ENGINEERING GEOLOGY OF SOILS AND WEATHERED ROCKS OF FAIRFAX COUNTY, VIRGINIA

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INTRODUCTION

Fairfax County has diverse geologic and physiographic conditions, with the eastern part of the county made up of non-consolidated sediments (soils) of the Coastal Plain, the middle part made up of crystalline rocks of the Piedmont, and the western part made up of sedimentary and crystalline rocks of the Triassic Lowland. On these rocks there is usually soil and weathered rock which has originated from in-situ weathering of the underlying bedrock. The physical and engineering properties of the soils and weathered rocks are generally dependent on the properties of the unweathered rocks from which they are derived. Physical and engineering properties of Coastal Plain sediments are a reflection of their geologic origin and subsequent loading history, and, in some cases, weathering.

This report presents generalized relationships between the geologic setting and engineering characteristics of soil and weathered rock throughout Fairfax County. For discussion purposes, the geologic units that control soil and weathered rock associations are placed in one of three major groups: Non-consolidated Materials, Sedimentary Bedrock, and Metamorphic and Igneous Bedrock. Each of these groups is further subdivided, based on significant differences in engineering behavior. Engineering properties of soils and weathered rocks associated with these subdivisions are presented in tables 1-3, with additional discussion in the following text. Map locations of the subdivisions are referenced primarily to the surface materials map of Fairfax County, Va.(Langer, 1977), and to a lesser extent to the bedrock map of Fairfax County, Va. (Drake and Froelich, 1977). It is also intended that this report be used in conjunction with textual information on those maps. Those maps are not included as part of this report, but they are available for purchase.

Non-consolidated Materials are geologic materials that would be classified as engineering soils, as shown in table 1. Table 2 lists properties of weathered products developed in-situ on Sedimentary Bedrock, and table 3 lists properties of weathered products developed in-situ on Metamorphic and Igneous Bedrock.

The tables are intended for use primarily by engineering geologists, engineers, contractors, and planners. The purpose of the report is to present map-related descriptions and evaluations of the natural units of weathered rock and earth so that users can anticipate the properties of each unit, and infer behavior for proposed uses.

The report is not intended to take the place of thorough site or subdivision evaluation. Detailed field and laboratory investigations are necessary for final site or subdivision evaluation, and for engineering design.

Major sources of information for this report include "Surface materials map of Fairfax County, Va.", (Langer, 1977), "Preliminary bedrock map of Fairfax County, Va.", (Drake and Froelich, 1977); conversations with consulting engineers throughout the area and use of their unpublished engineering reports; conversations with Virginia Department of Highways engineers and geologists and use of their unpublished reports; subsurface investigation reports for the Washington, D. C., area METRO system by Mueser, Rutledge, Wentworth and Johnston; and testing data from the U. S. Geological Survey soil mechanics laboratory, Reston, Virginia.

Usage of the word "non-consolidated" has been made to avoid the alternative "unconsolidated", which has a different meaning for engineers than to geologists. Other terminology conforms to standard engineering usage; engineering connotation should be used with words of possible dual interpretation, such as "soil", "compacted", "over-consolidated", "consistency", and "well-graded".

Metric units are used throughout the text and in the tables, Conversion factors between English and metric units are listed after the table of contents.

There is some variation in engineering usage of consistency and compactness terms. To avoid confusion, the system used for this report is as follows:

Qualitative and Quantitative Expressions for Consistency of Fine-Grained Soils and Compactness of Coarse-Grained Soils

Fine-Grained Soils

Consistency	Field Investigation	Unconfined Compressive Strength (kgf/cm^2)	Standard Penetration Resistance, blows per foot
Very soft	Easily penetrated several inches by fist	Less than 1.0	Less than 2
soft	Easily penetrated several inches by thumb	1.0-2.0	2-4
Medium	Can be penetrated several inches by thumb with moderate effort	2.0-4.0	4-8
Stiff	Readily indented by thumb but penetrated only with great effort	4.0-8.0	8-15
Very stiff	Readily indented by thumbnail	8.0.-16.0	15-30
Hard	Indented with difficulty by thumbnail	Over 16.0	Greater than 30

Coarse-Grained Soils

Compactness	Standard Penetration Resistance, blows per foot
Very loose	Less than 4
Loose	4 - 10
Medium compact	10 - 30
Compact	30 - 50
Very compact	Greater than 50

NON-CONSOLIDATED MATERIALS

Non-consolidated materials are deposits that behave as engineering soils, irrespective of degree of weathering or of depth. They are unlithified sediments -- sand, gravel, silt, and clay, and include man-made fill. All materials of the Coastal Plain are in this grouping; also included are alluvium, and colluvium and lag gravel throughout the county. The primary bases for categorization as a particular unit of table 1 are strength and compressibility properties, and dominant textures.

Standard engineering techniques for exploration and design are applicable for most of these materials. Exceptions noted include: units with cemented and uncemented boulders; units with iron oxide-cemented layers; units in which very thin zones of severely weathered and weakened soils are present within soils so strong that they are extremely difficult to sample using conventional soil mechanics exploration and sampling tools; and units in which joints and tectonically related shear zones cut through stiff to hard soils. Zones of softened soils, joints, and shear zones can be important to slope stability, to settlement of foundations, and to other types of design problems.

SEDIMENTARY ROCKS

Cemented and lithified sedimentary rocks of the Triassic Lowland are in this grouping; they include shale, siltstone, sandstone, and conglomerate. Rocks described as shales in the map units below would almost always be classified as mudstones by engineering geologists. Map units in table 2 are based on variations of engineering properties within the weathering profile, such as strength and compressibility properties, and dominant textures.

Definition of Weathering Profile

Weathered products are derived from chemical weathering or from disaggregation of the cemented or lithified strata, with the final product somewhat dependent on the original bedrock mineralogy. Agricultural soil horizons are not used as a primary basis for discussion of the weathering sequence in table 2 because the A-horizon has little or no engineering significance, and a well-defined, deep B-horizon is developed only on shale. Beneath the A-horizon the weathered products typically grade gradually from residuum to weathered to unweathered rock. Residuum is defined as the intensely weathered parent rock weathered in-situ, and is soil-like in consistency with less than 10 percent hard unweathered rock; residuum commonly retains the structure of the parent rock with additional fractures and partings, except in the B-horizon of the agricultural soil zone, which is very thin for most rocks. Unweathered rock usually has no joint fillings, and no chemical or physical alteration or weakening of the parent rock. Many relict structures normally persist in both residuum and weathered rock, resulting in planes of weakness far more numerous and continuous than in typical non-consolidated sediments.

Bedrock Control of Weathering Profile

Disaggregation, in combination with leaching of carbonate or ferruginous cement at some localities, is the predominant means of formation of weathered products of the unit Sandstone, and the unit Siltstone and Shale. The unit Conglomerate commonly includes a large proportion of boulder- and gravel-sized chunks of quartz and mica schist, originating from the Piedmont to the east; the matrix is micaceous arkose. Chemical weathering of the feldspars and micas of the mica schist and the matrix is the dominant means of weathering of the unit Conglomerate.

For the unit Conglomerate, residuum is typically quite deep and makes up a much larger fraction of the weathered sequence. The thickness of weathered products for the unit Sandstone and the unit Siltstone and Shale is usually much thinner than for the unit Conglomerate. Most weathered products of the unit Sandstone and the unit Siltstone and Shale have more than 10 percent hard rock pieces.

Where rocks of highly contrasting lithologies overlie one another, differences in mechanical properties can change abruptly with depth. Weaker, more weathered layers underlie much stronger strata at some places, requiring careful field examinations for foundation design and seismic evaluations of rippability.

Joints and Faults

Joints in these rocks are the types typically present in layered sedimentary rocks, in that joints are normal to bedding and usually do not form continuous through-going planes across layers of greatly differing physical properties. Partings parallel to bedding planes are also commonly found at the contacts of layers of highly contrasting lithologies.

North-trending faults are present along the eastern margin of the Triassic Lowland, with multiple zones of shearing near the ground surface at some places. These zones can be as thin as a fraction of an inch, and have sheared material much weaker than the surrounding rock. This sheared material can be of a soft consistency near the ground surface. Potential problems related to these faults include poor drainage, slope instability, and uneven settlement of deep foundations.

METAMORPHIC AND IGNEOUS ROCKS

Rocks in this grouping include the following: (1) contact metamorphosed sediments of the Triassic Lowland; (2) polyfoliated micaceous schists, phyllites, and gneisses of the Piedmont crystalline terrane (historically referred to as the Wissahickon Formation); and (3) acid to basic igneous intrusive rocks. Igneous rocks of the Piedmont have been metamorphosed and foliated to varying degrees; igneous and metamorphosed rocks of the Triassic Lowland are not foliated. Units in table 3 were chosen on the basis of having significant variations in engineering properties within the weathering profiles. Weathered profiles are controlled primarily by variations of mineralogy, and by the presence of foliation, parting planes, and joints.

Definition of Weathering Profile

Weathered products of table 3 are derived almost exclusively from in-situ chemical weathering and leaching of bedrock. Usually there is a systematic vertical development of the weathering profile above the bedrock, with rather unique zones having different physical and engineering properties. Very generalized relationships between the weathered zones and some engineering properties are shown in table 4, modified after Deere and Patton (1971). Table 4 has three major zones: residual soil, weathered rock, and unweathered rock. Residual soil is comprised of the A- and B-horizons of the pedologist, and also includes saprolite. Saprolite is sometimes referred to as the C-horizon. Saprolite is defined here as the weathering product of crystalline bedrock that was decomposed in-situ to the consistency of a soil, while retaining the original rock structure, foliation, and jointing. Saprolite is normally present directly beneath the B-horizon, but occasionally "unstructured" saprolite (i.e., with no relict planes of preferred weakness) as much as 1 m thick underlies the B-horizon. Joints in saprolite are normally cemented with manganese and other oxides, but parting planes and planar zones of other origins are commonly not cemented.

Beneath the saprolite the weathering profile typically grades into rather ill-defined zones of weathered rock and unweathered rock. Weathered rock characteristically has 10 percent or more core-stones, stones so hard they must be beaten with a hammer to be broken. Joints are slightly cemented to stained, and there is some alteration of the minerals most susceptible to weathering, generally the feldspars and biotite. Unweathered rock has no visible alteration of minerals, although joints may be stained due to oxidation.

Bedrock Control of Weathering Profile

Different bedrock types can have weathering profiles that have major differences in physical and engineering properties. Weathering products depend primarily on the mineralogy of the bedrock and its structure. For example, granites and ultramafic rocks have extreme differences in depths of weathering, and the strength and compressibility characteristics in the same weathering zones are vastly dissimilar. These dissimilarities arise in part because, as a generalization, rocks with abundant orthoclase feldspars weather to kaolinite-rich soils, rocks with abundant mafic minerals weather to montmorillonite-rich soils, and most weathering products of ultramafic rocks are removed by solution (Leo et al., 1977; Cleaves, 1974). Most minerals except quartz are altered in saprolite.

Properties of Soils and Weathered Rocks in the Weathering Profile

B-horizons on some types of rocks in Fairfax County are thick, highly plastic, and easily recognized, and have properties of critical importance to many design and construction problems. Where important the B-horizons are discussed in the table. Weathering in the B-horizon normally causes physical properties to change gradually with increasing depth, the materials becoming denser, less fractured and stronger. There are many important exceptions to this generalization, depending primarily on rock type. Beneath the B-horizon the original rock structure, volume, and mineral orientations are normally retained throughout the weathering profile, forming saprolite. Exceptions occur in the uppermost 1-2 m where roots, organisms, or mechanisms such as frost action have apparently destroyed all evidence of original rock structure.

Saprolite,with the structure and volume of the parent rock and less than 10 percent core-stones,is normally found in contact with the B-horizon, and has a density about half that of the parent rock. Saprolite has both soil-like and rock-like aspects, with the strength and compressibility of soil and fractures of rock. For trenches and cut slopes, parting planes and weakly cemented joints are generally of critical importance; for design of spread footings,the compressibility (a soil-like aspect) of weak saprolite is almost always the controlling factor. Compressibility can be estimated using conventional soil mechanics techniques, such as consolidometer tests and Standard Penetration Test (SPT) blow counts.

Weathered rock generally has only a few more fractures and parting planes than unweathered rock, and the rock-like aspect in which joints and parting planes control design is dominant for most problems. Important exceptions occur where the saprolite-weathered rock contact is erratic or highly irregular.

Unweathered rock has almost no joint fillings or coatings, and for most engineering construction problems strength along the joints or joint closure is of major importance. Joints in this grouping of metamorphic and igneous rocks are generally throughgoing for large distances, distances that are important to major construction activity. Near the Fall Line (i.e., the broad topographic zone where the Piedmont drops down to the Coastal Plain), joints are commonly offset 0.3-0.6 cm and interlocking of joints by this offset usually contributes to slope stability. Also near the Fall Line there are multiple thin zones of shearing parallel to foliation, at some places a few meters apart but typically spaced hundreds of meters. These zones are commonly referred to as "foliation shear zones". Within these zones the materials are typically highly micaceous and slickensided, and at some locations are chemically altered and much weaker than the parent rock. Although foliation shear zones are generally thin, 0.3-0.6 cm thick, in a few places they are thicker than 5cm.

Lateral Variations in Weathering

Mechanical properties of saprolite and weathered rock can change abruptly laterally where: (1) there are steeply dipping strata of interbedded foliated and nonfoliated rocks; and (2) where rocks of highly constrasting lithologies are in contact. The first condition is encountered most often in Schist, Metagraywacke, Gneiss, and Phyllite units of table 3. Foliated and nonfoliated strata are generally steeply dipping, with some important exceptions. Within these units highly micaceous sheared zones with many parting planes in the sheared zones are widespread and commonplace. These zones are as much as 1 m thick. They are not sheared as intensely or weakened as severely as the foliation shear zones discussed above.

One geologic setting where there are rocks with highly contrasting lithologies is near the contacts of igneous bodies in the Piedmont, where dikes of aplite 1 m or more thick occasionally cut across other rocks. At some places the thicker aplite dikes are associated with shattered and broken rock along the borders of the dike. The aplite is commonly weathered to a highly plastic clay soil near the ground surface, and is surrounded by stronger saprolite, weathered rock, or even unweathered rock. Although these dikes are most common near the borders of igneous rocks, some are tens of miles from the nearest contact shown on the bedrock map of Fairfax County, (Drake and Froelich, 1977). Potential problems related to these dikes include slope instability and settlement of deep foundations.

Contrasting rock types are also present where veins, dikes, and pods of hard quartz bodies are in the unit Granitoid Rocks, in the unit Gneiss, Schist, and Metagraywacke, and in the unit Phyllite. These quartz bodies may have originated at dikes associated with intrusion by the more acidic igneous rocks, or as material "sweated out" during metamorphism. Small veinlets of quartz a few centimeters in thickness are very common, and can present serious problems to engineering sampling and exploration of saprolite. The quartz veinlets commonly make it difficult to sample saprolite with Shelby tubes, and cause wide variations in SPT blow counts.

Where diabase intrudes sedimentary rocks in the Triassic Lowland, the mechanical and physical properties of weathered products change laterally in a rather predictable way. Sediments most highly metamorphosed are adjacent to diabase, where contact metamorphism has changed the original minerals in the sediments. Some sandstones are altered to a granite-like rock, and changes in other sediments can be as striking. In general, the highly metamorphosed rocks are tougher and stronger, and have a thinner development of weathered products than the parent sedimentary rocks further from the diabase.

EXPLANATION OF TABLES

The following discussion presents information for interpretation of data about soils and weathered rocks in tables 1-3, with an explanation of how the data are related to various engineering and construction problems. Each of the major headings below is a column heading in the tables.

Unified Soil Classification

This classification system uses the following letters, which are abbreviations for certain soil characteristics:

First letter	Second letter
G, gravel	W, well graded
S, sand	P, poorly graded
M, silt	M, silty
C, clay	C, clayey
O, organic	L, low plasticity
Pt, peat	H, high plasticity

The listing order of soils in the tables is in terms of major and minor occurrences, with minor occurrences enclosed in parentheses. Textural classification is normally easily accomplished by following standard procedures, but there are some situations where classification of saprolite can be misleading. Micaceous saprolite can have erroneous gradation curves of SM soils, because a large proportion of the "sand" sizes can be aggregates of weakly bound mica. This sand may break down to smaller particles and have a slippery feeling when rubbed between the fingers, and yet be nonplastic, and thus the soil should be classified as ML.

Some Potomac Group clays are very hard and appear to be gritty upon visual examination; the plasticity characteristics of some of these clays increase significantly upon intense remolding, which breaks down the gritty clay peds.

Some Potomac Group "sands" have a sandy texture upon visual examination. These sands originally were sand-size particles of feldspar, but have subsequently weathered to clay minerals. Their plasticity characteristics increase significantly upon intense remolding.

Total Unit Weight

The data in the tables are the range of wet unit weights common in natural occurrences. The weight of drainable water in soils is almost always small as compared to the total unit weight, and thus no distinction should usually be made in total unit weight of soil above and below the ground-water table.

Drainage and Natural Moisture Characteristics

This heading is subdivided into two columns, titled "Surface Drainage," and "Internal Drainage and Natural Moisture." "Surface Drainage" considers the permeability of the near-surface materials and influence of the topographic setting. "Internal Drainage and Natural Moisture" considers the permeability of the soils and proximity of the water table to the ground surface. Permeability is rated according to the following system:

Rating	Coefficient of permeability (cm/sec)
high	0.01 and greater
medium	0.001. - 0.01
low	0.00001 - 0.001
very low	0.00001 and smaller

Permeability of metamorphic and igneous rocks in the Piedmont and of igneous rocks in the Triassic Lowland is usually systematically related to the weathering profile. Figure 1 shows an idealized weathering profile, relating the relative permeability to the zones of weathering. Permeability of the clay-rich B-horizon is much less than that of saprolite immediately beneath. With increasing depth, clay content of the saprolite zone decreases and cementation of joints decreases, increasing the permeability; porosity may also increase significantly with increasing depth in saprolite (Nutter and Otton, 1969). Highest permeability occurs in the weathered rock zone, where joints are open, where there may be numerous parting planes, and where any saprolite probably has a sandy texture with little or no clay. In unweathered rock permeability usually decreases greatly because joints are closer and there is no saprolite.

Various types of parent bedrock can have significantly different weathering profiles, causing differences in permeabilities associated with the zones of weathering. Despite these differences, the saprolite zone, weathered rock, and unweathered rock all have low permeabilities, with the permeability of weathered rock about twice that of saprolite, and unweathered rock less permeable than weathered rock. A highly plastic B-horizon invariably has a very low permeability.

Throughout the Piedmont on hilltops and on slopes greater than about 5 to 10 percent, the ground-water table is almost invariably too deep to be of major concern to construction of homes and small industrial buildings. However, ground water seeps and springs are commonly found in valleys and where unweathered rock is near the surface, especially during the spring of the year.

In the Triassic Lowland, the rock units Siltstone and Sandstone are most permeable in the residuum and weathered rock zones; in those zones, however, the permeability is usually low but can be medium. Both these zones commonly have many open joints and partings. The rock unit Conglomerate typically has low permeability throughout the weathering profile, because of the lack of joints and parting planes. The permanent ground-water table is of minor concern for the great majority of construction activities in these three units. In broad swales and above impermeable colluvial deposits over these units, however, there may be seasonal perched water tables. These perched water tables are present approximately during November through March, and during prolonged rainy seasons. Areas with perched water tables in the Triassic Lowland can be detected during dry seasons by grey mottles in the B-horizon and underlying material.

Home construction is often delayed by seasonal perched water tables throughout the county. At many places in the Coastal Plain there is a seasonal perched water table above a fragipan in the unit Upland Gravel, and above Potomac Group sediments. Perched water tables can be drained with French drain systems at many places in Fairfax County, eliminating water problems in basements.

In the upland areas of the Coastal Plain, there are also many perched water tables in sand-filled channels and in the sand-rich facies of sediments. Control of ground water for both minor and major excavations usually does not require pumping large volumes of water throughout a large area, but instead should be concentrated on draining buried channels with clean single-sized sands. Such channels occur at many places; they are common at unconformities separating different geologic units. Sands associated with facies changes can also usually be drained by permitting water to seep into the excavation for a short time period.

In broad swales and lowlands in the Coastal Plain, the ground-water table is near the ground surface at many places. Control of ground water generally involves pumping or other expensive procedures.

Suitability As Compacted Material

In the tables, factors considered for use of naturally occuring soils as compacted material include: ease of drying wet materials, the relation of natural to optimum moisture content, plasticity of the materials, and mica content.

Soils of high plasticity and organic materials are generally unsuitable because of the difficulty of drying or wetting them in the field, the difficulty of control of compaction moisture, and other adverse properties. Soils of medium to high plasticity with natural moisture contents exceeding the optimum cannot usually be dried and compacted economically for road work, and are discarded. Micaceous, silty soils so commonly encountered in the Piedmont are generally easily dried and wetted, and can normally be dried and used economically as compacted road fill where natural moisture contents are up to 8 to 10 percent above optimum; however, very careful control of compaction moisture is required to achieve proper field compaction of these soils. Highly micaceous, fine-grained silts (i.e., silts that have enough mica to impart a slippery feel to the soil, even though the mica cannot be seen with the naked eye) can be very difficult to compact, as they have a tendency to shove (displace laterally) during compaction even at optimum moisture content. Cement stabilization is sometimes used on fine-grained micaceous silts to make the soil strong enough to support heavy equipment.

Field compaction of micaceous silts according to T-180 [1/] (ASTM D-1557-70) density-moisture specifications is commonly extremely difficult and sometimes almost impossible. T-99 [1/] (ASTM D-698-70) specifications are adequate for foundation loads up to 2 kgf/cm^2 for footings supporting homes and spread footings supporting light industrial buildings.

Field tests to determine the moisture content and density of micaceous soils should not be made with nuclear devices. Mica reflects fast neutrons, preventing absorption by hydrogen. Density measurements in micaceous soils can err as much as 10 percent, and moisture contents as much as 50 percent.

A problem sometimes encountered in the unit Siltstone and Shale is weakening and softening of hard, rock-like material that has been compacted according to rockfill specifications. Within a few years after compaction the "rock" may deteriorate to a soft, clay-rich material, causing settlement and slope instability. The writer believes such deteriorating rock-like materials can be detected by means of a slake durability laboratory test. Such deteriorating "rock" should not be used as backfill in utility excavations, because of the continuing long-term problems caused by settlement of the backfill.

Excavation Properties

For cuts ranging from about 2-4 m deep, factors considered in the tables are excavation and stability problems of construction-period excavations, for both utilities and buildings.

A significant problem in both the Piedmont and the Triassic Lowland is determination of the depth of weathered material that can be excavated with earth moving equipment. In the Piedmont and for igneous rocks of the Triassic Lowland, materials having SPT blow counts up to about 100 can be ripped with heavy equipment (Caterpillar D-9 with single tooth). In the Triassic Lowland, sedimentary rock units that cannot be augered with a 15 cm diameter auger powered by a Mobile B-52 are probably too hard to be ripped.

Wall stability can be adversely affected by swelling and weakening of saprolite, especially where exposed to water. Micaceous saprolite is especially susceptible to the effects of water, and can change from a hard to a medium or even soft consistency within 12 to 24 hours after an excavation is opened. Water should also be kept from micaceous saprolite that is to support foundation loads, because the saprolite can swell and become highly compressible, potentially causing large settlements.

Erodibility

Erosion properties are characterized for remolded materials and for naturally occurring materials at the ground surface.

Remolded and compacted clean and silty coarse-grained soils are always easily eroded. Clean and silty coarse-grained soils in the natural state are easily eroded unless slightly cemented. Coarse-grained materials with enough clay to be designated as GC or SC are much more resistant to erosion.

Silty soils of the Piedmont, Triassic Lowland, and of the Colluvium and Lag Gravel unit are extremely susceptible to surface erosion where disturbed by organic activity, by freezing and thawing, and wherever remolded by construction equipment. Saprolite is susceptible to piping; holes with diameters as much as 1 cm can occasionally be found in the proximity of joints. Tubes up 5 cm diameter can occasionally be found in silty residuum of the Triassic Lowland.

Shear Strength and Compressibility Characteristics

Factors discussed here include types of tests most suitable for determination of shear strength, typical shear strength data, testing techniques used for estimation of consolidation, and some typical compressibility data. For the Piedmont and Triassic Lowland, discussion is directed primarily to properties of the saprolite and residuum zones, except where these zones are so thin that homes and light industrial buildings are almost certain to be founded in underlying weathered rock or unweathered rock zones.

Strength test methods--Selection of the method for strength testing depends on the material to be tested and the problem of concern. Unconfined (U) compression tests are suitable for testing of homogeneous clays for construction-period problems. Unconsolidated undrained (UU) tests are required to restrain samples where failure in the undrained state may occur prematurely because of sand pockets, partings, fractures, or cracks; the test also partially compensates for sampling disturbance.

Direct shear tests are required for determination of drained residual shear strength parameters; direct shear tests can also be used to determine the strength properties along planar joints.

Drained triaxial tests (CD) are used to determine shear strength parameters for design of permanent slopes where the soils are not highly overconsolidated, and where failure of the slope would be in drained shear.

Strength test methods and characteristics of units--Homogeneous clays suitable for testing in unconfined compression are generally found only in non-consolidated materials of the Coastal Plain. UU tests are usually appropriate for construction-period problems in the units Alluvium, Colluvium and Lag Gravel, Potomac Group Sands, and Potomac Group Clays with slickensides and joints. UU tests should normally be used for testing saprolite and residuum for construction-period problems because of the multiple weaknesses caused by fractures, parting planes, and preferential weathering, and because of the positive pore-water pressure commonly developed during shearing of nearly saturated samples.

Direct shear tests should be used to determine residual shear strength parameters of highly plastic clays and highly plastic silts of the Potomac Group, for long-term strength problems; residual or near-residual shear strength parameters are used at many sites for design of permanent cut slopes comprised of these materials. Residual shear strength properties of Potomac Group materials should be determined on samples that have pre-cut shearing surfaces, or the strength properties should be measured on remolded samples. Intact samples can fail along surfaces not coincident with the plane of the shearing ring, possibly causing strength data to be too high. Direct shear tests are normally used to evaluate drained strength parameters of Potomac Group silts and clays of low plasticity and Potomac Group sands; for these materials, shear strength parameters selected for design of permanent cut slopes normally are between residual and peak, much above residual. Some designers use the peak drained shear strength of remolded soil (i.e., the "fully-softened" strength), consolidated under the weight of the overburden on the slope. This strength test method is used only for soils that are not intensely fractured, or do not have sufficient plasticity to become intensely fractured by shrinking and swelling.

Direct shear tests can also be used to determine shear strength properties along joints in saprolite and partings in residuum.

Saprolite and residuum commonly behave as brittle materials, with peak shear strengths (UU and CD) of intact samples at least 10 to 20 percent higher than the strength at slightly greater straining. For construction-period excavations in saprolite where slides could endanger lives, some designers use large-strain UU shear strengths, partially because of the difficulty of ensuring that the weakest zones have been found during exploration.

Colluvium in the Piedmont and Triassic Lowland has approximately equal peak and large-strain shear strengths.

Throughout the Piedmont, the UU shear strength of non-plastic saprolite (the most commonly encountered saprolite) and colluvium generally is about 0.5 kgf/cm^2 (UU) in the surface material affected by seasonal moisture changes, and where the water table approaches the ground surface at the toe of slopes. Saprolite buried beneath colluvium is commonly very weak for a depth of 1-2 m beneath the contact. The UU shear strength of saprolite usually increases fairly rapidly with depth to a value of about 1 kgf/cm^2 at 1.7 m increasing to 1.2-1.5 kgf/cm^2 at 3-5 m. UU test data are normally considered good approximations of the undrained shear strength in-situ for some types of problems, such as bearing capacity design.

UU strength envelopes of saprolite and residuum are commonly strongly curved at confining pressures greater than the overburden weight, and approach being flat at high confining pressures, probably because of the positive pore pressure developed during shearing. However, UU strength envelopes from nearby samples can have slopes of 20 to 30 degrees even at high confining pressures, because the sample is slightly drier or has a different texture. Thus caution should be exercised before accepting the premise that saprolite behaves as a strong frictional material.

A special problem in Potomac Group sediments is that at many places the sediments are intensely softened and fractured by weathering at the ground surface and along the unconformable contact with younger sediments. Another unique problem encountered in Potomac Group deposits is that unweathered sands, silts, and clays typically have a stiff to hard consistency, and at many places are too strong to be sampled with Shelby tubes. However, beneath and intersecting these strong soils thin, weak zones, typically 0.25 cm thick, may be present at various orientations. These weak zones commonly have a soft to medium consistency. Detection of these weak zones is difficult, yet they can be very important to short- and long-term slope stability.

Compressibility test methods and characteristics of units--Techniques used by major consultants to evaluate compressibility characteristics throughout Fairfax County include consolidometer, SPT, pressuremeter, and cone penetrometer testing. Conventional soil mechanics methods are most commonly used to estimate settlement of structures in non-consolidated materials of table 1. Geologic settings where large settlements can take place are in alluvium, which may be organic; within the upper 2-7m of the Potomac Group where surface weathering or landsliding has weakened or remolded the soils; in ancient landslides in the Potomac Group (which may be buried beneath younger sediments); and within zones in many units sheared by tectonism.

Control of settlement is almost always the governing criterion for dimensioning linear footings and spread footings in saprolite and residuum. Because of the presence of multiple quartz veins and hard zones of other materials, it is often difficult to get good samples for testing to calculate settlement in the unit Gneiss, Schist, and Metagraywacke, in the unit Phyllite, and to a lesser extent, in the unit Granitoid Rocks. In the past it has been common practice to use SPT data for design of columns with loads up to about 45,000 kgf. Numerous correlations have been prepared by different consultants. Figure 2 shows the range used by some consultants in the area; the figure is based on an allowable maximum settlement of 2.5 cm, with the assumption that the ground-water table is beneath the footing a depth at least one to two times the width of the footing. The higher loads are permitted for coarser-grained saprolite, such as that generally found in the unit Granitoid Rocks, and at the base of the weathering profile of the saprolite zone. Similar relations are used for design of footings on residuum of the Triassic Lowland.

Quartz veins commonly affect SPT data, making them unrealistically high. Judgment has been about the only criterion for eliminating erroneous data in the past. In recent years there has been a tendency to use other tools such as the cone penetrometer and the Menard pressuremeter to obtain design information in Fairfax County. Advantages of the cone penetrometer are the close spacing of data and the ability to eliminate many of the erroneous readings attributable to quartz veins and other thin hard zones. The pressuremeter also has the advantage of eliminating much of the influence of thin hard zones and quartz veins, and typically shows much less data scatter than SPT blow counts. However, the pressuremeter has been used primarily in weathered, weakly foliated rocks or in highly foliated rocks with steep dips, conditions which generally obtain in Fairfax County. It is the writer's opinion that the pressuremeter should be a good tool for estimating settlements in these geologic settings, because estimates based on the horizontal compressive strains should equal or exceed the actual vertical compressive strains; this opinion is based partly on consolidometer data showing that straining perpendicular to foliation commonly exceeds straining parallel to foliation, for a given stress. Highly foliated rocks with low-angle dips are not commonplace in Fairfax County.

Consolidometer data on saprolite near the ground surface typically show a very poorly defined quasi-preconsolidation stress, slightly greater than existing overburden load, based on the Casagrande construction method[2/] for estimating preconsolidation stress. With increasing depth the preconsolidation stress tends to become greater, but locally there can be much lower values. This preconsolidation stress is almost invariably the result of incomplete disintegration of the bedrock, rather than a reflection of past loading.

Some saprolite is susceptible to long-term settlement, and inclusion of "secondary compression" in settlement calculations should be made for many structures. Highly micaceous saprolite is thought to be especially prone to long-term settling.

Estimates of settlement at loads less than the quasi-preconsolidation stress are commonly made by conventional calculation methods based on the rebound during unloading of consolidometer samples. Settlement can be quite significant, even for loads less than the quasi-preconsolidation load. Throughout the county, the coefficient of compression (the change in void ratio per logarithmic cycle) during unloading typically varies from 0.03 to 0.06 for the most intensely decomposed saprolite, and during loading commonly ranges from 0.2 to 0.4. Very high coefficients can occur even on soils classified as SM. Void ratios up to 0.80 are not uncommon in the most intensely weathered saprolite.

Saprolite beneath Coastal Plain sediments commonly has higher compressibility and lower shear strength than the overlying sediments. At many locations thickness of the buried saprolite varies from 3-7m, but can be much greater. At some places saprolite beneath Coastal Plain deposits has clay-coated joints, with friction values as low as 10 degrees; apparently the clay has washed in from the overlying sediments.

Allowable Bearing Pressure

The tabulated allowable bearing capacities in the tables apply to conventional size footings, mats, caissons or piers with minimum dimension of the bearing area of at least 1m. Minimum values in the table are generally for situations where the water table is near the base of the foundation. The bearing values assume that the bearing soils will be maintained undisturbed, that flow of water across and through these soils will be prevented and that excavation equipment will be of a size and weight that will not remold the soils. Where a range of bearing pressures is given for a particular unit, the appropriate value must be chosen by referring to test data at a specific location. The tabulated values do not consider the effects of surcharge surrounding the bearing level of the foundation. For deeply buried footings, piers, or caissons in cohesionless strata these values may be increased by conventional analyses using the listed friction angles, after determining that settlements for increased bearing are tolerable. On the other hand, bearing pressures for small footings or blocks for support of temporary bracing, placed at or near the surface of cohesionless materials, must be decreased by conventional analyses which take into account the smaller footing widths.

Also noted in the tables are the types of piles commonly used in some of the units, where specific types are used because of the geologic character and the strength and compressibility properties of materials in the unit. H-piles are commonly used in soils with boulders, and for bridge foundations on saprolite or residuum where the many hard zones require a penetration type of pile. At some places displacement piles are sometimes used in very weak sediments.

Some units characteristically are much better for founding piles than other units, and are commonly sought by foundation designers. Some typical ranges of working loads of the more desirable strata, as limited by the strength of the bearing material, are as follows:

(1) Upland Gravel, compact sands of this unit not underlain by fine-grained soils nor by weathered materials of the underlying Potomac Group--45,000-63,000 kgf.

(2) Unweathered Potomac Group--54,000-72,000 kgf.

(3) Strong Saprolite--63,000-81,000 kgf.

(4) Unweathered Rock--108,000-180,000 kgf.

Not included in the table are notes relevant to the use of caissons, but criteria and suitability for using caissons are discussed below. Caissons are commonly used throughout the county to found heavy structures on the very strong, relatively incompressible materials. Materials meeting these criteria are unweathered Potomac Group sediments, very strong saprolite, and weathered and unweathered rock of the Piedmont. Strong residuum on the Triassic Lowland sedimentary rocks can also be used to found caissons, but with the exception of the Conglomerate unit is so thin that it is generally more economical to place the caisson in weathered or unweathered rock.

A problem occasionally encountered in the Potomac Group is instability of the soil around the bell-shaped excavation at the base of the caisson. Joints and shear zones can allow large chunks of soil to fall into the bell if these features are adversely oriented with respect to the zones of weakness.

The minimum criterion for using caissons in saprolite and residuum is an SPT blow count of about 100 blows per 2 in; the base of the caisson must be above the ground-water table. Careful inspection must be made of saprolite for a depth at least equal to the diameter of the bell (generally 1.7-2.7m), to ensure there are no sheared or weak zones. Allowable loads increase as the degree of weathering diminishes. Pressures permitted on unweathered rock range from about 5-100 kgf/cm^2, depending on joint spacing and orientation.

The types of physical properties that are normally critical to design of building foundations can be determined approximately by SPT data. For SPT blow counts less than about 60 per foot, in saprolite and residuum, compressibility of the mass is almost always the governing factor in design of footings for normal types of buildings. For higher blow counts, closure of joints normally dominates, but the shear strength of the mass or along joints can also be of critical concern, especially for blow counts near 60 per foot. Part of the geologic reason for this change of governing factors is that joints in the weaker saprolite are usually cemented and filled by various oxides; near the base of the saprolite zone and at greater depths, the extent of the joint filling and strength of the cementation are commonly greatly diminished.

Slope Stability

Both natural slope stability, and long- and short-term stability (i.e., construction-period) of cut slopes are considered here. Utility excavations are defined as near-vertical short-term cuts; long slopes are defined as permanent slopes having a height greater than about 5m, on angles less than about 60 degrees. More detailed discussions of the relationship of the geologic setting to different types of slope stability problems throughout the county are provided by Langer and Obermeier (1978) and by Obermeier (1979a, 1979b).

Conventional soil mechanics methods for exploration and design are adequate for most materials listed in the table of non-consolidated (table 1). Exceptions include the Alluvium and Upland Gravel units, where iron oxide-cemented layers and boulders are encountered and cannot be easily penetrated; such layers and boulders are rather common.

Another exception is for Potomac Group deposits, where natural and cut slope landslides are widespread and commonplace on permanent long slopes in Potomac Group clays and plastic silts, on slopes exceeding about 9 degrees (15 to 20 percent). Factors causing these slides include near-surface softening and fracturing, softening along the contact with the Upland Gravel and with the Colluvium and Lag Gravel units, joints and tectonically-related shear zones through otherwise stiff to hard deposits, water in joints, perched water zones, and concentrated water flow at the contact between the Upland Gravel unit and the underlying Potomac Group sediments. The most practical solutions for slope stabilization are normally dewatering and flattening of slopes. Joints can also cause construction-period problems in cuts (Withington, 1964).

Landslides are very rare in colluvium of the Piedmont, but excavations causing small changes in natural slope angles can initiate instabilities. Landslides (slumps) are generally related to water pressures from the underlying jointed bedrock; these slides can usually be stabilized most economically by drainage of the jointed rock. Although slides are rare in colluvium of the Piedmont, the influence of active creep is commonly observed on slopes greater than 17 degrees (30 percent). Apparently the colluvium does not move on natural terrain to depths greater than about 1-1.3m, but the near-surface movement can be very damaging to walls. It is suggested that the stability of structures can be ensured on many slopes by placing the foundations in underlying saprolite or in bedrock. Saprolite and weathered rock are stable on much steeper slopes than colluvium, because colluvium apparently has been weakened to the "residual" shear strength condition. Slopes on saprolite and stronger rock rarely fail in cuts sloping 27 degrees (50 percent) or less, and are usually stable at much higher angles. With the exception of the moderately plastic saprolite on mafic and ultramafic rocks, long slope failures on angles greater than 27 degrees almost invariably initiate along joints and shear zones. Joint spacing and orientation are critical to determination of stability of cuts in unweathered rock and in weathered rock zones.

Cut slopes in the Triassic Lowland behave in a manner generally similar to that of the Piedmont, with major exceptions being in the Triassic Lowland where: (1) there is a low probability of an adversely oriented through-going joint; and (2) rapid weathering of some siltstones undermines stronger, more resistant rocks. For rocks interbedded with siltstone having this characteristic,slopes of about 27 degrees or less should be considered for permanent stability.

Short-term stability of trenches excavated in the Piedmont and the Triassic Lowland normally depends primarily on the presence of adversely oriented, poorly cemented joints, partings, or shear zones.

Road Performance Characteristics

This section discusses the influence of water on pavement performance and on laboratory test data, techniques for sub-base stabilization, and factors causing distortion of roadways.

The highly plastic clays of the Potomac Group are susceptible to significant swelling and weakening, especially where subjected to concentrated flows of water. Sewer lines and improperly filled trenches are sites where problems commonly occur in the form of distressed pavements, misaligned curbs, and rough roadways. Highly plastic clays developed on bedrock of the Piedmont and the Triassic Lowland can also cause the same types of problems, but generally are not as susceptible as Potomac Group clays.

Lime stabilization can be very effective in elimination of the swelling of clays (especially clays over diabase) commonly requiring about 5 to 7 percent of lime (weight measure) to make a soil that is either non-plastic or of very low plasticity, with plasticity index less than 5. Lime treatment also makes the soil friable soon after application, commonly making field compaction much easier than for the plastic clays. These friable materials can be very frost susceptible, however, requiring cement stabilization according to specifications discussed below.

The micaceous silts so common in the Piedmont are especially troublesome to the performance of low- and medium-cost flexible pavements. Soils classified as A-4's and A-5's by the AASHTO Classification System[3/] almost invariably have very low soaked California Bearing Ratio[3/] (CBR) values, and are extremely susceptible to both frost heaving and frost softening. CBR values on samples of A-4 and A-5 soils compacted to Standard Proctor specifications commonly range from 15 to 25 on unsoaked samples, and from 3 to 5 on soaked samples. Frost softening is commonly so severe on roads with poor base drainage that pavements disintegrate completely under traffic loading during periods of thawing. About the only methods to ensure satisfactory performance on these types of soils are to provide for keeping the base dry by means of very good base drainage, or by soil stabilization with cement.

It should be realized that use of CBR data from soaked tests in combination with open-graded base courses is a highly empirical and sometimes unsatisfactory design approach for two reasons: (1) CBR soaked test data, even though commonly very low, may not realistically simulate the effects of frost on the soil, and the frost softening may be worse than the data indicate; and (2), base courses commonly used to drain pavements are not nearly adequate for removal of water in the base. Cement stabilization is sometimes used to stabilize these types of soils, because it eliminates the adverse effects of soaking and frost heaving and frost softening. For roads with moderate traffic loads, stabilization with 10 percent cement (volume measure) is generally adequate to make the soil strong enough to withstand breakdown by wetting and by frost action.

Pavement support problems are encountered in the Triassic Lowland where bedrock is close to the base of the pavement and water is perched above the bedrock. The most serious problems are on pavements underlain by silty residuum, and include frost heaving and softening, and pumping of rigid pavements. Cement stabilization is sometimes troublesome because of the difficulty of pulverizing the residuum and weathered rock into a fine-grained soil during construction, which precludes thorough mixing of cement and soil. These types of weathered materials are sometimes overlain with better quality material to eliminate potential support problems.

Seeps in layers of non-consolidated material and at the contact of relatively permeable soil above bedrock are responsible for widespread and severe damage to pavements, even on major highways. Standard base courses are commonly inadequate for removal of seeping water, causing problems such as pumping, subgrade weakening, and frost softening. Many of these problems can be eliminated by properly implacing drainage systems, located during construction.

Seismic Refraction Velocity Data and Interpretations

Typical seismic refraction compression wave velocity data are not presented in tables 1-3, but are discussed below. Such data are not provided in the tables because of similarities of seismic profiles for many units, and because data are unavailable for non-consolidated materials. Compression wave data taken with small seismographs can often be used to determine the depth of diggable and the depth of rippable weathered products on crystalline, metamorphosed, and sedimentary rocks of Fairfax County. (Velocity data and interpretations were obtained by personal communication from Steve Garrison, President, Garrison Geotech, Manassas, Va.)

Velocity profiles are usually highly dependent on whether the bedrock is sedimentary or crystalline. For sandstone, siltstone, and shale of the Triassic Lowland a typical velocity profile has two rather well defined zones, as follows:

Depth	Material Description	Compression Wave Velocity
0 to 1.7m	residuum, and weathered rock that can be augered	385- 485 m/s
> 1,7m	weathered rock that cannot be augered, and unweathered rock	1200-2750 m/s

Where velocities exceed 2750 m/s in the Triassic Lowland, the data indicate the presence of contact metamorphosed rocks or igneous intrusive rocks.

In contrast to the sedimentary rocks of the Triassic Lowland discussed above, velocity profiles of rocks of the Piedmont usually have three zones. The uppermost two zones are distinct and easily separable, but the distinction between the second and third zones is poorly defined at some places. These zones are as follows:

Depth	Material Description	Compression Wave Velocity
0-5 m	agricultural soil and saprolite zone	300 - 375 m/s
5-6 m	weathered rock zone	525 - 750 m/s
$>$ 6 m	unweathered rock zone	1000 - 4000 m/s

The number of zones in either the Piedmont or Triassic Lowland depends primarily on the depth of weathering, rocks with shallow weathered profiles having two zones, and rocks with deeper profiles having three zones. As examples, diabase and massive ultramafic rocks typically have two zones, whereas conglomerates have three.

Diggability--Materials with velocities between 750 and 1200 m/s are usually diggable with a backhoe such as a John Deere 450. At velocities less than 750 m/s, lighter power equipment is adequate.

As another criterion of diggability, residuum, saprolite, and weathered rock that can be augered can always be dug with a backhoe, whereas weathered rock that cannot be augered can only be chipped with a backhoe.

Rippability--Rippability varies greatly with equipment size and power rating, and charts showing correlations with compression wave velocity are in the "Handbook of Ripping" (Caterpillar Tractor Co., Peoria, Ill., 1972; publication no. AEO 36605-01). Rippability of sedimentary rocks of the Triassic Lowland and rocks with massive saprolite can usually be estimated by using the lower range of velocities in those charts; for highly foliated, steeply dipping crystalline rocks, ripping can be done in rocks having higher velocities, sometimes off the charts. About 1800 m/s is the highest velocity at which very heavy equipment (Caterpillar D9 with a ripper) can always be expected to rip weathered or fractured rock; in some cases this equipment can rip rocks having a velocity up to about 2750 m/s. Rock with higher velocities is not rippable and must be blasted.

The best direction for ripping layered or foliated rocks can be determined by field seismic testing. Ripping is most easily done in the down-dip direction. Dip direction can be determined by using a forward and reverse seismic profile.

Where there is a predominant joint orientation, it can be determined by using a radial pattern of seismic lines. The lowest velocity is perpendicular to the strike of joints, and the highest velocity is parallel to strike of the joints.

Blasting--Blasting must be used to break up rocks with velocities greater than 2750 m/s, and in some places rock with velocities as low as 1800 m/s can only be broken up by blasting. Blasting is sometimes difficult in igneous rocks that have sheeting joints parallel to the ground surface, especially diabase. These joints can effectively dissipate the blast energy, causing the rock to break into large blocks not easily handled or broken into smaller blocks.

Footnotes:

1. These tests are described in: 1978 Annual Book of ASTM Standards, American Society for Testing and Materials, Philadelphia, Pa., Part 19, pp. 157-162 and 223-228.
2. This method is discussed in: Foundation Engineering, Edited by G. A. Leonards, McGraw-Hill, 1962, 1136 pp.
3. Discussion is in the text: Principles of Pavement Design, E. J. Yoder, Wiley, 1959, 569 pp.

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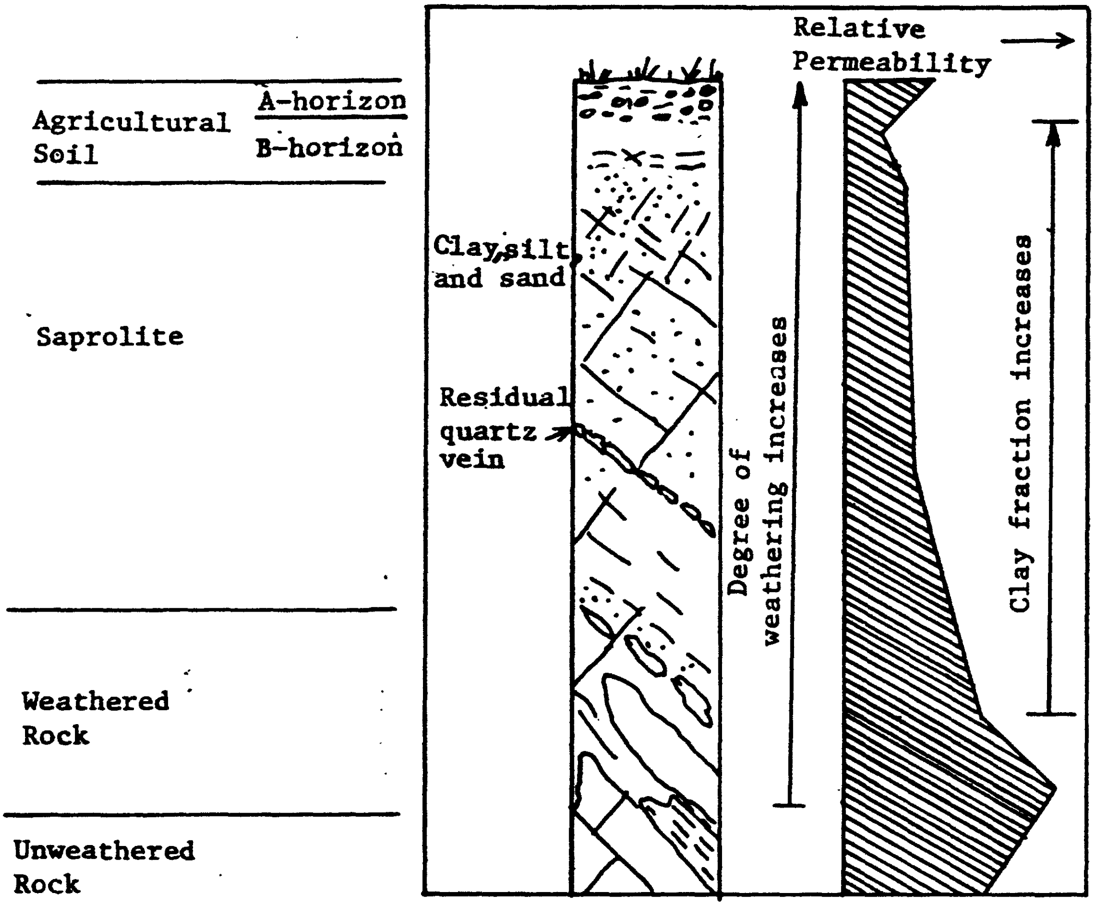

Figure 1. Idealized weathering and permeability profile, showing unweathered crystalline rock grading upward into agricultural soil (modified from Nutter and Otten, 1969, p. 14).

Corrected version, Aug. 1981

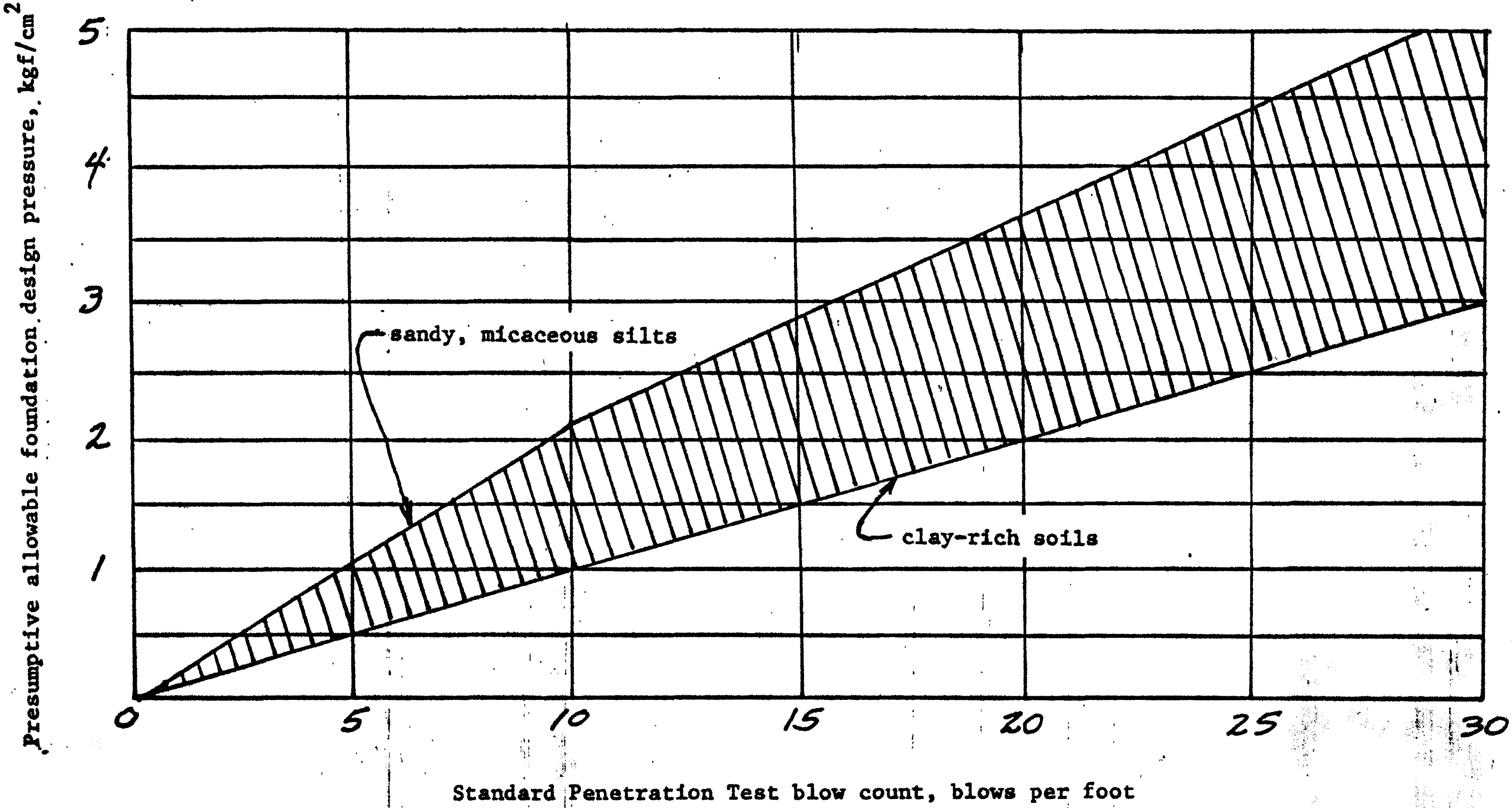

Figure 2. Relation of allowable foundation pressure on saprolite or residuum to Standard Penetration Test blow count for column loads of 12,500 to 45,000 kgf, where there is a deep gound-water table, no interaction between footings, allowable total settlement up to 2.5 cm, and blow counts remain constant or increase with depth.

Table 4.--Description of a weathering profile for igneous and metamorphic rocks (modified from Deere and Patton, 1971)

Zone		Description[1]	RQD[2] (NX Core percent)	Percent Core Recovery (NX Core)	Relative Permeability	Relative Strength	Common Thickness (meters)
I. Residual Soil	A-Horizon	-top soil, roots, organic material -zone of leaching and eluviation -may be porous	------	0	medium to high	low to medium	0.3
	B-Horizon	-characteristically clay-enriched, also accumulations of Fe, Al, and Si, hence may be cemented -no relict structures present	------	0	low	commonly low (high if cemented)	0.3
	Saprolite	-relict rock structures retained -silty grading to sandy material -less than 10% core stones -commonly micaceous	0 or not applicable	generally 0-10%	medium	low to medium (relict structures very significant)	1-15
II. Weathered Rock	Transition (from residual soil to partly weathered rock)	--highly variable, soil-like to rock-like -lines commonly fine to coarse sand (gruss) -10 to 95% core stones	variable, generally 0-50	variable, generally 10-90%	high (water losses common during drilling)	medium to low where weak -- structures and relict structures are present	0.3-3
	Partly Weathered Rock	-rock-like, soft to hard rock -joints stained to altered -some alteration of feldspars and micas	generally 50-75%	generally >90%	medium to high	medium to high[3]	0.3-3
III. Unweathered Rock		-no iron stains to trace along joints -no weathering of feldspars and micas -no sheared zones	>75% (generally >90%)	generally 100% generally 100%	low to medium	very high[3]	

[1] The descriptions provide the only reliable means of distinguishing the zones.

[2] RQD is the acronym for Rock Quality Designation, described in Deere et al, 1967.

[3] Considering only intact rock with no adversely oriented geologic structures.