Geotechnical Design Parameters for Retaining Walls, Sound Barrier Walls and Non-Critical Slopes

VDOT Staunton District

Staunton Materials Section
Virginia Department of Transportation

July 5, 2011
Revised July 25, 2013
Revised December 1, 2017

Introduction

This document is intended for use by the development community, localities, consultants, design-builders and Virginia Department of Transportation (VDOT) staff as a guide by providing the minimum requirements for soil parameters acceptable to VDOT for VDOT, Design-Build and Public/Private Partnership, Local Assistance and Land Development projects. These maximum strength properties are applicable to the design of foundations for retaining walls, sound barrier walls, light posts, culverts/pipes and non-critical slopes. The parameters contained herein shall not be used for the design of bridge foundations or retaining walls in excess of fifteen (15) feet height or retaining walls that support other structures. Site-specific in-situ and/or laboratory testing must be performed for analysis and design of bridge structure foundations, retaining walls and critical slopes. A critical slope is defined as any slope that is steeper than 2H:1V; that is greater than twenty-five (25) feet in height; that affects or supports a structure; that impounds water or whose failure would result in significant cost for repair or damage to property. The intent of this document is to provide the soil parameters that are acceptable to VDOT based upon correlations with the results of Standard Penetration Tests (SPT) and not supported by appropriate in-situ and laboratory testing. The design geotechnical engineer is ultimately responsible for his/her design and may use more conservative values than those contained herein. The affect of groundwater, softening, variability of in-situ soils and disturbance during construction shall be considered when evaluating the applicability of any soil properties. The Materials Division Manual of Instructions (MOI), Chapter 3 (VDOT, 2016, 1) requires slope stability analyses for slopes ten (10) feet in height or greater and for interim construction stages, end of construction condition and for design-life conditions. *Values for undrained shear strength are provided for short-term (undrained, i.e. total stress) analysis; values for friction angle are provided for long-term (drained, i.e. effective stress) analysis and are acceptable for cohesive soils only.* Values provided should not be used for obviously atypical materials such as: organic soils (OL or OH), weight of hammer (WOH) soil, weight of rod (WOR) soil, slickensided materials or degradable shales.

Correlations of Engineering Properties

This document is a summary of correlations between N_{60} values and general stratigraphic geotechnical properties for use in design of foundations for sound barrier walls, retaining walls and other structures. Although more specific correlations may exist, the following general stratum properties have been synthesized for design purposes. These general stratum properties have been determined based upon numerous correlations in the referenced literature, laboratory test results and engineering experience with local soils in the Staunton District. The SPT N_{60} values are derived from N_{field} values that are corrected for hammer energy, C_E, and length of rods, C_R. Gravel inclusions may increase individual N_{field} values. Design soil parameters for strata containing gravel inclusions should be chosen by excluding outlier N values. The design values provided in this document are reasonably conservative to allow for variation of properties between borings and current levels of field quality control during construction.

Valley & Ridge Physiographic Province

Soils in the Valley & Ridge Province (DMME, 2003, 2) generally derive from weathering of the in-place sedimentary rocks such as limestone, dolostone, shale and sandstone. Metamorphic schist, slate, phyllite, granite and gneiss are also present along the eastern border of the district. Soils in the Staunton District are typically comprised of the USDA's Appalachian Ridges and Valleys family (NRCS, 2010, 3): A-1 soils formed from acidic sandstones, shale and phyllites in the mountainous regions; A-3 soils formed from limestones and sandstones in valley uplands; A-2 soils formed from acidic shales in dissected valley uplands (parts of Augusta, Rockingham, Warren, Frederick and Clarke Counties) and small but highly variable alluvial deposits along existing and former waterways. Along the eastern border, B-1 soils formed from sandstones, granites and greenstones may be encountered.

Soils of the Staunton District are generally fine-grained clays and silts with low pH (acidic) and moderately low resistivity. Careful attention must be paid to pipe types selected and backfill for these pipes. Corrosion potential has typically dictated the use of concrete pipe in the Staunton District (see VDOT Road and Bridge Standard PC-1 for allowable pipe types). pH and resistivity testing is recommended to clearly define soil properties. Cut slopes in native soils are typically stable when graded to 2H:1V or flatter, but may require maintenance for creep failures during the typical life of a project (i.e. 20 to 30 years).

Limestones are highly soluble and contain karst formations such as boulders, pinnacles/slots, voids, sinkholes and caves – general locations are provided by the Department of Mines, Minerals and Energy (Hubbard, 1983, 1988 and 2001, 4-6). Voids may contain soil, water, air or any combination of these three. Rock Quality Designations (RQD) in these formations are highly variable with depth and location. Intact rock core compressive strengths and Rock Mass Rating (RMR) may vary greatly within the same formation. These rocks are often interbedded and weaker strata often underlie stronger upper strata. They generally dip toward valley floors with extensive folding, faulting and overturning deformations at higher elevations. The depth to bedrock is highly variable and can range from rock outcrop to around 200 feet in a very short horizontal distance. Clays formed from limestone bedrock tend to increase in water content and decrease in strength with depth – these formations also tend to have perched water tables at variable locations.

Staunton Materials Section recommends that a review of available geologic and soils information be conducted prior to geotechnical investigations – alluvium and karst formations in the Staunton District have required alternative drilling methods, in VDOT experience.

Typical boring layouts and minimum VDOT requirements (spacing, depth, sampling, etc.) are provided in the Materials Division Manual of Instructions. Additional borings may be necessary should atypical features be encountered (i.e. karst, variable depth to rock, etc.).

The following are typical stratum descriptions and associated properties:

Stratum I – Upper Zone/Soil – This stratum comprises near-surface soils, typically of the A and B horizons, which have a homogenous structure. They are generally of medium to high plasticity and are classified as CL, ML, CH, MH, OL, OH and combinations thereof. Surface soils typically have higher densities and preconsolidation pressures than underlying strata due to desiccation and aging, but are susceptible to loss of cohesion over time. Typical SPT N_{60} values range from 3 to 30 bpf. Higher values may be encountered in desiccated clays. Typical thickness is 0 to 3 feet. This stratum may not be present in all areas.

Table 1: Typical Engineering Design Properties (**Upper Zone/Soil**)

Sub-Stratum	SPT N_{60} Value (bpf)	Undrained Shear Strength, S_u (psf)[1]	Friction Angle, ϕ' (degrees)[2]	Moist Unit Weight (pcf)[3]	Saturated Unit Weight (pcf)[4, 5]
I-A	3 – 10[6]	200	18	110	117
I-B	>10≤20	500	20	115	122
I-C	>20	2000	25	125	132

Notes:

1. Undrained shear strength to be used in short-term (undrained/total stress) loading conditions only. For long-term (drained/effective stress) conditions, fully-softened strengths values (c´ = 0) shall be used.
2. Friction angle to be used in long-term (drained/effective stress) loading conditions only.
3. Natural condition, above the groundwater table
4. Saturated condition, below the groundwater table or shallow short-term conditions at surface
5. Submerged (or buoyant) unit weight = Saturated unit weight – Unit weight of water
6. For N_{60} values less than 3 bpf, specific in-situ or laboratory testing is required or the near-surface soft soils removed and replaced.

Stratum II - Residuum – This stratum comprises soils that have weathered from the parent bedrock but can be excavated with power equipment. Residuum in carbonate rocks does not retain the structure of the parent bedrock but residuum from sandstones may contain relict structure. Carbonate residuum is generally of high plasticity, is generally classified as CL, ML, CH, MH or combinations thereof and may contain boulders or soil domes (voids) in karst formations. Except for soft, saturated clays within three (3) feet of bedrock or in slots and voids, carbonate residuum tends to be overconsolidated – preconsolidation pressures typically decrease with depth due to age differential in the residual formation process and degree of weathering. Typical SPT N_{60} values range from 0 (Weight of Hammer) to 60 bpf. Typical thickness is 1 to 20 feet. This stratum may not be present in all areas. In karst terrain, residuum may be present in joints, slots and voids to depths greater than 100 feet.

Table 2: Typical Engineering Design Properties (**Residuum**)

Sub-Stratum	SPT N_{60} Value (bpf)	Undrained Shear Strength, S_u (psf)[1]	Friction Angle, ϕ' (degrees)[2]	Moist Unit Weight (pcf)[3]	Saturated Unit Weight (pcf)[4, 5]
II-A	3 – 10[6]	250	24	115	122
II-B	>10≤30	1000	26	120	127
II-C	>30	4000	28	130	137

Notes:

1. Undrained shear strength to be used in short-term (undrained/total stress) loading conditions only. For long-term (drained/effective stress) conditions, fully-softened strengths values (c´ = 0) shall be used.
2. Friction angle to be used in long-term (drained/effective stress) loading conditions only.
3. Natural condition, above the groundwater table
4. Saturated condition, below the groundwater table
5. Submerged (or buoyant) unit weight = Saturated unit weight – Unit weight of water
6. For N_{60} values less than 3 bpf, specific in-situ or laboratory testing is required or the near-surface soft soils removed and replaced.

Stratum III – Alluvium/Debris Flows/Breccias

This stratum comprises unconsolidated or poorly consolidated material that has been deposited under the action of flood events or fluvial action (alluvium), or under the action of mass-wasting events such as landslides (debris flows), or broken or fractured rock formed by the action of faults or erosion (breccias). Typically, alluvium and debris-flow deposits can range from unconsolidated, poorly-graded sands, to slightly cemented, well-graded gravels and to boulders in a matrix of finer material. Thicknesses can range from a thin veneer above bedrock in streambeds to very thick (100-ft or greater) sequences in valley fill. Engineering design properties will vary greatly in the case of alluvium and debris flows; therefore Staunton Materials Section suggests that site-specific sampling be employed to ensure that these deposits are fully characterized. Breccias form along fault surfaces and consist of angular deposits of the faulted lithology; they can also be formed as the result of erosion of the parent material. In either case, the clastic material can be unconsolidated, in which case it will have engineering properties similar to those of Decomposed/Weathered Rock (see below), or cemented, in which case the material will act as bedrock with the engineering properties governed by the strength of the cementing material (typically carbonate or, more rarely, iron oxide).

Stratum IV – Decomposed/Weathered Rock

Decomposed or weathered rock generally consists of material with SPT N_{60} values greater than 100 bpf, core recovery less than 85% and RQD less than 50%. In limestone formations, this stratum is difficult to differentiate from Stratum II as a sharp transition from soft overlying clay to hard bedrock is typical in boring logs.

Table 3: Typical Engineering Design Properties (**Decomposed/Weathered Rock**)

Stratum	SPT N_{60} Value (bpf)	Friction Angle, ϕ (degrees)	Moist Unit Weight[1] (pcf)	Saturated Unit Weight[2, 3] (pcf)
IV	>100	37	132	139

Notes:
1. Natural condition, above the groundwater table
2. Saturated condition, below the groundwater table
3. Submerged (or buoyant) unit weight = Saturated unit weight – Unit weight of water

Stratum V – Rock

Unweathered rock generally consists of limestone, dolostone, shale and sandstone with SPT N_{60} values greater than 100/2”, core recovery greater than 85% and RQD greater than 50%.

Table 4: Typical Engineering Design Properties (**Rock**)

Stratum	RQD (%)	Friction Angle, ϕ (degrees)	Moist Unit Weight[1] (pcf)	Saturated Unit Weight[2, 3] (pcf)
V	>50	45	160	165

Notes:
1. Natural condition, above the groundwater table
2. Saturated condition, below the groundwater table
3. Submerged (or buoyant) unit weight = Saturated unit weight – Unit weight of water

Fill Soils – Existing fills consist of compacted material derived from soil/weathered rock/excavated rock of Strata II through V above. Highly plastic clays of Strata I and II are not suitable as embankment fill or roadway subgrade without stabilization. Weathered shales of Stratum III quickly degrade over time to form soil with properties of Stratum II.

Table 5: Typical Engineering Design Properties **(Fill Soils)**

Stratum	Degree of Compaction	Undrained Shear Strength, S_u (psf)[1]	Friction Angle, ϕ' (degrees)[2]	Moist Unit Weight (pcf)[3]	Saturated Unit Weight (pcf)[4, 5]
FILL	>95% of VTM-1	1500	26	120	127

Notes:

1. Undrained shear strength to be used in short-term (undrained/total stress) loading conditions only. For long-term (drained/effective stress) conditions, fully-softened strengths values ($c' = 0$) shall be used.
2. Friction angle to be used in long-term (drained/effective stress) loading conditions only.
3. Natural condition, above the groundwater table
4. Saturated condition, below the groundwater table
5. Submerged (or buoyant) unit weight = Saturated unit weight – Unit weight of water

Groundwater – Groundwater is generally not encountered in the upper (soil/residuum) strata. Perched water is often encountered on the surface and overlying bedrock. Unpredictable flow along complex hydrogeologic systems produces artesian conditions near streams, rivers and springs in rock outcrops. Complex groundwater flow is typical in karst terrain.

Karst – The existence of karst features (described above) must be considered when designing or performing construction in any of the Staunton District's carbonate rock formations (see Hubbard references below). Aerial/satellite imaging of project sites is beneficial towards locating large areas of subsidence, while locating discrete features is often very difficult.

Experience in the Staunton District has shown that the inverted filter design is typically the most economical repair/mitigation for surficial sinkholes, voids and slots. A detail showing several applications is available at the end of this document. Deeper mitigation techniques include injection grouting, cap grouting/grout columns, surficial structures to bridge karst features (beams, slabs, reinforced foundations, etc.) and micropiles.

Shale, Siltstone, Claystone or Other Nondurable Rock – Fill consisting of these rock types (referred to as "shale" hereafter) has often created long-term problems in the Staunton District due to degradation of the shale over time (in the order of years to decades) and their tendency to be acid-producing materials. When exposed to water, some shales in the Staunton District degrade over time – this volume change has created issues in embankment settlement and slope stability. However, some shales have performed adequately over the design life of embankments. In order to differentiate between durable shale and nondurable shale, the following requirements shall be followed when designing/building with shales.

Shale shall be tested for durability according to ASTM D4644 – Standard Test Method for Slake Durability of Shales and Other Similar Weak Rocks. Shale shall be categorized as “Durable” if slake durability values are greater than 60% and “Nondurable” if slake durability values are less than or equal to 60%. Due to their consistently poor durability and high acid production, shales derived from the Millboro and Needmore Formations, or those containing pyrite, shall not be used as fill or subgrade material.

Embankment designs using durable shales shall be treated as rock (see Stratum IV and V) and built in accordance with Section 303 of the Specifications. Designs using nondurable shales shall use reduced strength values (Table 2, N>30?) and shall be compacted within ±2 percentage points of its optimum water content, in lifts no thicker than 8 inches uncompacted. The minimum acceptable density shall be determined in accordance with VTM-10, except that the percentage passing the No. 4 sieve may only be used to determine the corrected density whan a sample of the broken down shale (after roller patter) is used for this test. Roller patterns for these materials may require additional passes to fully break down the larger particles. All other procedures follow Section 303 of the Specifications. Embankment fills using nondurable shale shall be designed in accordance with Figure 1 (Strohm, 1980, 7).

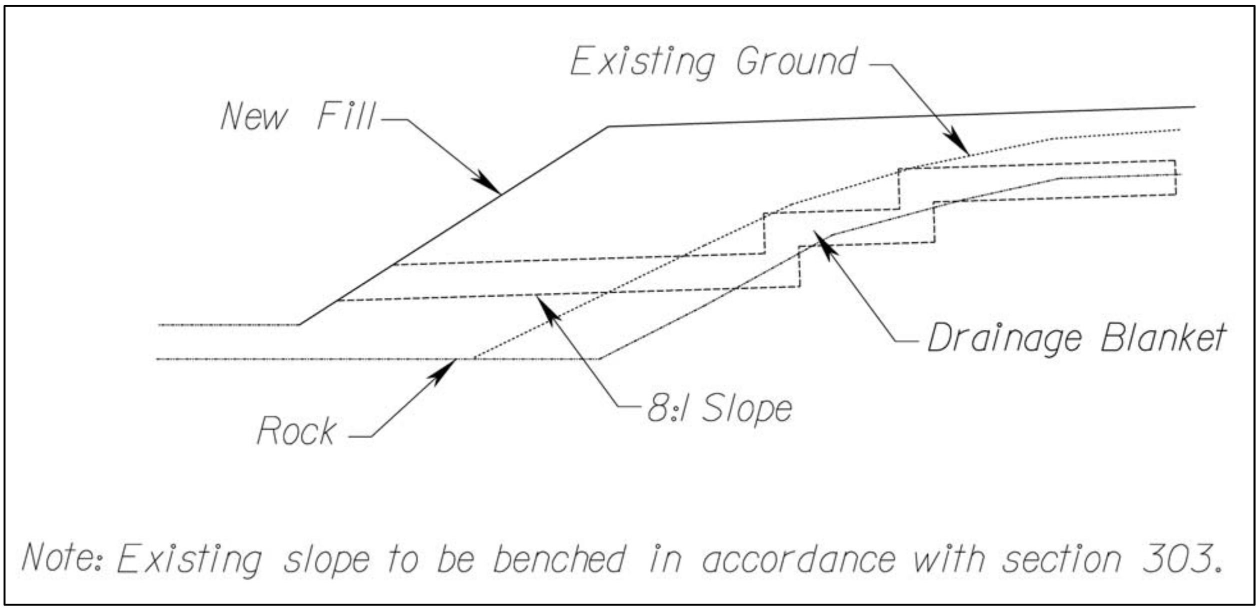


Figure 1: Rock Drainage Blanket Detail for Nondurable Shales

The current version of the Special Provision for Shale Fill shall be included in all contract documents.

Standard Penetration Test (SPT) “N” Value Correction to N_{60}

Based upon VDOT experience, the most significant corrections are for hammer energy, C_E, and length of rods, C_R. Corrections for automatic hammers have been recognized on projects where N values determined with automatic hammers are significantly less than N values determined with safety (manual) hammers. While there may be small differences in efficiency between different automatic hammers, we have assumed 95% efficiency for automatic hammers and 60%

efficiency for safety hammers. This results in a hammer energy correction factor of 1.58 (95/60) for automatic hammers and a correction factor of 1.0 for manual hammers.

The correction factors for length of rods are as follows:

Table 6: Rod Length Correction Factor, C_R (Skempton, 1986, 8)

Rod Length (feet)	C_R
<10	-
10-13	0.75
13-20	0.85
20-30	0.95
30-100	1.00
>100	<1.00

$$N_{60} = N_{field} \text{ x } C_E \text{ x } C_R$$

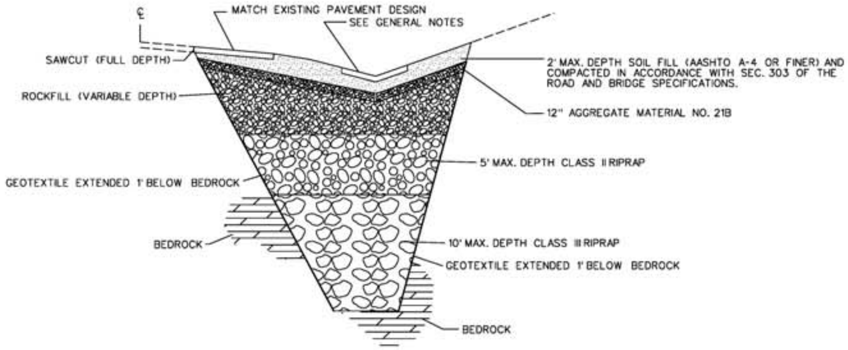
Although there are other correction factors for overburden, borehole diameter, liners, anvils, blow count frequency and hammer cushions, these have not been applied since they tend to unreasonably increase the corrected N value, based upon VDOT experience.

DESIGN FEATURES RELATING TO CONSTRUCTION OR TO REGULATION AND CONTROL OF TRAFFIC MAY BE SUBJECT TO CHANGE AS DEEMED NECESSARY BY THE DEPARTMENT

REVISED	FHWA REGION	STATE	FEDERAL AID PROJECT	STATE ROUTE	STATE PROJECT	SHEET NO.
	3	VA.				

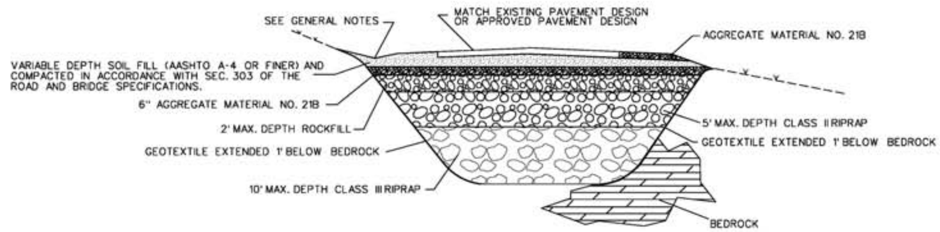
SINKHOLE IN DITCHLINE

(NOT TO SCALE)



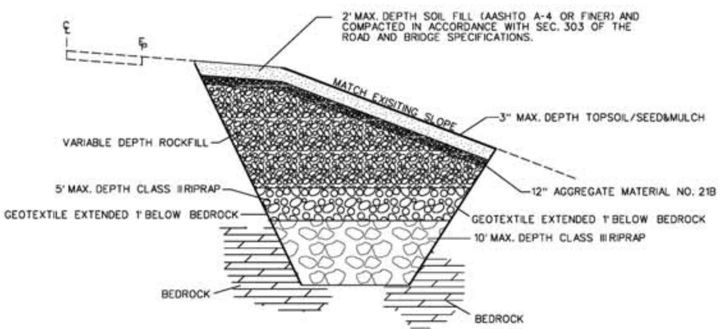
SINKHOLE AT GRADE/UNDER FILL

(NOT TO SCALE)



SINKHOLE IN SLOPE

(NOT TO SCALE)



GENERAL NOTES:

1. PRIOR TO ANY SINKHOLE EXCAVATION THE CONTRACTOR SHALL CONTACT THE DISTRICT MATERIALS ENGINEER.
2. EACH SINKHOLE SHOULD BE TREATED BASED ON THE SPECIFIC CONDITIONS OF THE SITE.
3. CONSECUTIVE LAYERS OF AGGREGATE SHALL BE PLACED IN SUCH A MANNER AS TO PREVENT MIGRATION OF SMALLER AGGREGATES INTO VOIDS IN LARGER AGGREGATES.
4. WHEN THE DEPTH OF A SINKHOLE OR A DEPRESSION IS LESS THAN 10', ROCKFILL SHALL BE USED FOR BACKFILL IN LIEU OF DRY RIP-RAP AND SHALL BE CAPPED WITH NO. 21B AGGREGATE, AND GEOTEXTILE AS NOTED ON THE APPLICABLE DETAIL.
5. TREATMENT SHALL INCLUDE CLEARING AND GRUBBING, STRIPPING TOPSOIL AND REMOVING EXCESS ORGANIC MATERIAL. ALL FOREIGN MATTER INCLUDING TRASH, AND OTHER REFUSE OR WASTE MATERIALS SHALL BE REMOVED.
6. EXCAVATION NECESSARY FOR PLACEMENT OF THE SINKHOLE FILL SHALL BE MEASURED AND PAID FOR AS REGULAR EXCAVATION IN ACCORDANCE WITH THE SECTION 303 OF THE SPECIFICATIONS. ALL OTHER MATERIAL SHALL CONFORM TO AND BE MEASURED AND PAID FOR IN ACCORDANCE WITH THE APPLICABLE SECTIONS.
7. GEOTEXTILE MATERIAL SHALL CONFORM TO THE CURRENT SPECIAL PROVISION FOR GEOTEXTILES.
8. WHEN GRADE OF DITCH IS LESS THAN 5%, MODIFIED PG-2A IS REQUIRED, EXTENDED 10' BEYOND DISTURBED AREA. WHEN GRADE OF DITCH EXCEEDS 5%, CONSTRUCT PER VDOT ROAD AND BRIDGE SPEC'S OR MATCH EXISTING, AS APPROVED BY THE ENGINEER.
9. IN THE EVENT SURFACE DRAINAGE CANNOT BE DIRECTED AWAY FROM THE SINKHOLE OR ROCK IS NOT ENCOUNTERED, THE CONTRACTOR SHALL CONTACT THE DISTRICT MATERIALS ENGINEER PRIOR TO ANY CONSTRUCTION.

SINKHOLE TREATMENT DETAILS

References

1. Virginia Department of Transportation. *Materials Division Manual of Instructions*. Richmond, VA: Virginia Department of Transportation, July 2016, Chapter 3. Available at http://www.virginiadot.org/business/materials-download-docs.asp.
2. Department of Mines, Minerals and Energy, Division of Mineral Resources. “Digital Representation of the 1993 Geologic Map of Virginia.” Department of Mines, Minerals and Energy, Division of Mineral Resources. Publication 174, 2003.
3. Soil Survey Staff. Web Soil Survey 3.0. National Resources Conservation Service, United States Department of Agriculture. Available at https://websoilsurvey.nrcs.usda.gov/app/.
4. Hubbard, David A. “Selected Karst Features of the Northern Valley and Ridge Province, Virginia.” Department of Conservation and Economic Development, Division of Mineral Resources. Publication 44, 1983.
5. Hubbard, David A. “Selected Karst Features of the Central Valley and Ridge Province, Virginia.” Department of Mines, Minerals and Energy, Division of Mineral Resources. Publication 83, 1988.
6. Hubbard, David A. “Selected Karst Features of the Southern Valley and Ridge Province, Virginia.” Department of Mines, Minerals and Energy, Division of Mineral Resources. Publication 167, 2001.
7. Strohm, W.E. *Design and Construction of Shale Embankments*. USDOT, TS-80-219, April 1980.
8. Skempton, A.W. “Standard Penetration Test Procedures and the Effects in Sand of Overburden Pressure, Relative Density, Particle Size, Aging and Overconsolidation.” *Geotechnique*, Vol. 36, No. 3: 425-447.
9. McGregor, Jeff A. and Duncan, J.M. “Performance and Use of the Standard Penetration Test in Geotechnical Engineering Practice.” Center for Geotechnical Practice and Research, 1998.
10. Sowers, George. *Building on Sinkholes*. Reston, VA: American Society of Civil Engineers, 1996. ISBN 0-7844-0176-4.
11. American Association of State Highway Transportation Officials. *AASHTO LRFD Bridge Design Specifications (6th Edition)*. Washington, D.C.: American Association of State Highway Transportation Officials, 2012.
12. Duncan, J.M.; Horz, R.C. and Yang, T.L. “Shear Strength Correlations for Geotechnical Engineering.” Center for Geotechnical Practice and Research, 1987.
13. VDOT Staunton District. “Staunton District Soil-Rock Properties Database.” Unpublished, 2017.