuitable	Unsuitable	Unsuitable	Unsuitable

1/ Suitable for use in low embankments with very low hazard only.

2/ Not suitable for embankments.

CONCRETE DETERIORATION IN SOILS

Concrete materials (foundations, water lines, canal linings, etc.) placed in soils deteriorate to varying degrees (Soil Survey Staff, 1971). The rate of deterioration is due to several soil factors, including (1) the amount of sulphates and (2) soil texture and acidity. Special cements and methods of manufacturing may be used to reduce the rate of deterioration in soils of high corrosivity. Three corrosivity classes can be used in making soil interpretations: (1) soils with low corrosivity for concrete generally include coarse textured and moderately coarse textured soils, organic soils that have pH greater than 6.5, medium and fine textured soils that have a pH greater than 6.0, and soils that contain less than 1,000 parts per million of water-soluble sulphate (as SO_4); (2) soils with moderate corrosivity for concrete generally include coarse textured and moderately coarse textured soils and organic soils that have a pH of 5.5 to 6.5, medium and fine textured soils that have a pH of 5.0 to 6.0, and soils that contain 1,000 to 7,000 parts per million of water-soluble sulphate (as SO_4); and (3) soils with high corrosivity for concrete generally include coarse textured and moderately coarse textured soils and organic soils that have a pH of 5.5 or less, medium and fine textured soils that have a pH of 5.0 or less, and soils that contain more than 7,000 parts per million of water-soluble sulphate (as SO_4).

UNCOATED STEEL CORROSIVITY IN SOILS

Rusting and corrosion of pipelines, cables and other uncoated steel structures in soils are a complex process only partially understood at present. Corrosion of uncoated steel is generally considered to be a physical-biochemical process that converts iron into its ions (Soil Survey Staff, 1971). Before corrosion can take place, soil moisture is necessary to form solutions of soluble salts. Any factors that influence the soil solution or the oxidation-reduction reactions taking place in the soil also influence the operation of the corrosion cell (steel in soil). Some of the soil environment factors affecting corrosion are the amount of water in the soil, the conductivity of the soil solution, the hydrogen ion activity in the soil solution (pH), the oxygen concentration (aeration), and the activity of organisms capable of causing oxidation-reduction reactions.

The estimation of corrosivity for untreated steel pipe is commonly based on (1) resistance to flow of electrical current, (2) total acidity (Soil Survey Staff, 1967), (3) soil drainage, (4) soil texture, and (5) conductivity of the saturation extract of the soil. Criteria for classes are based on unpublished and published research data (Soil Survey Staff, 1971).

Soils generally are assigned to one of three classes of corrosivity; low, moderate or high. Criteria can be given for five classes, but the five classes should be used only if knowledge of a specific soil warrants the finer distinctions for proper interpretation. In the classes commonly used, low and high are combined with very low and very high, respectively.

Soils with very low corrosivity for uncoated steel generally include somewhat excessively drained to excessively drained coarse textured soils that have little clay in the control section. Water and air move through these soils rapidly or very rapidly. The total acidity is below 4.0 meq per 100 grams of soil, or electrical resistivity of the soil at moisture equivalent (Soil Survey Staff, 1967) is above 10,000 ohm-cm at 60°F, or electrical conductivity of the saturation extract (Soil Survey Staff, 1967) is less than 0.1 mmho per centimetre at 25° C, (non-corrosive).

Soils with low corrosivity for uncoated steel generally include well drained soils that have a moderately coarse textured and medium textured control section and somewhat poorly drained soils that have a coarse textured control section. These soils are moderately permeable or rapidly permeable. Their total acidity ranges from 4.0 to 8.0 meq per 100 grams of soil, electrical resistivity at moisture equivalent is 5,000 to 10,000 ohm-cm at 60° F, or electrical conductivity of the saturation extract is 0.1 to 0.2 mmho per centimetre at 25°C, (slightly corrosive).

Soils with moderate corrosivity for uncoated steel generally include well drained soils that have a moderately fine textured control section and moderately well drained soils that have a medium textured control section. The moderate category also includes somewhat poorly drained soils that have a moderately coarse textured control section, and very poorly drained soils (including peats and mucks) in which the water table remains at the surface throughout the year. Permeability of these soils is moderately slow to slow. The total acidity ranges from 8.0 to 12.0 meq per 100 grams of soil, electrical resistivity at moisture equivalent is 2,000 to 5,000 ohm-cm at 60° F, or electrical conductivity of the saturation extract is 0.2 to 0.4 mmho per centimetre at 25° C, (moderately corrosive).

Soils with high corrosivity for uncoated steel generally include well drained and moderately well drained fine textured soils; moderately well drained, moderately fine textured soils; somewhat poorly drained soils that have medium textured and moderately fine textured control sections; and poorly drained soils that have coarse textured to moderately fine textured control sections. Very poorly drained soils are included when their water table fluctuates within 30 centimetres of the surface at some time during the year. The total acidity ranges from 12.0 to 16.0 meq per 100 grams of soil, electrical resistivity at moisture equivalent is 1,000 to 2,000 ohm-cm at 60° F, or electrical conductivity of the saturation extract is 0.4 to 1.0 mmho per centimetre at 25° C, (severely corrosive).

Soils with very high corrosivity for uncoated steel generally include somewhat poorly drained to very poorly drained fine textured soils. Mucks and peats that have a fluctuating water table are included. Total acidity is greater than 16 meq per 100 grams of soils, electrical resistivity at moisture equivalent is below 1,000 ohm-cm at 60° F, or electrical conductivity of the saturation extract is greater than 1.0 mmho per centimetre at 25° C, (very severely corrosive).

Because soil reaction (pH) correlates poorly with corrosion potential, pH is not included in the preceding features. Yet, there are some significant exceptions. A pH of 4 or less, almost without exception, indicates a high or very high soil corrosion potential. The most favourable pH for sulphate-reducing bacteria is 7; progressive departures in either direction indicate less and less favourable pH conditions. In wet or moist soils with anaerobic conditions, especially in clays that contain some organic matter and sulphur, a pH of about 7 is corroborating evidence for a rating of high or very high ratings that such soils would also receive on the basis of drainage and texture.

Ratings based on a single soil property or quality that place soils in relative corrosivity classes must be tempered by knowledge of other properties and qualities that affect corrosion. A study of soil properties in relation to local experiences with soil corrosivity helps soil scientists and engineers in making soil interpretations. Special attention should be given to those soil properties that affect the access of oxygen and moisture to the metal, the electrolyte, the chemical reaction in the electrolyte, and the flow of current through the electrolyte. A constant watch should be maintained for the presence of sulphides or of minerals such as pyrite that can be weathered readily, thus causing a high degree of corrosion in metals.

Using soil corrosivity interpretations without considering the size of the metallic structure or the differential effects of using different metals may lead to wrong conclusions. Construction, paving, fill and compaction, surface additions, and other factors that alter the soil can increase probability of corrosion by creating an oxidation cell that accelerates corrosion. Mechanical agitation or excavation that result in aeration and in non-uniform mixing of soil horizons may also accelerate the probability of corrosion. The probability of corrosion is greater for extensive installations that intersect soil boundaries or soil horizons than for installations that remain in one soil series or in one soil horizon.

IRRIGATION OF SOILS

Engineering interpretation of soils for irrigation projects in developing countries is usually a complicated and involved process, involving placement of dams, canals, and other structures as well as soils conditions. In many places adaptations of the U.S. Bureau of Reclamation procedures are used in selection and classification of irrigable land. Maletic and Hutchings (1967) have given an excellent general review of the USBR land classification for irrigation in the comprehensive book edited by Hagan et at (1967). Olson (1972) has reviewed some of the aspects of interpretive land classification in English-speaking countries. For the purposes of this publication, only a list will be given of the soil features and qualities important for consideration in determining suitable irrigation practices for a soil. These are (Soil Survey Staff, 1971); (1) available water capacity, (2) depth of soil as related to rooting zone, (3) slope determining method of application of water and affecting hazards of erosion, (4) rate of water intake, (5) need for drainage and depth to water table, (6) susceptibility to stream overflow, (7) salinity and alkalinity, (8) stoniness, (9) hazards of soil blowing, (10) presence of hardpan or other restrictive layers, (11) permeability below the surface layer, and (12) hazards of water erosion.

DRAINAGE OF SOILS

Theoretical and practical problems of soil drainage have been discussed at great length by many authors. Donnan and Houston (1967) have summarized some of the necessary considerations of drainage related to irrigation management; Reeve and Fireman (1967) have discussed some of the salt problems in relation to irrigation, for which drainage is one of the prescriptions. In general (Soil Survey Staff, 1971), soil features and qualities considered in determining suitable drainage for land improvement are those that affect installation and performance of surface and sub-surface drainage systems. These soil features and qualities affecting drainage are: (1) permeability, (2) texture, (3) structure, (4) depth to contrasting layers that influence the rate of water movement, (5) depth to water table, (6) slope, (7) stability of ditch banks, (8) flooding or ponding, (9) salinity and alkalinity and (10) availability of outlets.

RECOMMENDATIONS

In most developing countries a considerable amount of pedological soil information is being accumulated that can readily be adapted directly or indirectly, to engineering needs. In many cases establishment of an additional test (like determination of plasticity index) or tests, and classification of soils materials into an engineering soil classification system (like the unified soil classification system), can yield considerable benefits in making soil maps, descriptions and data more useful to engineers as well as to agriculturalists. Soil survey efforts in developing countries should start to provide engineering interpretations in addition to the agricultural interpretations included in soil survey reports. For further development and expansion, this publication provides an outline of some quantitative and qualitative procedures for improving the uses of soils in planning, design and construction of roads, runways, foundations, sewage disposal systems, dams, dikes, canals, levees, pipelines, terraces, irrigation systems, drainage systems, and other engineering structures. Performances of engineering structures in different soils are fully as variable, and fully as important to developing countries, as are measurements and predictions of yields from different soils resulting from different fertilizer inputs.

REFERENCES

Asphalt Institute. (1964) Soils manual for design of asphalt pavement structures. Manual Series Number 10. The Asphalt Institute, Asphalt Institute Building, College Park, Maryland, USA. 261 pages.

Donnan, W.W. and C.E. Houston. (1967) Drainage related to irrigation management. Pages 974-987 In Hagan, R.M. et al. (Editors), 1967. Irrigation of agricultural lands. Number 11 in the Agronomy Series of American Society of Agronomy, 677 South Segoe Road, Madison, Wisconsin, USA. 1 180 pages.

FAO (1965) Guidelines for soil profile description. Land and Water Development Division. Food and Agriculture Organization of the United Nations, Rome, Italy, 53 pages.

Hagan, R.M. et al. (1967) (Editors). Irrigation of agricultural lands. Number 11 in the Agronomy Series of American Society of Agronomy, 677 South Segoe Raod, Madison, Wisconsin, USA. 1 180 pages.

Maletic, J.T. and T.B. Hutchings. (1967) Selection and classification of irrigable land. Pages 125-173 In Hagan, R.M. et al. (Editors), 1967. Irrigation of agricultural lands. Number 11 in the Agronomy Series of American Society of Agronomy, 677 South Segoe Road, Madison, Wisconsin, USA. 1 180 pages.

Olson G.W. (1964) Application of soil survey to problems of health, sanitation and engineering. Memoir 387, Cornell University Agricultural Experiment Station, Ithaca, New York, USA. 77 pages.

Olson, G.W. (1972) Interpretative land classification in English-speaking countries: a working paper on some of the systems in current use and some of their adaptations. Food and Agriculture Organization of the United Nations, Rome, Italy. 66 pages.

Orvedal, A.C. (1963) The 7th Approximation: its application in engineering. Soil Science 96: 62-67.

PCA (1962) PCA soil primer. Portland Cement Association, Old Orchard Road, Skokie, Illinois, USA. 52 pages.

Reeve, R.C. and M. Fireman. (1967) Salt problems in relation to irrigation. Pages 988-1 008 In Hagan, R.M. et al (Editors), 1967. Irrigation of agricultural lands. Number 11 in the Agronomy Series of American Society of Agronomy, 677 South Segoe Road, Madison, Wisconsin, USA. 1 180 pages.

Soil Survey Staff. (1951) Soil survey manual, U.S. Department of Agriculture Handbook. Number 18. U.S. Government Printing Office, Washington D.C. USA. 503 pages.

Soil Survey Staff. (1967) Soil survey laboratory methods and procedures for collecting soil samples. Soil Survey Investigations Report Number 1. U.S. Government Printing Office, Washington, D.C. USA. 50 pages.

Soil Survey Staff. (1970) Selected chapters from the unedited text of the Soil Taxonomy of the National Cooperative Soil Survey. Soil Conservation Service, U.S. Department of Agriculture, Washington, D.C. USA. About 500 pages.

Soil Survey Staff. (1971) Guide for interpreting engineering uses of soils. Soil Conservation Service, U.S. Department of Agriculture. U.S. Government Printing Office, Washington, D.C. USA. 87 pages.