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Landslide Remediation Methodology For Low-Volume Roads In North-Central Pennsylvania

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LANDSLIDE REMEDIATION METHODOLOGY FOR LOW-VOLUME ROADS IN NORTH-CENTRAL PENNSYLVANIA

by

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TABLE OF CONTENTS

APPENDIX C: GEOTECHNICAL CALCULATIONS FROM LOYALSOCK STATE FOREST GEOTECHNICAL ENGINEERING REPORT

APPENDIX D: GEOTECHNICAL CALCULATIONS FROM WORLDS END STATE PARK GEOTECHNICAL ENGINEERING REPORT

LIST OF FIGURES

LIST OF TABLES

LIST OF IMAGES

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Landslide Remediation Methodology for Low-Volume Roads in North-Central Pennsylvania

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ABSTRACT

The study of landslides in north-central Pennsylvania is not well developed, and remediation methodology for landslide-prone and low-volume forest roads in the region can benefit from targeted and innovative engineering design strategies. Rockery walls may be an underutilized remediation methodology for low-volume forest roads in north-central Pennsylvania. Two landslide remediation projects in north-central Pennsylvania within the Lycoming and Sullivan counties can provide valuable insight into the existing methodology associated with low-volume forest road remediation in north-central Pennsylvania and outline a potentially under-utilized methodology that may improve engineering design, construction efficiency, and result quality. A review of the two landslide remediation projects within the context of a comprehensive literature review of existing knowledge on Pennsylvania landslides and forest road remediation will also sufficiently summarize the state of north-central Pennsylvania landslide remediation methodology. One of the two landslide remediation projects features a rockery wall solution, which is not common to Pennsylvania landslide remediation methodology, while the other utilizes typical landslide remediation techniques for the area. The efficiency of the rockery wall's engineering design was evaluated with the finite element method, utilizing the ABAQUS finite element modeling software. The evaluation of the finite element model of the rockery wall indicates that current design practice associated with rockery walls may be overly conservative. The construction efficiency of both landslide remediation projects was evaluated with multiple Site visits at different construction phases. The rockery wall's construction efficiency was comparable to traditional landslide remediation methodology, and the rockery wall was noticeably less intrusive in the state park environment compared to remediation of landslides via the typical remediation design of rip-rap benching with geogrid. It was also found that construction costs associated with landslide remediation along low-volume forest roads may be reduced by allowing for changes during construction, particularly in cases where stable bedrock may be encountered during excavation but could not be confirmed during the engineering design phase.

Section 1: Introduction

1.1: Overview

The study of landslides in north-central Pennsylvania is not well developed. The remediation methodology for landslide-prone and low-volume forest roads in the region can benefit from targeted and innovative engineering design strategies. The majority of the Pennsylvania Department of Conservation and Natural Resources (PA DCNR) state forest and park land lays in the north-central Pennsylvania region. Most of the low-volume roads owned by the PA DCNR are within north-central Pennsylvania. These roads often feature unique design needs that differ from broad Pennsylvania Department of Transportation (PennDOT) standards for engineering design. Annual Average daily traffic (AADT) is lower than that of a typical roadway, user vehicles are more capable of poor conditions, and budgets for engineering design are small compared to higher traffic roads. Recent case studies of landslides in PA DCNR state park and forest lands will help characterize the risk posed to these low-volume roadways and provide examples of successful design methods. A rockery wall, which was utilized for one case study location, will be examined with the finite element method to refine earth pressure distributions and evaluate design efficiency.

1.2: Methodology

This study's primary goal was to evaluate two existing geotechnical design projects that Navarro & Wright Consulting Engineers, Inc. (N&W) was contracted into by Larson Design Group for the PA DCNR. The work associated with these two projects was on state land and state park low-volume roads. The primary cause for work was related to landslide damage. The expectation is that the performed design work will have value on similar projects in the region where landslides have damaged low-volume state land and park roads.

1.3: Summary of Study

Within this thesis, a literature review was performed with the following in scope: landslides in north-central Pennsylvania (Section 2.1); landslide mechanisms and remediation methodology in rural, hilly, forested terrain (Section 2.2); existing case studies associated with rockery walls (Section 2.3); retaining wall design (Section 2.4); lateral earth pressure theory (Section 2.4); retaining wall selection (Section 2.5); and finite element modeling of geotechnical problems, particularly concerning retaining walls. Within the context of the reviewed literature, two case study regions were considered. The first region of interest is within Worlds End State Park in Sullivan County, Pennsylvania. This region features two case study Sites of interest along Mineral Spring Road, where landslides have damaged the roadway. The second region of interest is within Loyalsock State Forest in Lycoming County, Pennsylvania. This region features the relocation of the roadway up-slope due to numerous landslide events related to the nearby Pleasant Stream swelling due to extreme rain events. A review of the project scope, local and regional topography, geology, and immediate case study Site subsurface conditions for the two case study regions was performed in Section 3. The results of the engineering design performed for the two case study regions and the results of the finite element modeling of the rockery wall implemented at Worlds End State Park are provided in Section 4. Section 5 features a discussion on the efficiency of the engineering design results and construction methods and a review of the finite element modeling results' implications. Implications of the spatial topography in PA DCNR state lands are also reviewed. Section 6 reviews the performed research, summarizes the research conclusions and provides recommendations for future engineering design and research. Appendix A includes the geotechnical engineering report for Worlds End State Park and Appendix B includes the geotechnical engineering report for Loyalsock State Forest.

Section 2: Literature Review

2.1: Landslides in Pennsylvania

The study of landslides in southwestern Pennsylvania is well developed. References on maps, case studies, and hazards are available through a variety of sources. Many studies attribute primary drivers as the presence of the red beds, a layer of clay stone that is common along the steep valley walls of the region (Pomeroy, 1982), (Gray et al., 2011), (Briggs et al., 1975). North-Central Pennsylvania is predominantly rural, and landslide risk within the region has been studied significantly less. The risk of landslides was delineated across Pennsylvania's physiographic provinces, as shown in Figure 1 (Delano et al., 2001). This landslide risk map was generated utilizing publications across the state on landslide risk. Within the same publication, Delano generated a map of the most common types of landslides that occur within different Pennsylvania regions, as shown in Figure 2.

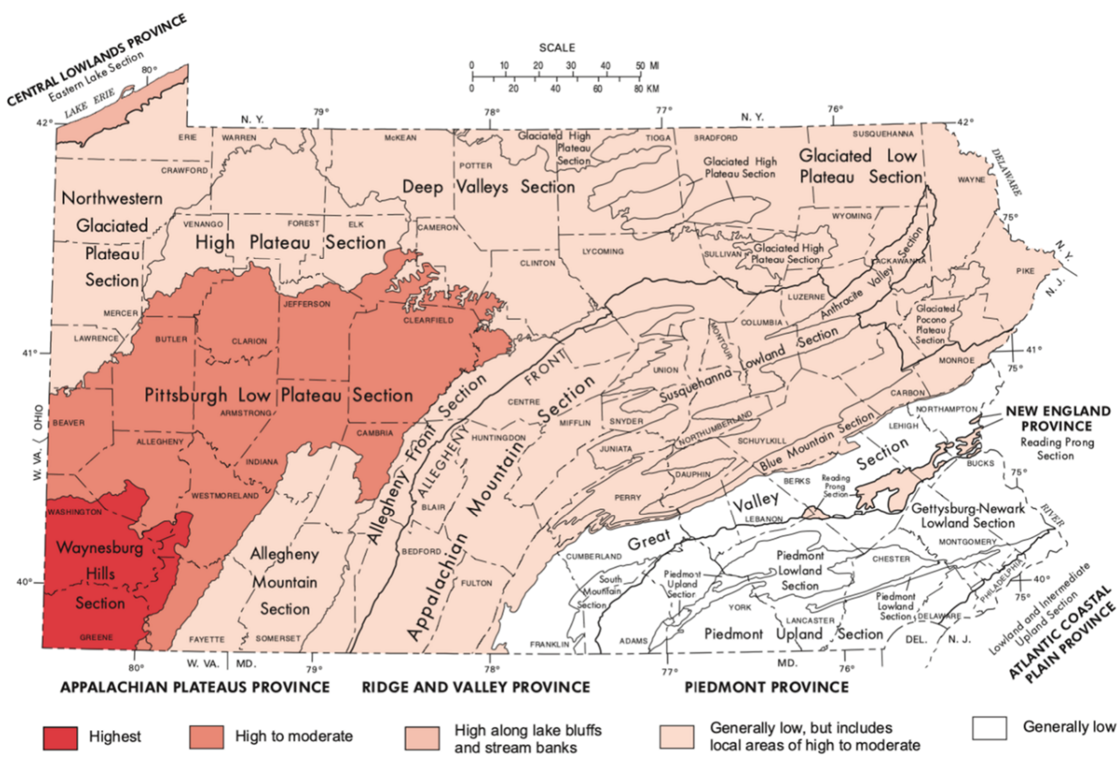


Figure 1: Map of landslide risk by physiographic province in Pennsylvania

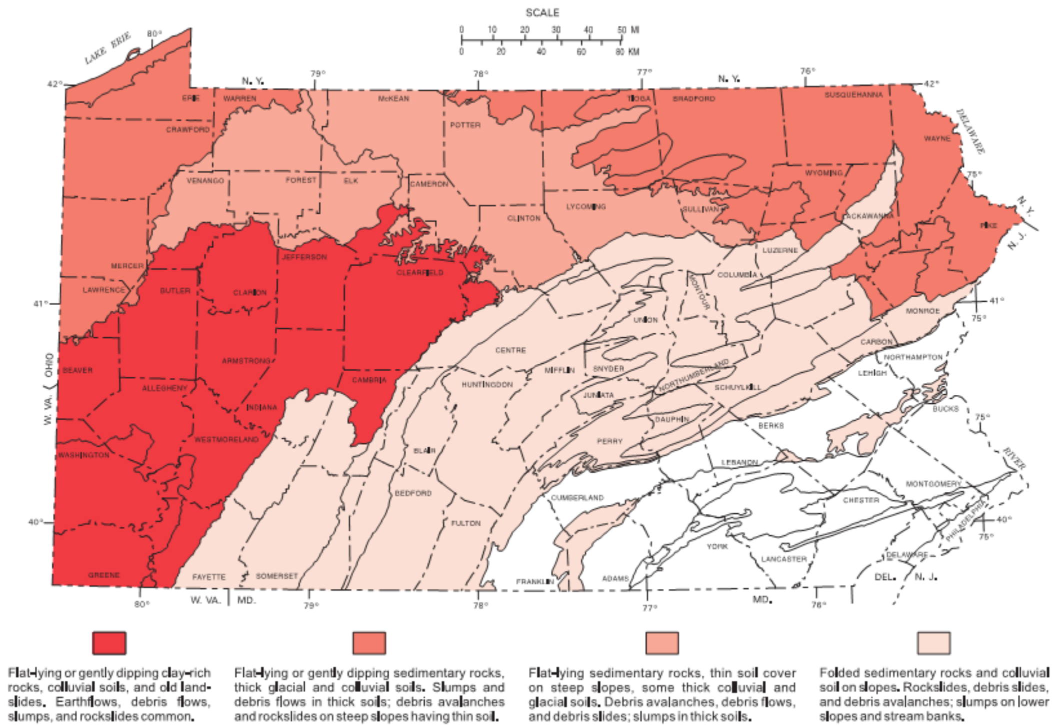


Figure 2: Map of most common forms of landslides in different regions of Pennsylvania

One of the publications utilized in this report mapped landslide risk areas and inventoried landslides within the 1°-by-2° Williamsport quadrangle (Delano et al., 1999). The Williamsport quadrangle is located between the 41° and 42° latitudes and -78° and -76° longitudes. The Williamsport quadrangle with inventoried landslides and areal risk is shown in Figure 3. The legend descriptions associated with Figure 3 have been transcribed and provided for legibility in Table 1.

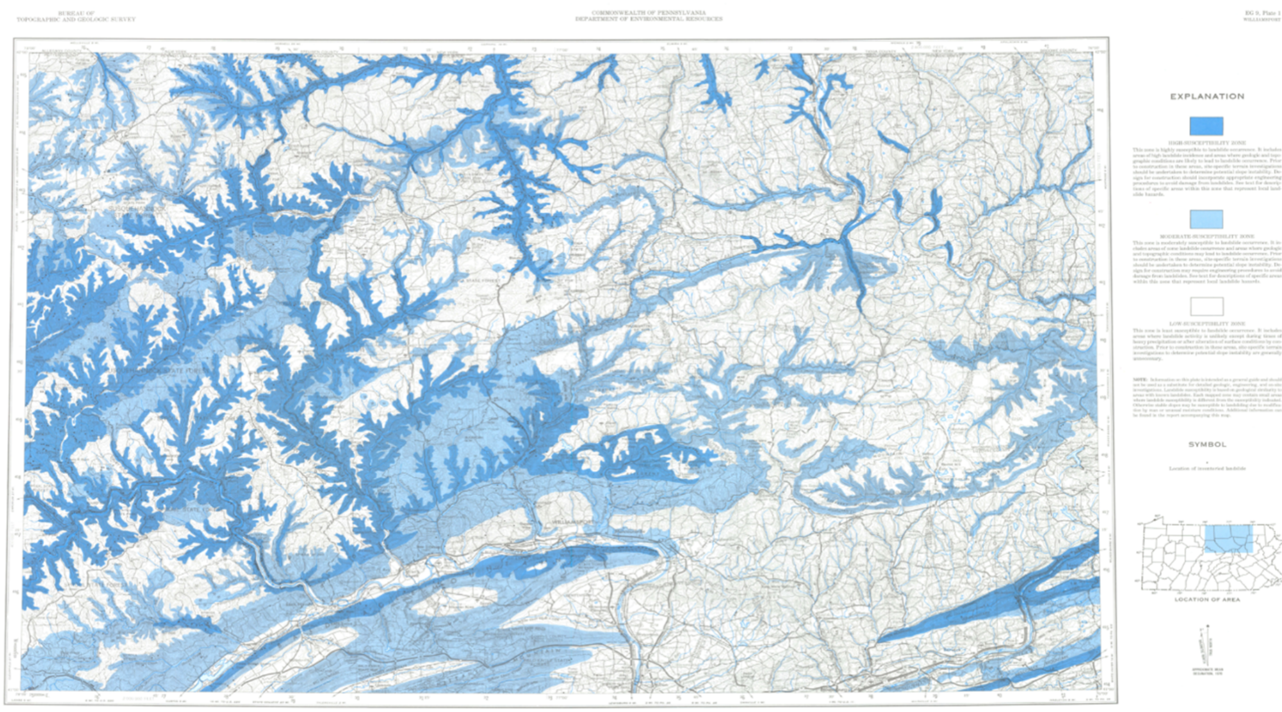


Figure 3: Map of landslide risk within the Williamsport 1-by-2 degree quadrangle

Table 1: Legend for landslide susceptibility zones

Color	Type	Description
	High-Susceptibility Zone	This zone is highly susceptible to landslide occurrence. It includes areas of high landslide incidence and areas where geologic and topographic conditions are likely to lead to landslide occurrence. Prior to construction in these areas, Site-specific terrain investigations should be undertaken to determine potential slope instability. Design for construction should incorporate appropriate engineering procedures to avoid damage from landslides. See text for descriptions of specific areas within this zone that represent local landslide hazards.
	Moderate-Susceptibility Zone	This zone is moderately susceptible to landslide occurrence. It includes areas of some landslide occurrence and areas where geologic and topographic conditions may lead to landslide occurrence. Prior to construction in these areas, Site-specific terrain investigations should be undertaken to determine potential slope instability. Design for construction may require engineering procedures to avoid damage from landslides. See text for descriptions of specific areas within this zone that represent local landslide hazards.
	Low-Susceptibility Zone	This zone is least susceptible to landslide occurrence. It includes areas where landslide activity is unlikely except during times of heavy precipitation or after alteration of surface conditions by construction. Prior to construction in these areas, Site specific terrain investigations to determine potential slope instability are generally unnecessary.

Additional landslides and changes to the local topography after 1999 have occurred. More accurate estimates of elevation with Light Detection and Ranging (LIDAR) data (PAMAP, 2008) has been generated, however to date there is no public landslide inventory for the Williamsport quadrangle region beyond the 1999 publication by Delano et al. Five landslides within the 1999 inventory are recorded near the Pleasant Stream Road project. No landslides are recorded near the Worlds End State Park project (Figure 4).

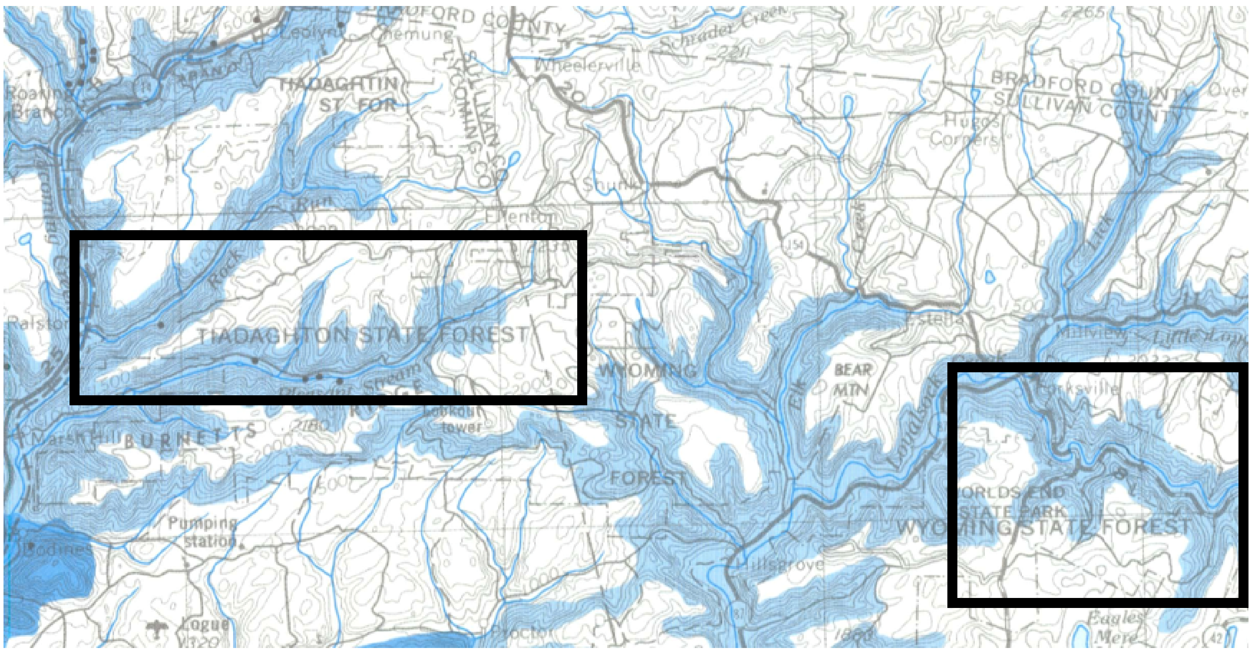


Figure 4: Map of landslide susceptibility and recorded landslides from the Williamsport quadrangle at Worlds End State Park and Loyalsock State Forest

The pitfalls in landslide susceptibility maps is well established - it is impossible to accurately determine all landslides' locations in a given area utilizing only aerial, radar, and LIDAR data (Wills et al., 2002, Westen, 2008). North-central Pennsylvania needs additional case studies to supplement the existing data and increase the understanding of underlying drivers for landslides in the region. Within the 1999 publication, Delano defined ten index landslides. These landslides were intended to be examples of different general forms of landslides within the Williamsport quadrangle. One of the primary factors that influence the form of a landslide is the geologic and topographic setting. In order to review only the landslide types relevant to the Worlds End State Park and Loyalsock State Forest projects, these index landslide locations were overlain onto a geologic and topographic map of the region (Figure 5).

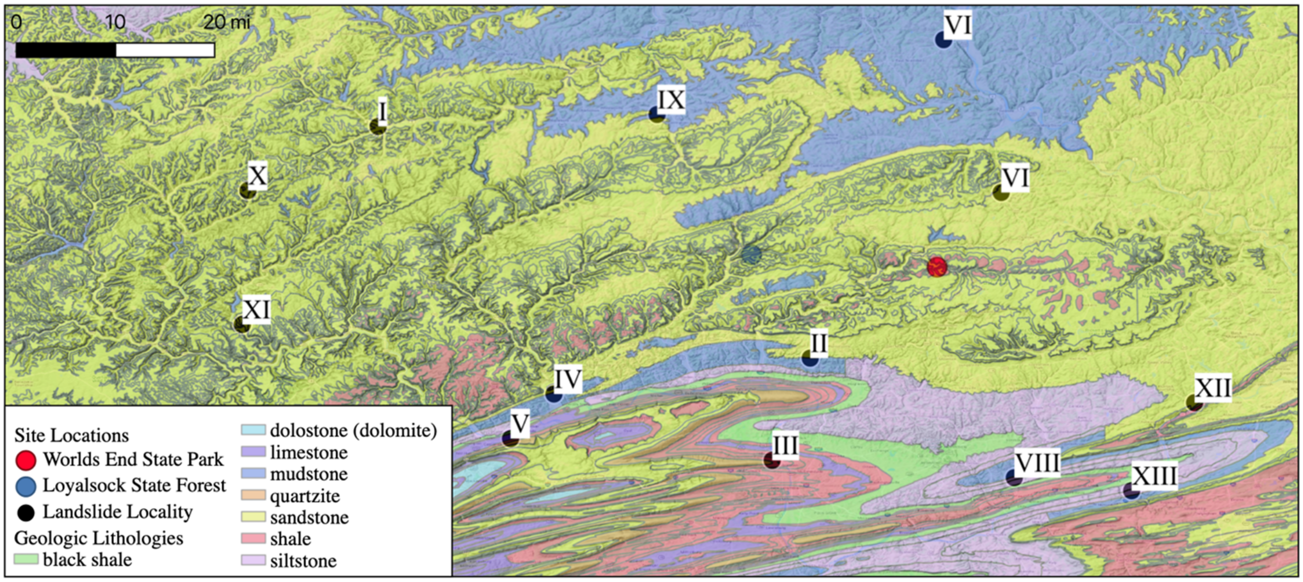


Figure 5: Index landslide locations by Delano et al., 1999, overlain on a topographic and geologic map

By inspection of each slide's topographic and geologic setting, it can be determined that those most similar to the conditions at Worlds End State Park and Loyalsock State Forest were I, X, XI, IX, and VI. Information provided by Delano on these landslides is provided in Table 2.

Table 2: Summary of relevant index landslides from Delano et al., 1999

Landslide Index Number	Slide Height (ft)	Total Slope Height (ft)	Soil Type	Geology Primary/Secondary	Failure Driver
I	80	800	Glacial Lake Colluvium and Clay	Sandstone/Siltstone	Clay and water
VI	60	120	Glacial Lake Clay Till and Colluvium	Sandstone/Siltstone	Stream Erosion of Toe
IX	50	200	Till Overlain by Glaciolacustrine Clay and Colluvium	Mudstone/Siltstone	Water, Steep (45 degree) Slope, and Sliding Along Bedrock Surface
X	500	500	Boulder Colluvium	Sandstone/Siltstone	Late Pleistocene Glacial Events - Now Stabilized by Dense Forestry
XI	167	250	Boulder Colluvium	Sandstone/Siltstone	Highway Construction Removing Toe of Slope and Sliding Along Bedrock Surface

Landslide I is a slump failure in the Huntley Mountain geologic formation. The bedrock is dipping gently upslope on the landslide. Surficial soils include glacial lake deposits, ground moraine, and local colluvium. Stiff glacial clay was noted at the toe of the slope, and local colluvium higher up on the slope. The slump is approximately 300' long, 535' wide at the toe, and at a slope between 25 and 30 percent. The local relief of the slump is approximately 80' and is located at the toe of a slope of approximately 800' in height. Numerous tiered scarps indicate a series of smaller failures that may have contributed to the overall failure.

Landslide VI is a slump-earthflow in the Lock Haven geologic formation. The bedrock dips approximately 5 degrees downslope. Surficial soils include silty clay interbedded with silt and varved glacial lake deposits, glacial till, and colluvium. The slide is approximately 190' long, 1,100' wide, and the local relief is 60'. Significant fill was added above the primary scarp, and the toe is wet and heavily vegetated.

Landslide IX is described as an area of older and more recent, active and inactive, landslide slumps and earthflows in the Lock Haven geologic formation. The bedrock dips approximately 11 degrees southwest, perpendicular to the slide face. The surficial glacial till and glaciolacustrine clay and colluvium rests directly on the shallow shaly siltstones, which serves as a surface against which some landslide rotational failure occurs. Other failure mechanisms include the erosion of the toe by a small stream. The slide is approximately 50' wide and of local relief of 200'.

Landslide X is described as an ancient debris flow. The bedrock is flat and consists of the Catskill and Huntley Mountain formation. The surficial boulder colluvium rests directly on the shallow Huntley Mountain formation bedrock and is residual in nature. The region of the debris flow is described as being heavily forested, with many of the trees exhibiting significant rotation. The slope is approximately 500' high, 500' wide, and of a 30-degree slope.

Landslide XI is described as an active rockslide and debris slide region. The bedrock is fractured and consists of the Catskill and Huntley Mountain formations. The bedrock dips 10 degrees into the slope. The surficial material is boulder colluvium overlying lake deposits and bedrock. The slide is approximately 167' long, 205' wide, and of a 37 to 42-degree slope.

2.2: Landslide Mechanisms and Remediation Methodology in Rural, Hilly, Forested Terrain

Low-volume forestry roads provide unique problems in engineering design. Forest roads in engineering design are defined as roads with difficult ground access and slope stability problems, a need to utilize primarily local construction materials, and a more significant need for drainage and erosion protection measures (Fookes et al., 1984). It is well established that the clearing of vegetation and cutting into slopes for the placement of a roadway is a common cause of later landslides along forest roads (Montgomery et al., 2000, Borga, 2005). The correlation with poor drainage and high pore water pressure is similarly established (Petley, 2004). Forestry roads typically also have less funding than high-volume roadways. These factors contribute to a higher risk of recorded and unrecorded landslides along forestry roads.

2.3: Rockery Wall Existing Case Studies

Rockery walls can be a solution to remediation of forestry roads, where cost is an issue, and the conventional retaining wall design is beyond the project area's needs and requirements and likely contractors. In areas where scenic tourism is a factor, the rockery wall can also be an inobtrusive design option that does not impact the viewshed's commercial value. A literature review was performed to summarize existing case studies on rockery walls, which was tabulated in Table 3 below.

Table 3: Existing case studies on rockery walls

Site	Site Condition	Dimension	Material
2320 Trail Ridge Court, Reno, Nevada	Exposed rockery walls were significantly higher than design - 14 feet instead of 10. It is likely that a large storm caused increased lateral pressure and the lower wall failed, causing the upward wall to fail as well.	Tiered Ten-Foot Rockery Walls	Clay (CL) to Sandy Clay (SC) to six feet, followed by a Fat Clay (CH). Below the fill is alluvium outwash and gravel deposits followed by claystone, siltstone and sandstone of the Tertiary Hunter Creek Formation.
Taylor River Road, Gunnison County, Colorado	The toe of marginally stable talus slopes, glacial and terrace deposits along a proposed roadway. The project Site has undergone uplift, folding, thrust faulting and glaciation, resulting in a mixture of precambrian and metamorphic rocks of weak to strong strength.	Tiered rockery walls of varying heights not to exceed ten feet and with a minimum base width of one half of the proposed height.	The soil slopes consist of rock talus, Sandy Gravel (GP), Clayey Gravel and Sand (GC/SC), Poorly Graded Sand (SP), Silty Sand (SM) and Sandy Clay with Clayey Sand (SC/CL). Rock slopes range from 6 to 65 feet in height and range in slope from 45 to 90 degrees.
Schoharie Creek, Village of Hunter, Greene County, New York	Shallow bedrock, significant stream erosion, and tiered landslides	Tiered four-foot Rockery Walls	Bedrock
Guanella Pass Road, Pike and Arapaho National Forests, Colorado	Winding pass across mountains, with frequent rockfall and steep slopes	11.5-foot high and tiered 10.0-foot high walls with base widths of one-half of height	Precambrian bedrock and glacial soils

2.4: Retaining Wall Design

The primary source of literature for rockery wall history and design standards is the Federal Highway Administration (FHWA) Publication No. FHWA-CFL/TD-06-006 Rockery Design and Construction Guideline, published in 2006. Rockeries are categorized as a type of retaining wall, and like many retaining wall types, has a specific set of circumstances in which it is viable for a project Site. Braja M. Das defines four subcategories of retaining walls: gravity retaining walls, semi-gravity retaining walls, cantilever retaining walls, and counterfort retaining walls (Das, 2014). Gravity retaining wall stability is primarily associated with the system's weight. Semigravity retaining walls are similar to gravity retaining walls, albeit with steel reinforcement that is typically located at the back face. Cantilever retaining walls are made up of a thin stem and a wide base slab and rely on the resisting moment of the soil above the slab. Counterfort retaining walls are similar to cantilever retaining walls, albeit with thin intermittent slabs that connect the base slab to the stem as an additional reinforcement. A list of typical Site requirements and subsurface conditions that each retaining wall type is practical for is tabulated in Table 4.

Table 4: Summary of typical retaining wall choices and their advantages and disadvantages

Retaining Wall Type	Advantages	Disadvantages
Gravity Retaining Walls	Cost-effective at low heights	Not applicable for high walls
Semigravity Retaining Walls	Cost-effective at low heights	Not applicable for high walls
Cantilever Retaining Walls	Economical to moderate heights (approximately 25 feet) Can be precast, which shortens construction timelines	Poor performance when groundwater is high
Counterfort Retaining Walls	Can be precast Effective for tall walls (>20 feet)	Expensive compared to other retaining walls

According to FHWA design standards, rockery walls are to be evaluated as static structures with driving and resisting forces, assumed to be free to rotate around the rockery base. A subsurface investigation into the underlying subsurface gradations, densities, and bedrock (if applicable) should be undertaken to begin rockery design. From this information, soil and rock strength parameters should be developed and the approximate location of the piezometric surface delineated. The effective friction angle can be based on published values, so long as the value is conservative and the geotechnical engineering designer is firmly familiar with the region's geologic and surficial conditions. The soil's unit weight can similarly be based on established parameters, so long as soil density and gradation are available. In general, cohesion in granular soils is conservatively evaluated as zero unless a thorough laboratory testing program shows otherwise, and the tested soil has a consistent presence across the project location. A Coulomb interface friction angle between the soils and the rockery should be determined. FHWA recommends the chosen value be between two-thirds of the friction angle and equal to the friction angle. The lateral earth pressure coefficient can be calculated utilizing these initial parameters. To optimize the design of the rockery, the allowable back cut angle of the crushed rock can be iteratively varied. Below is the suggested equation for calculating the lateral earth pressure coefficient, and in Figure 6 a generalized outline of the parameters and forces involved in a typical rockery is provided.

$$K_a = \frac{\cos^2(\psi + \phi)}{\cos^2(\psi) * \cos(\delta - \psi) * \left[1 + \sqrt{\frac{\sin(\phi + \delta) * \sin(\phi - \beta)}{\cos(\delta - \psi) * \cos(-\delta - \beta)}}\right]^2} \tag{1}$$

K_A = Lateral Earth Pressure Coefficient (Coulomb's Method)

ψ = Allowable Backcut Angle

ϕ = Effective Friction Angle of Retained Soil

δ

= Interface Friction Angle Between Retained Soil and Backfill Material (Typically Equal to $\frac{2}{3}\phi$)

β = Angle of Surficial Soil

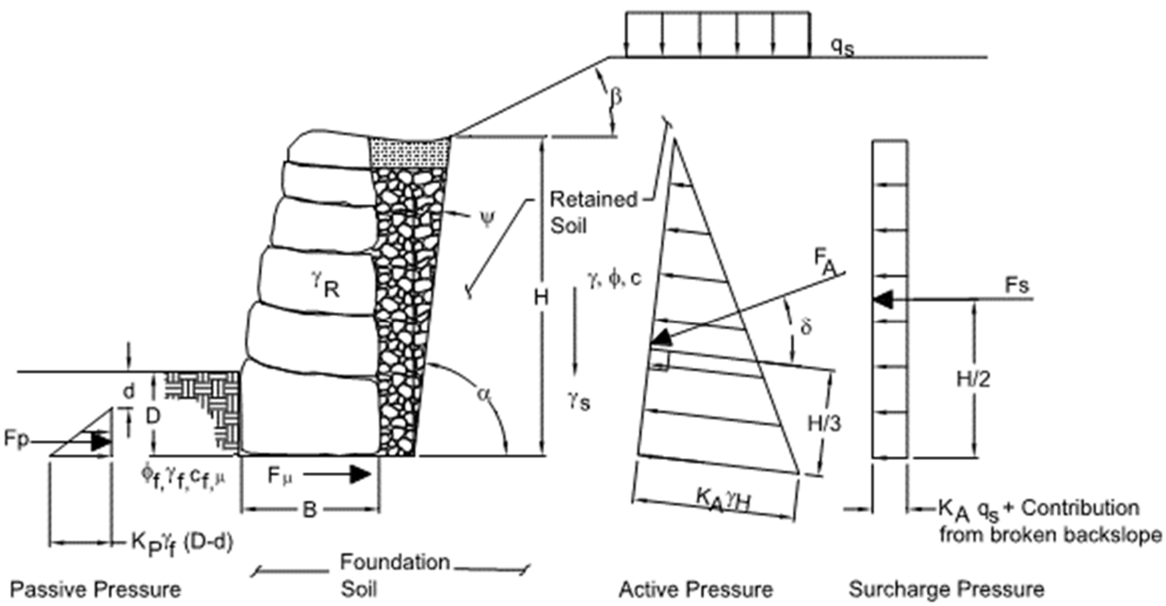


Figure 6: Generalized diagram of rockery parameters and dimensions from FHWA Rockery Design and Construction Guidelines

Utilizing the calculated value of the horizontal earth pressure coefficient, the lateral earth pressures can be evaluated, and their resultant force on the back of the rockery.

$$F_H = F_{A,H} + F_S = \frac{1}{2}\gamma_S K_A H^2 \cos(\delta - \psi) + q_S K_A H \quad (2)$$

γ_S = Effective Unit Weight of Retained Soil

H = Height of Rockery Wall

q_S = Surcharge Load Above Retained Soil

It is assumed that rockeries resist this force through friction forces. It is suggested that the unit weight of the rockery be conservatively evaluated at 150 pcf. The normal forces' distribution should generally be as shown in Figure 7.

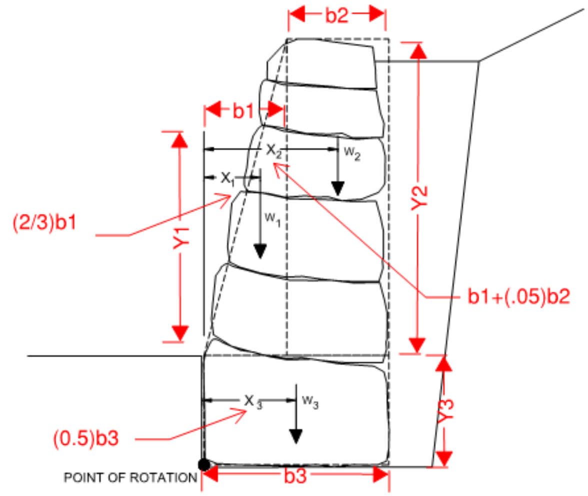


Figure 7: Distribution of forces on a typical rockery wall

Typical values for the friction coefficient of the rock to the subgrade vary from 0.4 to 0.7, based upon the material that the rockery is anticipated to rest upon. The resisting friction force can then be calculated.

$$F_{\mu} = \mu\left(W + F_{A,V}\right) \tag{3}$$

$$F_{\mu} = \mu\left[\Sigma W_i + \frac{1}{2}\gamma_S K_A H^2 \sin(\delta - \psi)\right] \tag{4}$$

W_i = Weight of Sections of Rockery

The passive pressure factor and the resisting passive pressure of the toe can also be utilized in sliding and overturning analysis; however, it should be utilized cautiously. At a minimum, the soil in front of the base rock should be compacted and of quality material if passive resistance is utilized in the design.

$$F_P = \frac{1}{2}\gamma_S K_P (D - d)^2 \tag{4}$$

where

$$K_P = \frac{\tan^2\left(45° + \frac{\phi_F}{2}\right)}{FS} \tag{5}$$

$D = \text{Embedment of Rockery}$

$d = \text{Surficial One Foot of Soil at Rockery Toe, to be Left Out of Resistance Calculation}$

By comparing the resisting and active forces involved at the rockery, the factor of safety against sliding can be determined for the structure.

$$FS_{SL} = \frac{F_\mu + F_P}{F_H} \tag{6}$$

To obtain the factor of safety against overturning, the overturning and resisting moments applied by the horizontal and normal forces within the rockery and surrounding soil should be calculated as shown.

$$M_O = \frac{1}{2}\gamma_S K_A H^2 \cos(\delta - \psi)\left(\frac{H}{3}\right) + q_S K_A H\left(\frac{H}{2}\right) \tag{7}$$

$$M_r = \Sigma W_i x_i + \frac{1}{2}\gamma_S K_A H^2 \sin(\delta - \psi)\left(\frac{H}{3}\tan(\psi) + B\right) + \frac{1}{2}\gamma_S K_P (D - d)^2\left(\frac{D - d}{3}\right) \tag{8}$$

$B = Minimum\ Width\ of\ Base\ Rock\ of\ Rockery$

$x_i = Distance\ from\ Point\ of\ Rotation\ of\ Rockery\ for\ Each\ Section$

Similar to the sliding analysis, resisting and overturning moments should be compared to ensure an adequate factor of safety. Reasonable factor of safety values are typically considered to be above 2.0. Notably, the resisting moment equation incorporates the passive resistance of the toe. This should only be incorporated into the equation if standards are specified in design that will guarantee activation of the toe.

$$FS_{OT} = \frac{M_r}{M_O} \tag{9}$$

FHWA provides guidelines on calculating the bearing pressure and eccentricity limits of the rockery wall and directs the reader to Principles of Foundation Engineering by Braja M. Das, Navfac 7.01, or other well-established methodology for guidelines on calculating the bearing capacity of the subgrade.

$$e = \frac{B}{2} - \frac{M_r - M_O}{W + \frac{1}{2}\gamma_S K_A H^2 \sin(\delta - \psi)} \tag{10}$$

$$q_{max} = \frac{W + \frac{1}{2}\gamma_S K_A H^2 \sin(\delta - \psi)}{B}\left(1 + \frac{6e}{B}\right) \tag{11}$$

$e =$ Eccentricity of $Footing\ (Base\ Rock)$

The AASHTO Bridge Design Manual, 2015, and the PennDOT addendum to LRFD methodology (DM-4) indicate the designer should utilize a semi-empirical method to evaluate the bearing capacity of bedrock. The suggested methodology is based on average rock Rock Quality Designation (RQD), lab unconfined compressive strength testing results, and Rock Mass Rating (RMR). Based on RMR and RQD, a coefficient for nominal bearing resistance, N_{ms}, is determined by referencing Table 5, and related to nominal and factored bearing capacity with the following equations.

Table 5: Values of coefficient Nms for estimation of the nominal bearing resistance of footings on broken or jointed rock, modified after Hoek (1983)[4]

Rock Mass Quality	General Description	RMR Rating(1)	RQD(2)	N_{ms}(3)				
				A	B	C	D	E
Excellent	Intact rock with joints spaced >10 ft. apart	100	95 - 100	3.8	4.3	5	5.2	6.1
Very Good	Tightly interlocking, undisturbed rock with rough unweathered joints spaced 3 to 10 ft. apart	85	90 - 95	1.4	1.6	1.9	2	2.3
Good	Fresh to slightly weathered rock, slightly disturbed with joints spaced 3 to 10 ft. apart	65	75 - 90	0.28	0.32	0.38	0.4	0.46
Fair	Rock with several sets of moderately weathered joints spaced 1 to 3 ft. apart	44	50 - 75	0.049	0.056	0.066	0.069	0.081
Poor	Rock with numerous weathered joints spaced 1 to 20 in. apart with some gouge	23	25 - 50	0.015	0.016	0.019	0.02	0.024
Very Poor	Rock with numerous highly weathered joints spaced <2 in. apart	3	< 25	Use q_{ult} for an equivalent soil mass				

(1) Geomechanics Rock Mass Rating (RMR) system, in accordance with D10.4.6.4

(2) Range of RQD values provided for general guidance only; actual determination of rock mass quality should be based on RMR

(3) Value of N_{ms} as a function of rock type refer to Table 10.6.3.2.2-2 for typical range of values of C_o for different rock types in each category

(4) AASHTO LRFD 2015 Bridge Design Manual Section 10.6.3.2.2-1

$$Q_{ult} = N_{ms} * C_o \quad (12)$$

$N_{ms} = Coefficient\ for\ Estimation\ of\ Nominal\ Bearing\ Resistance$

$C_o = Lab\ result\ for\ Unconfined\ Compressive\ Strength\ of\ Rock\ (tsf)$

$Q_{ult} = Nominal\ Bearing\ Capacity\ of\ Spread\ Footing\ on\ Bedrock$

$$Q_{Fact} = Q_{ult} * \ \phi \quad (13)$$

ϕ

$= Resistance\ Factor\ for\ Bearing\ Capacity\ of\ Spread\ Footing\ on\ Rock, as\ shown\ in\ Table\ 6$

$Q_{Fact} = Factored\ Bearing\ Capacity\ of\ Spread\ Footing\ on\ Rock$

Table 6: Typical resistance factors for spread footings (PennDOT DM-4 2015)

METHOD/SOIL/CONDITION					Resistance Factor
BEARING RESISTANCE	Φ_b	SAND	Semi-empirical procedure using SPT data		0.45
			Semi-empirical procedure using CPT data		0.45
			Theoretical Estimation -	Using Φ_f estimated from SPT data	0.45
				Using Φ_f estimated from CPT data	0.5
				Using Φ_f measured directly in lab or field tests	0.5
		Clay	Semi-empirical procedure using CPT data		0.45
			Theoretical Estimation -	Using shear resistance measured in lab tests	0.5
				Using shear resistance measured in field vane tests	0.5
				Using shear resistance estimated from CPT data	0.5
		Rock	Semi-empirical procedure, Carter and Kulhawy (1988)		0.5
		Plate Load Test			0.55
Sliding Resistance	Φ_f	Precast concrete placed on sand	Using Φ_f estimated from SPT data		0.9
			Using Φ_f estimated from CPT data		0.9
			Using Φ_f measured directly in lab or field tests		0.9
		Concrete cast-in-place on sand	Using Φ_f estimated from SPT data		0.8
			Using Φ_f estimated from CPT data		0.8
			Using Φ_f measured directly in lab or field tests		0.8
		Precast concrete placed on rock	Using δ from Table A3.11.5.3-1		1
			Using δ measured directly in lab or field tests		0.9
		Concrete cast-in-place on rock	Using δ from Table A3.11.5.3-1		1
			Using δ measured directly in lab or field tests		0.8
		Precast or cast-in-place concrete on clay			0.85
		Soil on soil			0.9
	Φ_p	Passive earth pressure component of sliding resistance			0.5

Finally, the rockery should be evaluated for global stability in an industry-standard slope stability program. RocScience SLIDE 8.0 is standard for evaluating global stability in PennDOT-related projects. FHWA recommends utilizing a design factor of safety of 1.5, 2.0, 1.5, and 1.5, for sliding, overturning, bearing, and global stability, respectively.

2.5: Lateral Earth Pressure Theory

In order to design retaining walls, estimates of the lateral pressures that retained soil and surcharges exert on the proposed structure are necessary. Two theories are most commonly used in engineering design: Coulomb (1776) and Rankine (1857). In order to quantify lateral earth pressure with either method, vertical surcharges and soil weights are multiplied by an earth pressure coefficient, which changes depending on if the evaluated pressure state is passive or active. Active pressure is defined by being from the direction of the retained soil, whereas passive pressure is defined as resisting forces that may be present at the toe of the system.

2.5.1: Coulomb's Earth Pressure Theory

The primary assumptions of Coulomb's earth pressure theory are as follows:

1. Soil is isotropic, homogenous, and has internal friction and cohesion.
2. The failure surface and backfill surface is derived as a plane surface.
3. Friction resistance is uniformly distributed along the failure surface and the soil to soil friction coefficient.
4. The resulting failure wedge is a rigid body experiencing translation.
5. The wall has friction.
6. The failure is modeled in plane-strain.

The formula and variable descriptions for the Coulomb's active and passive earth pressure coefficients are provided in the following equations and Figure 8.

$$K_a = \frac{sin^2(\alpha + \emptyset)}{sin^2(\alpha)\sin(\alpha + \delta)\left[1 - \sqrt{\frac{\sin(\emptyset + \delta)\sin(\emptyset + \beta)}{\sin(\alpha + \delta)\sin(\alpha + \beta)}}\right]^2} \qquad (14)$$

$$K_p = \frac{sin^2(\alpha - \emptyset)}{sin^2(\alpha)\sin(\alpha + \delta)\left[1 - \sqrt{\frac{\sin(\emptyset + \delta)\sin(\emptyset + \beta)}{\sin(\alpha + \delta)\sin(\alpha + \beta)}}\right]^2} \qquad (15)$$

$K_a = Active\ Earth\ Pressure\ Coefficient$

$K_p = Passive\ Earth\ Pressure\ Coefficient$

$\alpha = Angle\ of\ the\ back\ of\ the\ retaining\ wall$

$\emptyset = Internal\ friction\ angle\ of\ soil$

$\delta = Friction\ angle\ between\ soil\ and\ back\ of\ retaining\ wall$

The failure surface defined by Coulomb's earth pressure theory is as shown in Figure 2.10.

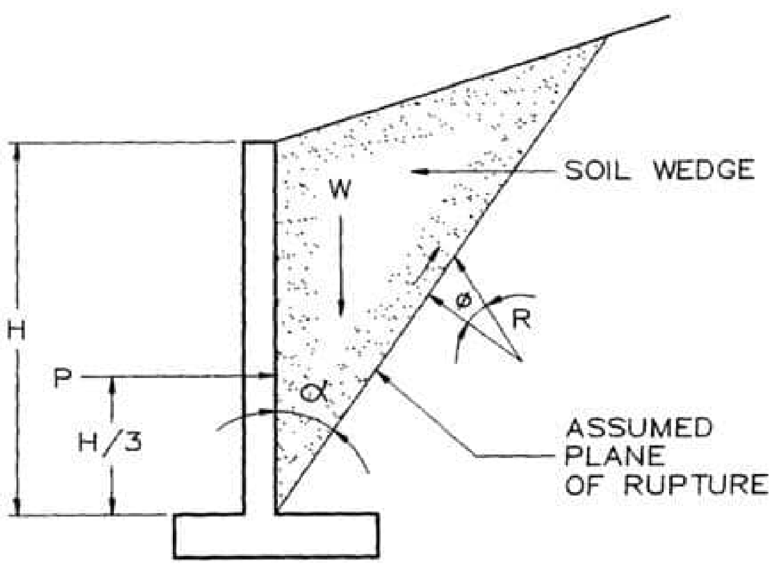


Figure 8: Depiction of Coulomb's lateral earth pressure theory soil wedge

2.5.2: Rankine Earth Pressure Theory

The primary assumptions of Rankine earth pressure theory are as follows:

1. The soil medium is cohesionless.
2. The retaining wall is frictionless ($\delta = 0$).
3. The soil-wall interface is vertical.
4. The failure surface is planar.
5. The resultant lateral force is parallel to the backfill surface.

The formula and variable descriptions for the Rankine active and passive earth pressure coefficients are provided below.

$$K_a = \frac{\cos(\beta) - \left(cos^2(\beta) - cos^2(\emptyset)\right)^{\frac{1}{2}}}{\cos(\beta) + \left(cos^2(\beta) - cos^2(\emptyset)\right)^{\frac{1}{2}}} * \cos(\beta) \qquad (16)$$

$$K_p = \frac{\cos(\beta) + \left(cos^2(\beta) - cos^2(\emptyset)\right)^{\frac{1}{2}}}{\cos(\beta) - \left(cos^2(\beta) - cos^2(\emptyset)\right)^{\frac{1}{2}}} * \cos(\beta) \qquad (17)$$

The failure surface defined by Rankine earth pressure theory is as shown in Figure 9.

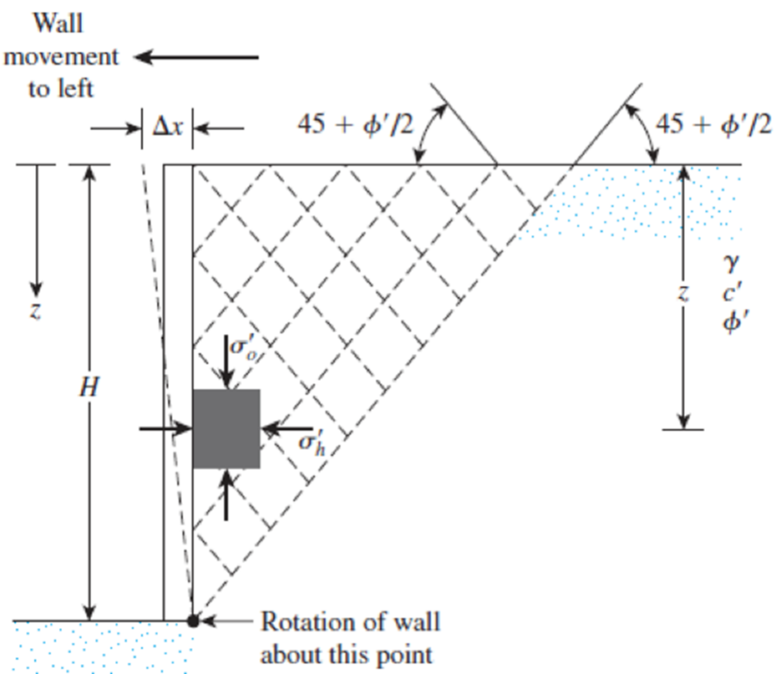


Figure 9: Rankine earth pressure theory depiction

2.6: Retaining Wall Selection

Retaining wall selection is typically based on the project budget and the specific needs and conditions of the project. Worlds End State Park included unique factors that had to be considered in retaining wall selection such as the nearby availability of suitable rock, a low volume/traffic road, low project budget, shallow bedrock and granular (high bearing strength) soils, shallow groundwater, and all materials and equipment will need to be transported along a narrow dirt road. Finally, the PA DCNR indicated that solutions which did not impact the commercial value of the viewshed were preferred and that all construction must be performed from the top of the slope, as disturbing the wetlands at the bottom of the slope would incur additional costs with associated remediations. Because of these project conditions, a Mechanically Stabilized Earth (MSE) retaining wall with rock facing and a rockery wall were evaluated. The MSE retaining wall with rock facing would maintain the aesthetic quality of the park and stabilize the road however, the cost of materials, transportation of materials, and cost of design would be significant. The rockery wall achieves similar goals and can take advantage of nearby suitable rock. Additionally, construction can generally be achieved with limited construction equipment, such as a small excavator.

2.7: Finite Element Modeling of Geotechnical Problems with ABAQUS

2.7.1: Overview of ABAQUS

ABAQUS is a finite element analysis (FEA) program capable of solving 2D and 3D (linear and non-linear) problems in geotechnical engineering. The program is capable of modeling interactions between different surfaces, which is helpful for modeling retaining wall stress distribution. The program can also accurately model the distribution of effective stress in soil. ABAQUS has frequently been used in academia to model geotechnical problems.

2.7.2: ABAQUS Model for Retaining Walls

The primary methodology of interest is that of Sam Helwany, presented in Chapter 7 of his text "Applied Soil Mechanics with ABAQUS Applications" (Helwany, 2007). Helwany provides a step-by-step methodology for defining model geometry and input parameters and constructing an accurate ABAQUS model for numerous geotechnical problems. In general, ABAQUS modeling consists of three phases – pre-processing, evaluation and simulation, and post-processing. Pre-processing includes the model geometry and all associated inputs. Evaluation and simulation involve processing the input data and output of stress and strain relationships. Post-processing can be managed via ABAQUS or a third-party program and is associated with evaluating the completed model.

Section 3: Methodology

3.1: Case Study Region and Site Descriptions

Two case study regions were examined: Mineral Spring Road at Worlds End State Park (1), and Pleasant Stream Road at Loyalsock State Forest (2). Both projects involved landslide remediation along a rural forestry road.

3.1.1: Worlds End State Park Introduction

The first case study region consists of landslide repairs along Mineral Spring Road in Worlds End State Park, Forks Township, Sullivan County, Pennsylvania. Two landslide Sites are of interest: Site 1 is encountered approximately 1,000 feet to the south of the intersection of Mineral Spring Road and State Route (SR) 154. Site 2 is encountered an additional 500 feet down the road from the first Site.

Site 1 was the location of a small culvert with a timber log and driven iron stake retaining system. Likely due to a severe storm event and inadequate drainage systems along the roadway, the culvert and retaining system failed. This Site's goal was to design an effective drainage system and restore the limits of the roadway while maintaining the general aesthetic of the state park and ensuring future slope stability. Additionally, due to wetlands at the base of the slope, it was made clear that a remediation design in which construction could be performed from the top of the slope would be preferable.

Site 2 is characterized by multiple terraced landslides of significant proportion, with one of the most recent landslides having a failure surface that cut through the northwestern edge of Mineral Spring Road. The goal for this Site is to remediate the slope to an adequate factor of safety such that future slides do not occur.

3.1.2: Worlds End State Park Topographic Setting

A professional land survey was performed for Site 1 and Site 2 at Worlds End State Park by N&W, with the primary goal of delineating the slope geometry at each Site. The topographic map generated by this survey is provided in Figure 10. Similarly, cross-sections of the slopes for Site 1 and Site 2 were generated with the survey data. These cross-sections are provided in Figure 11 and Figure 12.

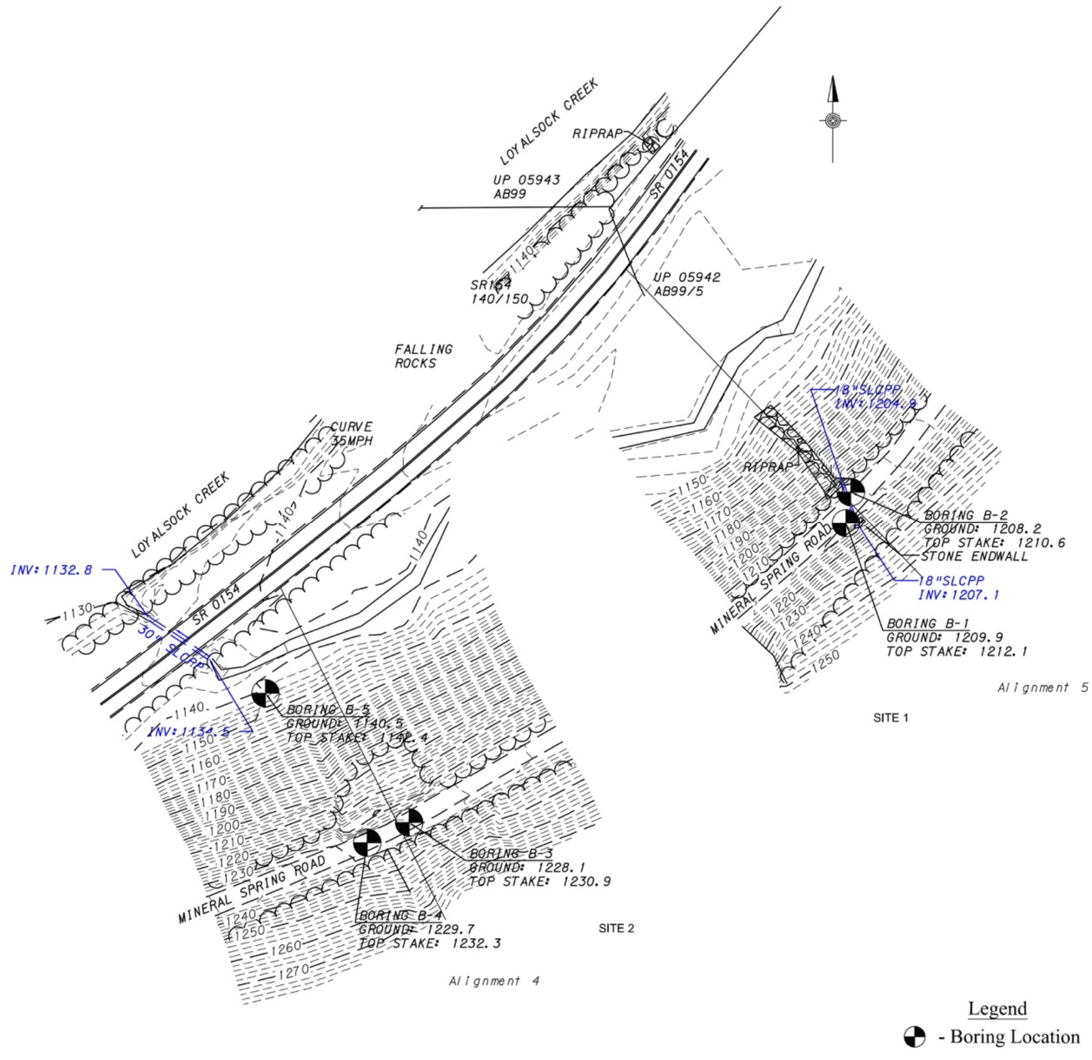


Figure 10: Topographic map of Site 1 and Site 2 at Worlds End State Park

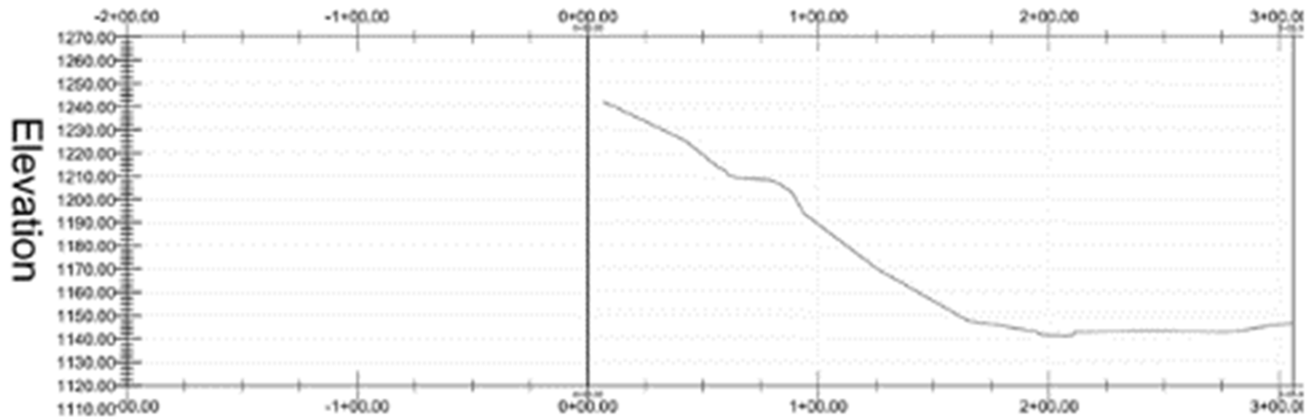


Figure 11: Cross-section of Site 1

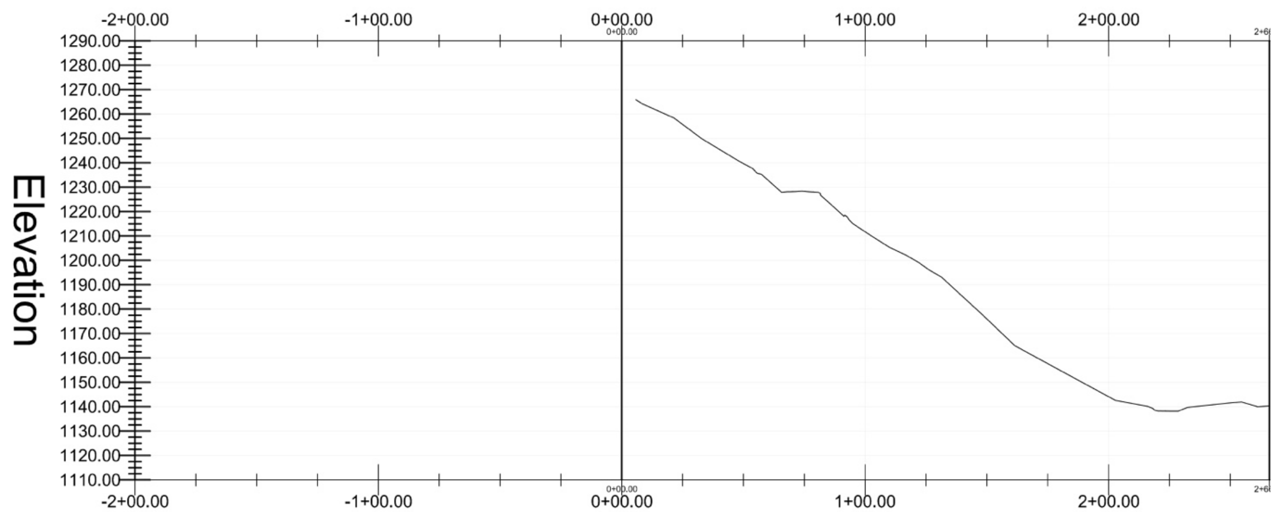


Figure 12: Cross-section of Site 2

3.1.3: Worlds End State Park Geology

According to the Geologic Map of Pennsylvania (Berg et al. 1980) the project Sites are underlain by the Huntley Mountain Formation (MDhm) of late Devonian and early Mississippian age. A geologic map of the site locations is provided as Figure 13. According to the book published by the Pennsylvania Geologic Survey and Geyer et al., 1982, Engineering Characteristics of the Rocks of Pennsylvania, and from analysis of the nearby bedrock outcrops at Worlds End State Park, the following information is available:

The Huntley Mountain Formation is composed of two sandstone sequences. The upper sandstone unit is generally tan to olive, fine to medium-grained, iron-stained quartzitic sandstone with shale and mudstone interbeds. The lower unit is generally gray to tan, fine-grained, argillaceous sandstone with some shale and mudstone interbeds. Conglomerate, up to six feet thick, occurs in the upper part of the formation. The thickness of the formation ranges from 525 to 730 feet. The rock has thin (1/2"-2") to medium (2"-2') bedding, of moderate (3"-6") thickness, and often featuring distinctive cross-bedding. Fractures are well developed and generally occur along steeply dipping joints and bedding plane openings. Joints are irregularly spaced (2" to >2') while close (2"-2') bedding produces a laminated pattern within the rock. The dip of the rock encountered at the Site was generally flat to shallow and dipping to the southeast, which generally matches the dip expected when analyzing the geologic map at the Site with standard geologic practice. The formation is moderately resistant to weathering, and typically is weathered to a moderate (1'-4') depth. Weathered surfaces are rough and many overhangs occur in natural bedrock outcrops. Weathered fragments are tabular and range to more than 4' in diameter. The thickness of the regolith is variable in talus, ranging from 1' to greater than 10'. The formation forms flanks of steep valley walls of incised plateaus, having topographic relief greater than 1,000'. Natural slopes are steep and show evidence of past movement in unconsolidated regions. Excavation is often difficult, but flaggy layers can be ripped near the top of rock. The drilling rate is moderate, and cut-slope stability is good in fresh rock cuts. There is some rockfall below exposed outcrop or cut-slopes, and cut-slope stability is poor in the overlying regolith which is generally made up of talus, colluvium and glacial material. Foundation stability is excellent after excavation to sound *material, but poor in areas of steep slopes. The formation is a good source of various colored flagstones and does not contain Acid- Bearing Rock (ABR). Average expected groundwater yield in the formation is 50 gallons per minute (gpm). Water is generally of good quality with the exception of possible high iron content. The formation has good surface drainage and joint and bedding planes provide a moderate secondary porosity and moderate permeability.*

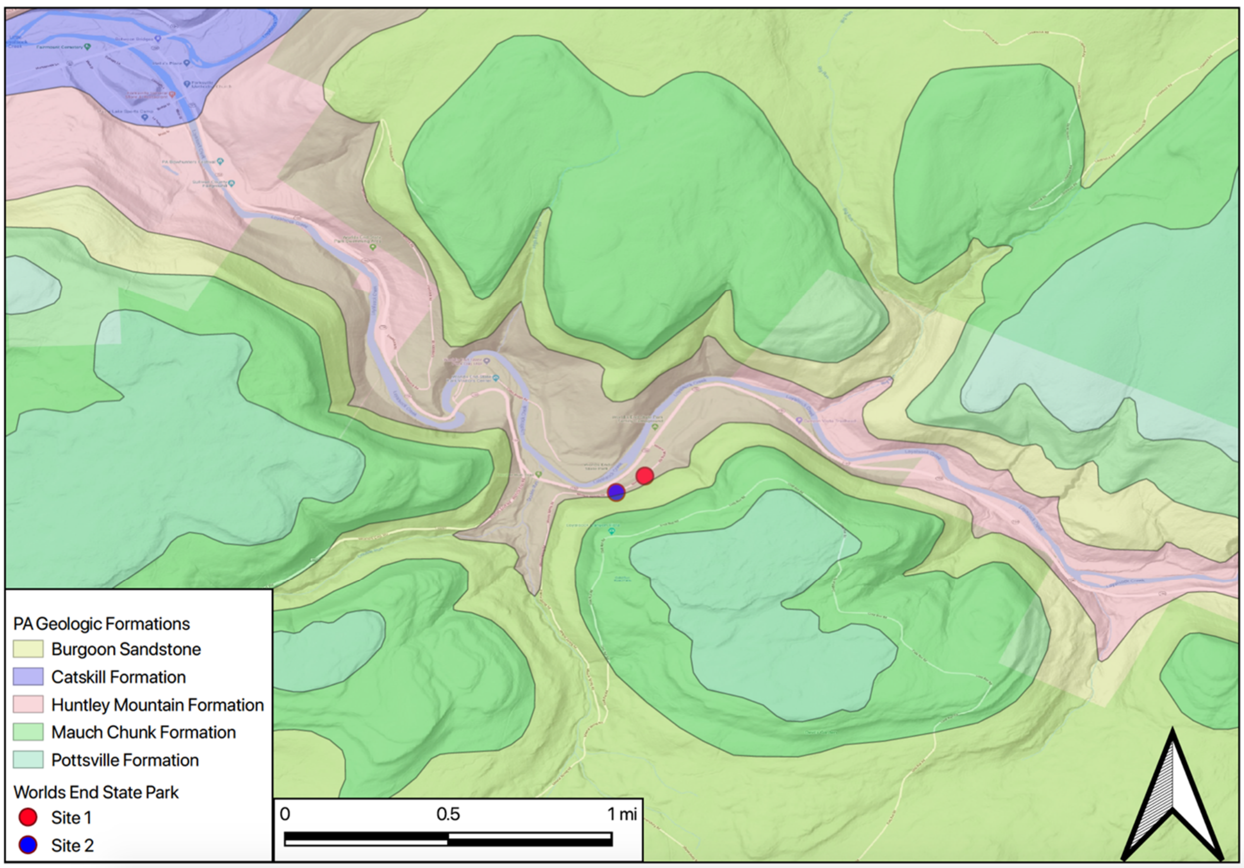


Figure 13: Geologic map of the project locations at Worlds End State Park in Sullivan County, Pennsylvania

3.2: Loyalsock State Forest Site Description

3.2.1: Loyalsock State Forest Introduction

The project is located on the northern slope parallel to the PA DCNR Pleasant Stream Road in McIntyre Township, Lycoming County, Pennsylvania. The existing roadway is Pleasant Stream

Road which varies from 14 to 20 feet wide across the project location and is a gravel forest road following the north side of Pleasant Stream. Previous flooding has caused Pleasant Stream Road to erode away in multiple locations. The roadway's proposed realignment generally follows an old railroad grade higher on the slope.

3.2.2: Loyalsock State Forest Topographic Setting

Larson Design Group provided proposed roadway cross-sections for every 100' in support of the geotechnical design. The proposed roadway cross-sections were reviewed and generalized into stationing groups, based on sections of cuts and fills that would require remediation. These groups are tabulated in Table 7 and Table 8.

Table 7: Proposed cut ranges and extents

Station to Station Limits	**Offset**	**Max Vertical Cut Distance from Existing to proposed Groundline (ft)**	**Slope**
12+00 to 17+00	Left and Right	10	1.5 (H) : 1.0 (V)
20+00 to 37+00	Left	10	1.5 (H) : 1.0 (V)
43+00 to 45+00	Left	5	1.5 (H) : 1.0 (V)
49+00 to 57+00	Left	9	1.5 (H) : 1.0 (V)
59+00 to 64+00	Left	6	1.5 (H) : 1.0 (V)
69+00 to 80+00	Left	9	1.5 (H) : 1.0 (V)
81+00 to 91+00	Left	15	1.0 (H) : 1.0 (V)
92+00 to 98+00	Left	5	1.5 (H) : 1.0 (V)
112+00 to 113+00	Left	3	1.5 (H) : 1.0 (V)
124+00 to 127+00	Left	5	1.5 (H) : 1.0 (V)
130+00 to 132+00	Left	5	1.5 (H) : 1.0 (V)
134+00 to 141+00	Left	8	1.5 (H) : 1.0 (V)

Table 8: Proposed fill ranges and extents

Station to Station Limits	Offset	Max Vertical Fill Distance from Existing to proposed Groundline (ft)	Slope
17+00	Right	10	1.5 (H) : 1.0 (V)
21+00	Right	3	1.5 (H) : 1.0 (V)
58+00	Left and Right	3	1.5 (H) : 1.0 (V)
97+00 to 104+00	Right	3	1.5 (H) : 1.0 (V)
114+00	Right	3	1.5 (H) : 1.0 (V)
135+00	Right	1	1.5 (H) : 1.0 (V)

3.2.3: Loyalsock State Forest Geology

Geology along the project location was found to be the Huntley Mountain Formation. A detailed description of this geologic formation can be found in Section 3.1.2. A geologic map of the Site region is provided in Figure 14.

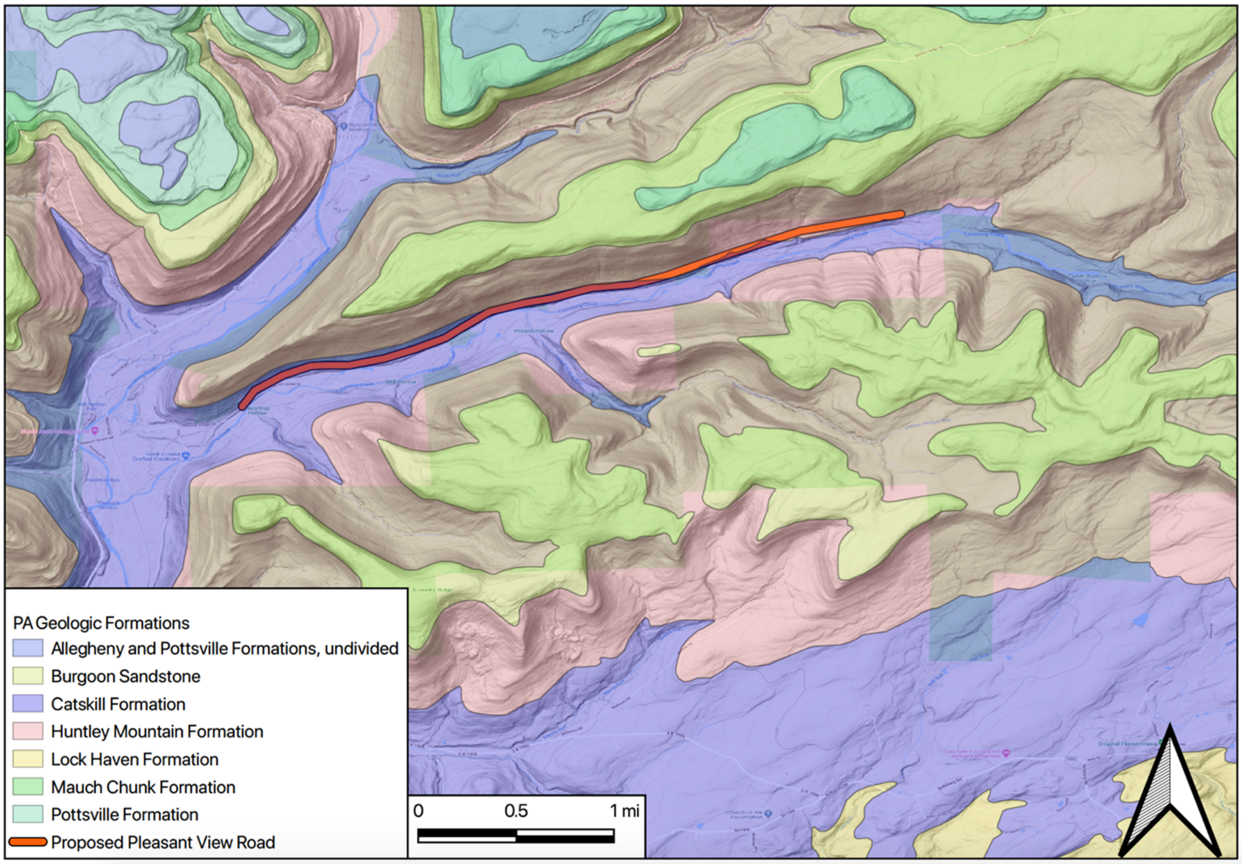


Figure 14: Geologic map of the project location at Loyalsock State Forest in Lycoming County, Pennsylvania

3.3: Problem Statement

Landslide mechanisms and variability in North-central Pennsylvania are not well established. Outdoor tourism in the region continues to grow. Thus, there is an expectation that infrastructure needs will continue to grow in the region. Outdoor recreation roads at state parks and forests within the region are a significant priority. Case studies and further investigations into landslides and landslide remediation methodology within north-central Pennsylvania will benefit future engineering design, particularly concerning remediations associated with the PA DCNR state park and forest locations in the region. For remediation along these low-volume roads, unique engineering solutions may be required to suit each project's criterion. A review of innovative and relatively low-cost engineering design solutions will assist future engineering design for low-volume roads in the region.

3.4: Spatial Review of Topography in North-Central Pennsylvania

In order to better understand the topographic setting of the landslides, Digital Elevation Models (DEMs) were obtained from the Pennsylvania Spatial Data Access portal (PASDA). These DEM datasets were generated in 2006 across Pennsylvania utilizing LIDAR and have been found accurate to 37 cm in forested areas (PASDA, 2006). DEM Data is provided in tile sets across Pennsylvania. The applicable tile sets for each project location are provided in Table 9.

Table 9: DEM tile sets for project locations

Location	DEM Tile Set
Worlds End State Park	48002280, 48002290
Loyalsock State Forest	48002180, 48002190, 48002200, 48002290, 49002180, 49002190, 49002200

Slope calculations were performed in a Geographic Information System (GIS) program on the DEM data, and the results were overlain on the white to black DEM at 30% transparency to generate Figure 15 and Figure 16.

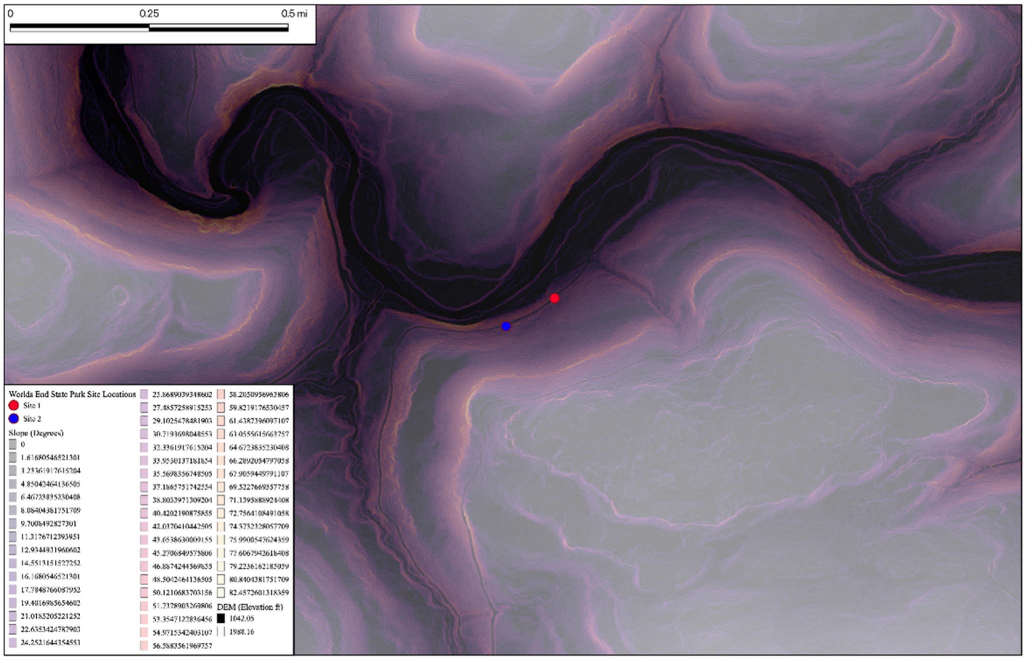


Figure 15: Visualization of slope variance at Worlds End State Park

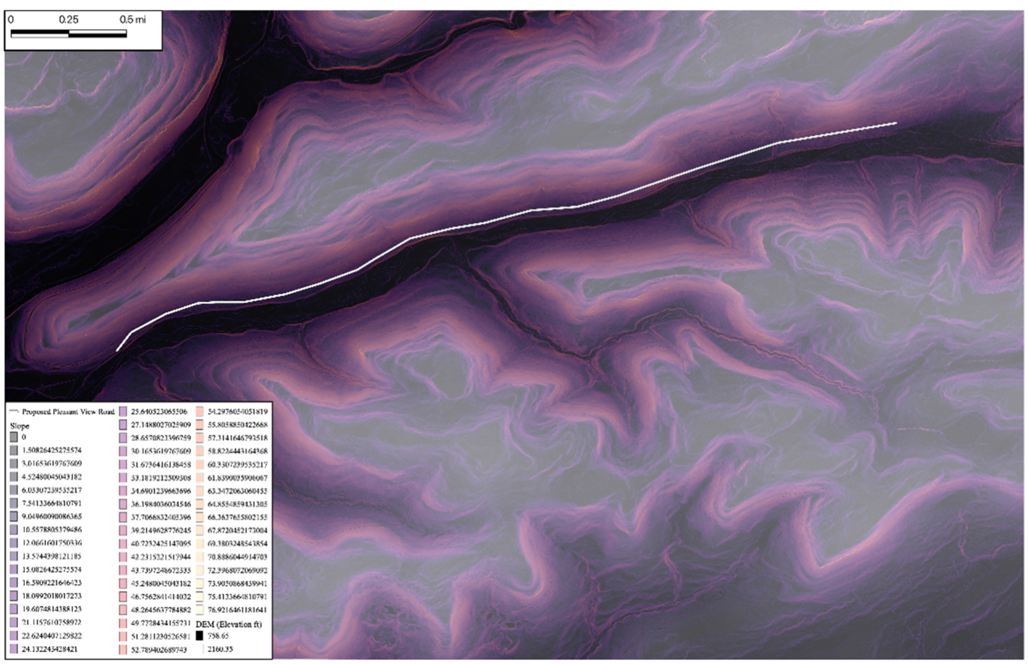


Figure 16: Visualization of slope variance at Loyalsock State Forest

The overlaying of slope maps over DEM maps can allow a user to see problematic high-slope regions and search for patterns of high and low slopes that may be related to slope scarps along hillsides. From a cursory inspection of the maps, it is evident that landslides could be occurring along most of the valley walls at each project location.

To quantify the extent of the state parks and forests within Northern Pennsylvania, GIS Shapefiles were obtained from the PASDA portal, which delineate these regions' bounds (Figure 17).n`

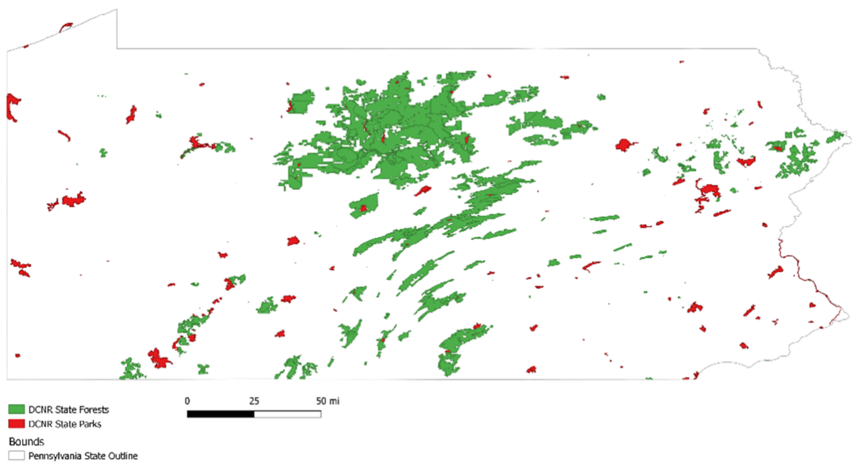


Figure 17: View of DCNR state forest and park land in Pennsylvania

Areas were calculated in square miles for the DCNR State Forests and State Parks, which resulted in approximately 465 square miles of DCNR State Park land and 3,446 square miles of state forestry land. These shapefiles were then merged and extracted by applicable counties to obtain measurements of state lands within the two counties of interest – Lycoming and Sullivan County (Figure 18).

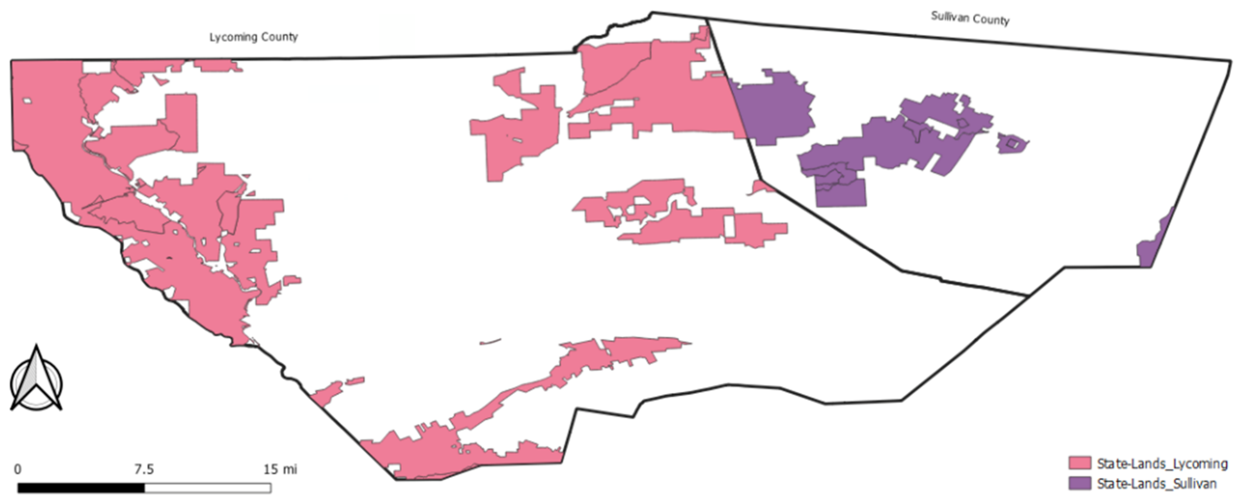


Figure 18: View of state park and forest land within Lycoming County and Sullivan County

Table 10: Area of state park and forest land by County

County	**Area of County (mi²**	**Area of State Lands (mi²)**	**Percent of County Area (%)**
Lycoming	1657.8	320.4	19.3
Sullivan	604.0	69.0	11.4

DEM datasets were obtained for each County and the slope degree calculation was run for each, as shown in Figure 19 and Figure 20.

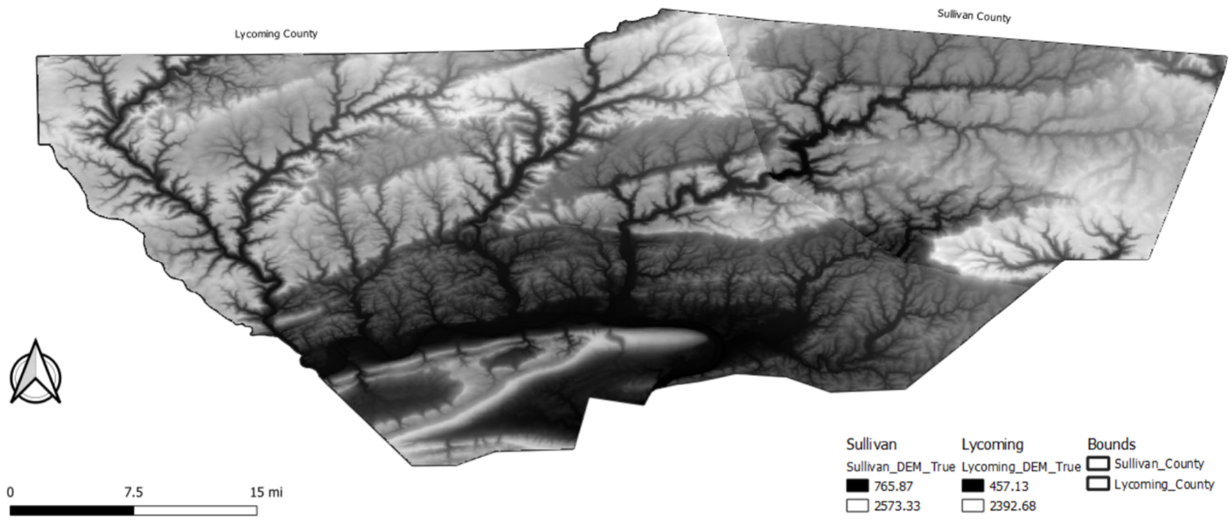


Figure 19: DEM datasets for Lycoming County and Sullivan County

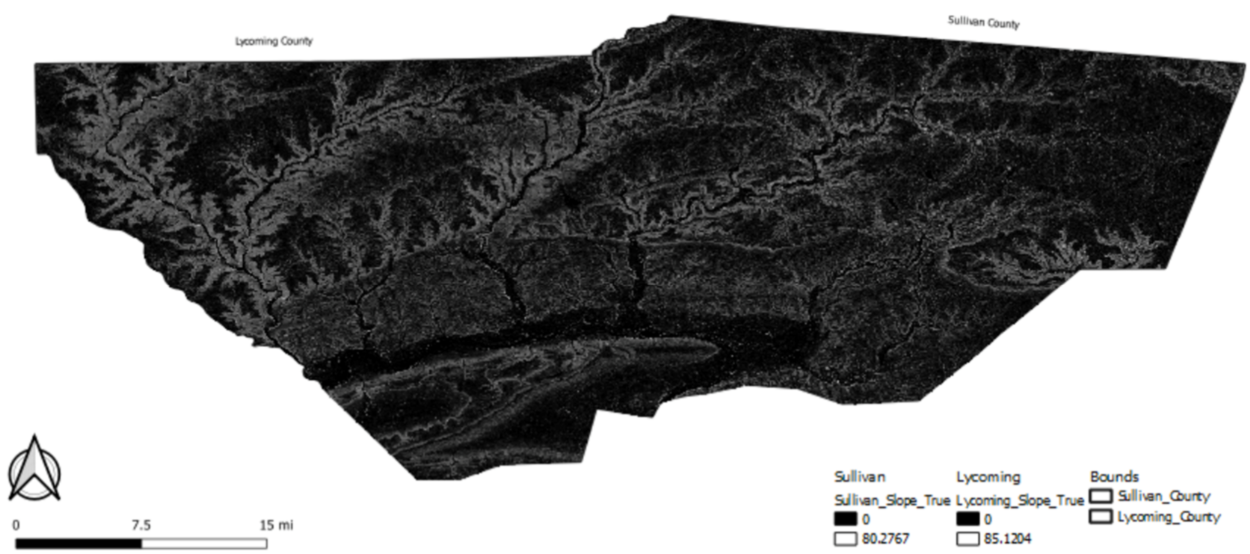


Figure 20: Slope datasets for Lycoming County and Sullivan County

GIS raster layers attribute 3.2' by 3.2' pixels values. In the case of a slope map, each pixel has a specified degree. The distribution of pixel degree values for Lycoming and Sullivan County are provided in Figure 21 and Figure 22.

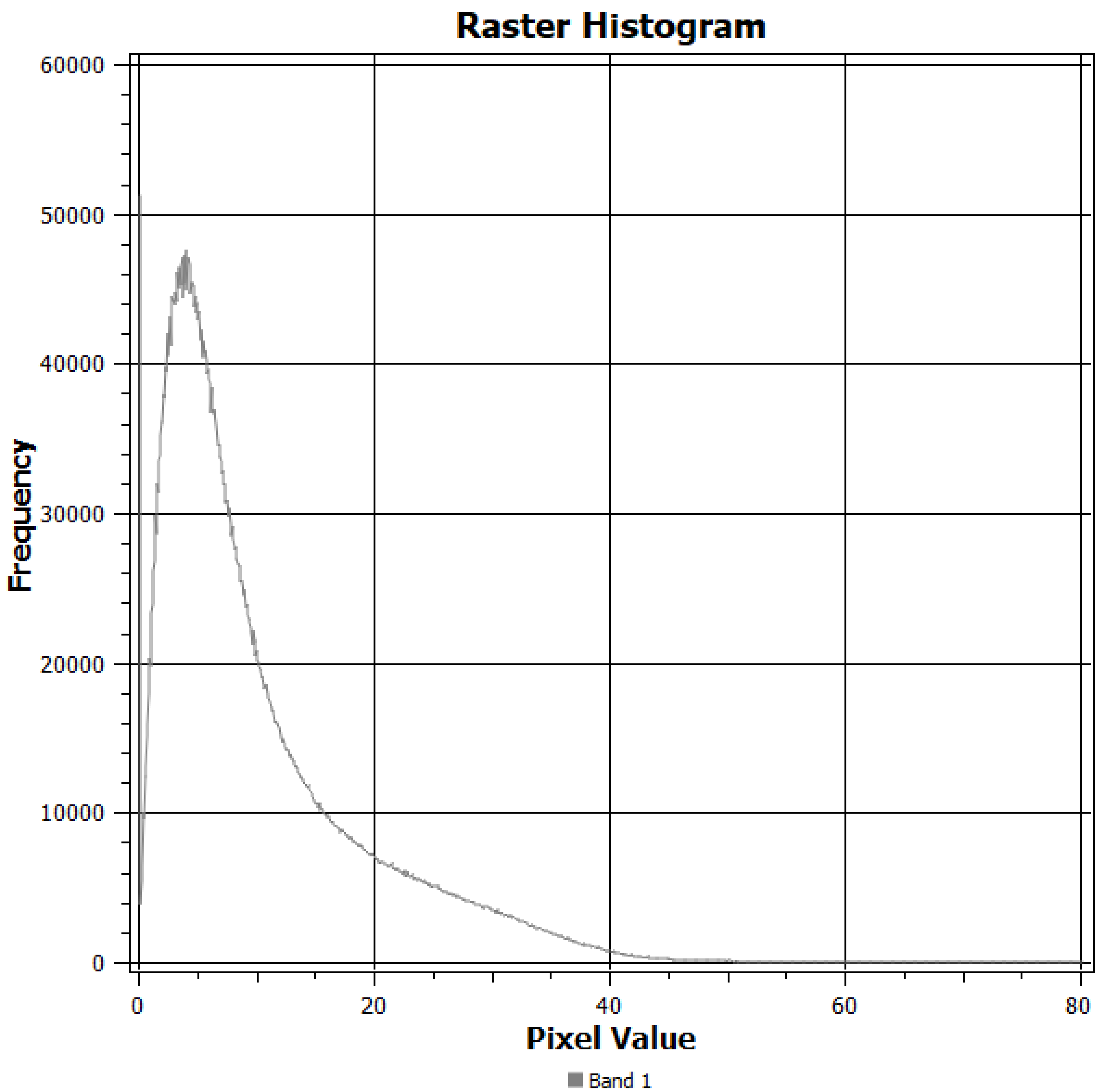


Figure 21: Histogram of slope degree frequency in Sullivan County

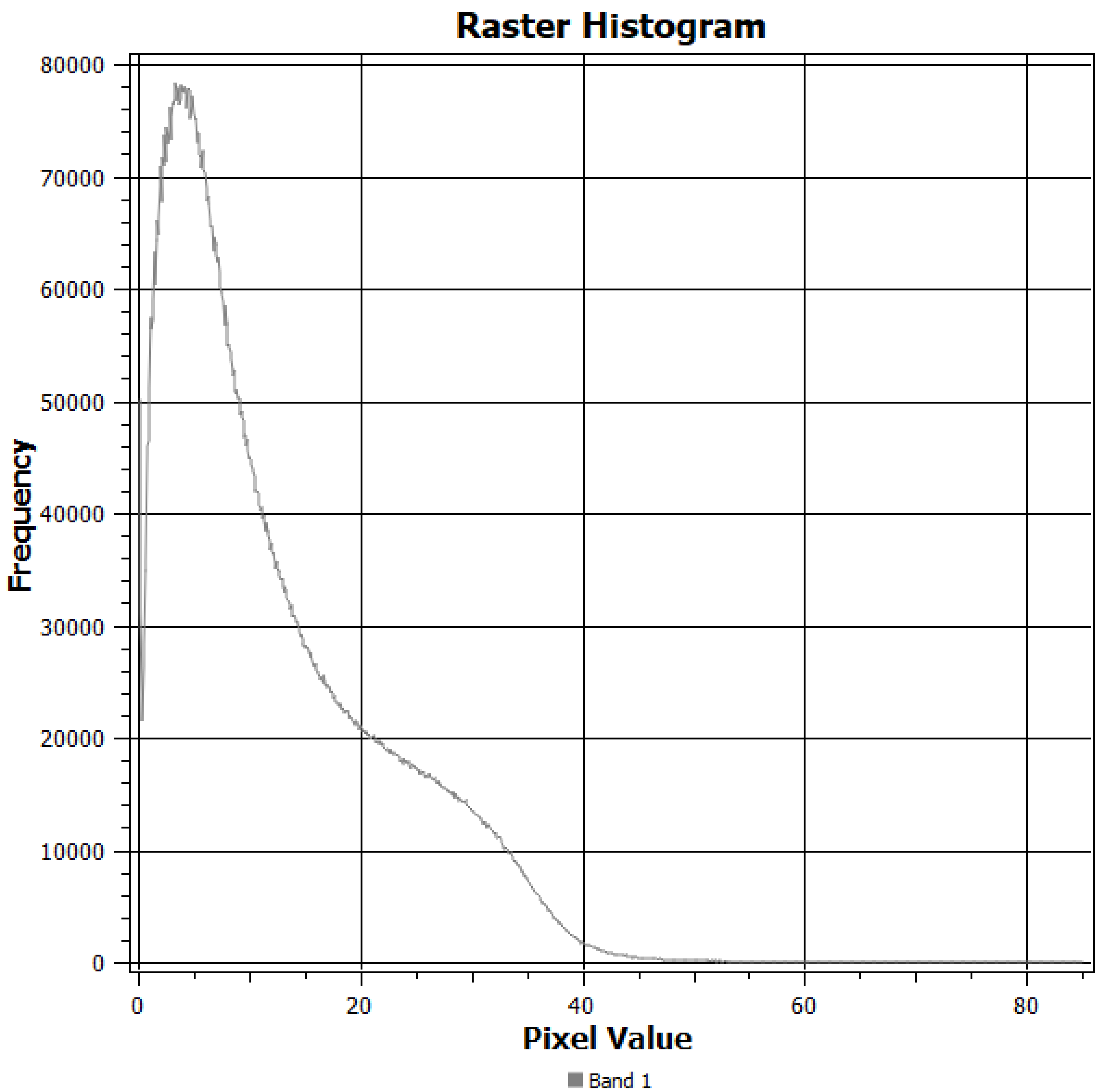


Figure 22: Histogram of slope degree frequency in Lycoming County

As slopes with degrees of steepness greater than 20 degrees can be reasonably expected to be higher risk, it was decided to extract and ignore pixels with slope degree values less than 20. This is done in GIS with the raster calculator tool by setting pixels with a slope degree value greater than or equal to 20 as 1 and pixels with a slope degree value less than 20 as 0. This formula for the two respective slope datasets is as follows:

$\big((\text{Sullivan\_Slope\_True@1} < 20) * 0\big) + (("Sullivan\_Slope\_True@1" >= 20) * 1)$

$((\text{Lycoming\_Slope\_True@1} < 20) * 0) + ((\text{"}Lycoming\_Slope\_True@1\text{"} >= 20) * 1)$

Where Sullivan_Slope_True is the name of the Sullivan County slope raster and Lycoming_Slope_True is the name of the Lycoming County slope raster. The result of the raster calculator expression is shown in Figure 23. The spatial coverage of these potential risk areas is provided in Table 11.

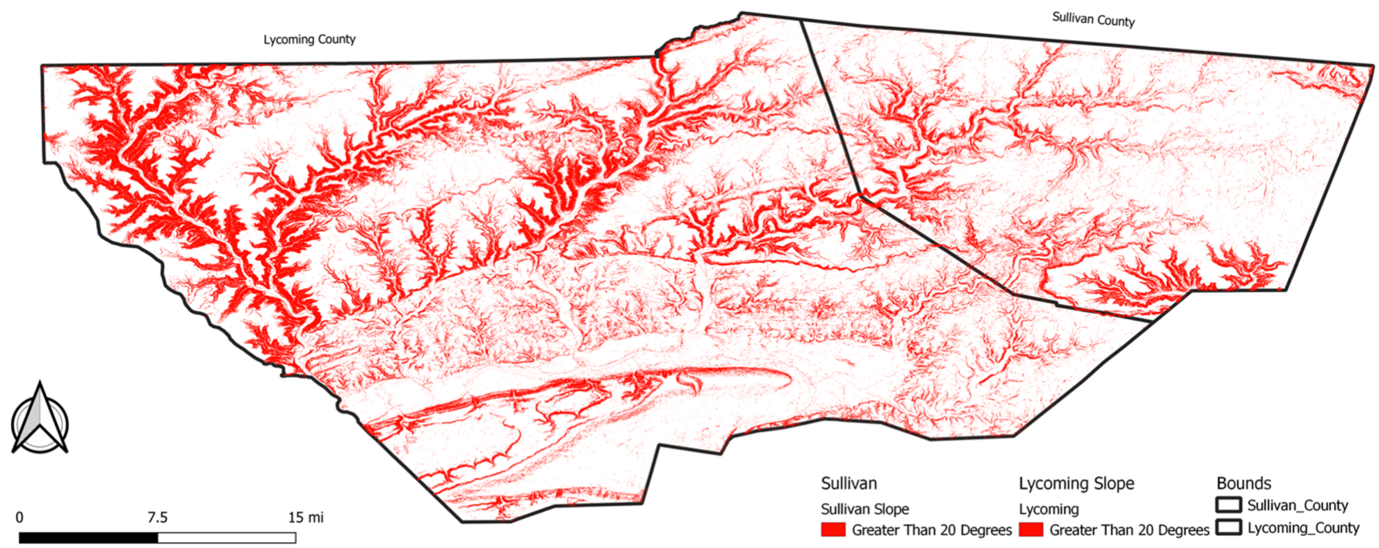


Figure 23: Pixels with a slope degree value greater than or equal to 20 degrees within Lycoming County and Sullivan County

Table 11: Tabulation of pixel area for pixels with a slope degree value greater than 20

County	Area of County (mi^2)	Area of Pixels with Slope Degree Value Greater than 20 (mi^2)	Percent of County Area (%)
Lycoming	1657.8	975.8	58.9
Sullivan	604.0	64.0	10.6

The calculated risk areas within these two counties were then compared to the PA DCNR State Lands vector files, which resulted in a spatial view of pixels with a slope degree value greater than

20 within PA DCNR State Lands in Sullivan and Lycoming County. This resultant map is shown in Figure 24, and the corresponding spatial coverage is tabulated in Table 12.

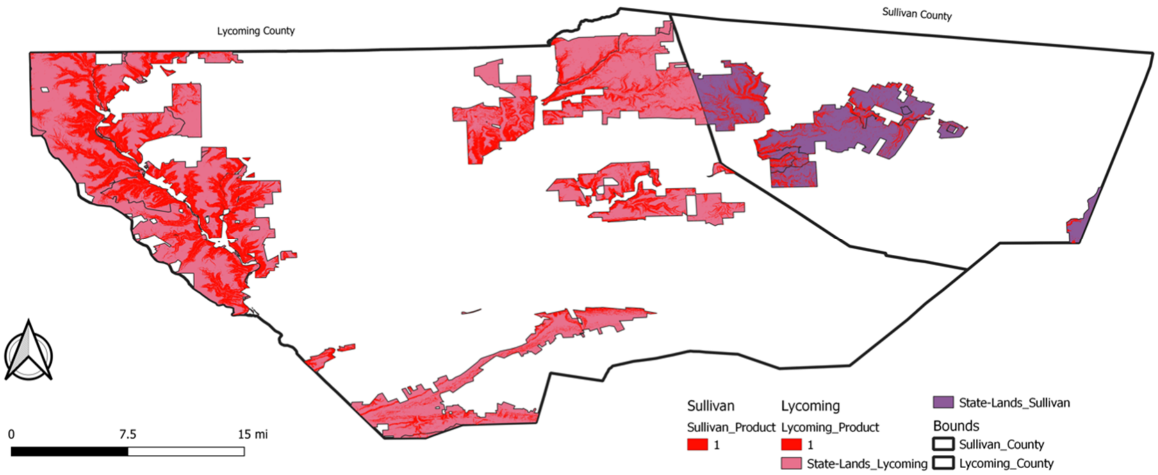


Figure 24: View of pixels with a slope degree value greater than 20 degrees within PA DCNR state park and forest land

Table 12: Tabulation of pixel area for pixels in PA DCNR state park and forest land with slope degree values greater than 20

County	**Area of County (mi^2)**	**Area of State Lands (mi^2)**	**Area of Pixels with Slope Degree Value Greater than 20 (mi^2)**	**Percent of County Area (%)**	**Percent of State Land Area (%)**
Lycoming	1657.8	320.4	104.5	6.3	32.6
Sullivan	604.0	69.0	13.6	2.2	19.7

3.5: Subsurface Investigation

3.5.1: Worlds End State Park Subsurface Investigation

Five (5) borings were drilled and inspected by N&W personnel between August 14th and August 15th of 2019 to evaluate the subsurface conditions in support of the proposed remediation at the two Sites. Site 1 was defined by B-1 and B-2, which were performed at the top of the roadway. Site 2 was defined by B-3, B-4 and B-5. B-3 and B-4 were performed from the top of the roadway, and B-5 was performed at the base of the slope, to characterize the cross-sectional changes in the subsurface. Continuous Standard Penetration Testing (SPT) and wireline rock coring were performed in all borings.

Soil at Site 1 was generally characterized by three consistent soil layers, followed by bedrock. Layer 1 was sampled from ground surface to 4.0' and 8.5' below ground surface (bgs) in borings B-1 and B2, respectively, and consisted of loose to very dense sandy gravel (fill / A-1-b / GM). Layer 2 was encountered until 10.0' and 12.9' bgs, and consisted of dense to very dense sandy gravel (residuum / a-2-4 / gm). Layer 3 was encountered until 12.1' and 16.0' bgs and was described as Mechanically Broken Rock (MBR). Silty sandstone and sandy siltstone were then encountered and cored until the borings were terminated at 22.0' and 26.0' for B-1 and B-2, respectively. Bedrock was generally described as being soft to medium hard, weathered, and exhibiting open fractures with shallow to sheer dip at close to moderate spacing. Bedding orientation was described as flat.

Soils at Site 2 were heterogenous, but consistent with the soil examined during the field reconnaissance. At the initial reconnaissance, N&W personnel inspected the failure plane of the landslide and identified the local soils along the landslide as sandy gravel with large sections of silt. The boring program confirmed that these layers are most likely laterally continuous towards the roadway. Boring B-3 encountered medium dense to very dense sandy gravel (fill, A-1-b / GM) to 6.0' bgs, followed by MBR until bedrock was encountered at 10.0' bgs and cored to 20.0' bgs. Boring B-4 encountered medium dense to dense gravelly, sandy silt (fill / A-4 / SM) to 5.5' bgs, followed by very dense sandy gravel (residuum / a-2-4 / gm) until bedrock was encountered at

12.0’ bgs and cored to 22.0’ bgs. Boring B-5 was performed downslope from the slide to evaluate the cross-sectional change in subsurface layers across the project slope, and consisted of very loose to very dense gravel (colluvium / A-1-a / GM) until 17.0’ bgs, followed by a thin medium dense sand (alluvium / a-1-b / sm) until 19.5’ bgs, followed by MBR until bedrock was encountered at 20.1’ bgs.

Long-term (>24-hours) groundwater readings were obtained from B-1, B-3, and B-4, and conclusions were drawn as to the typical groundwater level at each of the Sites. Site 1 has an average groundwater elevation of 1192.8’, and Site 2 has an average groundwater elevation of 1221.3’ at the top of the slope and 1122.7’ at the bottom of the slope.

3.5.2: Loyalsock State Forest Subsurface Investigation

Four (4) roadway borings and two (2) structure borings, designated B-1 through B-6, were drilled and inspected by N&W personnel between July 2nd and July 3rd of 2019 to evaluate the subsurface conditions in support of the proposed roadway. SPT and wireline rock coring were performed in the borings.

Soil from Borings B-1 through B-3 were described as residuum, consisting of medium dense to very dense gravel, some sand, little silt, and trace clay, until sandstone bedrock was encountered between 12.1 and 12.6 feet below ground surface (bgs). Soil from Boring B-4 was described as very dense fill, consisting of cobbles and gravel to 4.7 feet bgs, followed by cobbles and boulders until sandstone bedrock was encountered at 9.2 feet bgs. Soil from Boring B-5 was described as medium dense to dense fill, consisting of gravel, some sand, trace silt and trace clay to 8.0 feet bgs, followed by very dense alluvium, consisting of gravel, some sand, trace silt and trace clay to 26.0 feet bgs. Soil from Boring B-6 was described as loose to dense fill, consisting of gravel, some sand, trace silt and trace clay to 16.5 feet bgs, followed by very dense alluvium, consisting of boulders and cobbles, some gravel, and trace silt to 25.0 feet bgs. Sandstone bedrock was generally described as being medium hard and thinly bedded with flat to shallow dip. All borings encountered small (<1/2”) soil or clay seams in the bedrock. Overall bedrock recovery was 95% and overall RQD was 48%.

Long-term (>24-hours) groundwater readings were obtained from B-5 and were found to be approximately 20.2 feet bgs. Short-term groundwater readings averaged 12.5 feet bgs.

3.6: Laboratory Testing

3.6.1: Worlds End State Park Laboratory Testing

Representative soil samples collected from Borings B-2, B-3, B-4, and B-5 were tested to verify field descriptions, determine gradation, Atterberg limits, natural moisture content, and unit weight. A bulk soil sample from B-6 was tested for soil corrosion potential. Rock core samples from B-1 and B-4 were tested for unconfined compressive strength. The laboratory soil test results are provided in Table 13, and the laboratory rock test results are provided in Table 14.

Table 13: Summary of laboratory soil testing at Worlds End State Park

Boring	Sample	Depth (ft)	Laboratory Test	Moisture (%)	USCS	Soil Unit Weight (pcf)
B-2	S-1 to S-4	0 – 8.0	USCS / Moisture (%)	9.7	GM	*NT
B-2	S-1	0 – 2.0	Soil Unit Weight	*NT	*NT	106.6
B-3	S-1 to S-3	0 – 6.0	USCS / Moisture (%)	6.1	GM	*NT
B-4	S-1 to S-2	0 – 4.0	USCS / Moisture (%)	9.8	SM	*NT
B-5	S-2 to S-8	2.0 – 14.4	USCS / Moisture (%)	10.1	GM	*NT
B-5	S-5	8.0 – 10.0	Soil Unit Weight	*NT	*NT	122.1

*NT – Soil test was not performed on sample

Table 14: Summary of laboratory rock testing at Worlds End State Park

Boring	Sample	Depth (ft)	Rock Type	Unconfined Compressive Strength (tsf)
B-1	R-1	12.1 – 14.5	Silty Sandstone	741.0
B-4	R-1	12.0 – 14.0	Sandstone	825.1

3.6.2: Loyalsock State Forest Laboratory Testing

Representative soil samples collected from Borings B-1, B-2, B-3, B-5, and B-6 were tested to verify field descriptions, determine pertinent engineering characteristics, and determine gradation, Atterberg limits, natural moisture content, specific gravity, and corrosion potential. Due to the limited quantity of material obtained, a compoSite sample from B-1, B-2, and B-3 was used for a direct shear soil test to obtain soil strength parameters. A bulk soil sample from B-6 was tested for corrosion potential. Rock core samples from B-2 and B-3 were tested for unconfined compressive strength. The laboratory soil test results are provided in Table 15.

Table 15: Summary of laboratory soil testing at Loyalsock State Forest

Boring	**Sample**	**Depth (ft)**	**Moisture (%)**	**USCS**	**Friction Angle (°)**
B-1	S-2 to S-7	2.0 – 12.6	7.3	SM	*NT
B-2	S-2 to S-7	2.0 – 12.4	7.7	SM	*NT
B-3	S-2 to S-6	2.0 – 11.7	7.8	GM	*NT
B-5	S-2 to S-4	2.0 – 8.0	8.8	GP-GM	*NT
B-5	S-5 to S-13	8.0 – 26.0	8.4	GM	*NT
B-6	S-2 to S-8	2.0 – 16.0	7.1	GW-GM	*NT
B-1 / B-2 / B-3	Composite Sample of Similar Materials	2.0 – 12.6	*NT	*NT	32.6

*NT – Soil test was not performed on sample

Section 4: Results

4.1: Review of Investigation

Two landslide remediation design projects with the DCNR were chosen as case studies to be evaluated in north-central Pennsylvania. Existing literature on landslides and forest roads in north-central Pennsylvania was evaluated and compared to the chosen DCNR projects. Structure selection and design methodology for geotechnical design were reviewed. The topography, geology, and spatial data for each Site were considered. Next, the final design recommendations will be reviewed.

4.2: Worlds End State Park Design

The PA DCNR, through Larson Design Group, requested a solution from N&W at Site 1 along Mineral Springs Road that could be cost-effective, aesthetically pleasing to park attendees, and constructed from the top of Mineral Springs Road (to avoid wetlands at the bottom of the slope).

The requested goals at Site 2 along Mineral Springs Road were to maintain the park's aesthetic and provide a long-term solution to the many landslides along the slope. The slope was significantly steeper and taller than the slope at Site 1, however, there were no access restrictions at the base of the slope.

The calculation package with design parameters and methodology associated with the Worlds End State Park Geotechnical Engineering Report (GER) provided by N&W is included in Appendix D.

4.2.1: Rockery Wall at Site 1

To meet the project requirements, N&W proposed a 12.0' high and 32.0' long rockery wall, with a 6.0' embedment and a 36" chinked steel pipe to manage drainage along the roadway.

Design soil and rock parameters were based upon the subsurface exploration and laboratory testing program results and established publications on reasonable correlations of design values. Based upon the NAVFAC DM 7.01 correlations (NAVFAC, 1986) between SPT blow counts and angles of internal friction and dry unit weight, the design friction angle is 36 degrees. As obtained from lab testing results, the dry unit weight is 106.6 pcf. Based on the tested natural moisture content of 10.6%, the approximate design moist unit weight of soil is 125 pcf. The selected friction factor between the rockery and the bedrock bearing stratum was 0.6, as directed by the FHWA Rockery Design and Construction publication for a rockery bearing on bedrock. An additional surcharge load of 240 psf was assumed to act on the rockery due to the overlying roadway. The stone's unit weight was conservatively assumed to be 145 pcf instead of the FHWA recommended 150 pcf. This was done because the local rock that will likely be used for the rockery is sandstone and siltstone, which may have a slightly lower unit weight (Gillette, 1918). Passive resistance was utilized in overturning design, but a provision was included in the design documents that an additional base stone be placed in front of the original base stone to engage passive resistance. Based on the equations in Section 2.4, the following parameters in Table 16 were obtained.

Table 16: Tabulation of calculated pressures and moments associated with the rockery wall at Worlds End State Park

Parameter	Description	Value
K_a (dim)	Active Earth Pressure Coefficient	0.14
F_H (lb)	Horizontal Force on Back of Rockery	3367
F_μ (lb)	Friction Force Resisting Lateral Pressures	8804
K_P (dim)	Passive Earth Pressure Coefficient	2.6
F_P (lb)	Passive Resisting Force at Toe	4001
M_O (lb-ft)	Overturning Moment about Toe	21,988
M_r (lb-ft)	Resisting Moment about Toe of Rockery	50856
q_{max} (psf)	Maximum Bearing Pressure	4970
q_a (psf)	Allowable Bearing Capacity for a Factor of Safety of 3.0	15,193

Global stability was evaluated with RocScience SLIDE 8.0. Based on the design methodology in 2.4 and the proposed dimensions of the rockery, the following factors of safety in

Table 17 were achieved. The results of the RocScience SLIDE 8.0 analysis are provided in Figure 25.

Table 17: Values for factor of safety and their associated failure condition at the rockery wall at Worlds End State Park

Parameter	Factor of Safety
Sliding	3.8
Overturning	2.3
Internal Overturning	5.8
Bearing Capacity	3.0
RS SLIDE Global Stability (Bishop / Janbu)	1.4 / 1.3

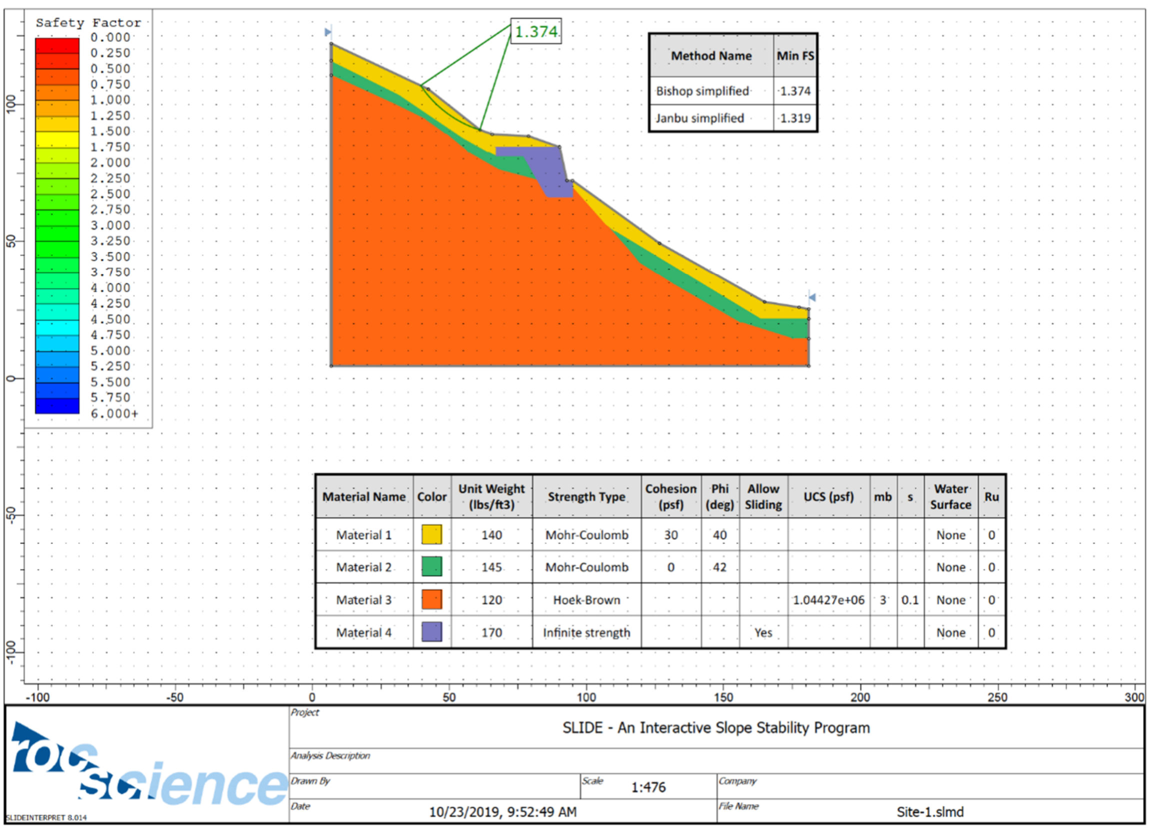


Figure 25: RocScience SLIDE 8.0 Analysis of global stability of rockery wall at Worlds End State Park

4.2.2: Slope Stability at Site 2

Due to the significant height and degree of steepness increase at Site 2, it was determined that a rockery wall would not be feasible. Additionally, the slope's height and steepness was such that an alternative retaining wall would be cost-prohibitive. Thusly, it was decided to bench rock at various grades not to exceed 1.5 (H) : 1.0 (V) with 4.0' minimum lift widths and implement a rock key at the base of the slope, as shown in Figure 26. This slope detail was verified with RocScience SLIDE 8.0, as shown in Figure 27.

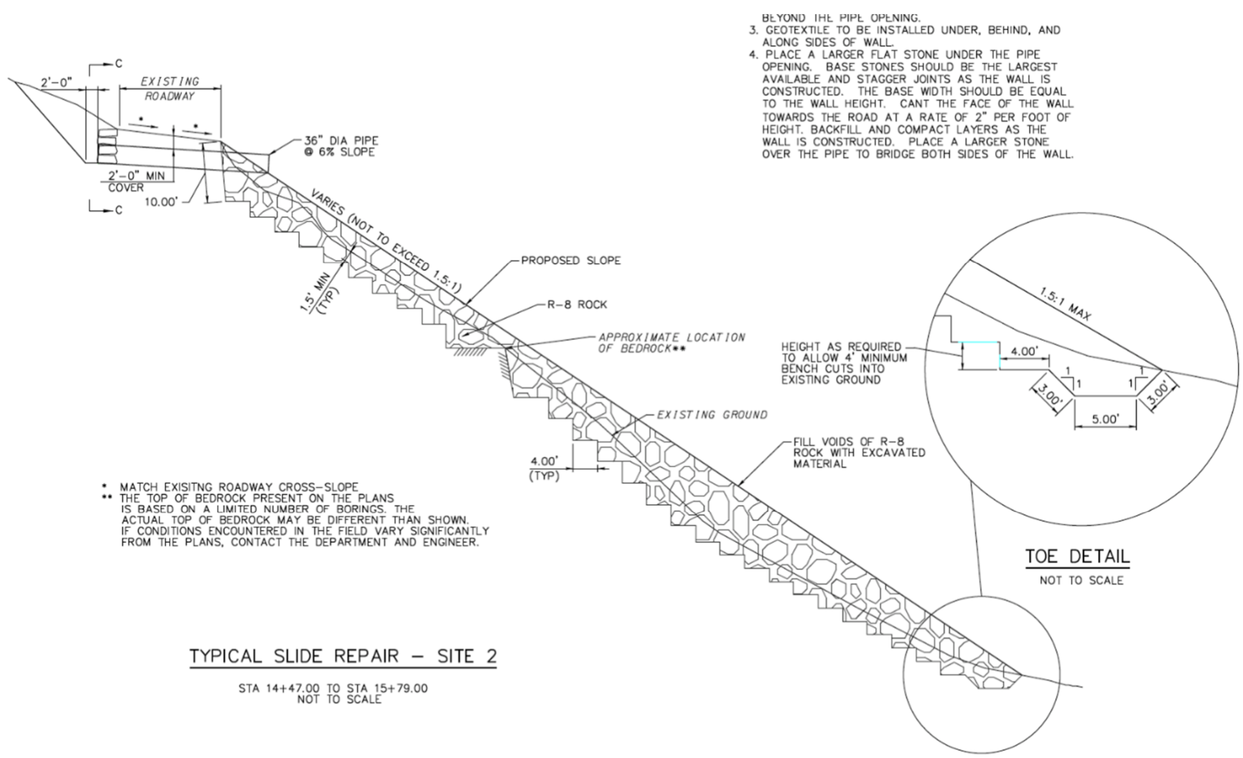


Figure 26: Rip-rap benching detail for landslide remediation at Site 2 at Worlds End State Park

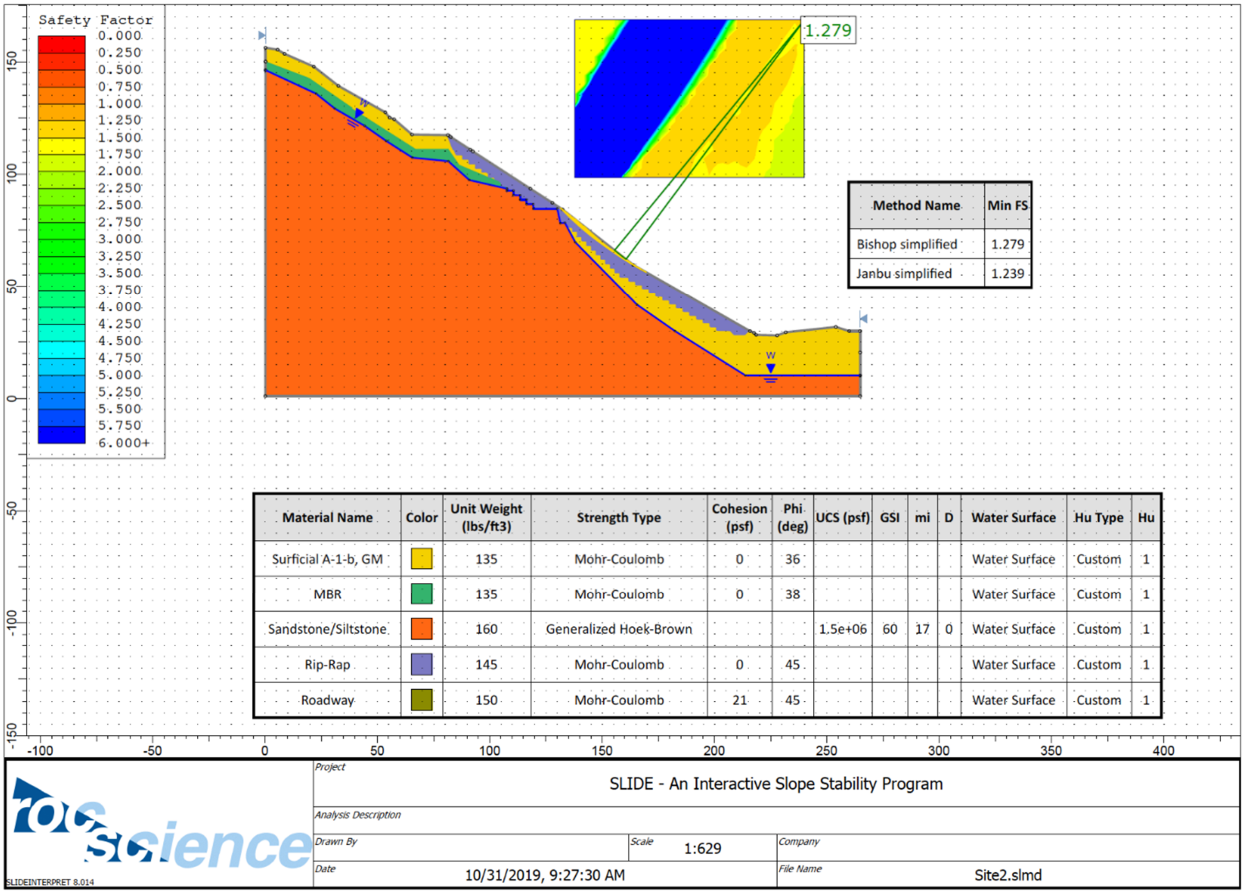


Figure 27: RocScience SLIDE 8.0 global stability analysis of rip-rap benching landslide remediation at Site 2 at Worlds End State park

4.3: Loyalsock State Forest Design

The PA DCNR, through Larson Design Group, contracted N&W to provide geotechnical slope recommendations along a new roadway alignment for Pleasant Stream Road along an old railroad grade.

The calculation package with design parameters and methodology associated with the Loyalsock State Forest Geotechnical Engineering Report (GER) provided by N&W is included in Appendix C.

4.3.1: Slope Stability

The proposed roadway cross-sections were reviewed and generalized into groups of stationing, based on the required slope detailing. Slope detailing was analyzed utilizing the results from the subsurface boring program and RocScience Slide 8.0 to verify a Factor of Safety above 1.25. Cuts and fills less than 4 feet in height and of insignificant width and concern were deemed to be part of grading operations and are not included in these characterizations. These groups, their stationing, range of cut/fill depth, and required detail is provided in the cut and fill tables below. Detail 1 is to be used in areas where conflict with private properties is a concern and consists of rock benching with R-8 and geogrid to create a 1.0(H) to 1.0(V) slope. Prior to implementing Detail 1, subsurface conditions must be field verified and approved by the engineer. Detail 2 is to be used in the case of fill on the downslope and consists of a key at the base of the slope and sliver fill of R-8 at a 1.5(H) to 1.0(V) slope. Detail 3 is to be utilized for steep embankment fill conditions and consists of rock, suiting the requirements of PennDOT Pub 408 Section 206.1.1.1d, benched at a 1.5(H) to 1.0(V) slope. The details and their associated SLIDE analysis are provided as Figures 28, 29, and 30. The chosen detail and extent of the detail on the project is tabulated in Table 18 and Table 19.

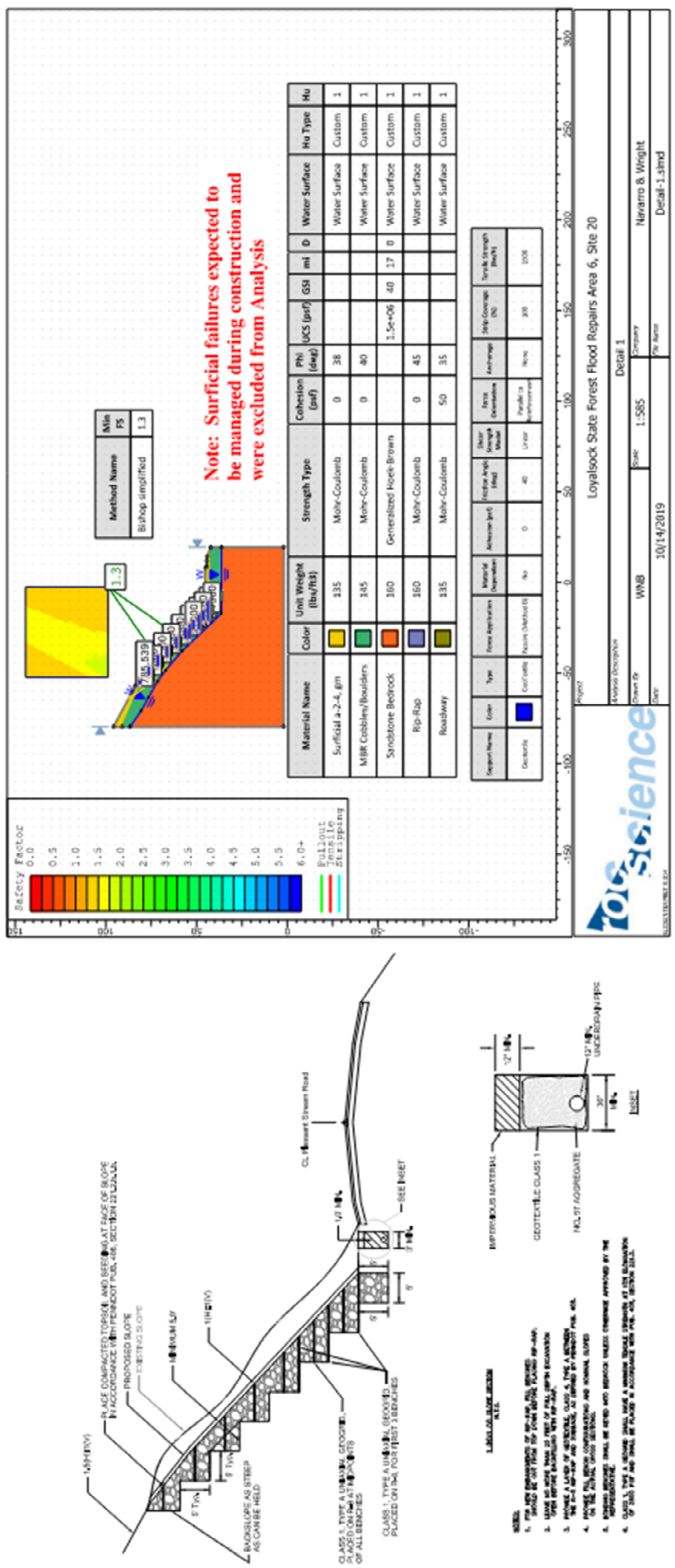
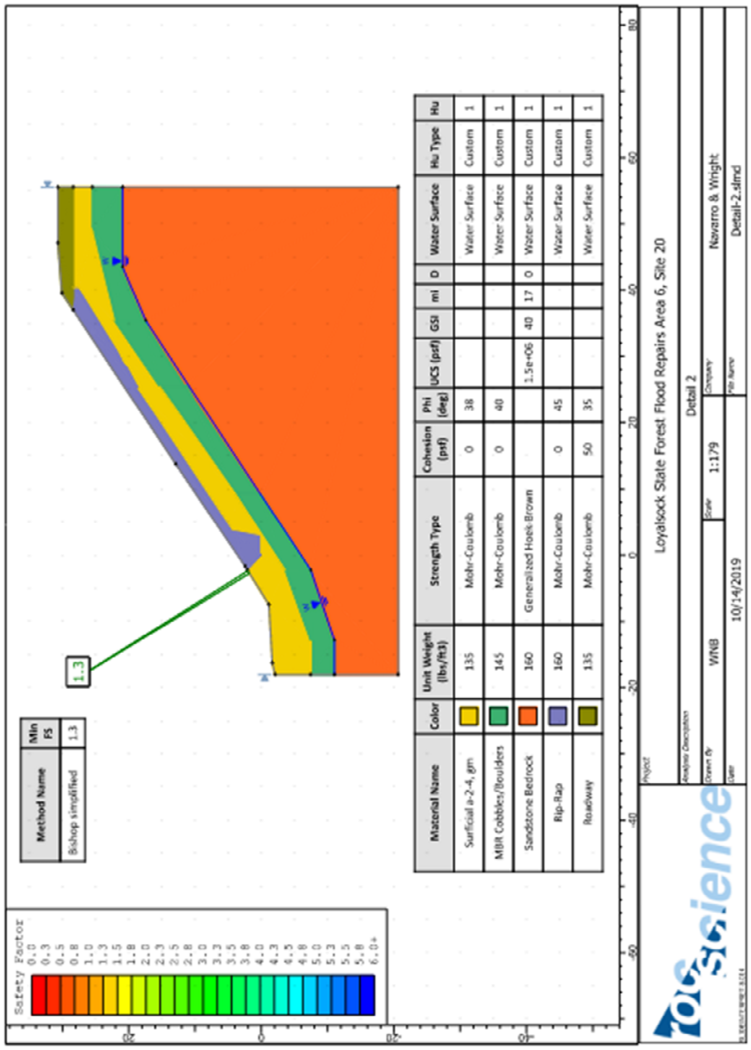


Figure 28: RocScience SLIDE 8.0 global stability evaluation of Detail 1 and Detail 1



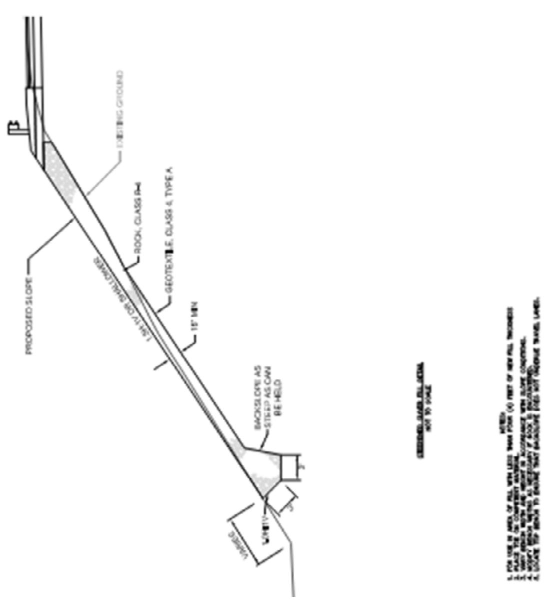


Figure 29: RocScience SLIDE 8.0 global stability evaluation of Detail 2 and Detail 2

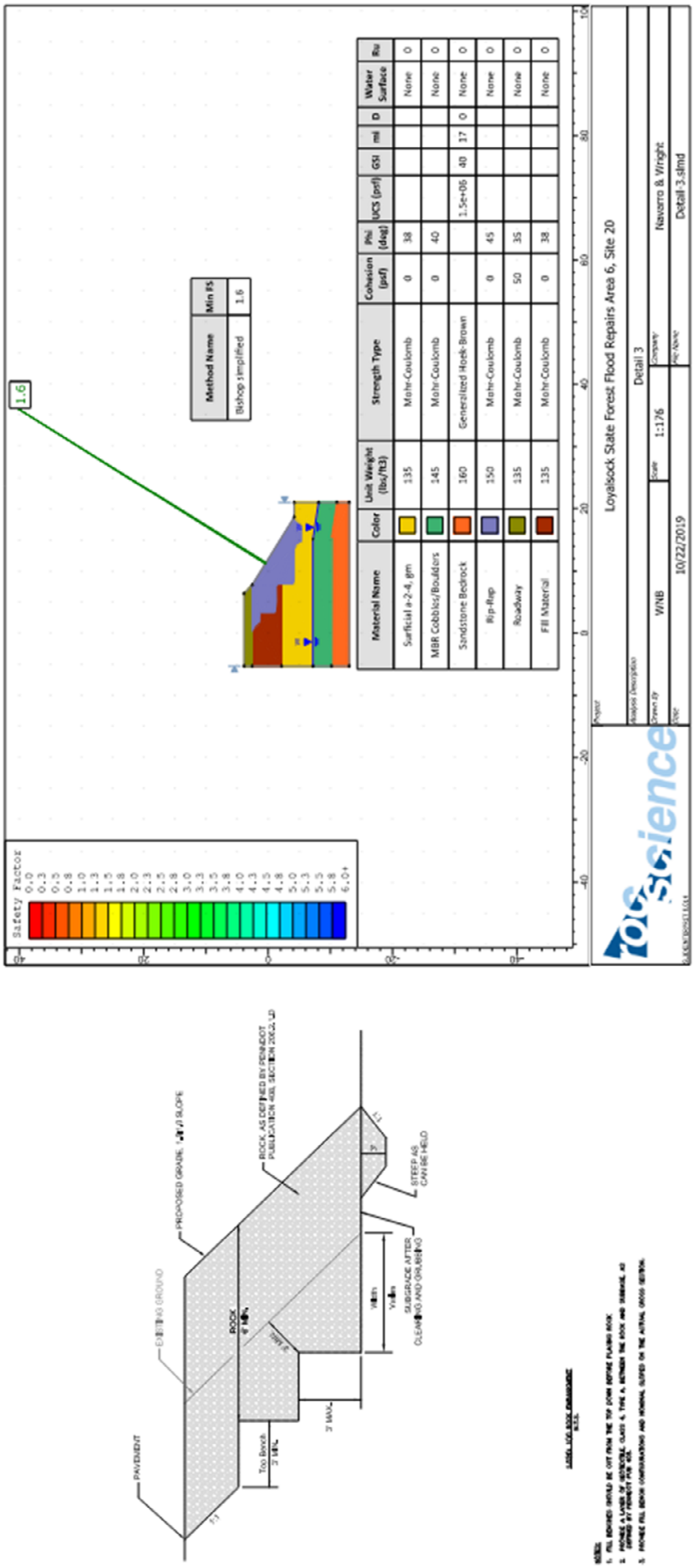


Figure 30: RocScience SLIDE 8.0 global stability evaluation of Detail 3 and Detail 3

Table 18: Proposed cut slope remediation type and extent

Approximate Station to Station Limits (ft)	Offset	Max Vertical Cut Distance from Existing to Proposed Groundline (ft)	Slope	Construction Detail
81+00 to 91+00	Left	15	1.0 (H):1.0 (V)	1

Table 19: Proposed fill slope remediation type and extent

Approximate Station to Station Limits (ft)	Offset	Max Vertical Fill Distance from Existing to Proposed Groundline (ft)	Slope	Construction Detail
58+00	Left and Right	3	1.5 (H):1.0 (V)	3
97+00 to 104+00	Right	5	1.5 (H):1.0 (V)	2
114+00	Right	3	1.5 (H):1.0 (V)	3
135+00	Right	1	1.5 (H):1.0 (V)	3

N&W initially recommended implementing rip-rap and benching on all 1.0(H) to 1.0(V) cut slopes. This recommendation was based on N&W's professional opinion that the recommended slope treatments would increase the stability of the excavation operations and reduce the potential for unstable conditions that could lead to slope failures or landslides. After considering N&W's recommendation, the PA DCNR decided to proceed with the 1.0(H) to 1.0(V) cut slopes without any additional treatments based upon the PA DCNR's previous experience with similar projects and the potential to encounter bedrock in the area. Encountering bedrock would allow for stable bedrock cut-slopes in place of the proposed 1.0(H) to 1.0(V) soil cut slopes. The design analysis that N&W performed indicated that the proposed soil cut slope geometry will result in a factor of safety below the industry and PennDOT standard of 1.25. The PA DCNR was willing to accept total liability for the lower factor of safety, and the maintenance cost associated with fixing the roadway will likely be less than the cost associated with implementing rip-rap and geotextile across the slope.

4.4: Spatial Review of Topography Results

The methodology discussed in Section 3.4 for calculating area extent of slope degree was performed for slope degree values of 20, 25, 30, 35, 40, and 45 degrees. The results of these calculations are within Table 20.

Table 20: Tabulation of pixel area for varying slope degree values in state park and forest land in Sullivan County and Lycoming County

Slope Degree Value	Area of pixels within Lycoming State Lands (mi^2)	Percentage of Lycoming State Lands	Area of pixels within Sullivan State Lands (mi^2)	Percentage of Sullivan State Lands
20	104.5	32.62%	13.6	13.01%
25	73.96675287	23.09%	8.411598783	8.05%
30	41.8737628	13.07%	4.539574542	4.34%
35	14.18522188	4.43%	1.930267914	1.85%
40	2.920844671	0.91%	0.634013567	0.61%
45	0.757887082	0.24%	0.205731811	0.20%

4.5: Finite Element Model Results

An ABAQUS dynamic model to model the horizontal earth pressure was generated. The model's geometry is shown in Figure 31, and the mesh is shown in Figure 32.

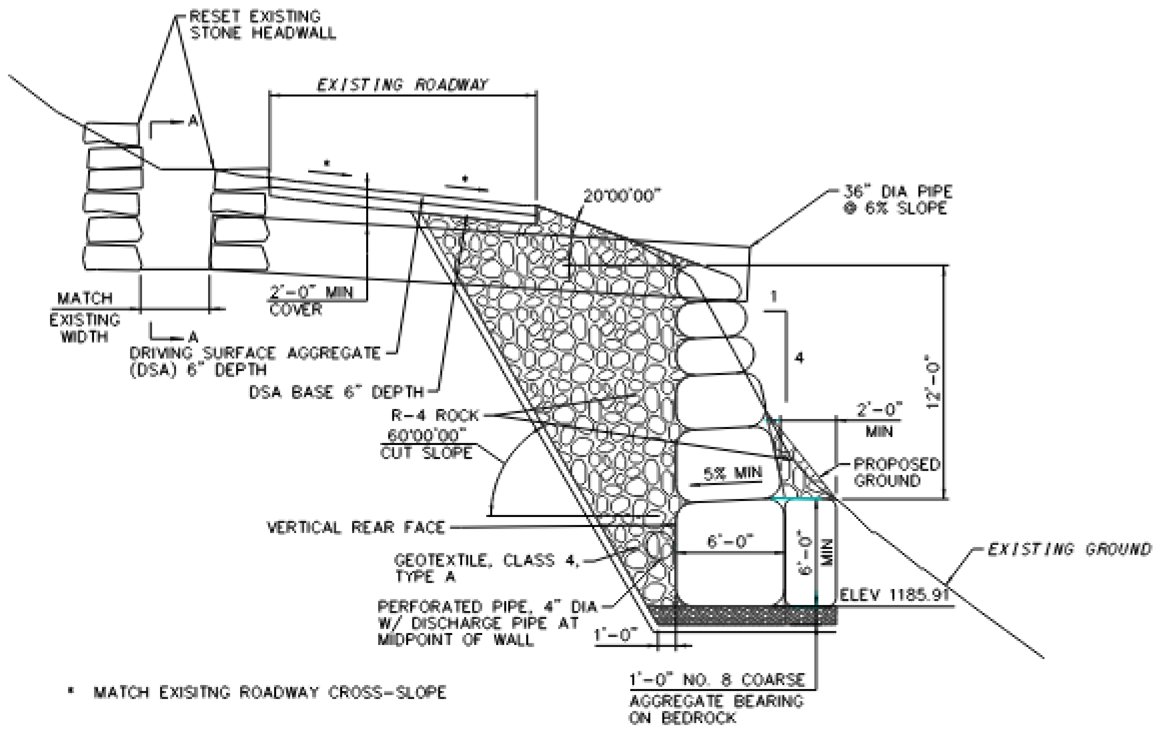


Figure 31: Geometry of the proposed rockery wall at Worlds End State Park

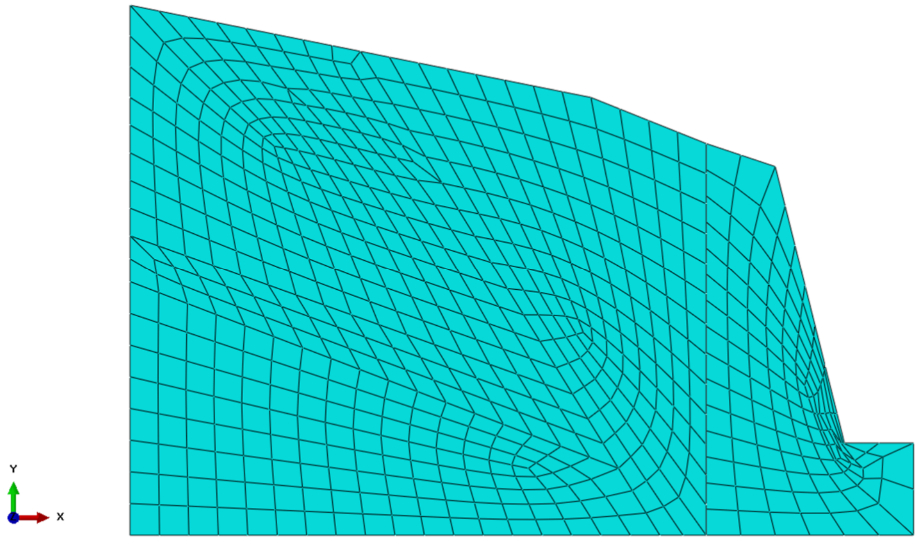


Figure 32: Distribution of ABAQUS Finite Element Model mesh for the rockery wall and soil at Worlds End State Park

The distribution of active earth pressure along the rockery-wall interaction plane is as shown in Figure 33. The tabulation of horizontal pressure (S11), force, and moment at each node is provided in Table 21 and the horizontal pressure (X) over depth (Y) is graphed in Figure 34.

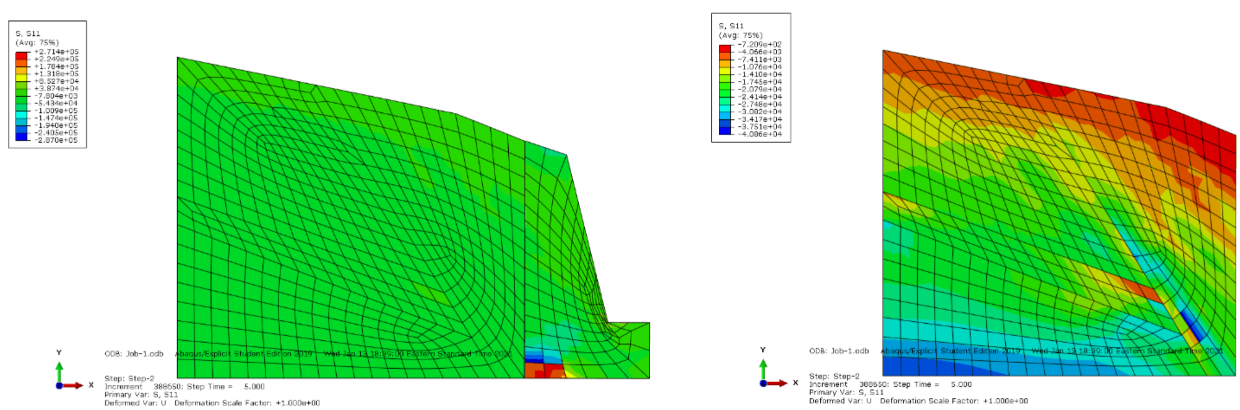


Figure 33: Lateral earth pressure (S11) distribution within the soil and rockery wall (left) and soil (right)

Table 21: Distribution of horizontal earth pressure over depth along the plane of interaction

S11 (Pa)	S11 (ksf)	Force (Kips)	Moment (kip-ft)
-967.35	-0.0202	0.0362	0.5921
-1685.41	-0.0351	0.0705	1.0606
-3479.37	-0.0726	0.1118	1.5357
-4711.18	-0.0983	0.1901	2.3624
-9214.82	-0.1924	0.2776	3.0861
-11117.8	-0.2321	0.2714	2.6623
-8760.83	-0.1829	0.2718	2.3105
-11145.5	-0.2327	0.3982	2.8643
-18018.5	-0.3763	0.5192	3.0553
-20004.3	-0.4177	0.5172	2.3675
-17876.2	-0.3733	0.4834	1.5806
-17530.3	-0.3661	0.5241	1.0282
-20856.2	-0.4355	0.6709	0.4386
-28274.6	-0.5905		
SUM:		4.3430	24.9450

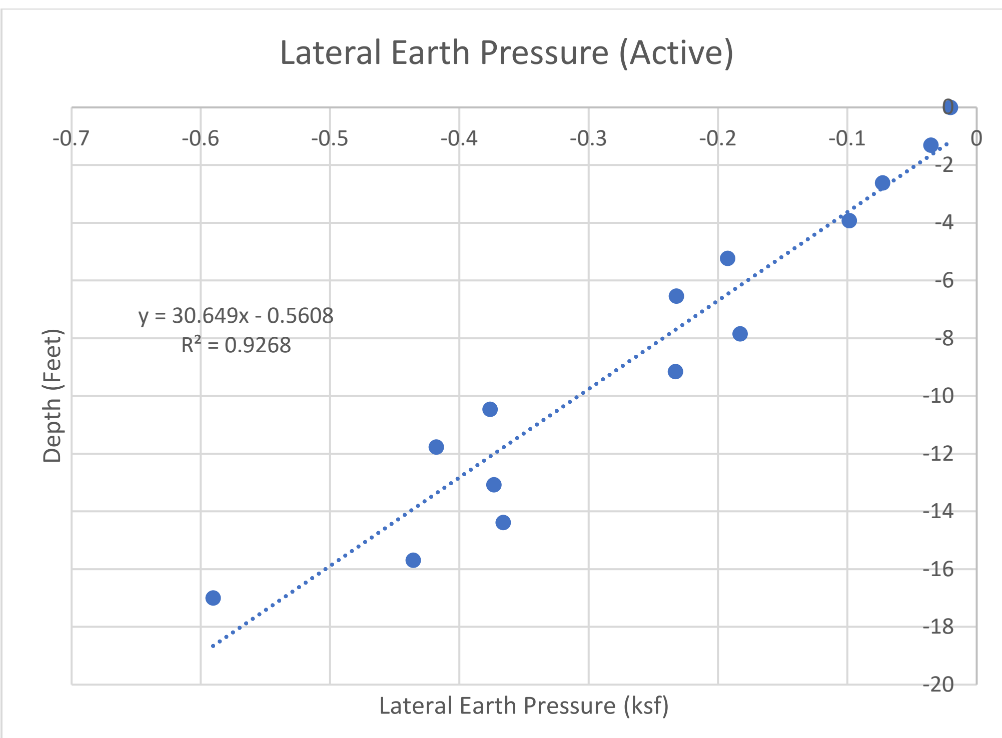


Figure 34: Graph of lateral earth pressure (S11) exerted by the soil along the interaction plane against the rockery wall, over depth

Section 5: Discussion

5.1: Design Results

In order to quantify the efficiency of design at each Site, performance ratios were calculated on all designs. The performance ratio is generally considered to be the ratio of the required factor of safety against the obtained factor of safety. In general, the closer the performance ratio is to 1.0, the more efficient the design. Performance ratios below 1.0 indicate the design does not meet the required factor of safety. Performance ratios above 1.0 indicate the design exceeds the required factor of safety, and may be overdesigned. The formula for this is provided below.

$$Performance\ Ratio = \frac{Obtained\ Factor\ of\ Safety}{Required\ Factor\ of\ Safety} \tag{18}$$

5.1.1: Design Results at Worlds End State Park

Based on the design criteria, acceptable factors of safety were obtained for the rockery wall at Site 1. The performance ratio, i.e., the obtained factor of safety divided by the required minimum factor of safety, can be a good indicator of design efficiency. The performance ratios for the rockery wall at Site 1 are provided in Table 22.

Table 22: Performance ratios for the rockery wall design at Site 1 at Worlds End State Park

Parameter	Obtained Factor of Safety	Required Factor of Safety	Performance Ratio
Sliding	3.8	1.5	2.5
Overturning	2.3	2.0	1.15
Internal Overturning	5.8	2.0	2.9
Bearing Capacity	3.0	3.0	NA
RS SLIDE Global Stability (Bishop / Janbu)	1.4 / 1.3	1.3	1.08 / 1.0

Overturning controlled the design of the structure, and thusly has the lowest performance ratio outside of global stability.

The landslide at Site 2 was remediated by rock benching and the implementation of a rock key. The performance ratio for this slope is tabulated in Table 23.

Table 23: Performance ratios for design of the slope remediation at Site 2 at Worlds End State Park

Parameter	Obtained Factor of Safety	Required Factor of Safety	Performance Ratio
RS SLIDE Global Stability (Bishop / Janbu)	1.3 / 1.3	1.3	1.0

This factor of safety and performance ratio for 1.5 (H) : 1.0 (V) slopes is typical, and generally considered to be acceptable by FHWA.

5.1.2: Design Results at Loyalsock State Forest

Regions of Pleasant Stream Road were categorized by types of slope and suggested remediation. Detail 1 was designed to remediate slopes at 1.0(H):1.0(V). Detail 2 was designed to remediate thin (<4.0') embankment slopes at 1.5(H):1.0(V). Detail 3 was designed to remediate slopes of 1.5(H):1.0(V) and shallower. The factors of safety and performance ratios for each detail are tabulated within Table 24.

Table 24: Performance ratios for slope remediation along Pleasant Stream Road at Loyalsock State Forest

Detail	**Obtained Factor of Safety**	**Required Factor of Safety**	**Performance Ratio**
1	1.3	1.3	1.0
2	1.3	1.3	1.0
3	1.6	1.3	1.2

5.2: Spatial Landslide Variability

Based on the spatial evaluations of slope degree distribution performed in Section 3.4 and Section 4.4, a graph of the distributions of slope degree greater than 20° within the state park and state forest lands of Lycoming and Sullivan County was generated (Figure 35).

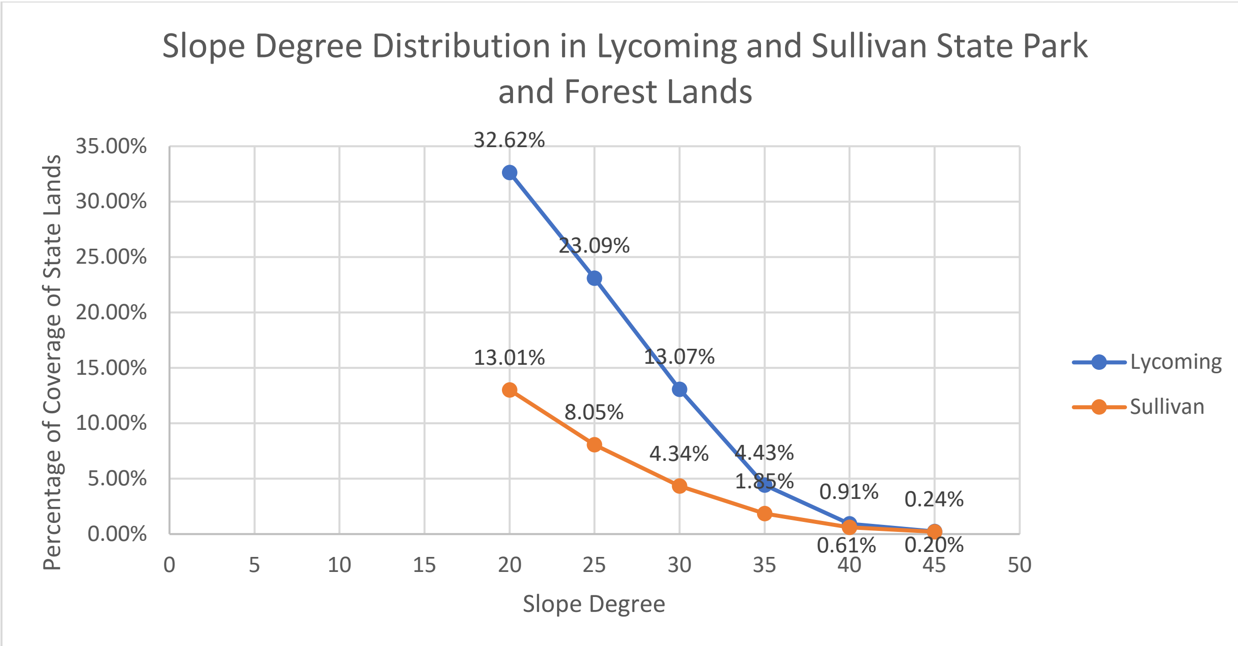


Figure 35: Distribution of slope degree value in state park and forest land within Sullivan County and Lycoming County

From the data and by visual inspection of the graph, two inferences can be made: (1) it is evident that there is consistently more slope area between 20 and 35 degrees in Lycoming state lands than Sullivan state lands; (2) The areal distribution of slopes greater than 40 degrees is similar for Lycoming and Sullivan state lands. Thus, it is reasonable to assume that more earth-slump and low-angle landslide events occur in Lycoming County state lands. This assumption agrees with the existing landslide hazard map by Delano et al., 2001, discussed in Section 2. The slope degrees values in state lands with the background of the Delano et al. map is shown in Figure 36. The slope degree values in state lands with a white background for clarity is shown in Figure 37.

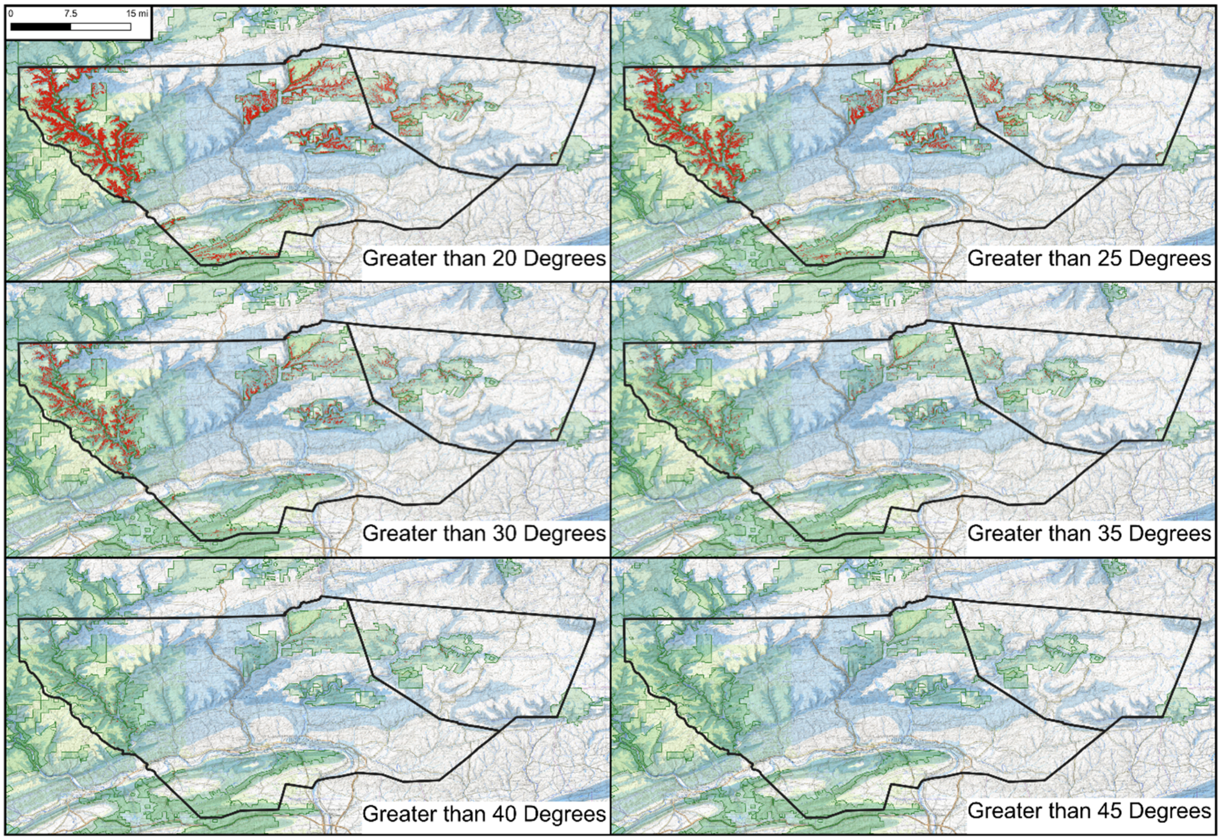


Figure 36: View of state land slope degree values in Lycoming County and Sullivan County on the backdrop of the digitally georeferenced Delano et al., 2001, landslide hazard map

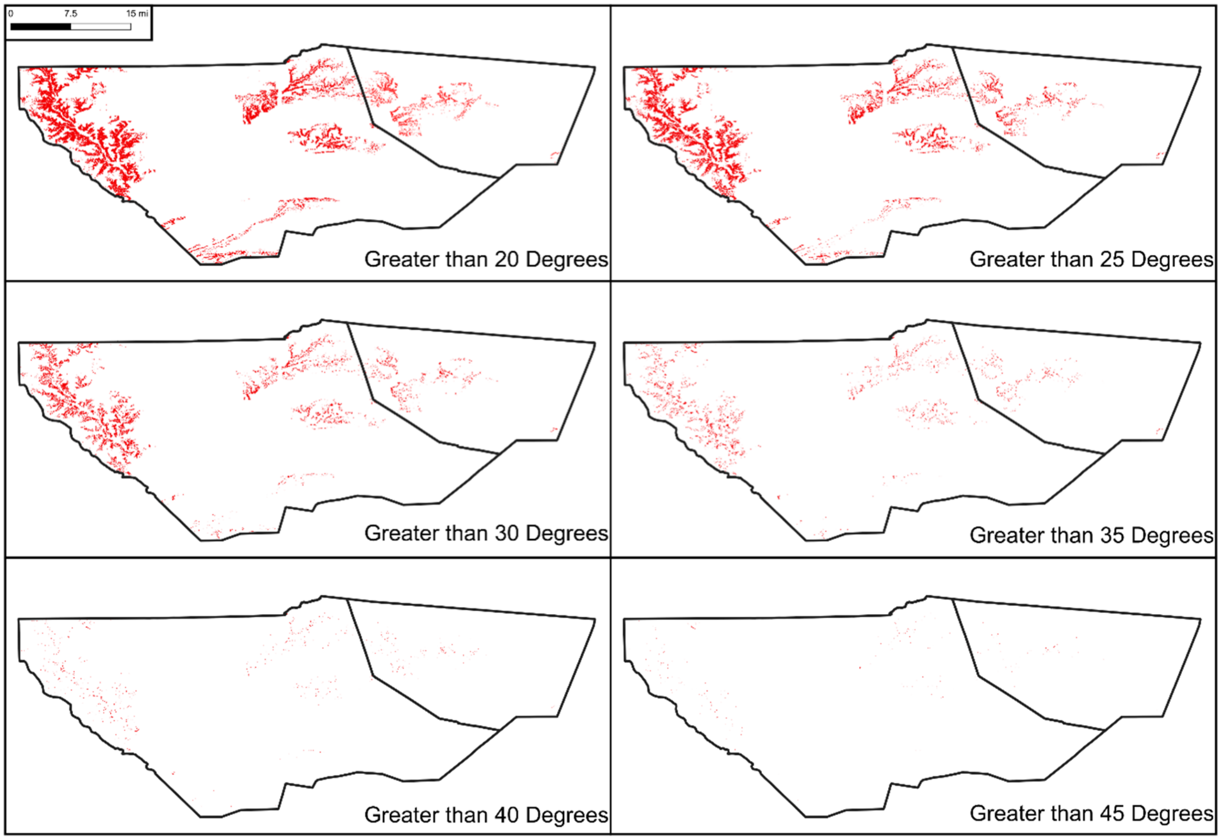


Figure 37: View of state land slope degree values in Lycoming County and Sullivan County

5.3: Applications for Future Design of Rural, Forestry Road Design

The rockery wall at Worlds End State Park (Site 1) proved to be an effective and affordable method of repairing the roadway and maintaining the rural park's aesthetic quality. This was largely achievable through the availability of suitable rock from local quarries. The rockery wall also allowed for a low-impact approach in construction, as minimal clearing and staging were required beyond the roadway.

The rock benching at Worlds End State Park (Site 2) is a typical methodology for remediation of forest roads with slope stability issues. The advantages are primarily in ease of design and construction. To remediate a slope, in general, it is relatively safe to bench angular rock rip-rap at slopes of less than 1.5(H):1.0(V). The disadvantages are primarily in the quantity of rock required and the cost. There is also a disadvantage in the rock's spread and the impact on surrounding vegetation. The proposed remediation extended to the bottom of the slope, encompassing approximately 100’ of local relief.

N&W initially recommended significant remediation along Pleasant View Stream Road, and the PA DCNR decided not to remediate. While N&W had to relinquish liability for this decision formally, there is credence to the cost vs. benefit analysis associated with this decision. The road traffic is very low, as this road is primarily used for hunting or access to a small (<20) number of residences. After consideration from all parties, it was decided that the cost of maintenance would likely be less than the cost of remediating the extensive range of steep slopes. It is also likely that the dense vegetation present along the roadway is maintaining the steep slopes. The contribution to soil cohesion from dense root systems in the soil matrix is strongly contested and not widely accepted in engineering. Finally, it was expected that, while not verified by the boring program, shallow bedrock would allow for steeper cut slopes. This was proven during construction, as the cut slopes' excavation did encounter stable sandstone and siltstone bedrock at all points along the 1.0 (H):1.0 (V) slope sections.

5.4: Comparison of Design Choice at Worlds End State Park

The design choices at Site 1 and Site 2 of Worlds End State Park provide a comparison of two engineering solutions to a common problem. The slope below the road experienced instability and required engineering design and remediation to be stable. Subsurface conditions and slope angles were similar.

Site 1 was remediated by the use of a rockery wall. The extent of excavation was more significant than at Site 2, as shown in the rockery's excavated footprint below (Image 1).

Image 1: Footprint of rockery wall with placed AASHTO No. 8 coarse aggregate at Site 1 at Worlds End State Park

Additionally, the blocks' size in the rockery system requires an experienced contractor to maneuver and stack. The base blocks, before placement, are shown in Image 2.

Image 2: Blocks utilized for base stone of rockery wall at Site 1 at Worlds End State Park

These rocks were approximately 6.0’ by 4.0’ by 8.0’, with the longest section running into the slope. Two layers of these larger stones were placed as base-bearing stones. After the base stones, 2.0’ by 3.0’ by 8.0’ stones were stacked until the required height was reached, tapering the face at a 4.0(V):1.0(H) slope. A drainage pipe was chinked into the wall near the top to manage roadway drainage. The final build is shown from the top of the roadway in Image 3, and from just below the wall in Image 4.

Image 3: View of rockery wall and drainage pipe from top of road, directly above rockery wall at Site 1 at Worlds End State Park

Image 4: View of rockery wall from down-slope at Site 1 at Worlds End State Park

Site 2 was remediated by utilizing clean aggregate benched into the slope at a 1.5(H):1.0(V) slope. Due to this methodology's nature, the entirety of the slope had to be remediated. As water was likely the main instigator of the original landslides at this location, drainage systems were implemented as well. The drainage tubes can be viewed from the top of the slope, as shown in Images 5 and 6.

Image 5: View of roadway grade above remediated slope at Site 2 at Worlds End State Park

Image 6: View of drainage system at top of remediated slope at Site 2 at Worlds End State Park

The extent of clearing and remediation is also shown in Images 5 and 6 and in Image 7, taken from the bottom of the slope.

Image 7: View of remediated area from down-slope at Site 2 at Worlds End State Park

While both remediation options at Worlds End State Park have successfully repaired the damage caused by the landslides, the options have significantly different and distinct pros and cons. Immediately following construction, a conversation was had with the contractor. The contractor's opinion is that the more straightforward construction was the rockery wall. It was also noted that certain aspects of the benching had a high-risk component. It was not possible to bench the riprap where the rock outcrops 2/3 of the way up the slope. This was expected and modeled in design. However, the condition did not allow the excavator to move up the slope with the benching. This resulted in higher costs as two excavators were required, working in tandem to complete the rock placement safely. The rockery was still more expensive from a cost standpoint than the rock benching.

5.5: Construction of Pleasant Stream Road at Loyalsock State Forest

It was assumed during design that many of the steep slopes along the roadway would be rock cuts, but borings were not available to verify this information. This assumption proved to be valid in all steep slope areas during construction. Excavators were utilized to clear outcrop areas at a minimum of every 100' along the steep slope areas to verify rock dip, dip direction, and general quality was sufficient to utilize the steep cut. These exposed areas are shown in Image 8, Image 9, Image 10, and Image 11.

Image 8: View of steeply dipping interbedded sandstone and siltstone at the base of a proposed steep slope at Loyalsock State Forest

Image 9: View of sandstone at base of proposed steep slope at Loyalsock State Forest

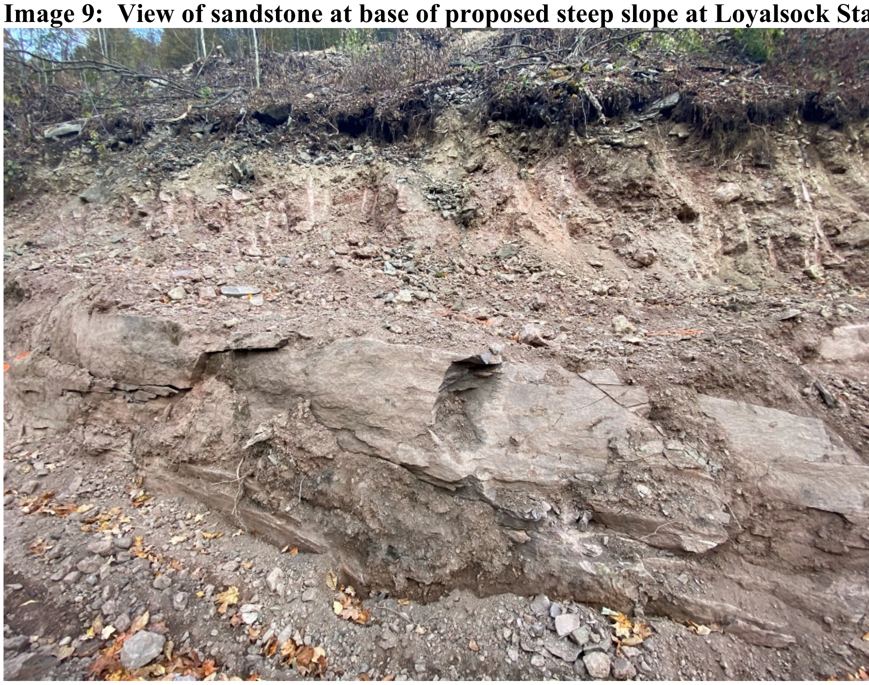


Image 10: View of crossbedding in sandstone at base of proposed steep slope at Loyalsock State Forest

Image 11: View of exposed outcrop at base of proposed steep slope at Loyalsock State Forest

To maintain the stability of the rock cuts, blasting was not permitted. All slopes were excavated with typical construction methods, the most common being ripping with excavator teeth. Bedrock of sufficient quality was encountered in all areas where steep slopes were anticipated, and soil benching with geosynthetics was not required.

5.6: ABAQUS Finite Element Model Comparison to Hand Calculations

The hand calculations results found the horizontal force on the back of the rockery wall to be 3.367 kips and the rotating moment to be 21.998 kip-ft. Utilizing the ABAQUS finite element method, a horizontal force of 4.343 kips and rotating moment of 24.945 kip-ft was calculated. This was likely due to the generalizations of geometry necessary for the hand calculation. By comparing these two numbers, it can be assumed that active earth pressure modeling with ABAQUS is more accurate. The hand calculation's horizontal force was approximately 77.5% of the ABAQUS horizontal force. The hand calculation's rotating moment was approximately 88.15% of the ABAQUS overturning moment. These numbers imply that hand calculations for rockery wall stability may underestimate lateral earth pressure force by 22.5% and overturning moment by 11.85% for similarly sized rockery walls. The comparison of overturning and sliding performance has been tabulated in Table 25.

Table 25: Comparison of performance ratios for design of the rockery wall at Site 1 at Worlds End State Park for the FHWA Rockery Design and Construction Guidelines methodology and ABAQUS methodology

Parameter	Obtained Factor of Safety (Hand Calculation)	Obtained Factor of Safety (ABAQUS)	Required Factor of Safety	Performance Ratio (Hand Calculation)	Performance Ratio (ABAQUS)
Sliding	3.8	2.0	1.5	2.5	1.3
Overturning	2.3	2.0	2.0	1.15	1.0

These results show that the rockery wall performance ratios for sliding and overturning are still at or above 1.0, which concludes the wall is within acceptable design standards. It is also arguable that with more accurate design, such as with the finite element method, lower factors of safety may be viable. Lower required factor of safety values can reduce costs associated with construction of future rockery walls.

5.7: Limitations

The examined data and conclusions within this study were isolated to two small park land regions in North Central Pennsylvania. Overall trends in geology, physiographic province, and spatial variability were reviewed to generally quantify other areas where this data may be applicable, particularly in park land in North Central Pennsylvania.

The engineering design performed at each location was based on a subsurface investigation with limited borehole coverage. However, subsurface conditions were verified during construction and found to generally match the assumed conditions based on the subsurface investigation and laboratory testing program.

The ABAQUS model assumed the materials would exhibit low plasticity and the plasticity was modeled with the Mohr-Coulomb plasticity model. The Mohr-Coulomb elastic-plastic model assumes perfectly plastic deformation, which is not always the case. However, plastic deformation will be a minor portion of the system's overall deformation, and approximate plasticity estimations were acceptable for the study goals.

Section 6: Conclusions

6.1: Review of Work

In support of this thesis, a literature review was performed. The primary areas of focus for the literature review were the following: landslides in north-central Pennsylvania (Section 2.1); landslide mechanisms and remediation methodology in rural, hilly, forested terrain (Section 2.2); existing case studies associated with rockery walls (Section 2.3); retaining wall design (Section 2.4); lateral earth pressure theory (Section 2.4); retaining wall selection (Section 2.5); and finite element modeling of geotechnical problems, particularly concerning retaining walls.

A review of the two case study regions was performed, in which the existing project scope, local topography and geology, and subsurface conditions was reviewed. The need for future investigations of north-central Pennsylvania landslides and remediation methodology for rural forestry roads in the region was identified. LIDAR data was utilized to evaluate the variability of slope within state park and forest lands.

The geotechnical design results at each project location were reviewed, including factors of safety for each evaluated design condition. Worlds End State Park included remediation of two landslides (Site 1 and Site 2) with a rockery wall at Site 1 and rip-rap benching with geogrid at Site 2. Loyalsock State Forest included several rip-rap benching with geogrid and cut slope options to relocate a forest road due to various landslides and washouts. The resultant percentages by square area of slope degree within state park and forest lands were presented. The finite element model of the rockery wall at Worlds End State Park was introduced, which included the calculated lateral earth pressures generated from the model.

Performance ratios for the design of the structures at the two case study regions were calculated, and their implications were discussed. Slope variability in state park and forest lands was found to agree with previously published data on north-central Pennsylvania landslides. The region's primary landslide mechanism is most likely earth slump and low-angle rotational landslides. A review of the construction was performed during and after the completion of the two case study projects. Changes to design during construction and the design choices' pros and cons were reviewed. Lateral earth pressure was estimated via the finite element method and compared to the pressures calculated from the industry-standard methodology. Potential limitations to the thesis investigation were performed, including considerations for extraneous variability of topography and geology and complex particle interactions beyond the scope of the utilized finite element method.

6.2: Primary Conclusions

There are four (4) resultant conclusions from this thesis study. These are summarized below.

1. The review of spatial topography and geology of state park and forest lands within Sullivan and Lycoming County indicates that the Pennsylvania Department of Conservation and Natural Resources will likely continue to see earth slump and shallow rotational landslides along their local forestry roads. Approximately 33% of Lycoming state lands and 13% of Sullivan state lands include slopes greater than 20 degrees, and the majority of these slope regions are within rural, forested terrain. The rockery wall is suitable for remediation of shallow landslides along low-volume roadways and is frequently not utilized in areas where it would be beneficial to preserve the area's aesthetic quality such as in state park and forest land.
2. Two major adjustments to typical engineering practice at the case study locations significantly improved efficiency and cost of construction: the allowance for changes in

cut slopes based on encountered conditions during excavation (1); the utilization of a rockery wall option, which is currently not common practice for engineering design in Pennsylvania (2). These adjustments may be useful for future remediation of forestry roads in north-central Pennsylvania state lands.

3. Rockery wall design methodology provided in the Federal Highway Administration (FHWA) Rockery Design and Construction Guidelines under-estimates lateral earth pressure and, by extension, overturning moment acting on the back of the rockery wall. This may result in an overly conservative design of rockery walls due to high factors of safety, which increases the cost of construction.

6.3: Recommendations

Based on the study findings and conclusions, several future design recommendations are presented. Future engineering design associated with landslide remediation of forestry roads in north-central Pennsylvania should consider the rockery wall as a feasible option. Engineering designers should be open to design changes based on excavation in the field, and budget should be allocated for the engineering geologist to evaluate cut slopes during construction. Future research should review the FHWA Rockery Design and Construction Guidelines and refine the Lateral Earth Pressure estimation suggested by the text – lateral earth pressure at the Worlds End State Park rockery was under-estimated by the FHWA methodology.

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APPENDIX

APPENDIX A: ENGINEERING TEST BORING LOGS

pennsylvania
DEPARTMENT OF TRANSPORTATION

ENGINEER'S LOG

Boring **B-1** ECMS

District: County: Sullivan
SR Section
Baseline: Mineral Spring Road
Sta. Offset
Segment Offset
Coordinates:
Lat. Long.
2291099.6000 E 475560.1000 N
Ground Elev. 1209.9 ft.
Water Level Elev./Elapsed Time:
Initial 1194.9 ft. Elapsed 0.0 hr.
Final 1192.8 ft. Elapsed 15.5 hr.
Driller: K. Bassett
Company: N & W

Drilling Start: 08/14/2019 3:00 pm
Drilling Complete: 08/14/2019 5:30 pm
Grouting Complete: 08/15/2019 11:00 am
Rig: Acker Track Rig
Hammer Type: Automatic
SPT Hammer Efficiency:
Assumed 0.8 Measured
Hammer Calibration Date:
Hole Type: Continuous SPT - Rock Core
Casing Type: Flush Joint Casing - Spun
Casing I.D.: 3.00 in Casing Depth: 12.1 ft.
Rock Core Method: Double Tube Wire Line-NQ
Inspector: Ben Bardo
Inspector Cert. No. 023-97

COMMONWEALTH OF PENNSYLVANIA
REGISTERED PROFESSIONAL
DAVID SCOTT CROTSLEY
GEOLOGIST
PG/PE Seal, Signature and Date

Final Log Checked and Approved
By: David Crotsley
Date: 11/18/2019

NOTE: N values and all graphical plots are for information only.

ELEV.	GRAPHIC	MATERIAL DESCRIPTION COMMENTS - OBSERVATIONS	AASHTO / USCS	SAMPLE DEPTH	SAMPLE No.	BLOW COUNTS (Blows/ 0.5ft)	N_{60} --- RQD %	REC (ft.)	REC (%)	◇ RQD % ◇ ⊙ Soil/Rock Rec.% ⊙ 20 40 60 80 ▲ SPT (N_{60}) ▲ 10 20 30 40
		GRAVEL, some fine to coarse Sand, little Silt, medium dense to very dense, moist, homogeneous, well graded, sub-angular, low plastic fines, olive brown, fill.	a-2-4 / gm		S-1	3-7-8-9	20	2.0	100	
				2.0	S-2	15-27-28-15	73	1.6	80	
		4.0'/El. 1205.9		4.0						
1205		Fine to coarse **SAND**, some fine Gravel, little Silt, trace Clay, dense to very dense, moist to wet, homogeneous, well graded, angular, medium plastic fines, red brown, residuum. *S-3: Contains some silt.*	a-2-4 / gm		S-3	10-15-18-14	44	2.0	100	
				6.0	S-4	27-50/.3'	>67	0.4	50	
				6.8	A-1					
				8.0	S-5	50/.4'	>67	0.4	100	
				8.4	A-2					
1200		10.0'/El. 1199.9		10.0	S-6	50/.3'	>67	0.3	100	
		MECHANICALLY BROKEN ROCK.		10.3	A-3					
	TOR 1197.8	*12.1': Top of rock.* 12.1'/El. 1197.8		12.0	S-7	50/.1'	>67	0.1	100	
		Silty **SANDSTONE**, red brown, fine grained, dull luster, soft to medium hard, weathered, indistinct bedding, fractured, close to medium spacing, shallow to sheer dip, large fracture opening, *(Rec=97%, RQD=44%)*.		12.1	R-1		33%	2.4	100	
1195				14.5						

pennsylvania
DEPARTMENT OF TRANSPORTATION

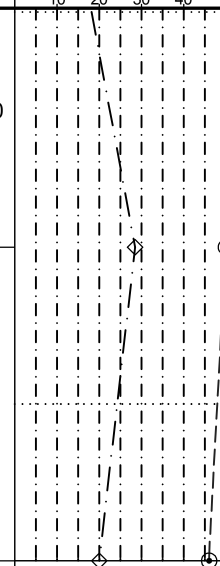
ENGINEER'S LOG

Boring **B-1** ECMS ______ District: ______ County: Sullivan

SR ______ Section ______

Sta. ______ Offset ______

NOTE: N values and all graphical plots are for information only.

ELEV.	GRAPHIC	MATERIAL DESCRIPTION COMMENTS - OBSERVATIONS	AASHTO / USCS	SAMPLE DEPTH	SAMPLE No.	BLOW COUNTS (Blows/ 0.5ft)	N_{60} --- RQD %	REC (ft.)	REC (%)	◇ RQD % ◇ ⊙ Soil/Rock Rec.% ⊙ 20 40 60 80 ▲ SPT (N_{60}) ▲ 10 20 30 40
		13.9': 1/2" Clay seam. *14.0' to 14.5': Vertical fractures.* Silty **SANDSTONE**, red brown, fine grained, dull luster, soft to medium hard, weathered, indistinct bedding, fractured, close to medium spacing, shallow to sheer dip, large fracture opening, *(Rec=97%, RQD=44%)*. *(Layer continued from the previous page.)*			R-2		57%	3.5	100	
1190				18.0	R-3		40%	3.7	92	
		21.0' to 21.5': Vertical fractures. 22.0'/El. 1187.9								
		Bottom of boring.								
1185										
1180										
1175										

pennsylvania DEPARTMENT OF TRANSPORTATION

ENGINEER'S LOG

Boring **B-2** ECMS

District: County: Sullivan

SR Section

Baseline: Mineral Spring Road

Sta. Offset

Segment Offset

Coordinates:

Lat. Long.

2291103.1000 E 475582.5000 N

Ground Elev. 1208.2 ft.

Water Level Elev./Elapsed Time:

▽ Initial 1191.0 ft. Elapsed 0.0 hr.

▼ Final NR Elapsed NR

Driller: K. Bassett

Company: N & W

Drilling Start: 08/15/2019 9:00 am

Drilling Complete: 08/15/2019 11:30 am

Grouting Complete: 08/15/2019 11:45 am

Rig: Acker Track Rig

Hammer Type: Automatic

SPT Hammer Efficiency:

Assumed 0.8 Measured

Hammer Calibration Date:

Hole Type: Continuous SPT - Rock Core

Casing Type: Flush Joint Casing - Spun

Casing I.D.: 3.00 in Casing Depth: 16.0 ft.

Rock Core Method: Double Tube Wire Line-NQ

Inspector: Ben Bardo

Inspector Cert. No. 023-97

COMMONWEALTH OF PENNSYLVANIA REGISTERED PROFESSIONAL DAVID SCOTT CROTSLEY GEOLOGIST PG005198

P.G./P.E Seal, Signature and Date

Final Log Checked and Approved

By: David Crotsley

Date: 11/18/2019

Lab Testing Performed on Sample

NOTE: N values and all graphical plots are for information only.

ELEV.	GRAPHIC	MATERIAL DESCRIPTION COMMENTS - OBSERVATIONS	AASHTO / USCS	SAMPLE DEPTH	SAMPLE No.	BLOW COUNTS (Blows/ 0.5ft)	N_{60} --- RQD %	REC (ft.)	REC (%)	◇ RQD % ◇ ⊙ Soil/Rock Rec.% ⊙ 20 40 60 80 ▲ SPT (N_{60}) ▲ 10 20 30 40
		Fine to coarse **GRAVEL**, some fine to coarse Sand, little Silt, trace Clay, loose to medium dense, damp, homogeneous, well graded, sub-angular, non-plastic, red brown, fill.	A-1-b / GM		S-1	3-2-3-2	7	0.7	35	
				2.0	S-2	2-2-2-4	5	0.3	15	
1205				4.0	S-3	3-2-3-6	7	0.7	35	
				6.0	S-4	2-2-8-8	13	0.1	5	
1200		8.5'/El. 1199.7		8.0						
		Fine to coarse **GRAVEL**, some fine to coarse Sand, little Silt, very dense, moist to damp, fissured, well graded, angular, non-plastic, red brown, residuum.	a-2-4 / gm		S-5	5-29-21-21	67	1.8	90	
				10.0	S-6	22-25-22-23	63	1.6	80	
		S-7: Mostly fine to coarse sand and silt. 12.9'/El. 1195.3		12.0	S-7	29-50/.4'	>67	0.9	100	
1195		**MECHANICALLY BROKEN ROCK**.		12.9	A-1					
				14.0 / 14.2	S-8	50/.2'	>67	0.2	100	

PENNDOT ENGINEER'S LOG - PENNDOT_GINT_VERSION_1.2.2.3_9-21-2016.GDT - 12/2/19 10:50 - N:_2017\1712RE802 DCNRWO23_WORLDSEND_GT\BORING LOGS\WORLDSEND_DCNR_TYPEDLOGS.GPJ

pennsylvania
DEPARTMENT OF TRANSPORTATION

ENGINEER'S LOG

Boring **B-2** ECMS ______ District: ______ County: Sullivan

SR ______ Section ______

Sta. ______ Offset ______

NOTE: N values and all graphical plots are for information only.

Lab Testing Performed on Sample

ELEV.	GRAPHIC	MATERIAL DESCRIPTION COMMENTS - OBSERVATIONS	AASHTO / USCS	SAMPLE DEPTH	SAMPLE No.	BLOW COUNTS (Blows/ 0.5ft)	N_{60} --- RQD %	REC (ft.)	REC (%)	◇ RQD % ◇ ⊙ Soil/Rock Rec.% ⊙ 20 40 60 80 ▲ SPT (N_{60}) ▲ 10 20 30 40
		MECHANICALLY BROKEN ROCK. *(Layer continued from the previous page.)* 16.0'/El. 1192.2			A-2					
	TOR 1192.2			16.0 16.0	S-9	50/.0'	>67	0.0	0	
1190		Sandy **SILTSTONE**, red brown to olive gray, fine grained, dull luster, soft to medium hard, moderately weathered to slightly weathered, thin bedding with flat dip, fractured, close to moderate spacing, shallow to sheer dip, open fractures, *(Rec=100%, RQD=44%)*. *17.0': 1/4" clay seam.*		18.5	R-1		0%	2.5	100	
				22.0	R-2		74%	3.5	100	
1185		26.0'/El. 1182.2			R-3		58%	4.0	100	
1180 1175		Bottom of boring.								

ENGINEER'S LOG

Boring **B-3** ECMS ____

District: ____ County: Sullivan

SR ____ Section ____

Baseline: Mineral Spring Road

Sta. ____ Offset ____

Segment ____ Offset ____

Coordinates:

Lat. ____ Long. ____

2290785.9000 E 475345.1000 N

Ground Elev. 1228.1 ft.

Water Level Elev./Elapsed Time:

Initial 1221.8 ft. Elapsed 0.0 hr.

Final 1219.5 ft. Elapsed 19.0 hr.

Driller: K. Bassett

Company: N & W

Drilling Start: 08/14/2019 12:30 pm

Drilling Complete: 08/14/2019 2:00 pm

Grouting Complete: 08/15/2019 10:00 am

Rig: Acker Track Rig

Hammer Type: Automatic

SPT Hammer Efficiency:

Assumed 0.8 Measured ____

Hammer Calibration Date: ____

Hole Type: Continuous SPT - Rock Core

Casing Type: Flush Joint Casing - Spun

Casing I.D.: 3.00 in Casing Depth: 10.0 ft.

Rock Core Method: Double Tube Wire Line-NQ

Inspector: Ben Bardo

Inspector Cert. No. 023-97

COMMONWEALTH OF PENNSYLVANIA REGISTERED PROFESSIONAL DAVID SCOTT CROTSLEY GEOLOGIST PG005198

P.G./P.E. Seal, Signature and Date

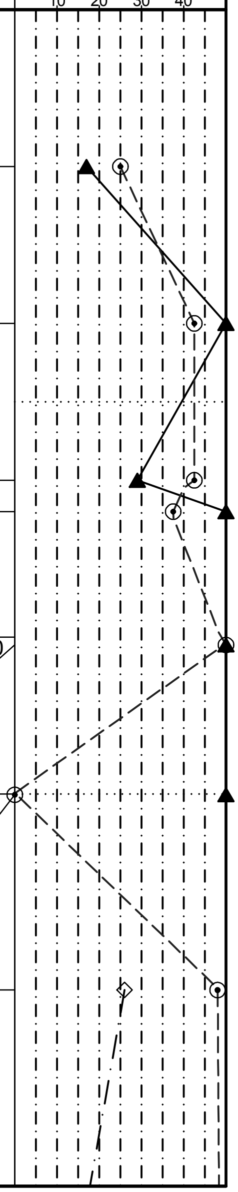
Final Log Checked and Approved By: David Crotsley

Date: 11/18/2019

Lab Testing Performed on Sample

NOTE: N values and all graphical plots are for information only.

ELEV.	GRAPHIC	MATERIAL DESCRIPTION COMMENTS - OBSERVATIONS	AASHTO / USCS	SAMPLE DEPTH	SAMPLE No.	BLOW COUNTS (Blows/ 0.5ft)	N_{60} --- RQD %	REC (ft.)	REC (%)	◇ RQD % ◇ ⊙ Soil/Rock Rec.% ⊙ 20 40 60 80 ▲ SPT (N_{60}) ▲ 10 20 30 40
		Fine to coarse **GRAVEL**, some fine to coarse Sand, little Silt, trace Clay, contains rock fragments, medium dense to very dense, damp, homogeneous, well graded, sub-angular, low plastic fines, red brown, fill.	A-1-b / GM	2.0	S-1	9-9-4-10	17	1.0	50	
1225		*Note: Run off from mountain observed @ 25.0' west of boring B-3.*		4.0	S-2	17-12-38-10	67	1.7	85	
		6.0'/El. 1222.1		6.0	S-3	10-10-12-9	29	1.7	85	
		MECHANICALLY BROKEN ROCK.		6.4	S-4	50/.4'	>67	0.3	75	
				8.0	A-1					
1220				8.1	S-5	50/.1'	>67	0.1	100	
		10.0'/El. 1218.1		10.0	A-2					
	TOR 1218.1			10.0	S-6	50/.0'	>67	0.0	0	
		SANDSTONE, light gray, fine to coarse grained, hard to very hard, weathered, laminated bedding with shallow dip, fractures, close to moderate spacing, shallow dip, open fractures, *(Rec=99%, RQD=14%)*. *11.2': 1/2" Clay seam.*		12.5	R-1		52%	2.4	96	
1215		*13.4': 1/2" Clay seam.* 14.4'/El. 1213.7			R-2		29%	3.4	97	



pennsylvania
DEPARTMENT OF TRANSPORTATION

ENGINEER'S LOG

Boring **B-3** ECMS ______ District: ______ County: Sullivan

SR ______ Section ______

Sta. ______ Offset ______

NOTE: N values and all graphical plots are for information only.

Lab Testing Performed on Sample

ELEV.	GRAPHIC	MATERIAL DESCRIPTION COMMENTS - OBSERVATIONS	AASHTO / USCS	SAMPLE DEPTH	SAMPLE No.	BLOW COUNTS (Blows/ 0.5ft)	N_{60} --- RQD %	REC (ft.)	REC (%)	◇ RQD % ◇ ⊙ Soil/Rock Rec.% ⊙ 20 40 60 80 ▲ SPT (N_{60}) ▲ 10 20 30 40
1210		Sandy **SILTSTONE**, olive brown, fine grained, dull luster, very soft, highly weathered to moderately weathered, laminated bedding with shallow dip, fractures, narrow to moderate spacing, shallow dip, large fracture opening, *(Rec=99%, RQD=23%)*. *(Layer continued from the previous page.)* *14.4': 1.0" Clay seam.* *15.4': 1.0" Clay seam.* *14.4' to 20.0': Rust stained fractures.* *16.7': 1/3" Clay seam.* 20.0'/El. 1208.1		16.0	R-3		20%	4.0	100	
1205		Bottom of boring.								
1200										
1195										

pennsylvania
DEPARTMENT OF TRANSPORTATION

ENGINEER'S LOG

Boring **B-4** ECMS

District: County: Sullivan

SR Section

Baseline: Mineral Spring Road

Sta. Offset

Segment Offset

Coordinates:

Lat. Long.

2290755.8000 E 475330.7000 N

Ground Elev. 1229.7 ft.

Water Level Elev./Elapsed Time:

Initial 1222.7 ft. Elapsed 0.0 hr.

Final 1221.3 ft. Elapsed 20.5 hr.

Driller: K. Bassett

Company: N & W

Drilling Start: 08/14/2019 11:45 pm

Drilling Complete: 08/14/2019 12:30 pm

Grouting Complete: 08/15/2019 10:00 am

Rig: Acker Track Rig

Hammer Type: Automatic

SPT Hammer Efficiency:

Assumed 0.8 Measured

Hammer Calibration Date:

Hole Type: Continuous SPT - Rock Core

Casing Type: Flush Joint Casing - Spun

Casing I.D.: 3.00 in Casing Depth: 12.0 ft.

Rock Core Method: Double Tube Wire Line-NQ

Inspector: Ben Bardo

Inspector Cert. No. 023-97

COMMONWEALTH OF PENNSYLVANIA
REGISTERED PROFESSIONAL
DAVID SCOTT CROTSLEY
GEOLOGIST
PG005199

P.G./P.E Seal, Signature and Date

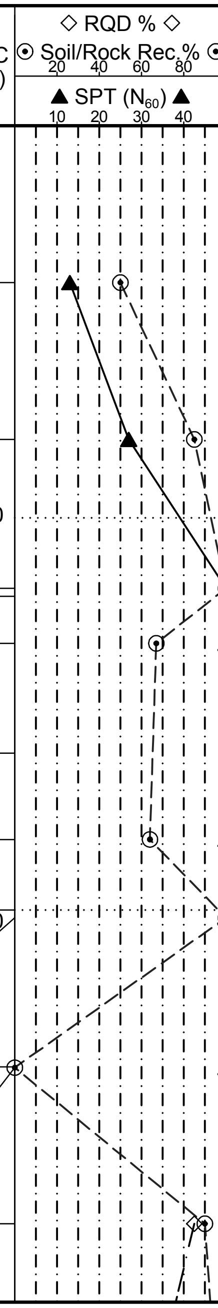
Final Log Checked and Approved By: David Crotsley

Date: 11/18/2019

Lab Testing Performed on Sample

NOTE: N values and all graphical plots are for information only.

ELEV.	GRAPHIC	MATERIAL DESCRIPTION COMMENTS - OBSERVATIONS	AASHTO / USCS	SAMPLE DEPTH	SAMPLE No.	BLOW COUNTS (Blows/ 0.5ft)	N_{60} --- RQD %	REC (ft.)	REC (%)
		SILT, some fine to coarse Sand, some fine Gravel, trace Clay, medium dense to very dense, moist, homogeneous, well graded, sub-angular, low plastic fines, red brown, fill.	A-4 / SM		S-1	7-7-3-6	13	1.0	50
		Note: Run off from mountain observed @ 12.0' east of boring B-4.		2.0	S-2	5-7-13-29	27	1.7	85
1225		5.5'/El. 1224.2		4.0	S-3	22-16-22-50/.4'	>51	1.9	100
		Fine to coarse **GRAVEL**, some fine to coarse Sand, little Silt, very dense, wet, homogeneous, well graded, angular, olive brown, residuum.	a-2-4 / gm	5.9	A-1				
				6.0	S-4	23-50/.1'	>67	0.4	67
				6.6	A-2				
				8.0	S-5	18-15-50/.1'	87	0.7	64
				9.1	A-3				
1220				10.0	S-6	50/.1'	>67	0.1	100
				10.1	A-4				
	TOR 1217.7	12.0'/El. 1217.7		12.0	S-7	50/.0'	>67	0.0	0
1215		**SANDSTONE**, light gray, fine to coarse grained, dull luster, hard to very hard, weathered, laminated bedding with shallow dip, fractured, close to moderate spacing, shallow to steep dip, open fractures, *(Rec=94%, RQD=59%).* *12.4', 12.8', and 13.5': 1/2" Clay seams.*		12.0	R-1		85%	1.8	90
				14.0					



PENNDOT ENGINEER'S LOG - PENNDOT_GINT_VERSION_1.2.2.3_9-21-2016.GDT - 12/2/19 10:50 - N:_2017\1712RE802 DCNRWO23_WORLDSEND_GT\BORING LOGS\WORLDSEND_DCNR_TYPEDLOGS.GPJ

pennsylvania
DEPARTMENT OF TRANSPORTATION

ENGINEER'S LOG

Boring **B-4** ECMS ______ District: ______ County: Sullivan

SR ______ Section ______

Sta. ______ Offset ______

NOTE: N values and all graphical plots are for information only.

Lab Testing Performed on Sample

ELEV.	GRAPHIC	MATERIAL DESCRIPTION COMMENTS - OBSERVATIONS	AASHTO / USCS	SAMPLE DEPTH	SAMPLE No.	BLOW COUNTS (Blows/ 0.5ft)	N_{60} --- RQD %	REC (ft.)	REC (%)	◇ RQD % ◇ ⊙ Soil/Rock Rec.% ⊙ 20 40 60 80 ▲ SPT (N_{60}) ▲ 10 20 30 40
		15.4'/El. 1214.3 *15.4' and 16.4': 1/8" Clay seams.* Sandy **SILTSTONE**, red brown to olive brown, fine grained, dull luster, very soft, moderately weathered, laminated bedding with shallow dip, fractured, narrow to moderate spacing, shallow to steep dip, large fracture opening, *(Rec=100%, RQD=17%)*. *15.4' to 22.0': Rust stained fractures.* *19.2': 1/2" Clay seam.*			R-2		50%	4.0	100	
1210				18.0	R-3		10%	4.0	100	
		22.0'/El. 1207.7								
1205		Bottom of boring.								
1200										
1195										

PENNDOT ENGINEER'S LOG - PENNDOT_GINT_VERSION_1.2.2.3_9-21-2016.GDT - 12/2/19 10:50 - N:_2017\1712RE802 DCNRWO23_WORLDSEND_GT\BORING LOGS\WORLDSEND_DCNR_TYPEDLOGS.GPJ

pennsylvania
DEPARTMENT OF TRANSPORTATION

ENGINEER'S LOG

Boring **B-5** ECMS

District: County: Sullivan

SR Section

Baseline: Mineral Spring Road

Sta. Offset

Segment Offset

Coordinates:

Lat. Long.

2290682.6000 E 475437.9000 N

Ground Elev. 1140.5 ft.

Water Level Elev./Elapsed Time:

Initial 1122.7 ft. Elapsed 0.0 hr.

Final NR Elapsed NR

Driller: K. Bassett

Company: N & W

Drilling Start: 08/15/2019 1:00 pm

Drilling Complete: 08/15/2019 3:30 pm

Grouting Complete: 08/15/2019 3:45 pm

Rig: Acker Track Rig

Hammer Type: Automatic

SPT Hammer Efficiency:

Assumed 0.8 Measured

Hammer Calibration Date:

Hole Type: Continuous SPT - Rock Core

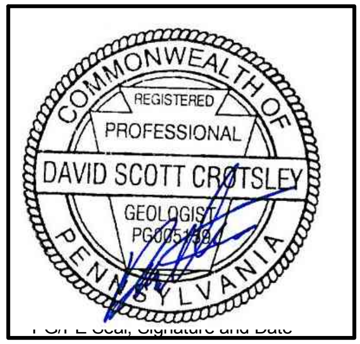
Casing Type: Flush Joint Casing - Spun

Casing I.D.: 3.00 in Casing Depth: 20.1 ft.

Rock Core Method: Double Tube Wire Line-NQ

Inspector: Ben Bardo

Inspector Cert. No. 023-97



Final Log Checked and Approved

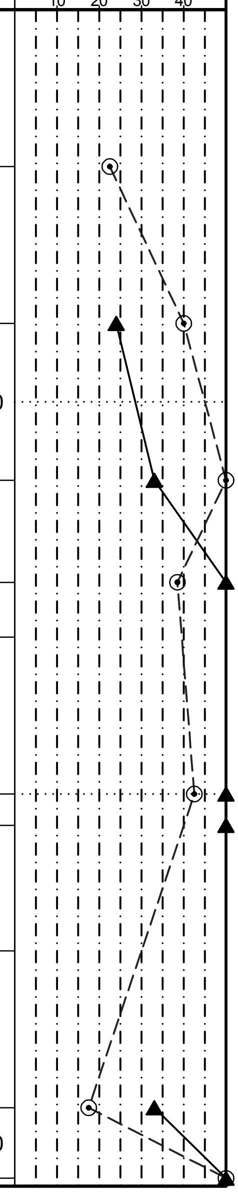
By: David Crotsley

Date: 11/18/2019

Lab Testing Performed on Sample

NOTE: N values and all graphical plots are for information only.

ELEV.	GRAPHIC	MATERIAL DESCRIPTION COMMENTS - OBSERVATIONS	AASHTO / USCS	SAMPLE DEPTH	SAMPLE No.	BLOW COUNTS (Blows/ 0.5ft)	N_{60} --- RQD %	REC (ft.)	REC (%)	◇ RQD % ◇ ⊙ Soil/Rock Rec.% ⊙ ▲ SPT (N_{60}) ▲
1140		**TOPSOIL.** 1.0'/El. 1139.5			S-1	WOH/12"-1-1		0.9	45	
		Fine to coarse **GRAVEL**, some fine to coarse Sand, little Silt, trace Clay, very loose to very dense, wet, homogeneous, well graded, sub-rounded, non-plastic, brown, colluvium, *some cobbles*.	A-1-a / GM	2.0	S-2	2-5-13-9	24	1.6	80	
				4.0	S-3	10-11-14-15	33	2.0	100	
1135				6.0	S-4	15-35-50/.3'	113	1.0	77	
				7.3	A-1					
				8.0	S-5	17-16-22-21	51	1.7	85	
				10.0	S-6	50/.4'	>67			
1130				10.4	A-2					
				12.0	S-7	12-14-11-12	33	0.7	35	
				14.0	S-8	7-50/.4'	>67	0.9	100	
				14.9						



PENNDOT ENGINEER'S LOG - PENNDOT_GINT_VERSION_1.2.2.3_9-21-2016.GDT - 12/2/19 10:50 - N:_2017\1712RE802 DCNRW023_WORLDSEND_GT\BORING LOGS\WORLDSEND_DCNR_TYPEDLOGS.GPJ

pennsylvania
DEPARTMENT OF TRANSPORTATION

ENGINEER'S LOG

Boring **B-5** ECMS ________ District: _____ County: Sullivan ________

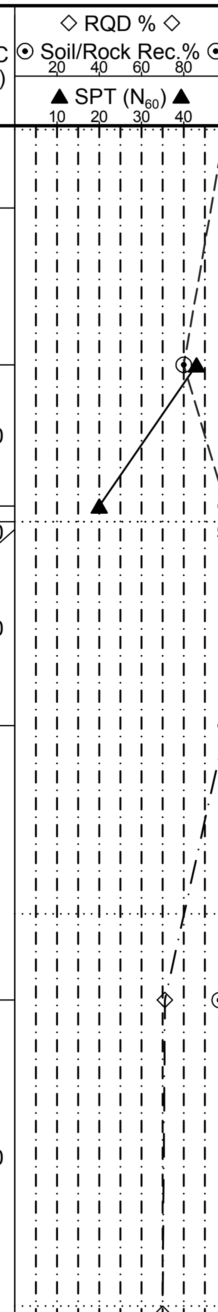
SR ________ Section ________

Sta. ________ Offset ________

NOTE: N values and all graphical plots are for information only.

Lab Testing Performed on Sample

ELEV.	MATERIAL DESCRIPTION COMMENTS - OBSERVATIONS	AASHTO / USCS	SAMPLE DEPTH	SAMPLE No.	BLOW COUNTS (Blows/ 0.5ft)	N_{60} --- RQD %	REC (ft.)	REC (%)
1125	Fine to coarse **GRAVEL**, some fine to coarse Sand, little Silt, trace Clay, very loose to very dense, wet, homogeneous, well graded, sub-rounded, non-plastic, brown, colluvium, *some cobbles*. *(Layer continued from the previous page.)* 17.0'/El. 1123.5	A-1-a / GM		A-3				
			16.0	S-9	32-22-10-10	43	1.6	80
	Fine **SAND**, some Silt, medium dense, wet, homogeneous, poorly graded, sub-angular, non-plastic, brown, alluvium. 19.5'/El. 1121.0	a-1-b / sm	18.0	S-10	5-7-8-50/.3'	>20	1.8	100
	MECHANICALLY BROKEN ROCK. 20.1'/El. 1120.4		19.8	A-4				
			20.0	S-11	50/.1'	>67	0.1	100
1120	TOR 1120.4		20.1					
	SILTSTONE, red brown, dull luster, soft, fresh, indistinct bedding, fractured, close to medium spacing, shallow to sheer dip, tight fractures.			R-1		100%	2.5	100
			22.6	R-2		71%	3.4	97
1115			26.1	R-3		70%	4.0	100
	27.5' to 30.1': Red brown and gray. *28.0' and 28.5': Slickensides.* *Boring grouted upon completion.* 30.1'/El. 1110.4							
1110	Bottom of boring.							



PENNDOT ENGINEER'S LOG - PENNDOT_GINT_VERSION_1.2.2.3_9-21-2016.GDT - 10/21/19 14:24 - \\NC-SERVER1\PROJECTS_2017\1712RE802 DCNR\GEOTECHNICAL\WO 20 AREA 6 SITE 20 LOYALSOCK STATE FOREST\TYPED LOGS\LOYALSOCK STATE FOI

pennsylvania
DEPARTMENT OF TRANSPORTATION

ENGINEER'S LOG

Boring **B-1** ECMS

District: 20 County: Lycoming

SR Section

Baseline: Pleasant Stream Rd

Sta. 18+50.0 Offset 6.0 ft. RT.

Segment Offset

Coordinates:

Lat. Long.

2190727.1000 E 482802.5200 N

Ground Elev. 1004.4 ft.

Water Level Elev./Elapsed Time:

Initial 997.1 ft. Elapsed 120.0 hr.

Final NR Elapsed NR

Driller: K. Bassett

Company: N & W

Drilling Start: 07/03/2019 1:15 pm

Drilling Complete: 07/03/2019 1:30 pm

Grouting Complete: 07/03/2019 2:00 pm

Rig: Acker XLS Track

Hammer Type: Automatic

SPT Hammer Efficiency:

Assumed 0.8 Measured

Hammer Calibration Date:

Hole Type: Continuous SPT - Rock Core

Casing Type: Flush Joint Casing - Spun

Casing I.D.: 3.00 in Casing Depth: 12.6 ft.

Rock Core Method: Double Tube Wire Line-NQ

Inspector: Ben Bardo

Inspector Cert. No. 023-97

COMMONWEALTH OF PENNSYLVANIA
REGISTERED PROFESSIONAL
DAVID SCOTT CROTSLEY
GEOLOGIST
PG003150

Final Log Checked and Approved

By: David Crotsley

Date: 10/21/2019

Lab Testing Performed on Sample

NOTE: N values and all graphical plots are for information only.

ELEV.	GRAPHIC	MATERIAL DESCRIPTION COMMENTS - OBSERVATIONS	AASHTO / USCS	SAMPLE DEPTH	SAMPLE No.	BLOW COUNTS (Blows/ 0.5ft)	N_{60} --- RQD %	REC (ft.)	REC (%)	◇ RQD % ◇ / ⊙ Soil/Rock Rec.% ⊙ 20 40 60 80 / ▲ SPT (N_{60}) ▲ 10 20 30 40
		TOPSOIL. 0.5'/El. 1003.9			S-1	8-10-16-31	35	1.7	85	
		GRAVEL, some Sand, little Silt, trace Clay, contains rock fragments, dense to very dense, damp to moist, homogeneous, well graded, sub-angular, non-plastic, red brown, residuum.	A-1-b / SM	2.0	S-2	17-42-50/.0'	123	1.0	100	
				3.0	A-1					
1000				4.0	S-3	50/.4'	>67	0.3	75	
				4.4	A-2					
				6.0	S-4	19-30-30-50/.4'	>80	1.9	100	
				7.9	A-3					
995				8.0	S-5	26-30-35-28	87	2.0	100	
				10.0	S-6	12-16-25-28	55	2.0	100	
		12.6': Spoon refusal. 12.6'/El. 991.8		12.0	S-7	26-50/.1'	>67	0.6	100	
990	TOR 991.8	**SANDSTONE**, red brown to gray, fine grained, dull luster, medium hard, slightly weathered, laminated bedding with shallow dip, fractured, narrow to moderate spacing, shallow dip, narrow fracture opening.		12.6	R-1		55%	2.0	100	
				14.6						

pennsylvania
DEPARTMENT OF TRANSPORTATION

ENGINEER'S LOG

Boring **B-1** ECMS ______ District: 20 County: Lycoming Sheet 2 of 2

SR ______ Section ______

Sta. 18+50.0 Offset 6.0 ft. RT.

NOTE: N values and all graphical plots are for information only.

Lab Testing Performed on Sample

ELEV.	GRAPHIC	MATERIAL DESCRIPTION COMMENTS - OBSERVATIONS	AASHTO / USCS	SAMPLE DEPTH	SAMPLE No.	BLOW COUNTS (Blows/ 0.5ft)	N_{60} --- RQD %	REC (ft.)	REC (%)	◇ RQD % ◇ ⊙ Soil/Rock Rec.% ⊙ 20 40 60 80 ▲ SPT (N_{60}) ▲ 10 20 30 40
		SANDSTONE, red brown to gray, fine grained, dull luster, medium hard, slightly weathered, laminated bedding with shallow dip, fractured, narrow to moderate spacing, shallow dip, narrow fracture opening. *(Layer continued from the previous page.)* *16.0': 1/8" soil seam.*			R-2		40%	3.0	100	
		Boring grouted upon completion. 17.6'/El. 986.8								
		Bottom of boring.								
985										
980										
975										
970										

pennsylvania
DEPARTMENT OF TRANSPORTATION

ENGINEER'S LOG

Boring **B-2** ECMS ______

District: 20 County: Lycoming

SR ______ Section ______

Baseline: Pleasant Stream Rd

Sta. 20+00.0 Offset 8.0 ft. RT.

Segment ______ Offset ______

Coordinates:

Lat. ______ Long. ______

2190866.9500 E 482855.6500 N

Ground Elev. 1006.1 ft.

Water Level Elev./Elapsed Time:

▽ Initial 990.3 ft. Elapsed 0.0 hr.

▼ Final NR Elapsed NR

Driller: K. Bassett

Company: N & W

Drilling Start: 07/03/2019 11:45 am

Drilling Complete: 07/03/2019 1:00 pm

Grouting Complete: 07/03/2019 1:30 pm

Rig: Acker XLS Track

Hammer Type: Automatic

SPT Hammer Efficiency:

Assumed 0.8 Measured ______

Hammer Calibration Date: ______

Hole Type: Continuous SPT - Rock Core

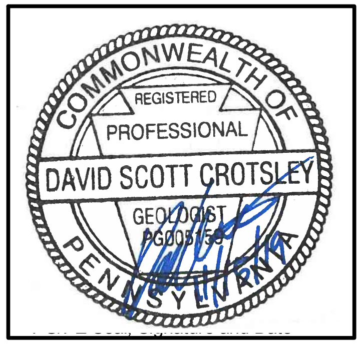
Casing Type: Flush Joint Casing - Spun

Casing I.D.: 3.00 in Casing Depth: 12.4 ft.

Rock Core Method: Double Tube Wire Line-NQ

Inspector: Ben Bardo

Inspector Cert. No. 023-97



Final Log Checked and Approved

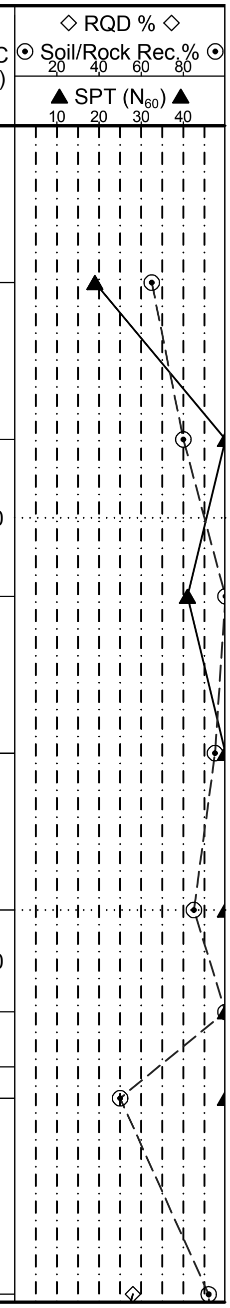
By: David Crotsley

Date: 10/21/2019

Lab Testing Performed on Sample

NOTE: N values and all graphical plots are for information only.

ELEV.	GRAPHIC	MATERIAL DESCRIPTION COMMENTS - OBSERVATIONS	AASHTO / USCS	SAMPLE DEPTH	SAMPLE No.	BLOW COUNTS (Blows/ 0.5ft)	N_{60} --- RQD %	REC (ft.)	REC (%)
		TOPSOIL. 0.2'/El. 1005.9							
1005		**GRAVEL**, some Sand, little Silt, trace Clay, medium dense to very dense, homogeneous, well graded, sub-angular, low plastic fines, red brown, residuum.			S-1	2-3-11-16	19	1.3	65
				2.0	S-2	4-20-18-14	51	1.6	80
				4.0	S-3	14-14-17-13	41	2.0	100
1000			A-1-b / SM	6.0	S-4	19-19-19-36	51	1.9	95
				8.0	S-5	29-27-22-18	65	1.7	85
995				10.0	S-6	15-17-50/.3'	89	1.3	100
				11.3	A-1				
		12.4'/El. 993.7		12.0	S-7	50/.4'	>67	0.2	50
	TOR 993.7	**SANDSTONE**, red brown, fine grained, dull luster, medium hard, fresh, thin bedding with flat dip, fractured, close to moderate spacing, flat to steep dip, narrow fracture opening.		12.4	R-1		56%	2.3	92
				14.9					



pennsylvania
DEPARTMENT OF TRANSPORTATION

ENGINEER'S LOG

Boring **B-2** ECMS

District: 20 County: Lycoming

SR Section

Sta. 20+00.0 Offset 8.0 ft. RT.

NOTE: **N values and all graphical plots are for information only.**

Lab Testing Performed on Sample

ELEV.	GRAPHIC	MATERIAL DESCRIPTION COMMENTS - OBSERVATIONS	AASHTO / USCS	SAMPLE DEPTH	SAMPLE No.	BLOW COUNTS (Blows/ 0.5ft)	N_{60} --- RQD %	REC (ft.)	REC (%)	◇ RQD % ◇ ⊙ Soil/Rock Rec.% ⊙ 20 40 60 80 ▲ SPT (N_{60}) ▲ 10 20 30 40
990		**SANDSTONE**, red brown, fine grained, dull luster, medium hard, fresh, thin bedding with flat dip, fractured, close to moderate spacing, flat to steep dip, narrow fracture opening. *(Layer continued from the previous page.)* *17.2': 1/8" Soil seam.* 17.4'/El. 988.7			R-2		32%	2.5	100	
985		Bottom of boring.								
980										
975										

pennsylvania DEPARTMENT OF TRANSPORTATION

ENGINEER'S LOG

Boring **B-3** ECMS

District: 20 County: Lycoming

SR Section

Baseline: Pleasant Stream Rd

Sta. 21+50.0 Offset 6.0 ft. RT.

Segment Offset

Coordinates:

Lat. Long.

2191008.1800 E 482094.7300 N

Ground Elev. 1007.2 ft.

Water Level Elev./Elapsed Time:

Initial 995.2 ft. Elapsed -0.3 hr.

Final NR Elapsed NR

Driller: K. Bassett

Company: N & W

Drilling Start: 07/03/2019 9:30 am

Drilling Complete: 07/03/2019 11:45 am

Grouting Complete: 07/05/2019 2:00 pm

Rig: Acker XLS Track

Hammer Type: Automatic

SPT Hammer Efficiency:

Assumed 0.8 Measured

Hammer Calibration Date:

Hole Type: Continuous SPT - Rock Core

Casing Type: Flush Joint Casing - Spun

Casing I.D.: 3.00 in Casing Depth: 12.1 ft.

Rock Core Method: Double Tube Wire Line-NQ

Inspector: Ben Bardo

Inspector Cert. No. 023-97

COMMONWEALTH OF PENNSYLVANIA REGISTERED PROFESSIONAL DAVID SCOTT CROTSLEY GEOLOGIST PG003158

Final Log Checked and Approved

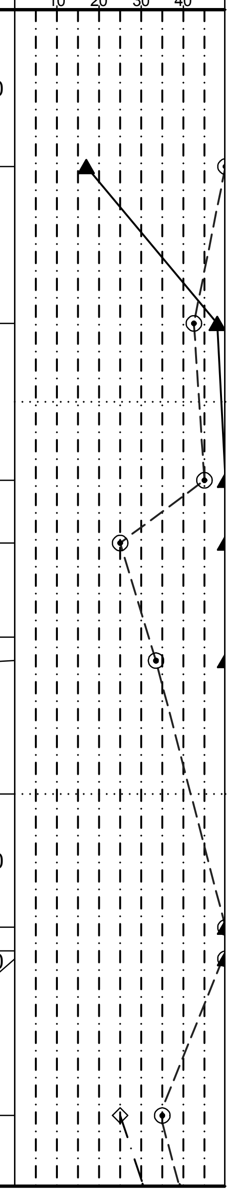
By: David Crotsley

Date: 10/21/2019

Lab Testing Performed on Sample

NOTE: N values and all graphical plots are for information only.

ELEV.	MATERIAL DESCRIPTION COMMENTS - OBSERVATIONS	AASHTO / USCS	SAMPLE DEPTH	SAMPLE No.	BLOW COUNTS (Blows/ 0.5ft)	N_{60} --- RQD %	REC (ft.)	REC (%)
	TOPSOIL. 0.3'/El. 1006.9							
				S-1	2-5-8-8	17	2.0	100
1005	**GRAVEL**, some Sand, little Silt, trace Clay, contains rock fragments, medium dense to very dense, moist to wet, heterogeneous, well graded, sub-angular, low plastic fines, brown to olive brown, residuum. *3.0': Soil is wet.*	A-1-b / GM	2.0	S-2	8-12-24-36	48	1.7	85
			4.0	S-3	18-41-21-24	83	1.8	90
			6.0	S-4	28-50/.3'	>67	0.4	50
1000			6.8	A-1				
			8.0	S-5	50/.3'	>67	0.2	67
			8.3	A-2				
			10.0	S-6	28-38-43-50/.2'	>108	1.7	100
	12.1'/El. 995.1		11.7	A-3				
995	TOR 995.1		12.0	S-7	50/.1'	>67	0.1	100
	SANDSTONE, red brown, fine grained, dull luster, medium hard, fresh, thin bedding with flat to shallow dip, fractured, narrow to moderate spacing, flat to shallow dip, tight to narrow fracture openings. *12.5': 1/8" Clay seam.*		12.1	R-1		50%	1.4	70
			14.1					



pennsylvania
DEPARTMENT OF TRANSPORTATION

ENGINEER'S LOG

Boring **B-3** ECMS ____ District: 20 County: Lycoming

SR ____ Section ____

Sta. 21+50.0 Offset 6.0 ft. RT.

NOTE: N values and all graphical plots are for information only.

Lab Testing Performed on Sample

ELEV.	GRAPHIC	MATERIAL DESCRIPTION COMMENTS - OBSERVATIONS	AASHTO / USCS	SAMPLE DEPTH	SAMPLE No.	BLOW COUNTS (Blows/ 0.5ft)	N_{60} --- RQD %	REC (ft.)	REC (%)	◇ RQD % ◇ ⊙ Soil/Rock Rec.% ⊙ 20 40 60 80 ▲ SPT (N_{60}) ▲ 10 20 30 40
		SANDSTONE, red brown, fine grained, dull luster, medium hard, fresh, thin bedding with flat to shallow dip, fractured, narrow to moderate spacing, flat to shallow dip, tight to narrow fracture openings. *(Layer continued from the previous page.)* 17.1'/El. 990.1			R-2		87%	3.0	100	
990		Bottom of boring.								
985										
980										
975										

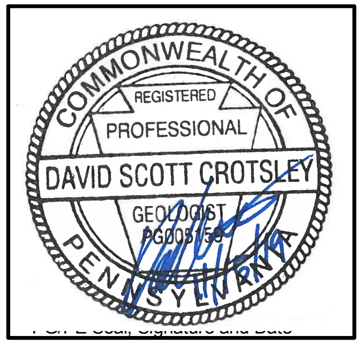
pennsylvania
DEPARTMENT OF TRANSPORTATION

ENGINEER'S LOG

Boring **B-4** ECMS

District: 20 County: Lycoming
SR Section
Baseline: Pleasant Stream Rd
Sta. 76+50.0 Offset 4.0 ft. RT.
Segment Offset
Coordinates:
Lat. Long.
2198225.6600 E 484483.3000 N
Ground Elev. 1065.7 ft.
Water Level Elev./Elapsed Time:
▽ Initial 1055.7 ft. Elapsed 0.0 hr.
▼ Final NR Elapsed NR
Driller: K. Bassett
Company: N & W

Drilling Start: 07/02/2019 3:30 pm
Drilling Complete: 07/02/2019 5:00 pm
Grouting Complete: 07/03/2019 5:30 pm
Rig: Acker XLS Track
Hammer Type: Automatic
SPT Hammer Efficiency:
Assumed 0.8 Measured
Hammer Calibration Date:
Hole Type: Continuous SPT
Casing Type: Flush Joint Casing - Spun
Casing I.D.: 3.00 in Casing Depth: 6.2 ft.
Rock Core Method: Double Tube Wire Line-NQ
Inspector: Ben Bardo
Inspector Cert. No. 023-97



P.G. Seal, Signature and Date

Final Log Checked and Approved
By: David Crotsley
Date: 10/21/2019

NOTE: N values and all graphical plots are for information only.

ELEV.	GRAPHIC	MATERIAL DESCRIPTION COMMENTS - OBSERVATIONS	AASHTO / USCS	SAMPLE DEPTH	SAMPLE No.	BLOW COUNTS (Blows/ 0.5ft)	N_{60} --- RQD %	REC (ft.)	REC (%)	◇ RQD % ◇ ⊙ Soil/Rock Rec.% ⊙ 20 40 60 80 ▲ SPT (N_{60}) ▲ 10 20 30 40
1065		**TOPSOIL.** 0.3'/El. 1065.4			S-1	2-7-50/.4'	76	1.4	100	
		COBBLES and fine to coarse **GRAVEL**, some fine to coarse Sand, little Silt, very dense, moist, homogeneous, well graded, sub-rounded, non-plastic, brown, fill.	a-2-4 / gm	1.4	A-1					
				2.0	S-2	19-11-16-50/.1'	>36	1.6	100	
				3.6	A-2					
		4.7'/El. 1061.0		4.0	S-3	29-50/.2'	>67	0.4	57	
1060	OTH	**COBBLES** and **BOULDERS**, very dense, moist, heterogeneous, well graded, sub-rounded, brown to light brown, fill.		4.7	A-3					
				6.0	S-4	50/.2'	>67	0.1	50	
		9.2'/El. 1056.5		6.2	R-1		25%	1.6	80	
1055	TOR 1056.5	**SANDSTONE**, light brown, fine grained, dull luster, hard, highly weathered to weathered, thin bedding with flat dip, fractured, close spacing, flat to shallow dip, narrow fracture opening. *9.2' to 10.2: Highly weathered with poor recovery.* *10.5': 1/8" Clay seam.* 11.2'/El. 1054.5		8.2	R-2		0%	2.0	67	
		Bottom of boring.								

pennsylvania
DEPARTMENT OF TRANSPORTATION

ENGINEER'S LOG

Boring **B-5** ECMS

District: 20 County: Lycoming

SR Section

Baseline: Pleasant Stream Rd

Sta. 103+61.0 Offset 10.0 ft. LT.

Segment Offset

Coordinates:

Lat. Long.

2198719.9500 E 485354.8600 N

Ground Elev. 1090.5 ft.

Water Level Elev./Elapsed Time:

▽ Initial 1076.2 ft. Elapsed 0.0 hr.

▼ Final 1070.3 ft. Elapsed 19.8 hr.

Driller: K. Bassett

Company: N & W

Drilling Start: 07/02/2019 12:15 pm

Drilling Complete: 07/02/2019 2:00 pm

Grouting Complete: 07/03/2019 11:15 am

Rig: Acker XLS Track

Hammer Type: Automatic

SPT Hammer Efficiency:

Assumed 0.8 Measured

Hammer Calibration Date:

Hole Type: Continuous SPT

Casing Type: Flush Joint Casing - Spun

Casing I.D.: 3.00 in Casing Depth: 24.0 ft.

Rock Core Method: Double Tube Wire Line-NQ

Inspector: Ben Bardo

Inspector Cert. No. 023-97

COMMONWEALTH OF PENNSYLVANIA
REGISTERED PROFESSIONAL
DAVID SCOTT CROTSLEY
GEOLOGIST
PG005158

P.G. Seal, Signature and Date

Final Log Checked and Approved

By: David Crotsley

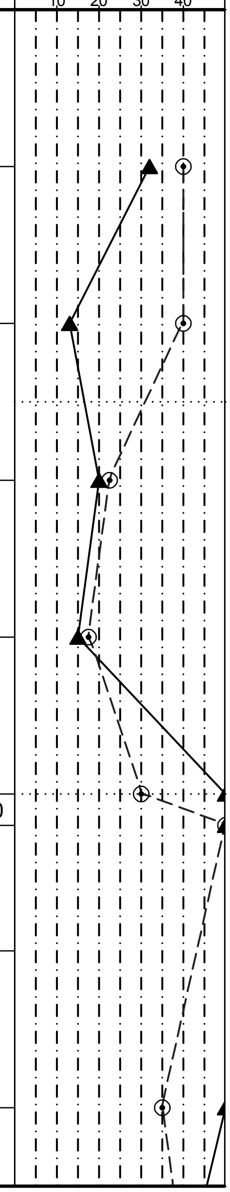
Date: 10/21/2019

Lab Testing Performed on Sample

NOTE: N values and all graphical plots are for information only.

ELEV.	GRAPHIC	MATERIAL DESCRIPTION COMMENTS - OBSERVATIONS	AASHTO / USCS	SAMPLE DEPTH	SAMPLE No.	BLOW COUNTS (Blows/ 0.5ft)	N_{60} --- RQD %	REC (ft.)	REC (%)
1090		**TOPSOIL.** 0.5'/El. 1090.0							
		GRAVEL, some Sand, trace Silt, trace Clay, medium dense to dense, moist, homogeneous, well graded, sub-rounded, non-plastic, brown, fill.	A-1-a / GP-GM		S-1	3-5-19-6	32	1.6	80
				2.0	S-2	3-5-5-5	13	1.6	80
				4.0	S-3	5-4-11-9	20	0.9	45
1085				6.0	S-4	11-6-5-6	15	0.7	35
		8.0'/El. 1082.5		8.0					
		GRAVEL, some Sand, trace Silt, trace Clay, contains rock fragments, very dense to medium dense, moist, homogeneous, well graded, sub-rounded, non-plastic, brown to gray, alluvium.	A-1-a / GM		S-5	21-18-34-22	69	1.2	60
				10.0	S-6	50/.4'	>67	0.4	100
1080				10.4	A-1				
				12.0	S-7	27-24-18-18	56	1.4	70
	▽			14.0					

◇ RQD % ◇
⊙ Soil/Rock Rec.% ⊙ 20 40 60 80
▲ SPT (N_{60}) ▲ 10 20 30 40



pennsylvania
DEPARTMENT OF TRANSPORTATION

ENGINEER'S LOG

Boring **B-5** ECMS

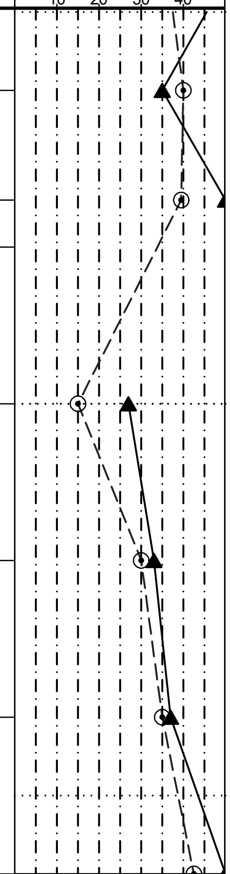
District: 20 County: Lycoming

SR Section

Sta. 103+61.0 Offset 10.0 ft. LT.

NOTE: N values and all graphical plots are for information only.

Lab Testing Performed on Sample

ELEV.	GRAPHIC	MATERIAL DESCRIPTION COMMENTS - OBSERVATIONS	AASHTO / USCS	SAMPLE DEPTH	SAMPLE No.	BLOW COUNTS (Blows/ 0.5ft)	N_{60} --- RQD %	REC (ft.)	REC (%)	◇ RQD % ◇ ⊙ Soil/Rock Rec.% ⊙ 20 40 60 80 ▲ SPT (N_{60}) ▲ 10 20 30 40
1075		**GRAVEL**, some Sand, trace Silt, trace Clay, contains rock fragments, very dense to medium dense, moist, homogeneous, well graded, sub-rounded, non-plastic, brown to gray, alluvium. *(Layer continued from the previous page.)*	A-1-a / GM		S-8	21-13-13-10	35	1.6	80	
				16.0	S-9	29-36-50/.4'	115	1.1	79	
				17.4	A-2					
				18.0	S-10	10-12-8-9	27	0.6	30	
1070				20.0	S-11	6-13-12-11	33	1.2	60	
				22.0	S-12	18-13-15-12	37	1.4	70	
1065		26.0'/El. 1064.5		24.0	S-13	17-15-23-29	51	1.7	85	
1060		Bottom of boring.								

pennsylvania
DEPARTMENT OF TRANSPORTATION

ENGINEER'S LOG

Boring **B-6** ECMS

District: 20 County: Lycoming

SR Section

Baseline: Pleasant Stream Rd

Sta. 104+06.0 Offset 2.0 ft. LT.

Segment Offset

Coordinates:

Lat. Long.

2198753.0500 E 485345.9100 N

Ground Elev. 1090.4 ft.

Water Level Elev./Elapsed Time:

▽ Initial 1074.6 ft. Elapsed 0.0 hr.

▼ Final NR Elapsed 23.5 hr.

Driller: K. Bassett

Company: N & W

Drilling Start: 07/02/2019 9:00 am

Drilling Complete: 07/02/2019 11:30 am

Grouting Complete: 07/03/2019 11:00 am

Rig: Acker XLS Track

Hammer Type: Automatic

SPT Hammer Efficiency:

Assumed 0.8 Measured

Hammer Calibration Date:

Hole Type: Continuous SPT

Casing Type: Flush Joint Casing - Spun

Casing I.D.: 3.00 in Casing Depth: 25.0 ft.

Rock Core Method: Double Tube Wire Line-NQ

Inspector: Ben Bardo

Inspector Cert. No. 023-97

COMMONWEALTH OF PENNSYLVANIA
REGISTERED PROFESSIONAL
DAVID SCOTT CROTSLEY
GEOLOGIST
PG003156

Final Log Checked and Approved

By: David Crotsley

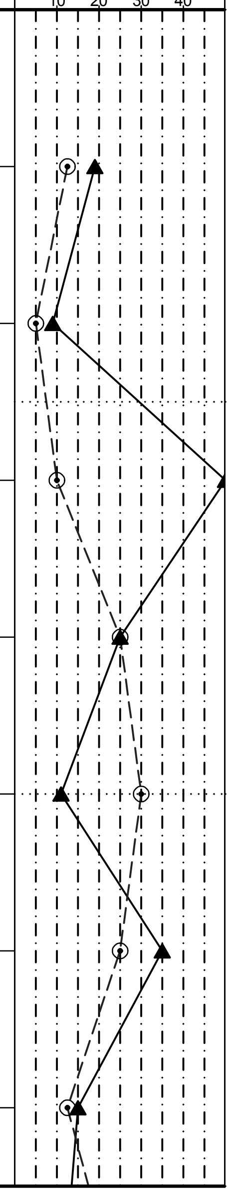
Date: 10/21/2019

Lab Testing Performed on Sample

NOTE: N values and all graphical plots are for information only.

ELEV.	GRAPHIC	MATERIAL DESCRIPTION COMMENTS - OBSERVATIONS	AASHTO / USCS	SAMPLE DEPTH	SAMPLE No.	BLOW COUNTS (Blows/ 0.5ft)	N_{60} --- RQD %	REC (ft.)	REC (%)
1090		**TOPSOIL.** 0.3'/El. 1090.1			S-1	2-7-7-6	19	0.5	25
		GRAVEL, some Sand, trace Silt, trace Clay, loose to dense, moist, homogeneous, well graded, sub-rounded, non-plastic, brown, fill.		2.0	S-2	7-4-3-5	9	0.2	10
				4.0	S-3	6-36-4-6	53	0.4	20
1085				6.0	S-4	19-11-8-4	25	1.0	50
		8.0' to 16.0': Small bulk sample collected.	A-1-a / GW-GM	8.0	S-5	4-5-3-4	11	1.2	60
1080		*10.0': Approximate stream bed.*		10.0	S-6	7-7-19-10	35	1.0	50
				12.0	S-7	6-5-6-9	15	0.5	25
				14.0					

◇ RQD % ◇
⊙ Soil/Rock Rec.% ⊙
▲ SPT (N_{60}) ▲



ENGINEER'S LOG

pennsylvania DEPARTMENT OF TRANSPORTATION

Boring **B-6** ECMS ______

District: 20 County: Lycoming

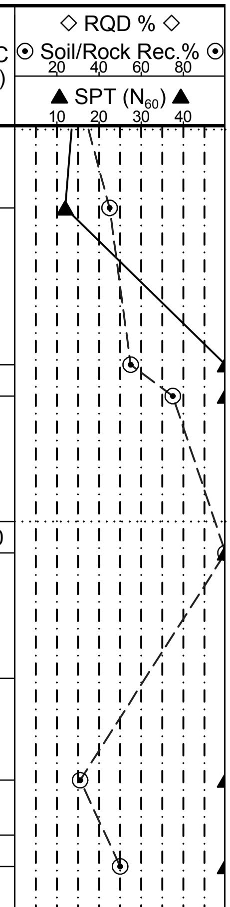
SR ______ Section ______

Sta. 104+06.0 Offset 2.0 ft. LT.

NOTE: N values and all graphical plots are for information only.

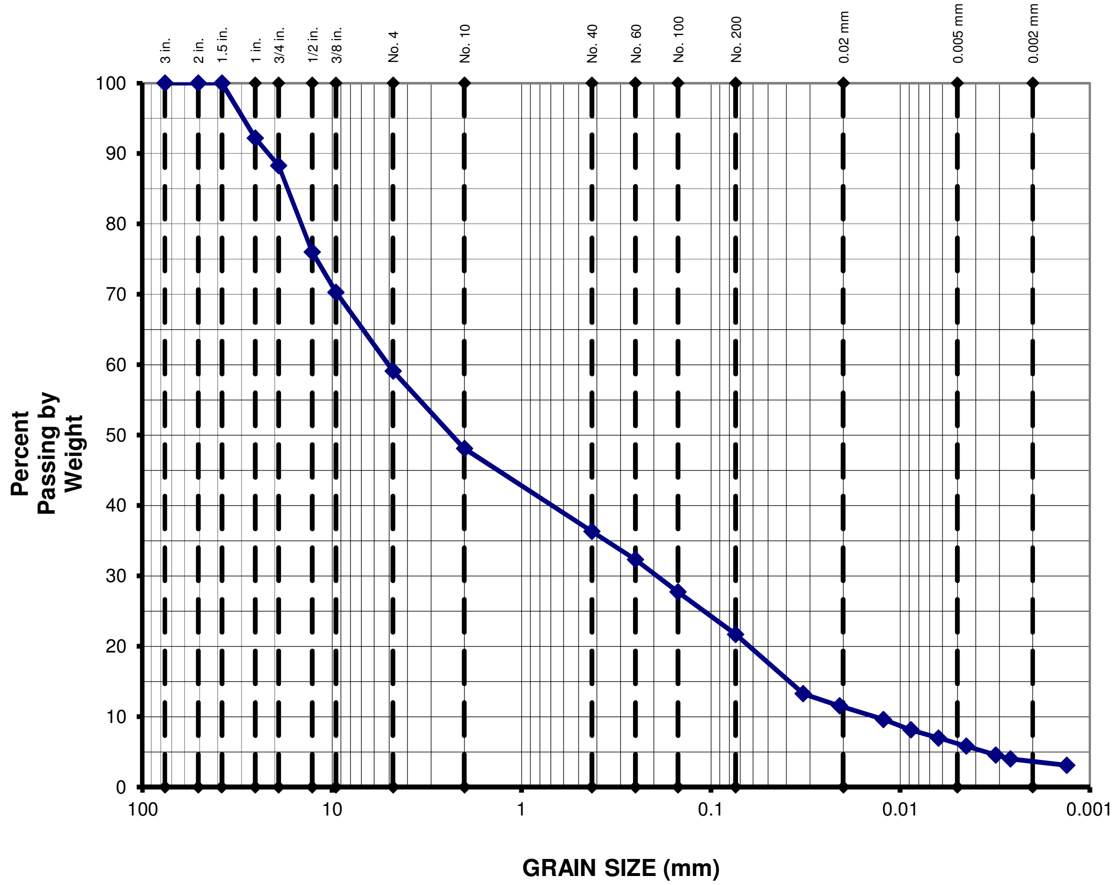
Lab Testing Performed on Sample

ELEV.	GRAPHIC	MATERIAL DESCRIPTION COMMENTS - OBSERVATIONS	AASHTO / USCS	SAMPLE DEPTH	SAMPLE No.	BLOW COUNTS (Blows/ 0.5ft)	N_{60} --- RQD %	REC (ft.)	REC (%)
1075		16.5'/El. 1073.9	A-1-a / GW-GM	16.0	S-8	4-3-6-11	12	0.9	45
		BOULDERS and **COBBLES**, some fine to coarse Gravel, trace Silt, contains rock fragments, very dense, moist, homogeneous, well graded, sub-angular, non-plastic, light brown, alluvium.	a-1-a / gw	18.0	S-9	11-38-32-16	93	1.1	55
				18.4	S-10	50/.4'	>67	0.3	75
				20.0	A-1				
1070				20.4	S-11	50/.4'	>67	0.4	100
				22.0	A-2				
				23.3	S-12	46-40-50/.3'	120	0.4	31
				24.0	A-3				
		24.4' to 25.0': Advanced casing in sandstone boulders.		24.4	S-13	50/.4'	>67	0.2	50
		25.0'/El. 1065.4			A-4				
1065		Bottom of boring.							
1060									



APPENDIX B: LABORATORY TESTING RESULTS

GRAIN SIZE DISTRIBUTION CURVE



GRAVEL		SAND			FINES	
COARSE	FINE	COARSE	MEDIUM	FINE	SILT	CLAY
40.9%		37.4%			21.7%	
11.7%	29.2%	11.0%	11.8%	14.6%	15.5%	6.2%

GRAVEL			SAND		FINES	
COARSE	MEDIUM	FINE	COARSE	FINE	SILT	CLAY
51.9%			26.4%		21.7%	
7.8%	21.9%	22.2%	11.8%	14.6%	18.4%	3.3%

Project:	Worlds End State Park	**Soil Type:**	silty GRAVEL with sand
Boring No.:	B-2		
Station:	-	**USCS Classification:**	GM
Offset:	-	**AASHTO Classification:**	A-1-b (0)
Sample No.:	S-1 to S-4	LL = NP	PL = NP
Depth:	0.0-8.0 ft	PI = NP	w = 9.7%
Spec. Grav.:	2.73		

Note: S-1 w%=10.6%, S-2 w%=10.5%, S-3 w%=9.4%, & S-4 w%=4.5%

NAVARRO & WRIGHT CONSULTING ENGINEERS, INC.

AASHTO R18

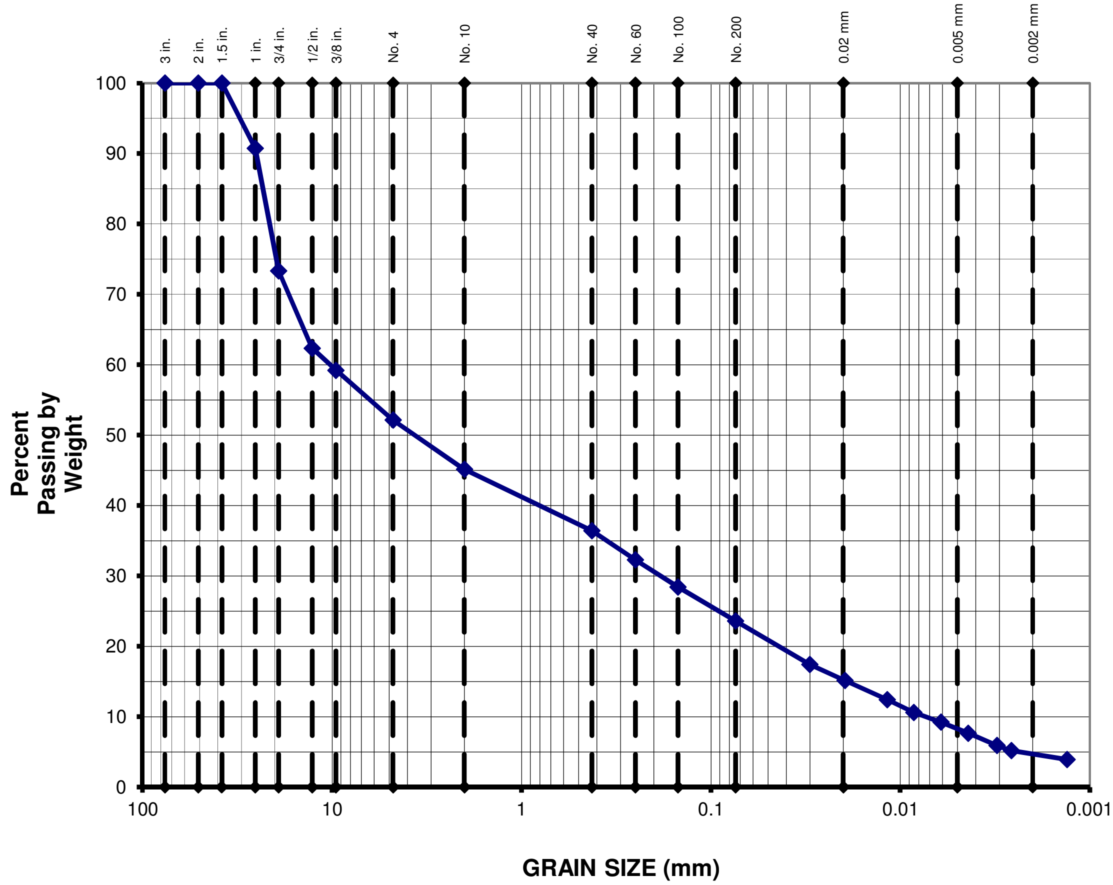
9/9/2019

Classification Testing Results

USCS & AASHTO

By: DFP Ckd: JDP

GRAIN SIZE DISTRIBUTION CURVE



GRAVEL		SAND			FINES	
COARSE	FINE	COARSE	MEDIUM	FINE	SILT	CLAY
47.8%		28.6%			23.6%	
26.7%	21.2%	7.0%	8.7%	12.8%	15.4%	8.2%

GRAVEL			SAND		FINES	
COARSE	MEDIUM	FINE	COARSE	FINE	SILT	CLAY
54.9%			21.6%		23.6%	
9.3%	31.5%	14.1%	8.7%	12.8%	19.3%	4.3%

Project: Worlds End State Park **Soil Type:** silty GRAVEL with sand
Boring No.: B-3
Station: - **USCS Classification:** GM
Offset: - **AASHTO Classification:** A-1-b (0)
Sample No.: S-1 to S-3 LL = 18 % PL = 16 %
Depth: 0.0-6.0 ft PI = 2 % w = 6.1%
Spec. Grav.: 2.7 (assumed)

Note: S-1 w%=5.9%, S-2 w%=4.9%, & S-3 w%=7.5%

NAVARRO & WRIGHT CONSULTING ENGINEERS, INC.

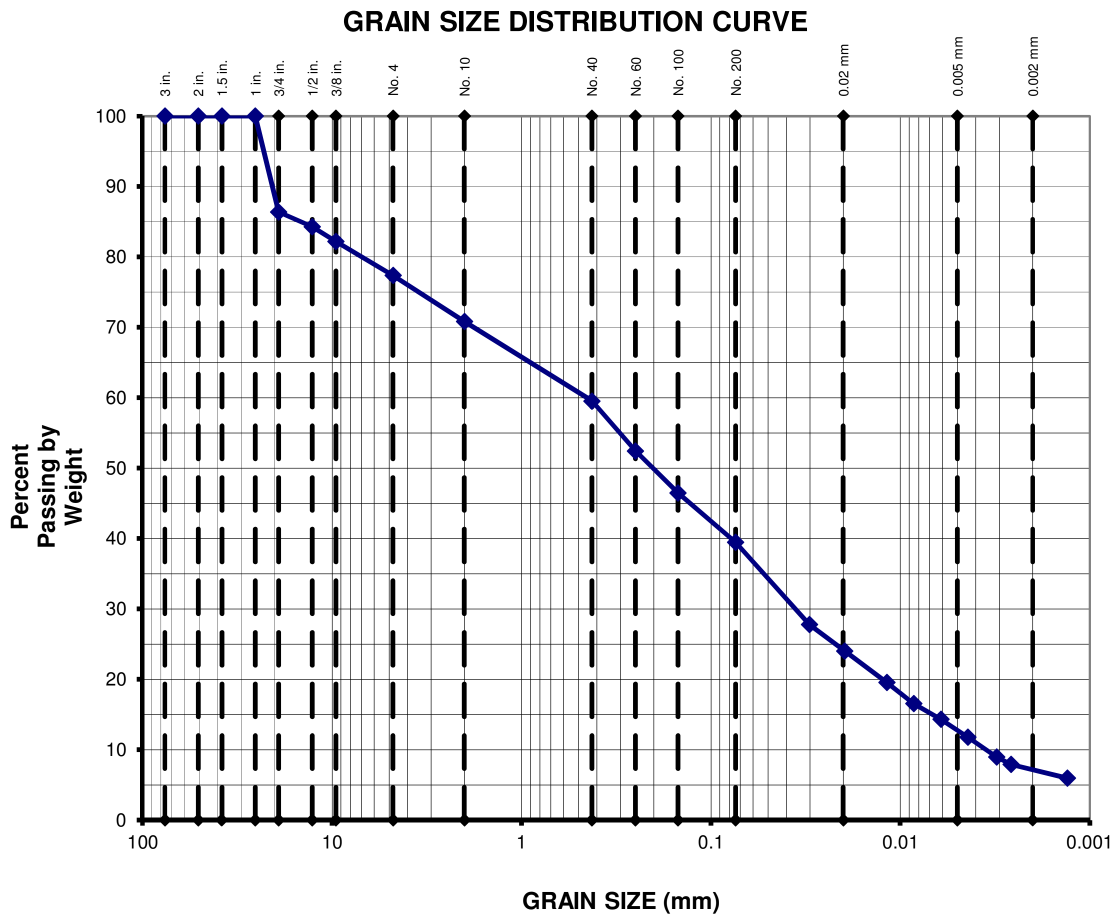
AASHTO R18

9/9/2019

Classification Testing Results

USCS & AASHTO

By: DFP Ckd: JDP



GRAVEL		SAND			FINES	
COARSE	FINE	COARSE	MEDIUM	FINE	SILT	CLAY
22.6%		37.9%			39.5%	
13.6%	9.0%	6.5%	11.3%	20.1%	26.8%	12.7%

GRAVEL			SAND		FINES	
COARSE	MEDIUM	FINE	COARSE	FINE	SILT	CLAY
29.1%			31.4%		39.5%	
0.0%	17.8%	11.3%	11.3%	20.1%	32.8%	6.7%

Project: Worlds End State Park
Soil Type: silty SAND with gravel
Boring No.: B-4
Station: -
USCS Classification: SM
Offset: -
AASHTO Classification: A-4 (0)
Sample No.: S-1 to S-2
LL = 19 % PL = 16 %
Depth: 0.0-4.0 ft
PI = 3 % w = 9.8%
Spec. Grav.: 2.71

Note: S-1 w%=11.9% & S-2 w%=8.0%

NAVARRO & WRIGHT CONSULTING ENGINEERS, INC.

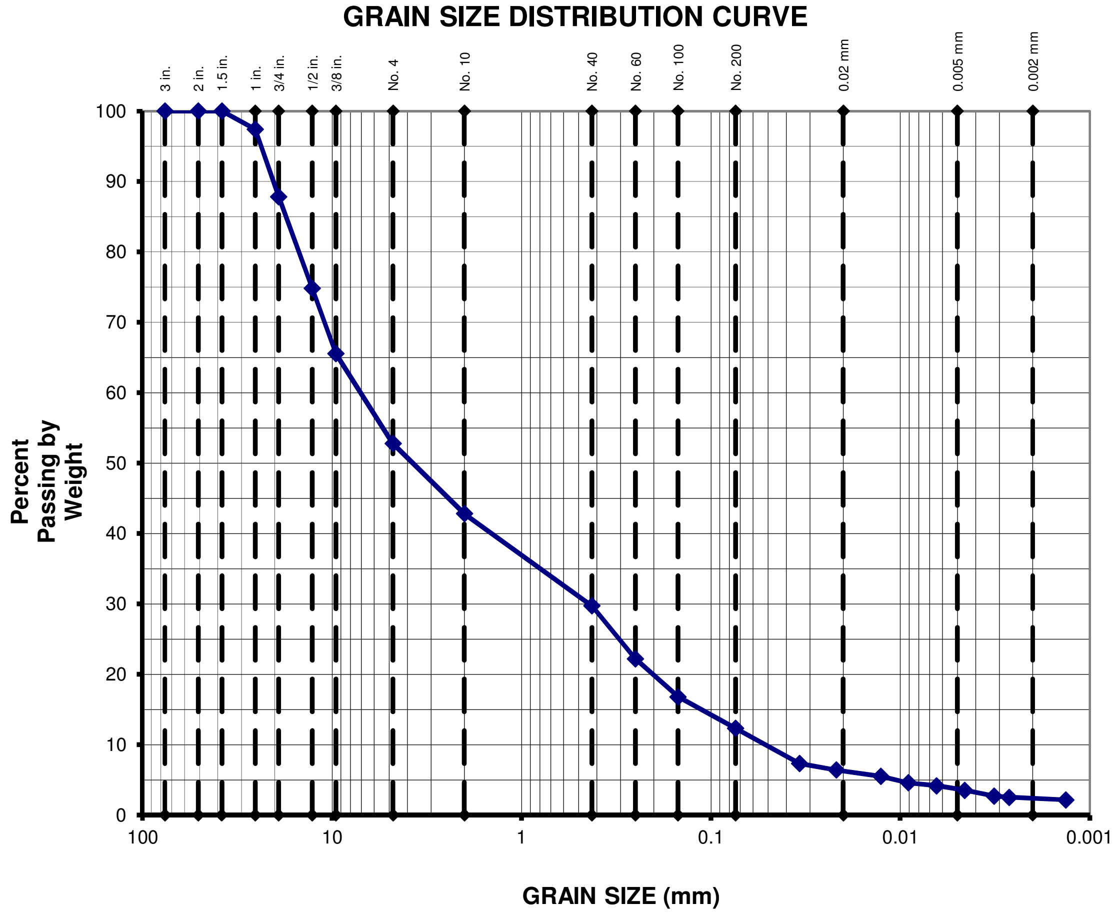
AASHTO R18

9/9/2019

Classification Testing Results

USCS & AASHTO

By: DFP Ckd: JDP



GRAVEL		SAND			FINES	
COARSE	FINE	COARSE	MEDIUM	FINE	SILT	CLAY
47.2%		40.4%			12.3%	
12.2%	35.1%	9.9%	13.1%	17.4%	8.7%	3.7%

GRAVEL			SAND		FINES	
COARSE	MEDIUM	FINE	COARSE	FINE	SILT	CLAY
57.2%			30.5%		12.3%	
2.6%	31.9%	22.7%	13.1%	17.4%	10.0%	2.3%

Project: Worlds End State Park
Soil Type: silty GRAVEL with sand
Boring No.: B-5
Station: -
USCS Classification: GM
Offset: -
AASHTO Classification: A-1-a (0)
Sample No.: S-2 to S-8
LL = NP PL = NP
Depth: 2.0-14.4 ft
PI = NP w = 10.1%
Spec. Grav.: 2.7 (assumed)

Note: S-2 w%=8.8 %, S-3 w%=8.3%, S-4 w%=10.0%, S-5 w%=11.1%, S-6 w%=11.9%, S-7 w%=11.1%, & S-8 w%=9.7%

NAVARRO & WRIGHT CONSULTING ENGINEERS, INC.

AASHTO R18

9/9/2019

Classification Testing Results

USCS & AASHTO

By: DFP Ckd: JDP

PROJECT NAME Worlds End State Park
PROJECT NUMBER 1712RE802-23
Date 9/9/2019

Boring No.	Sample Depth (ft.)	Rock Type	Sample Diam. (in)	Sample Height (in)	Load (lb)	Comp. Strength (tsf)	Failure Type	Sample Notes/ Remarks
B-1	12.1-14.5	silty sandstone	1.985	4.032	31850	741.0	shattered	R-1
B-4	12.0-14.0	sandstone	1.984	4.035	35430	825.1	shear	R-1
					Avg.	783.1		

Moisture Condition of Samples Air-dry
Temperature at Testing 72 deg.
Rate of Loading 150 lbs/sec
Direction of Load Application Vertical to core
ASTM D4543 Methods for Verifying Conformance to Dimensional & Shape Tolerances ES1, S1, FP1, & P1

NAVARRO & WRIGHT CONSULTING ENGINEERS, INC.

UNCONFINED COMPRESSIVE STRENGTH OF INTACT ROCK CORE

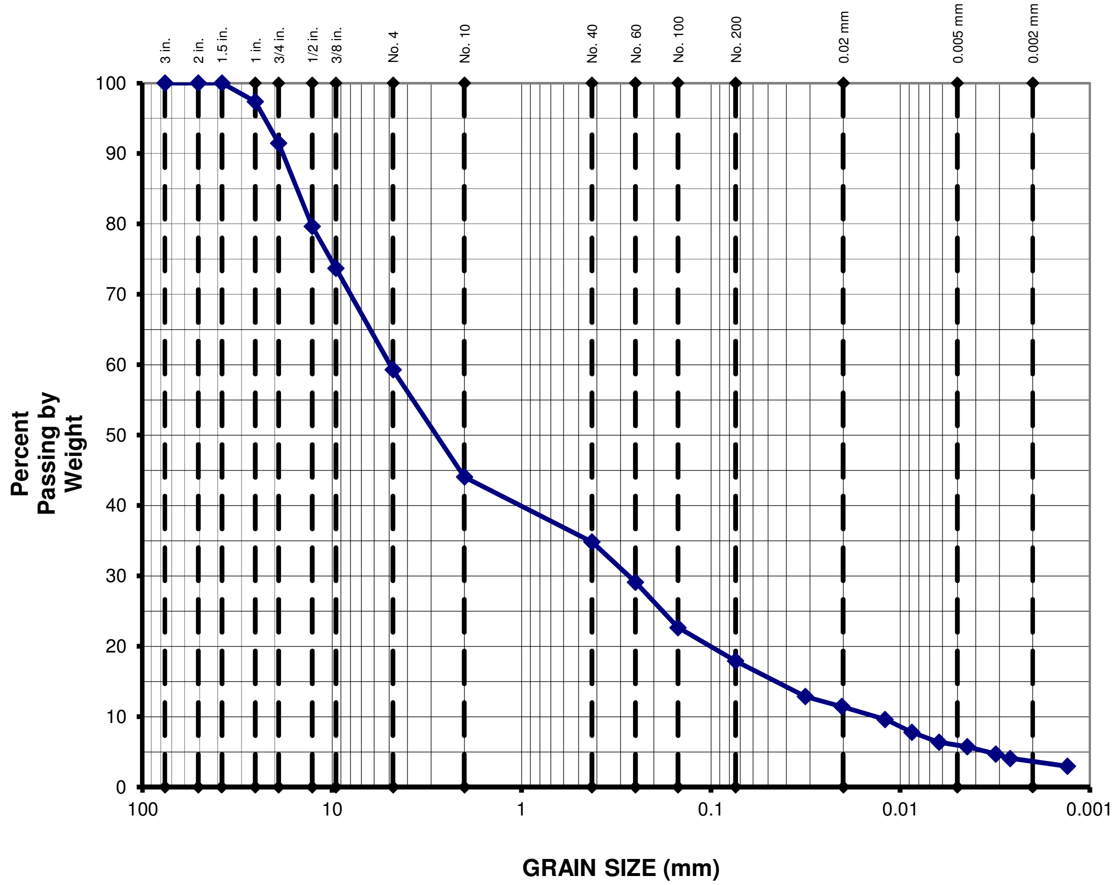
ASTM D7012-C

AAP® AASHTO R18

9/9/2019

By: JDP Ckd: DFP

GRAIN SIZE DISTRIBUTION CURVE



GRAVEL		SAND			FINES	
COARSE	FINE	COARSE	MEDIUM	FINE	SILT	CLAY
40.7%		41.4%			17.9%	
8.5%	32.2%	15.2%	9.3%	16.9%	12.0%	5.9%

GRAVEL			SAND		FINES	
COARSE	MEDIUM	FINE	COARSE	FINE	SILT	CLAY
55.9%			26.1%		17.9%	
2.6%	23.7%	29.6%	9.3%	16.9%	14.7%	3.3%

Project: Flood Repair-DR 4292 Area 6 Site 20 **Soil Type:** silty SAND with gravel
Boring No.: B-1
Station: 18 + 50.00 **USCS Classification:** SM
Offset: 6.0' RT **AASHTO Classification:** A-1-b (0)
Sample No.: S-2 to S-7 LL = NP PL = NP
Depth: 2.0-12.6 ft PI = NP w = 7.3%
Spec. Grav.: 2.7 (assumed)

NAVARRO & WRIGHT CONSULTING ENGINEERS, INC.

AASHTO R18

7/18/2019

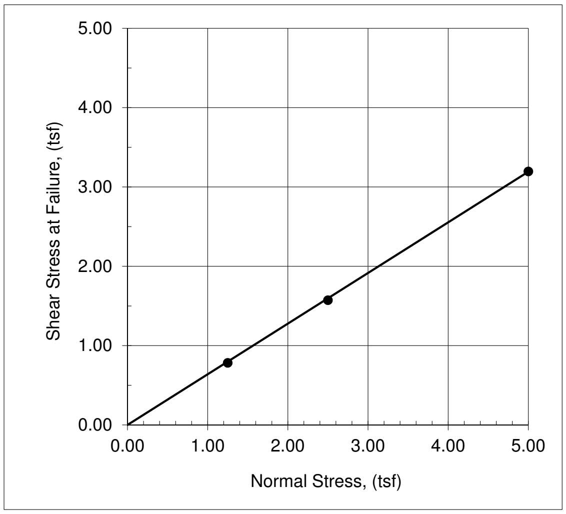
Classification Testing Results

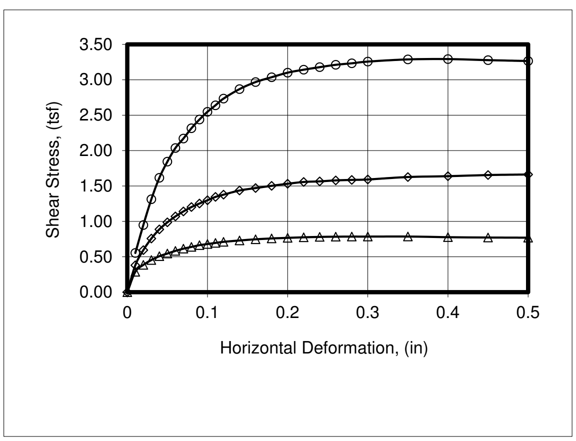
USCS & AASHTO

By: DFP Ckd: JDP

COHESION	**0.0**	**PSF**
FRICTION ANGLE	**32.6**	**Degrees**
TAN FRICTION ANGLE	**0.64**	

	SAMPLE NO.		1	2	3
Initial	Water Content, %	w_0	7.9%	7.9%	7.9%
	Dry Density, pcf	γ_d	120.4	120.4	120.4
	Moist Density, pcf	γ_m	130.0	130.0	130.0
	Void Ratio	e_0	0.40	0.40	0.40
	Saturation, %	S_0	53.8%	53.8%	53.8%
Void ratio after consolidation		e_c	0.27	0.23	0.17
Final	Water Content, %	w_f	13.1%	12.2%	11.5%
	Dry Density, pcf	γ_d	131.0	137.8	145.6
	Moist Density, pcf	γ_m	148.1	154.5	162.4
	Void Ratio	e_f	0.22	0.18	0.13





Sample Type: remolded (4 inch dia.)
Test Type: Consolidated/Drained
Loading Rate: 0.002 in/min
Soil Description: -

USCS/AASHTO: -
LL : - **PI:** -
Spec. Grav. = 2.70 (assumed)
Nat. Moisture = 7.6%
Project: Flood Repairs - DR 4292-6-20
Boring No.: B-1, B-2, B-3
Station: - **Offset:** -
Sample No.: S-2 to S-7 Composite
Sample Depth (ft.): 2.0-12.6
Tested By: JDP
Checked By: DFP

Normal Stress, tsf	1.250	2.500	5.000
Shear Stress at Failure,tsf	0.782	1.572	3.195
Residual Shear Stress, tsf	#N/A	#N/A	#N/A

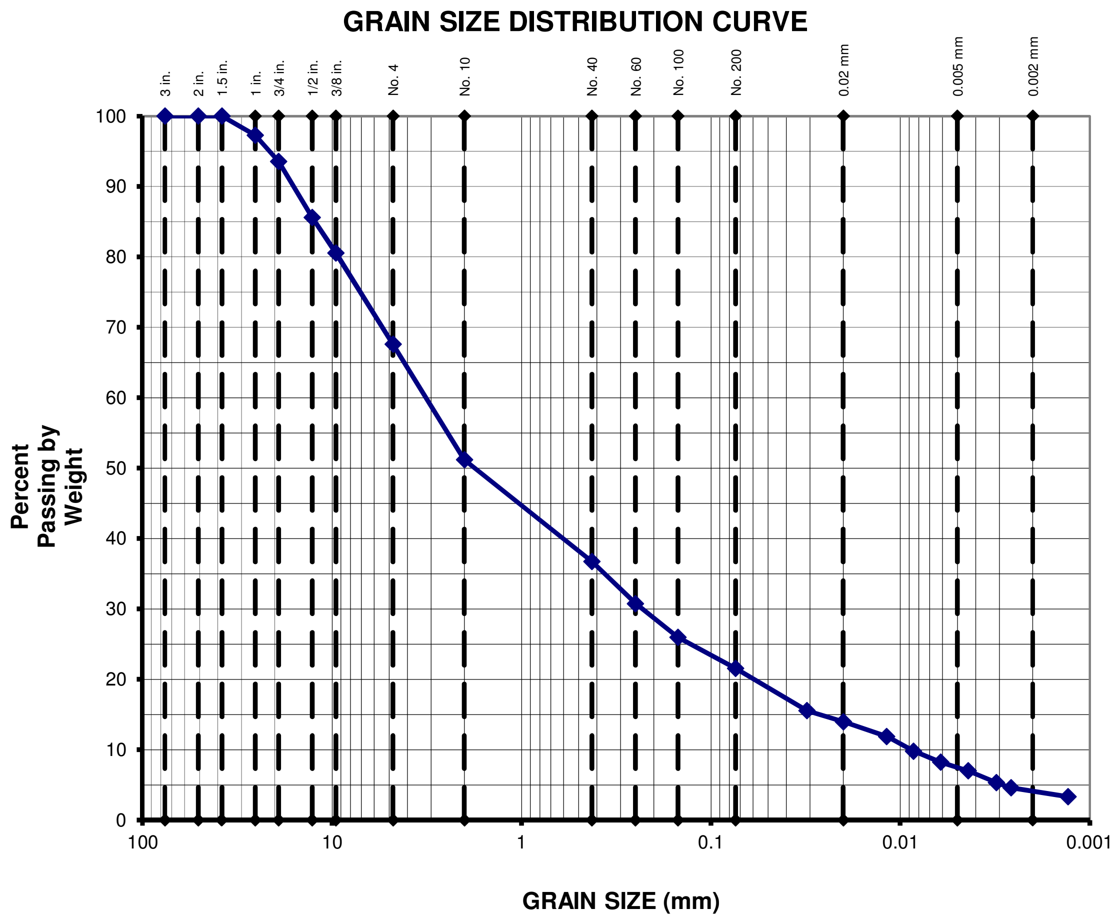
NAVARRO & WRIGHT CONSULTING ENGINEERS, INC.

AASHTO R18

DIRECT SHEAR TEST REPORT

AASHTO T 236-92
ASTM D 3080-04

7/16/2019



GRAVEL		SAND			FINES	
COARSE	FINE	COARSE	MEDIUM	FINE	SILT	CLAY
32.4%		46.0%			21.6%	
6.4%	26.0%	16.4%	14.4%	15.2%	14.1%	7.4%

GRAVEL			SAND		FINES	
COARSE	MEDIUM	FINE	COARSE	FINE	SILT	CLAY
48.8%			29.6%		21.6%	
2.7%	16.7%	29.4%	14.4%	15.2%	17.8%	3.7%

Project: Flood Repair-DR 4292 Area 6 Site 20 **Soil Type:** silty SAND with gravel
Boring No.: B-2
Station: 20 + 00 **USCS Classification:** SM
Offset: 8.0' RT **AASHTO Classification:** A-1-b (0)
Sample No.: S-2 to S-7 LL = 19 % PL = 17 %
Depth: 2.0-12.4 ft PI = 2 % w = 7.7%
Spec. Grav.: 2.73

NAVARRO & WRIGHT CONSULTING ENGINEERS, INC.

AASHTO R18

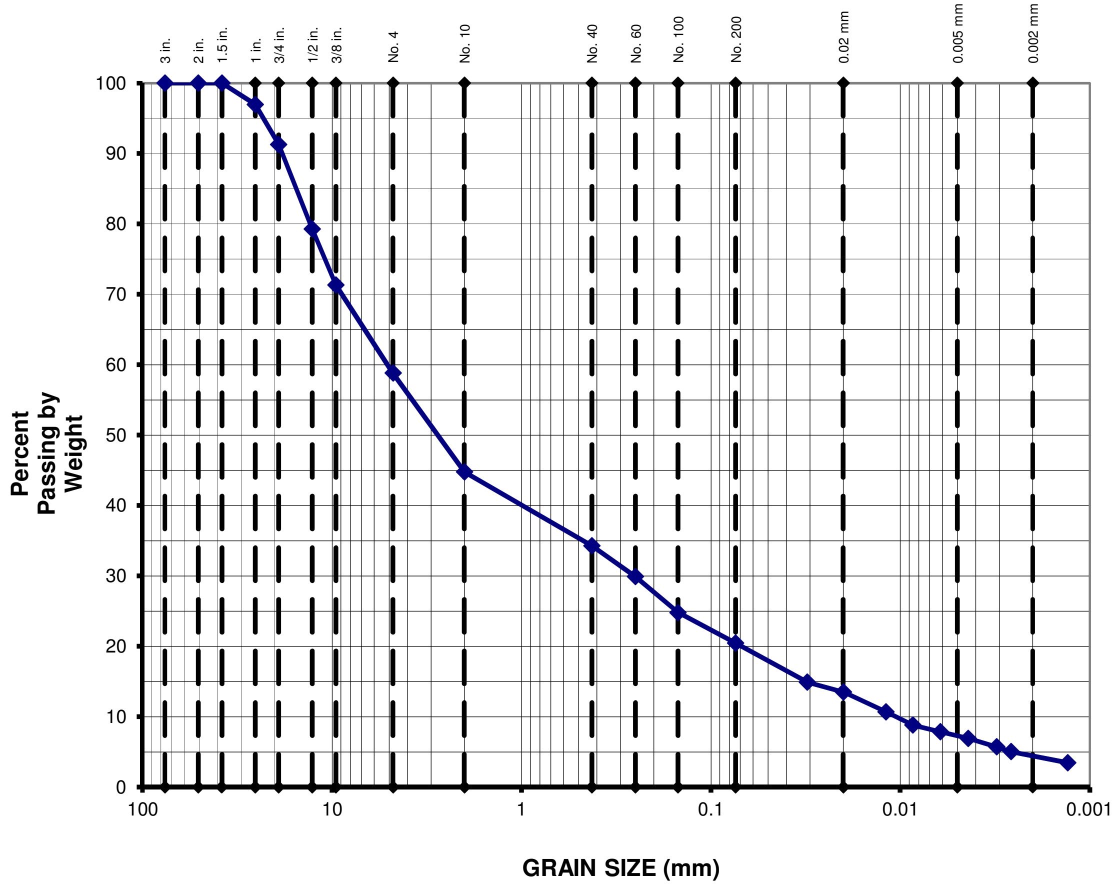
7/18/2019

Classification Testing Results

USCS & AASHTO

By: DFP Ckd: JDP

GRAIN SIZE DISTRIBUTION CURVE



GRAVEL		SAND			FINES	
COARSE	FINE	COARSE	MEDIUM	FINE	SILT	CLAY
41.2%		38.4%			20.4%	
8.7%	32.5%	14.0%	10.5%	13.8%	13.2%	7.3%

GRAVEL			SAND		FINES	
COARSE	MEDIUM	FINE	COARSE	FINE	SILT	CLAY
55.2%			24.4%		20.4%	
3.0%	25.6%	26.5%	10.5%	13.8%	16.2%	4.3%

Project: Flood Repair-DR 4292 Area 6 Site 20 **Soil Type:** silty GRAVEL with sand
Boring No.: B-3
Station: 21 + 50.00 **USCS Classification:** GM
Offset: 6.0' RT **AASHTO Classification:** A-1-b (0)
Sample No.: S-2 to S-6 LL = 20 % PL = 18 %
Depth: 2.0-11.7 ft PI = 2 % w = 7.8%
Spec. Grav.: 2.7 (assumed)

NAVARRO & WRIGHT CONSULTING ENGINEERS, INC.

AASHTO R18

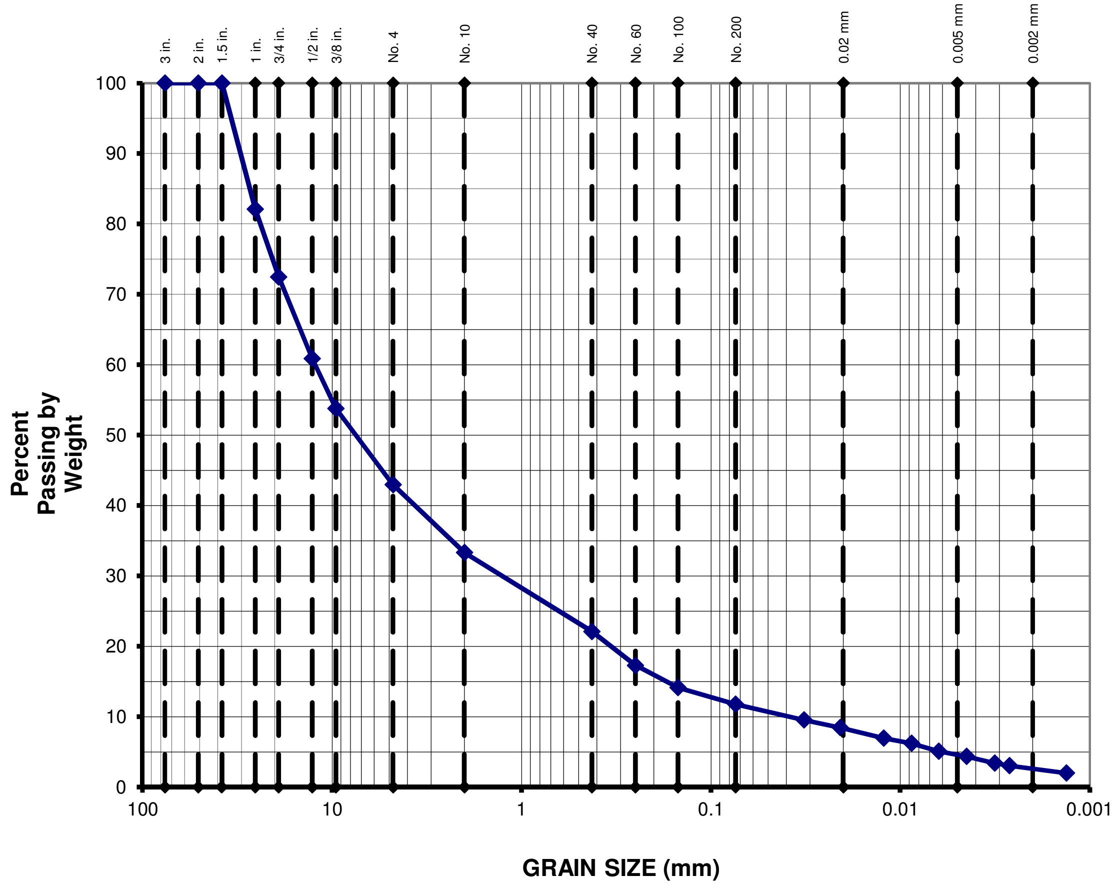
7/18/2019

Classification Testing Results

USCS & AASHTO

By: DFP Ckd: JDP

GRAIN SIZE DISTRIBUTION CURVE



GRAVEL		SAND			FINES	
COARSE	FINE	COARSE	MEDIUM	FINE	SILT	CLAY
57.0%		31.2%			11.8%	
27.5%	29.5%	9.7%	11.2%	10.3%	7.2%	4.6%

GRAVEL			SAND		FINES	
COARSE	MEDIUM	FINE	COARSE	FINE	SILT	CLAY
66.7%			21.5%		11.8%	
17.9%	28.3%	20.5%	11.2%	10.3%	9.2%	2.6%

Project: Flood Repair-DR 4292 Area 6 Site 20
Boring No.: B-5
Station: 103 + 61.00
Offset: 10.0' LT
Sample No.: S-2 to S-4
Depth: 2.0-8.0 ft
Spec. Grav.: 2.68

Soil Type: poorly graded GRAVEL with silt and sand
USCS Classification: GP-GM
AASHTO Classification: A-1-a (0)
LL = NP PL = NP
PI = NP w = 8.8%

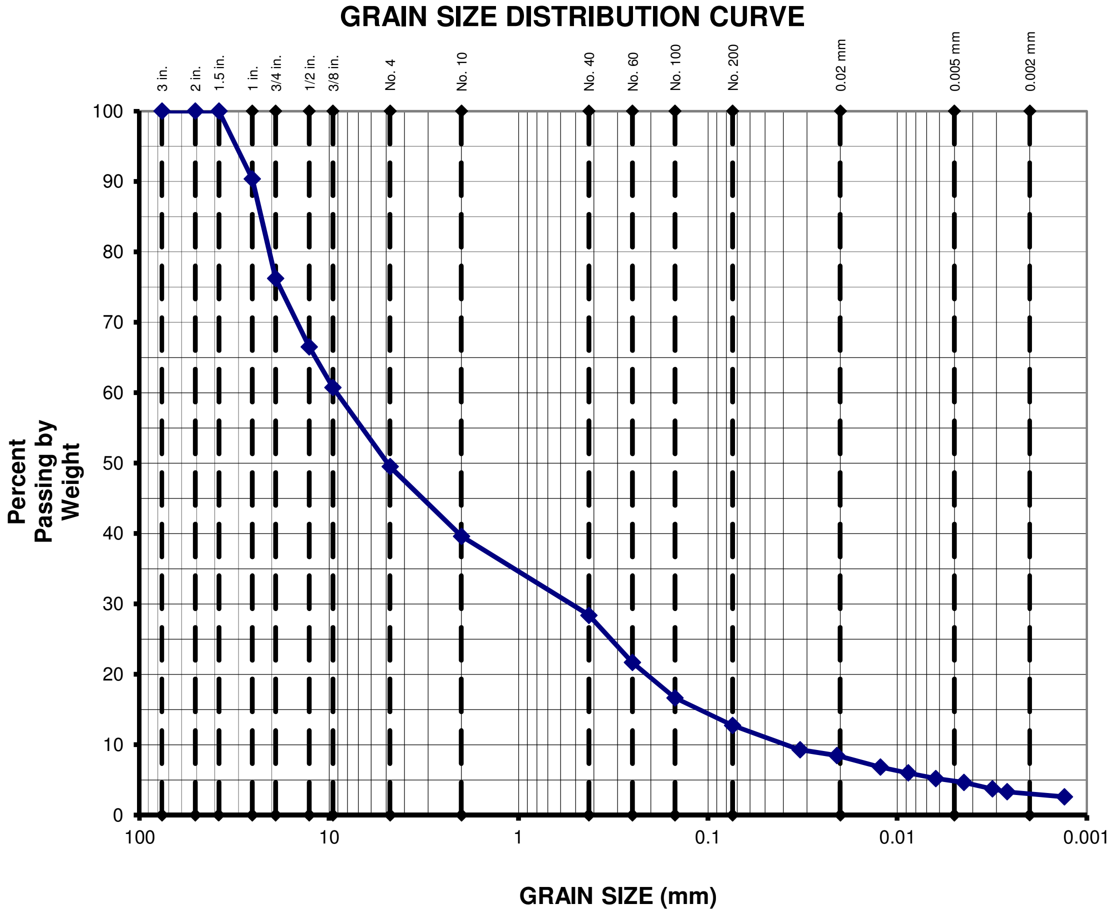
NAVARRO & WRIGHT CONSULTING ENGINEERS, INC.

7/18/2019

Classification Testing Results

USCS & AASHTO

By: DFP Ckd: JDP



GRAVEL		SAND			FINES	
COARSE	FINE	COARSE	MEDIUM	FINE	SILT	CLAY
50.5%		36.7%			12.8%	
23.8%	26.7%	9.9%	11.2%	15.6%	7.9%	4.8%

GRAVEL			SAND		FINES	
COARSE	MEDIUM	FINE	COARSE	FINE	SILT	CLAY
60.4%			26.9%		12.8%	
9.6%	29.6%	21.1%	11.2%	15.6%	9.9%	2.8%

Project: Flood Repair-DR 4292 Area 6 Site 20 **Soil Type:** silty GRAVEL with sand
Boring No.: B-5
Station: 103 + 61.00 **USCS Classification:** GM
Offset: 10.0' LT **AASHTO Classification:** A-1-a (0)
Sample No.: S-5 to S-13 LL = NP PL = NP
Depth: 8.0-26.0 ft PI = NP w = 8.4%
Spec. Grav.: 2.7 (assumed)

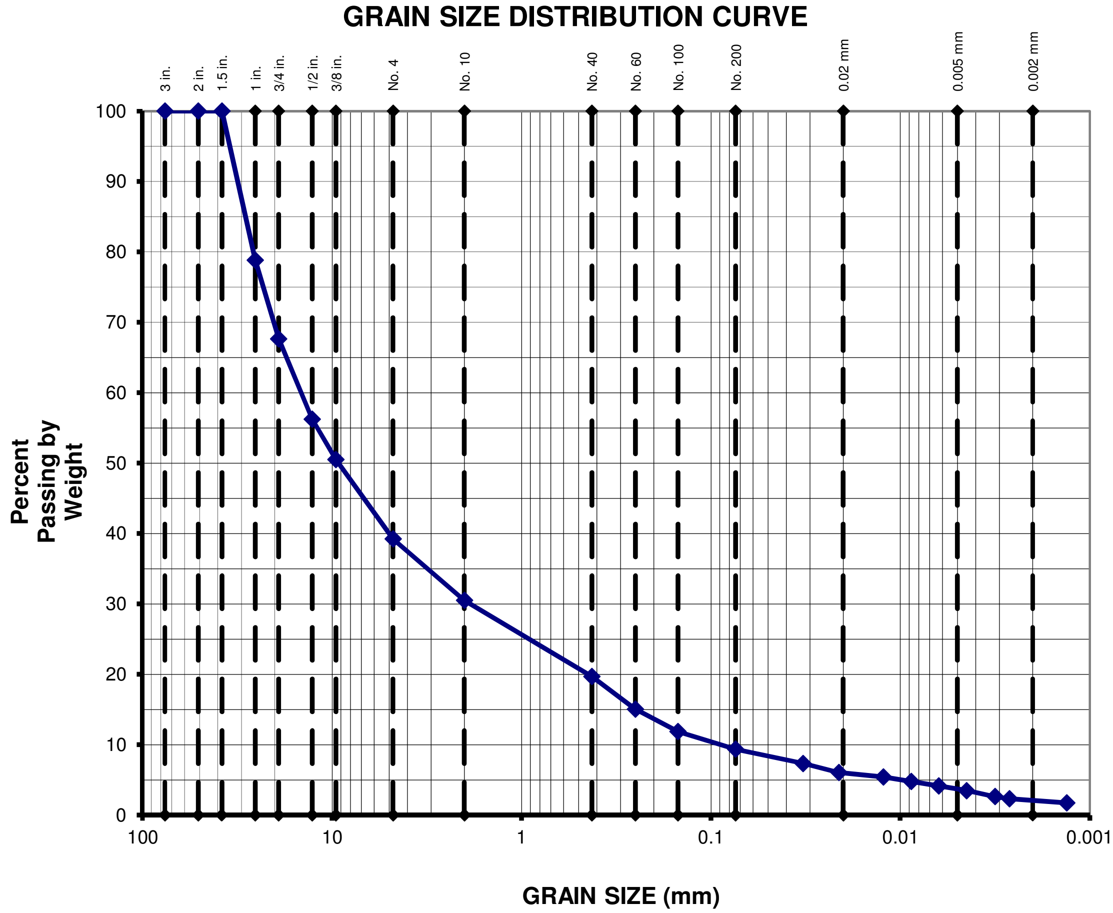
NAVARRO & WRIGHT CONSULTING ENGINEERS, INC.

7/18/2019

Classification Testing Results

USCS & AASHTO

By: DFP Ckd: JDP



GRAVEL		SAND			FINES	
COARSE	FINE	COARSE	MEDIUM	FINE	SILT	CLAY
60.7%		29.9%			9.4%	
32.3%	28.4%	8.7%	10.8%	10.3%	5.7%	3.7%

GRAVEL			SAND		FINES	
COARSE	MEDIUM	FINE	COARSE	FINE	SILT	CLAY
69.5%			21.2%		9.4%	
21.2%	28.3%	20.0%	10.8%	10.3%	7.4%	1.9%

Project:	Flood Repair-DR 4292 Area 6 Site 20	**Soil Type:**	well-graded GRAVEL with silt and sand
Boring No.:	B-6		
Station:	104 + 06.00	**USCS Classification:**	GW-GM
Offset:	2.0' LT	**AASHTO Classification:**	A-1-a (0)
Sample No.:	S-2 to S-8	LL = NP	PL = NP
Depth:	2.0-16.0 ft	PI = NP	w = 7.1%
Spec. Grav.:	2.7 (assumed)		

NAVARRO & WRIGHT CONSULTING ENGINEERS, INC.

AASHTO R18

7/18/2019

Classification Testing Results

USCS & AASHTO

By: DFP Ckd: JDP

Boring No.	Sample No.	Sample Depth (ft)	pH (H_2O)	pH ($CaCl_2$)	Chloride Content in Soil (mg/kg)	Sulfate Content in Soil (mg/kg)	Chloride Content in Water (mg/L)	Sulfate Content in Water (mg/L)	Soil Resistivity (kohms x cm)	* Soil Classification
B-6	Bulk	8.0-16.0	7.3	4.9	50	0	-	-	30.503	-

* Uppercase denotes laboratory classification, lowercase denotes visual classification.

Project: Flood Repairs - DR 4292 - Area 6, Site 20
Project #: 1712RE802
Test Date: 7/17/2019
Tested By: JDP
Checked By: DFP

NAVARRO & WRIGHT CONSULTING ENGINEERS, INC.

AASHTO R18

CHEMICAL TESTING SUMMARY

pH - ASTM D 4972 / AASHTO T289
Soil Resistivity ASTM G187
Chloride - AASHTO T291 / ASTM D512, Sulfate - AASHTO T290 / ASTM D516

PROJECT NAME Flood Repairs - DR 4292 - Area 6, Site 20
PROJECT NUMBER 1712RE802
Date 7/17/2019

Boring No.	Sample Depth (ft.)	Rock Type	Sample Diam. (in)	Sample Height (in)	Load (lb)	Comp. Strength (tsf)	Failure Type	Sample Notes/ Remarks
B-2	13.0-13.7	sandstone	1.988	4.013	54250	1258.4	shear	R-1
B-3	12.5-13.2	sandstone	1.989	4.025	61310	1420.7	conical	R-1
					Avg.	1339.5		

Moisture Condition of Samples Air-dry
Temperature at Testing 72 deg.
Rate of Loading 150 lbs/sec
Direction of Load Application Vertical to core
ASTM D4543 Methods for Verifying Conformance to Dimensional & Shape Tolerances ES1, S1, FP1, & P1

NAVARRO & WRIGHT CONSULTING ENGINEERS, INC.

UNCONFINED COMPRESSIVE STRENGTH OF INTACT ROCK CORE

ASTM D7012-C

AASHTO R18

7/17/2019

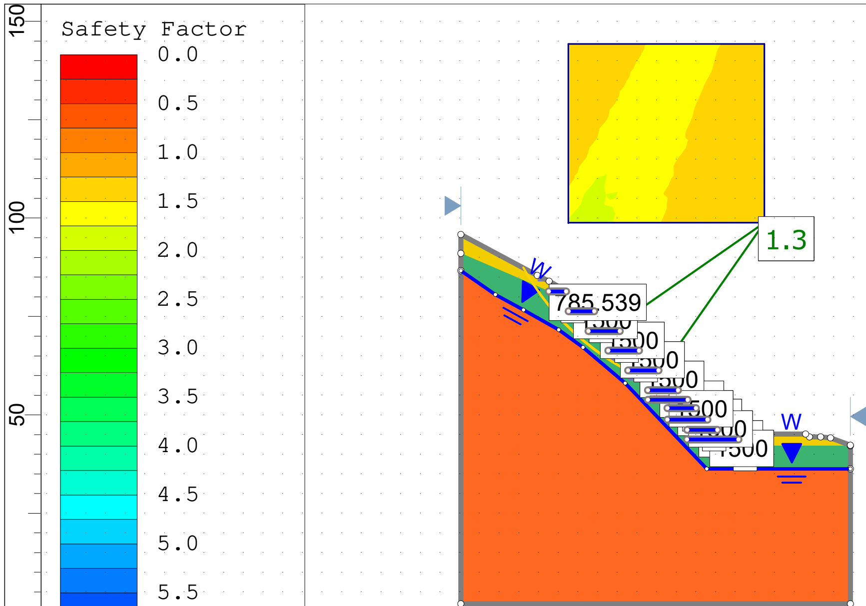
By: JDP Ckd: DFP

NAVARRO & WRIGHT GEOTECHNICAL LABORATORY
Unit Weight

PROJECT: Flood Repairs-DR 4292 Area 6, Site 20	Date: July 18, 2018
JOB No: 1712RE802	Tested By: DFP

Boring No.	Sample No.	Depth (ft.)	Diameter (in.)	Length (in.)	Unit Weight pcf (dry)	Water Content (%)
B-1	S-2 to S-7	2.0-12.6	1.47	3.83	131.6	7.3%
B-2	S-2 to S-7	2.0-12.4	1.40	1.62	121.4	7.7%
B-3	S-2 to S-6	2.0-11.7	1.43	3.08	134.5	7.8%
B-5	S-5 to S-13	8.0-26.0	1.54	3.78	117.1	8.4%

APPENDIX C: GEOTECHNICAL CALCULATIONS FROM LOYALSOCK STATE FOREST GEOTECHNICAL ENGINEERING REPORT



Method Name	Min FS
Bishop simplified	1.3

Note: Surficial failures expected to be managed during construction and were excluded from Analysis

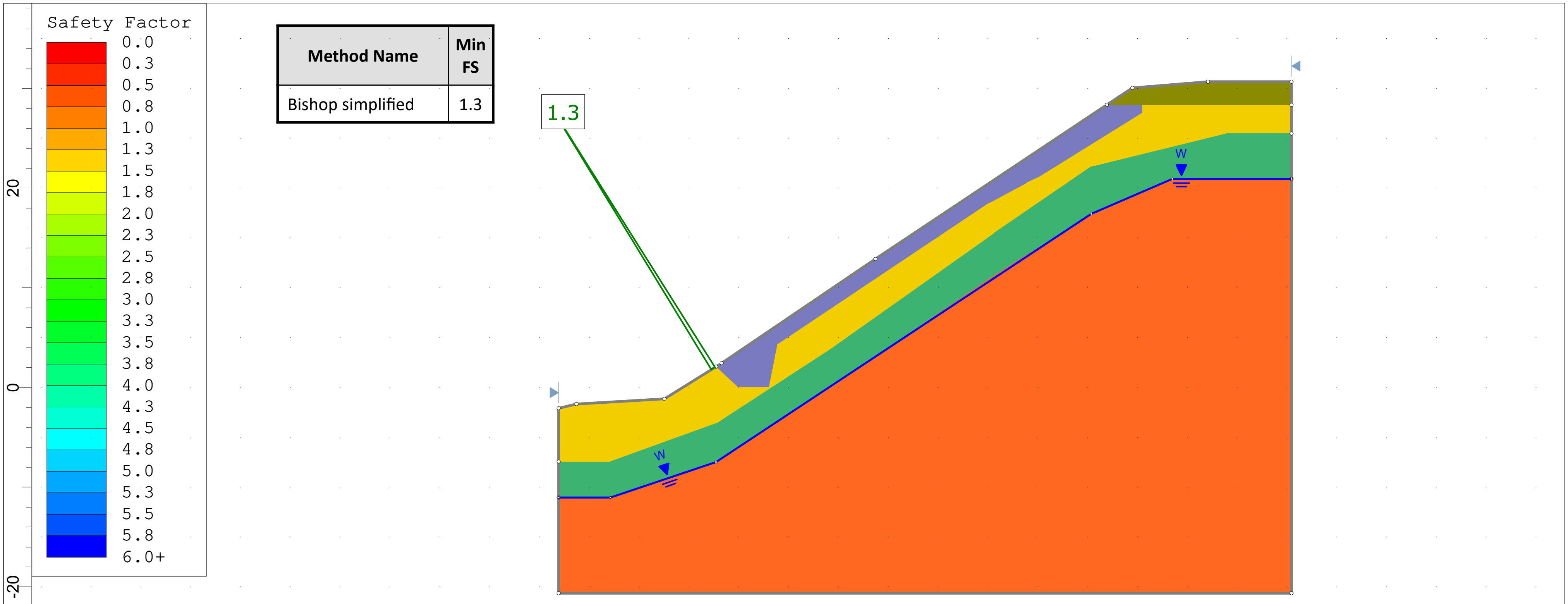
Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	UCS (psf)	GSI	mi	D	Water Surface	Hu Type	Hu
Surficial a-2-4, gm		135	Mohr-Coulomb	0	38					Water Surface	Custom	1
MBR Cobbles/Boulders		145	Mohr-Coulomb	0	40					Water Surface	Custom	1
Sandstone Bedrock		160	Generalized Hoek-Brown			1.5e+06	40	17	0	Water Surface	Custom	1
Rip-Rap		160	Mohr-Coulomb	0	45					Water Surface	Custom	1
Roadway		135	Mohr-Coulomb	50	35					Water Surface	Custom	1

Support Name	Color	Type	Force Application	Material Dependent	Adhesion (psf)	Friction Angle (deg)	Shear Strength Model	Force Orientation	Anchorage	Strip Coverage (%)	Tensile Strength (lbs/ft)
Geotextile		GeoTextile	Passive (Method B)	No	0	40	Linear	Parallel to Reinforcement	None	100	1500

-150 -100 -50 0 50 100 150 200 250 300

Project	Loyalsock State Forest Flood Repairs Area 6, Site 20		
Analysis Description	Detail 1		
Drawn By WNB	*Scale* 1:585	*Company*	Navarro & Wright
Date 10/14/2019		*File Name*	Detail-1.slmd

SLIDEINTERPRET 8.014

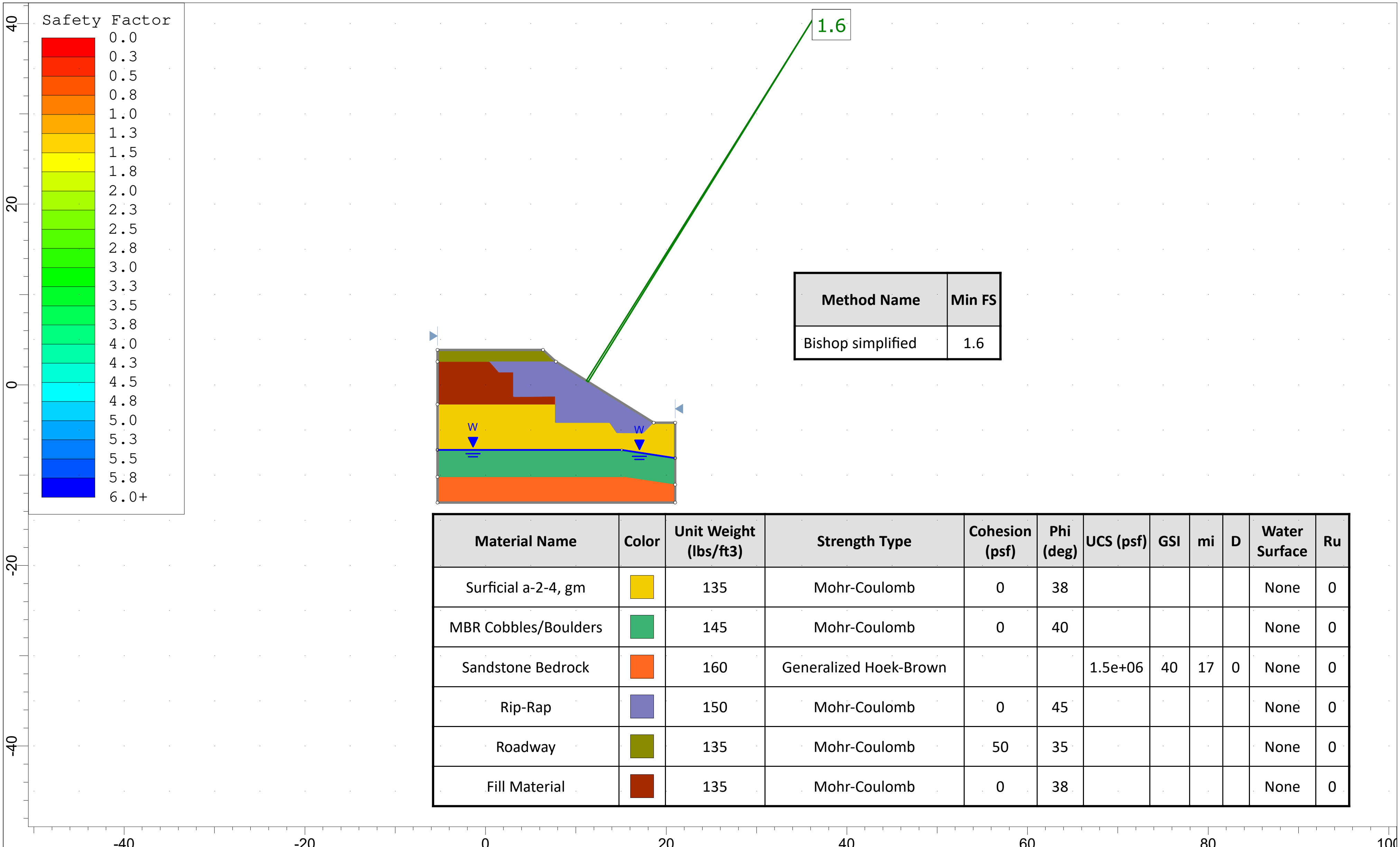


Method Name	Min FS
Bishop simplified	1.3

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	UCS (psf)	GSI	mi	D	Water Surface	Hu Type	Hu
Surficial a-2-4, gm		135	Mohr-Coulomb	0	38					Water Surface	Custom	1
MBR Cobbles/Boulders		145	Mohr-Coulomb	0	40					Water Surface	Custom	1
Sandstone Bedrock		160	Generalized Hoek-Brown			1.5e+06	40	17	0	Water Surface	Custom	1
Rip-Rap		160	Mohr-Coulomb	0	45					Water Surface	Custom	1
Roadway		135	Mohr-Coulomb	50	35					Water Surface	Custom	1

SLIDEINTERPRET 8.014

Project	Loyalsock State Forest Flood Repairs Area 6, Site 20
Analysis Description	Detail 2
Drawn By	WNB
Scale	1:179
Company	Navarro & Wright
Date	10/14/2019
File Name	Detail-2.slmd



Method Name	Min FS
Bishop simplified	1.6

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	UCS (psf)	GSI	mi	D	Water Surface	Ru
Surficial a-2-4, gm		135	Mohr-Coulomb	0	38					None	0
MBR Cobbles/Boulders		145	Mohr-Coulomb	0	40					None	0
Sandstone Bedrock		160	Generalized Hoek-Brown			1.5e+06	40	17	0	None	0
Rip-Rap		150	Mohr-Coulomb	0	45					None	0
Roadway		135	Mohr-Coulomb	50	35					None	0
Fill Material		135	Mohr-Coulomb	0	38					None	0

Project	Loyalsock State Forest Flood Repairs Area 6, Site 20		
Analysis Description	Detail 3		
Drawn By WNB	*Scale* 1:176	*Company*	Navarro & Wright
Date	10/22/2019	*File Name*	Detail-3.slmd

SLIDEINTERPRET 8.014

Soil Parameters for RocScience Analysis

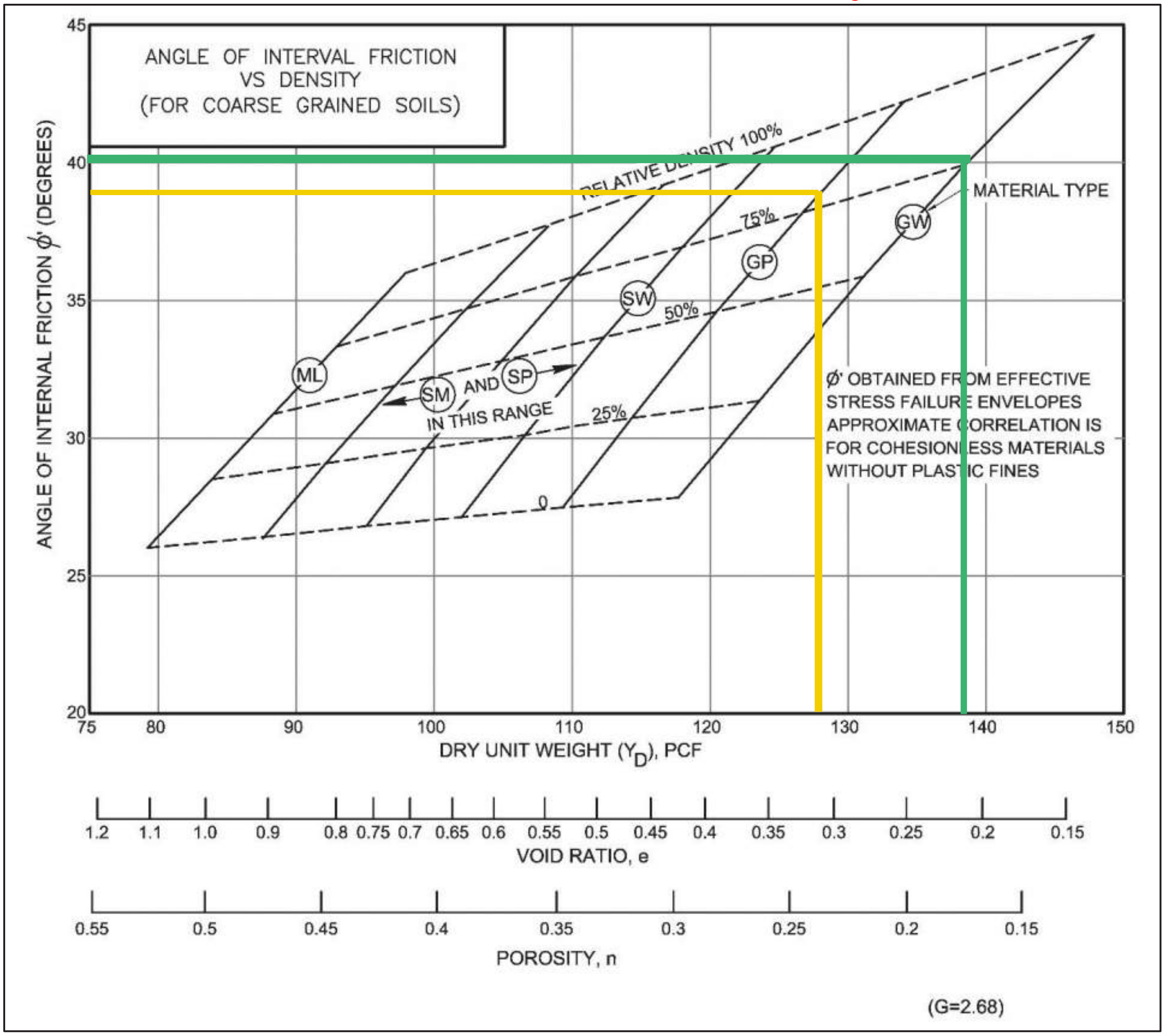


Figure 5.5.3.1.1-1 – Correlations of Effective Angle of Friction

Parameters based on material from B-4

Phi = 38 degrees

Moist Unit Weight = 128(1+0.05)= 135 pcf

Phi = 40 Degrees
Moist Unit Weight = 138(1+0.05) = 145 pcf
Fill material expected to be from nearby and thusly similar to surficial gm

Type A Rock

The vast majority of projects do not contain sufficiently thick layers of Type A Rock which can be excavated cleanly. Therefore, unless otherwise approved by PTC-Geotech, assume that all Type A Rock specified for a project will be obtained from an outside source. The utilization of Type A Rock should be limited to areas where significantly high drainage flow is anticipated or high strength is required, i.e., 1:1 embankment. In the contract, provide a borrow quantity for the amount of Type A Rock required for construction. Use typical strength parameters in the range of phi = 40 to 45 degrees or higher for Type A Rock design.

Type B Rock

In order to access the constructability of a project, during design, tabulate the quantity of Type B Rock available from the project excavation. Do not consider seams less than 10 ft thick or seams that are not greater than 90% pure in the tabulation. Furthermore, use a reduction factor of: 20% for seams 10 to 15 ft thick; 15% for seams 15 to 20 ft thick; and 10% for seams over 20 ft thick. Identify in-situ locations and quantities of Type B Rock available. Make comparisons between the rock available from excavations and the rock required for construction. If appropriate, consider staging.

Type B Rock is acceptable as rock toe material, even below drainage, where conditions are anticipated to be saturated and/or with normal seepage. The typical strength parameter range for Type B Rock is phi = 36 to 40 degrees.

Utilize Phi = 45 for Type A Rip Rap

Type C Rock

Type C Rock is an uncontrolled mixture of all rock available on the project excluding large quantities of slaking claystone, redbeds, and other forms of clay, silt, sand or mud. In some situations, Type C Rock can be specified for use when other rock types are not available. Typical strength parameters can not be readily defined because of the project specific nature of this rock type.

C. Dynamic Pile Load Testing Guidelines

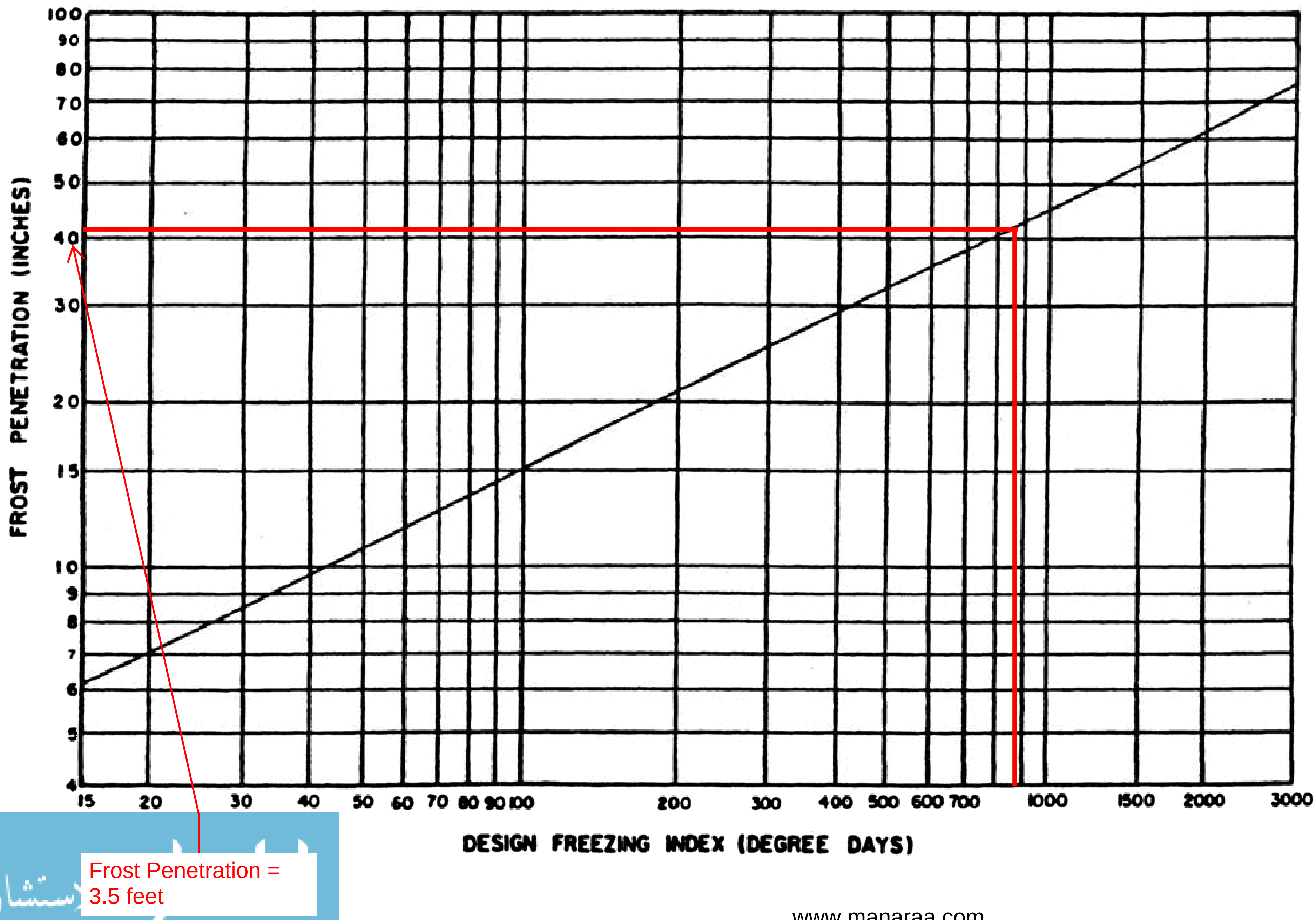
GENERAL

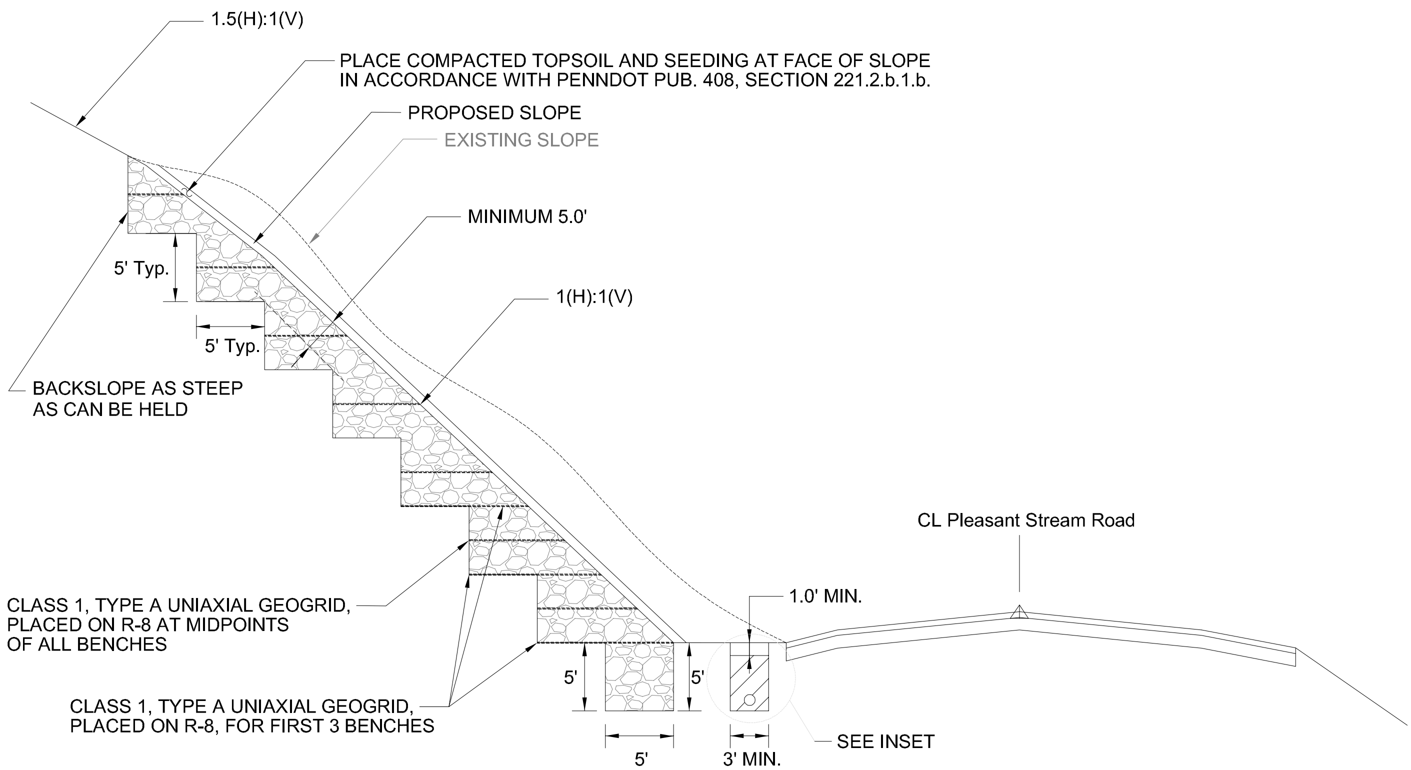
A. Driving in accordance with Section 1005.
B. Drive test and/or bearing piles to absolute refusal, unless otherwise indicated or directed.
C. The amount of Dynamic Pile Test locations is to be determined according to the characteristics of each structure. Specify two (2) tests per substructure unit unless otherwise directed.
D. The Engineer may request additional piles to be dynamically tested if the hammer and/or driving system is replaced or modified, the pile type or installation procedures are modified, the pile capacity requirements are changed, unusual blow counts or penetrations are observed on any other piling behavior different from normal installation.

DISTRICT 3			
Location	**Elevation**	**Index**	**Winter**
Bradford County			
Canton 1 mi. NW		1231	62-63
Towanda	1520	915	62-63
Columbia County			
Berwick	570	982	62-63
Millville 2 mi. SW	860	1179	62-63
Lycoming County			
English Center	880	1167	62-63
Williamsport Airport	527	886	62-63
Montour County			
Northumberland County			
Sunbury	480	925	62-63
Snyder County			
Sullivan County			
Eagles Mere	2020	1167	62-63
Tioga County			
Lawrenceville 2 mi. S	1000	1009	62-63
Wellsboro	1920	1329	62-63
Union County			

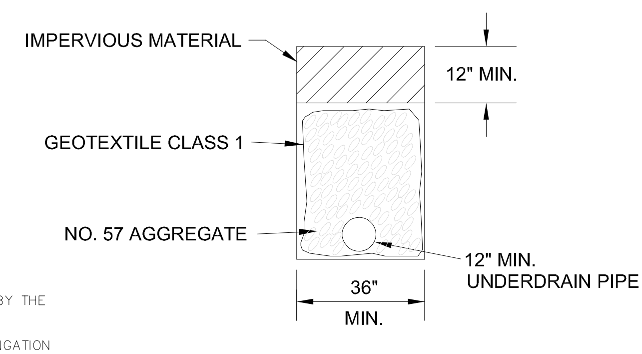
DISTRICT 4			
Location	**Elevation**	**Index**	**Winter**
Luzerne County			
Bear Ck. Dam	1700	1381	62-63
Freeland		1029	62-63
Scranton Wilkes-Barre (Airport WB)	940	921	62-63
Lackawanna County			
Scranton	746	930	62-63
Pike County			
Hawley	880	1225	62-63
Susquehanna County			
Montrose	1560	1380*	62-63
Wayne County			
Pleasant Mt. 1 mi. W	1800	1502*	62-63
Wyoming County			
Dixon	750	1101	62-63

FIGURE 9.1
DESIGN CHART FOR DETERMINATION OF FROST PENETRATION





1 (H):1 (V) SLOPE SECTION
N.T.S.



INSET

NOTES:

1. FOR NEW EMBANKMENTS OF RIP-RAP, FILL BENCHES SHOULD BE CUT FROM TOP DOWN BEFORE PLACING RIP-RAP.
2. LEAVE NO MORE THAN 25 FEET OF FULL DEPTH EXCAVATION OPEN BEFORE BACKFILLING WITH RIP-RAP.
3. PROVIDE A LAYER OF GEOTEXTILE, CLASS 4, TYPE A BETWEEN THE R-8 RIP-RAP AND SUBBASE, AS DEFINED BY PENNDOT PUB. 408.
4. PROVIDE FILL BENCH CONFIGURATIONS AND NOMINAL SLOPES ON THE ACTUAL CROSS SECTIONS.
5. BONDING BENCHES SHALL BE KEYED INTO BEDROCK UNLESS OTHERWISE APPROVED BY THE REPRESENTATIVE.
6. CLASS 1, TYPE A GEOGRID SHALL HAVE A MINIMUM TENSILE STRENGTH AT 10% ELONGATION OF 3800 PSF AND SHALL BE PLACED IN ACCORDANCE WITH PUB. 408, SECTION 221.3.

N:_2017\1712RE802 DCNR\Geotechnical\WO20 Area 6 Site 20 Loyalsock State Forest\CADD\SteppedSlopeDetail.dwg

1 (H):1 (V) Slope Section

Loyalsock State Forest Flood Repairs
Area 6 Site 20, McIntyre Township, Lycoming County, PA

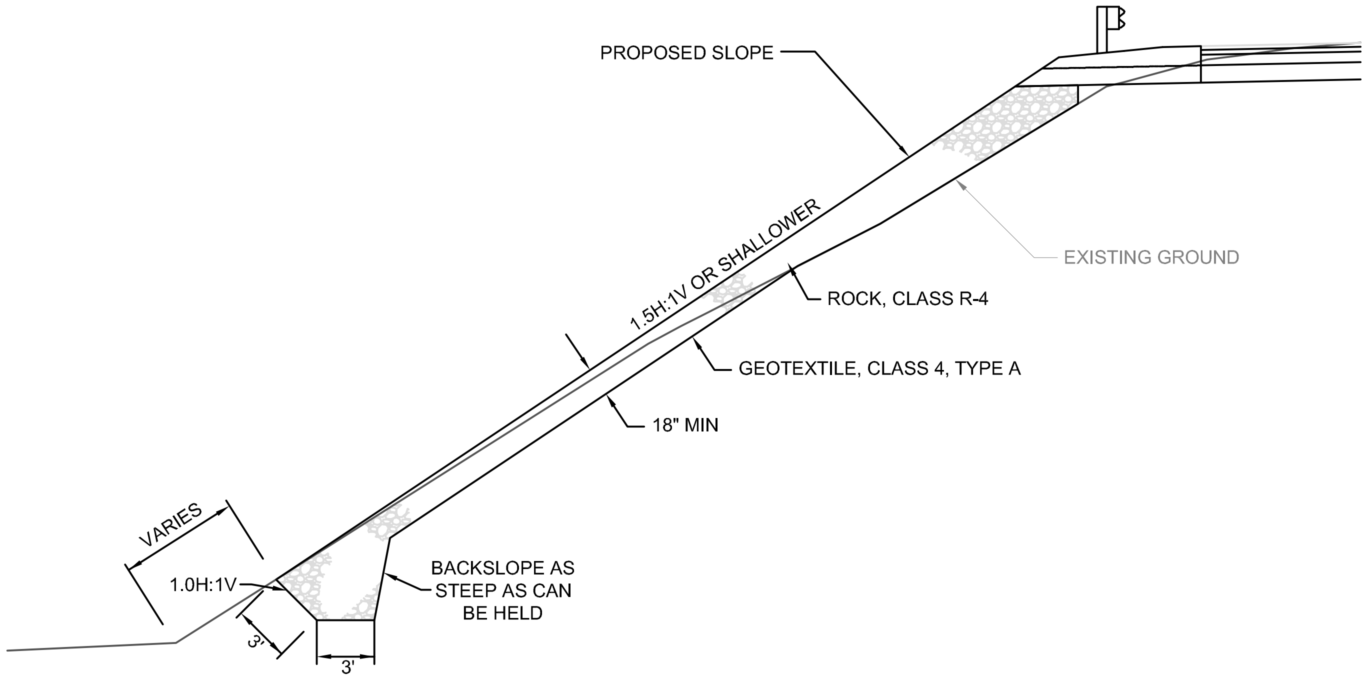
Detail: 1

Scale: N.T.S.

NAVARRO & WRIGHT CONSULTING ENGINEERS, INC.

Navarro & Wright Consulting Engineers, Inc.
151 Reno Avenue, New Cumberland, PA 17070
(717) 441-2216 (Telephone) (717) 695-7449 (Fax)

Date: 10/29/2019



STEEPENED SLIVER FILL DETAIL
NOT TO SCALE

NOTES:
1. FOR USE IN AREA OF FILL WITH LESS THAN FOUR (4) FEET OF NEW FILL THICKNESS
2. PLACE TOE ON COMPETENT MATERIAL.
3. VARY BENCH WIDTH AND HEIGHT IN ACCORDANCE WITH SLOPE CONDITIONS.
4. MODIFY BENCH WIDTHS AS NECESSARY IF ROCK IS ENCOUNTERED.
5. LOCATE TOP BENCH TO ENSURE THAT BACKSLOPE DOES NOT UNDERLIE TRAVEL LANES.

Steepened Sliver Fill Detail

Loyalsock State Forest Flood Repairs
Area 6 Site 20, McIntyre Township, Lycoming County, PA

Detail: 2

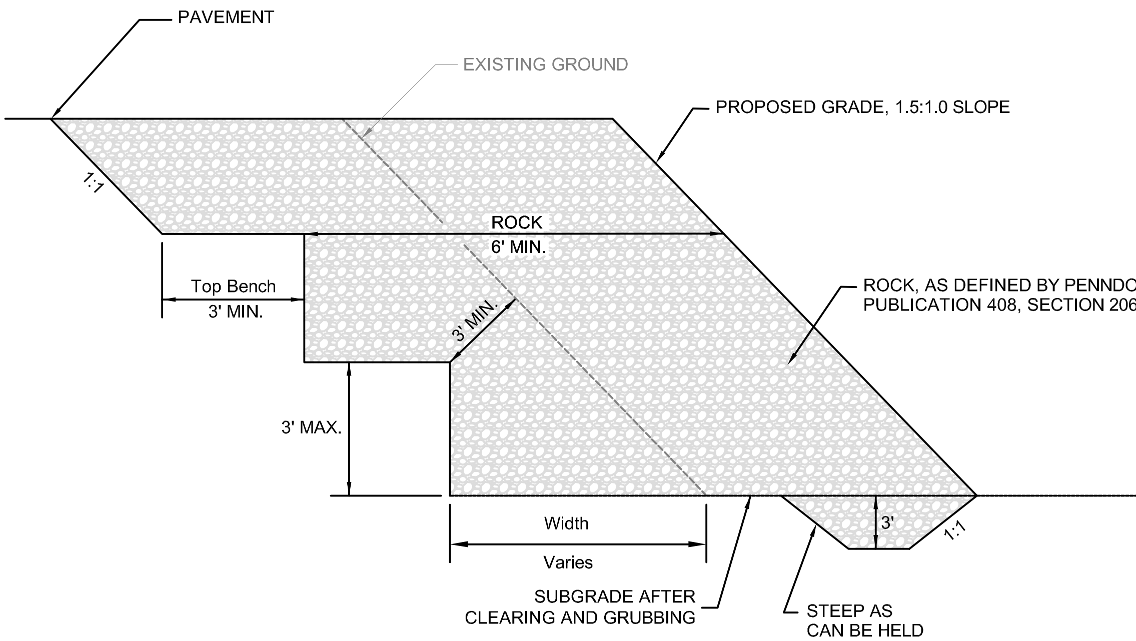
Scale: N.T.S.

NAVARRO & WRIGHT CONSULTING ENGINEERS, INC.

Navarro & Wright Consulting Engineers, Inc.
151 Reno Avenue, New Cumberland, PA 17070
(717) 441-2216 (Telephone) (717) 695-7449 (Fax)

Date: 11/8/2019

N:_2017\1712RE802 DCNR\Geotechnical\WO20 Area 6 Site 20 Loyalsock State Forest\CADD\SteppedSlopeDetail.dwg



1.5(H): 1(V) ROCK EMBANKMENT
N.T.S.

NOTES:

1. FILL BENCHES SHOULD BE CUT FROM THE TOP DOWN BEFORE PLACING ROCK
2. PROVIDE A LAYER OF GEOTEXTILE, CLASS 4, TYPE A, BETWEEN THE ROCK AND SUBBASE, AS DEFINED BY PENNDOT PUB 408.
3. PROVIDE FILL BENCH CONFIGURATIONS AND NOMINAL SLOPES ON THE ACTUAL CROSS SECTION.

N:_2017\1712RE802 DCNR\Geotechnical\WO20 Area 6 Site 20 Loyalsock State Forest\CADD\SteppedSlopeDetail.dwg

1.5(H): 1(V) Rock Embankment

Loyalsock State Forest Flood Repairs
Area 6 Site 20, McIntyre Township, Lycoming County, PA

Detail: 3

Scale: N.T.S.

NAVARRO & WRIGHT CONSULTING ENGINEERS, INC.

Navarro & Wright Consulting Engineers, Inc.
151 Reno Avenue, New Cumberland, PA 17070
(717) 441-2216 (Telephone) (717) 695-7449 (Fax)

Date: 11/08/2019

APPENDIX D: GEOTECHNICAL CALCULATIONS FROM WORLDS END STATE PARK GEOTECHNICAL ENGINEERING REPORT

JOB:	Mineral Springs Road Slide Repair at Worlds End State Park		
CALCULATED BY:	WNB	DATE	12/9/2019
CHECKED BY:		DATE	

Table of Contents

Item ***Sheet #***

Calculation Narrative

Purpose

Based on the scope of the project and site conditions, it is anticipated that a 12.0' high rockery wall, with a 6.0' embedment, will need to be designed for remediation at site 1, and rock benching will need to be designed at site 2.

Methodology

Boring logs and laboratory testing were reviewed to determine the strength characteristics of the soils and the general top of rock elevation. Utilizing the methods outlined in the FHWA Rockery Design and Construction Guidelines (Chapter 4), the proposed rockery wall was designed and factors of safety for sliding, overturning, and internal overturning were confirmed. The max bearing pressure of the rockery wall was also calculated, and compared to the anticipated bearing resistance, which was calculated with the Terzaghi bearing equation and typical LRFD methodology. RocScience Slide 8.0 was utilized to verify the global stability of the structure. At site 2, RocScience Slide 8.0 was utilized to verify that the proposed benching details resulted in a factor of safety against slope failure that was greater than 1.25.

Results and Conclusions

The rockery wall and slope benching detail will adequately remediate Mineral Springs Road at site 1 and site 2, and the remediation methods meet typical acceptable design Factors of Safety.

NAVARRO & WRIGHT CONSULTING ENGINEERS, INC.

By: WNB
Checked By: dsc

Rockery Wall Rock Recovery and RQD

B-1			
Run	R-1	R-2	R-3
Recovery (ft)	2.4	3.5	3.7
RQD (ft)	0.8	2	1.6
Run Length (ft)	2.4	3.5	4

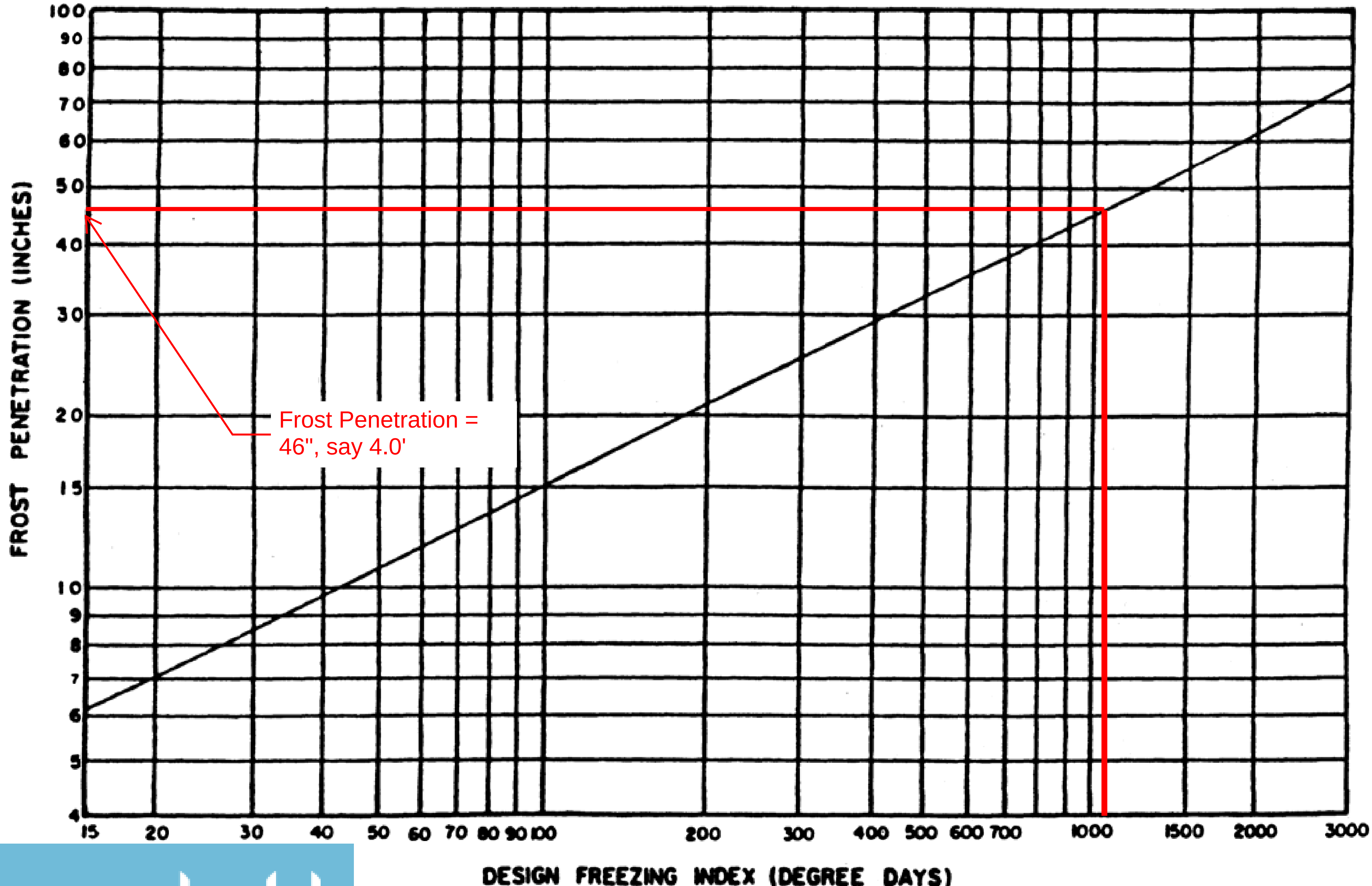
B-2			
Run	R-1	R-2	R-3
Recovery (ft)	2.5	3.5	4.0
RQD (ft)	0.0	2.6	2.3
Run Length (ft)	2.5	3.5	4.0

Average Recovery	98.49%
Average RQD	46.73%

DISTRICT 3			
Location	**Elevation**	**Index**	**Winter**
Bradford County			
Canton 1 mi. NW		1231	62-63
Towanda	1520	915	62-63
Columbia County			
Berwick	570	982	62-63
Millville 2 mi. SW	860	1179	62-63
Lycoming County			
English Center	880	1167	62-63
Williamsport Airport	527	886	62-63
Montour County			
Northumberland County			
Sunbury	480	925	62-63
Snyder County			
Sullivan County			
Eagles Mere	2020	1167	62-63
Tioga County			
Lawrenceville 2 mi. S	1000	1009	62-63
Wellsboro	1920	1329	62-63
Union County			

DISTRICT 4			
Location	**Elevation**	**Index**	**Winter**
Luzerne County			
Bear Ck. Dam	1700	1381	62-63
Freeland		1029	62-63
Scranton Wilkes-Barre (Airport WB)	940	921	62-63
Lackawanna County			
Scranton	746	930	62-63
Pike County			
Hawley	880	1225	62-63
Susquehanna County			
Montrose	1560	1380*	62-63
Wayne County			
Pleasant Mt. 1 mi. W	1800	1502*	62-63
Wyoming County			
Dixon	750	1101	62-63

FIGURE 9.1
DESIGN CHART FOR DETERMINATION OF FROST PENETRATION



ROCK MASS RATING (RMR)

Project:	Mineral Springs Road, Worlds End State Park, Rockery Wall
Substructure Unit:	
Applicable Borings:	B-1, B-2

A. CLASSIFICATION PARAMETERS AND THEIR RATINGS

	PARAMETER		RANGES OF VALUES						
1	Strength of Intact Rock Material	Point-load Strength Index	> 175 ksf	85-175 ksf	45-85 ksf	20-45 ksf	for this low range - Uniax. Comp. is pref.		
		Uniaxial Compressive Strength	>4320 ksf	2160-4320 ksf	1080-2160 ksf	520-1080 ksf	215-520 ksf	70-215 ksf	20-70 ksf
	Rating		**15**	**12**	7	**4**	**2**	**1**	**0**
	Input	7	Unconfined Compressive Strength from Lab Testing for Sandstone= 1482 KSF						
2	Drill Core Quality RQD		90-100%	75-90%	50-75%	25-50%	<25%		
	Rating		**20**	**17**	**13**	8	**3**		
	Input	8	Overall average RQD=46.73%						
3	Spacing of discontinuities		> 10 ft.	3-10 ft.	1-3 ft.	2 in.-1 ft.	< 2 in.		
	Rating		**30**	**25**	20	**10**	**5**		
	Input	20	Close to medium Spacing						
4	Condition of discontinuities		very rough surfaces, not cont., no sep. hard wall rock	slightly rough sep.< 0.05 in. hard wall rock	slightly rough sep.< 0.05 in. soft wall rock	Slicks on surfaces gouge < 0.2 in. sep. 0.05-0.2 in.mm; contin.	Soft gouge > 0.2 in. Seperation > 0.2 in. Continuous		
	Rating		**25**	**20**	12	**6**	**0**		
	Input	12	Slight to large discontinuity separation						
5	Groundwater		none	< 400 GPH	400-2000 GPH	> 2000 GPH			
		Ratio Joint water pressure / major principal stress	0	0.0 - 0.2	0.2 - 0.5	> 0.5			
		General Conditions	Completely Dry	Moist	Moderate Pressure	Severe Water Problems			
	Rating		**10**	**7**	**4**	**0**			
		7	Moist conditions only						

B. RATING ADJUSTMENT FOR JOINT ORIENTATIONS

Strike and Dip Orientations		Very Favorable	Favorable	Fair	Unfavorable	Very Unfavorable
Ratings	Tunnels	**0**	**-2**	**-5**	**-10**	**-12**
	Foundations	**0**	-2	**-7**	**-15**	**-25**
-2	Slopes	**0**	**-5**	**-25**	**-50**	**-60**
	Proposed foundations will bear on moderately weathered bedrock, with flat bedding joints					

C. ROCK MASS CLASSES DETERMINED FROM TOTAL RATING

Rating	100 - 81	80 - 61	60 - 41	40 - 21	<20
Class Number	I	II	III	IV	V
Description	Very Good Rock	Good Rock	Fair Rock	Poor Rock	Very Poor Rock

D. MEANING OF ROCK MASS CLASSES

Class Number	I	II	III	IV	V
Average stand up time	10 yrs. /15m span	6 mo./ 8 m sp.	1 wk./ 5 m span	10 hrs/ 2.5 m. span	30min./im span
Cohesion of the rock mass	> 4177 tsf	3133-4177 tsf	2089-3133 tsf	1044-2089 tsf	<1044 tsf
Friction angle of the rock mass	>45	35 - 45	25 - 35	15 - 25	<15

RMR = A1+A2+A3+A4+A5+B

RMR= 57

SPECIFICATIONS

this interval are variable in strength, the rock with the lowest capacity should be used to determine q_n. As a guide, Table 10.6.3.2.2-2P can be used to estimate C_o. For rocks defined by very poor quality, the value of q_n should be determined as the value of q_n for an equivalent soil mass.

COMMENTARY

Table A10.4.6.4-4. Values of the term in brackets (designated as N_{ms}) as a function of rock type and quality are presented in Table 10.6.3.2.2-1P, such that q_n can be determined using Eq. C10.6.3.2.2-1P.

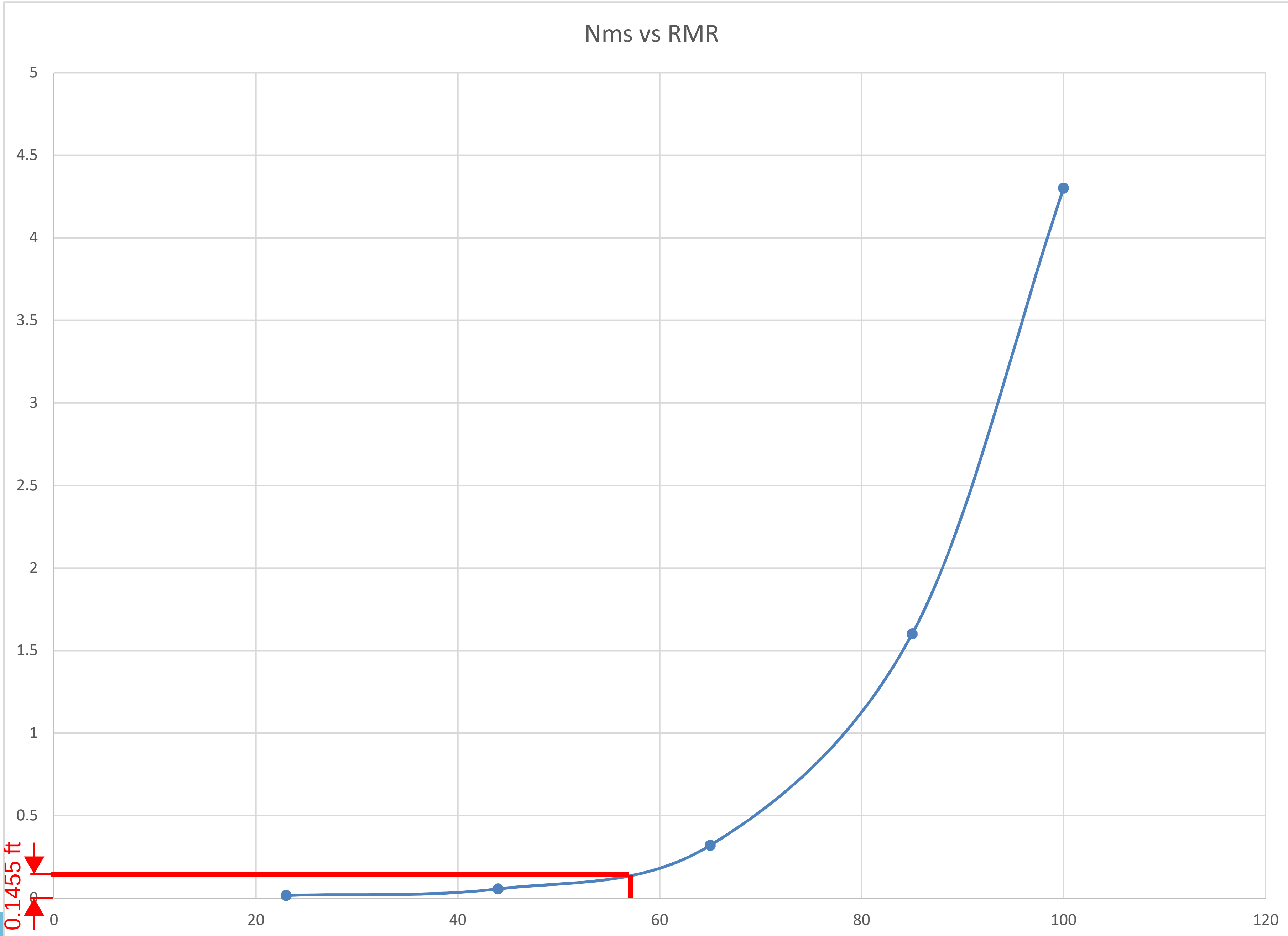
Table 10.6.3.2.2-1P – Values of Coefficient Nms for Estimation of the Nominal Bearing Resistance of Footings on Broken or Jointed Rock, Modified after Hoek (1983)

ROCK MASS QUALITY	GENERAL DESCRIPTION	RMR[1] RATING	RQD[2](%)	N_{ms}[3]				
				A	B	C	D	E
Excellent	Intact rock with joints spaced >10 ft. apart	100	95 - 100	3.8	4.3	5.0	5.2	6.1
Very Good	Tightly interlocking, undisturbed rock with rough unweathered joints spaced 3 to 10 ft. apart	85	90 - 95	1.4	1.6	1.9	2.0	2.3
Good	Fresh to slightly weathered rock, slightly disturbed with joints spaced 3 to 10 ft. apart	65	75 - 90	0.28	0.32	0.38	0.40	0.46
Fair	Rock with several sets of moderately weathered joints spaced 1 to 3 ft. apart	44	50 - 75	0.049	0.056	0.066	0.069	0.081
Poor	Rock with numerous weathered joints spaced 1 to 20 in. apart with some gouge	23	25 - 50	0.015	0.016	0.019	0.020	0.024
Very Poor	Rock with numerous highly weathered joints spaced< 2 in. apart	3	< 25	Use q_{ult} for an equivalent soil mass				

(1) Geomechanics Rock Mass Rating (RMR) System, in accordance with A10.4.6.4

(2) Range of RQD values provided for general guidance only; actual determination of rock mass quality should be based on RMR.

(3) Value of N_{ms} as a function of rock type; refer to Table 10.6.3.2.2-2P for typical range of values of C_o for different rock types in each category



Nms vs RMR
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0.1455 ft
0
20
40
60
80
100
120

NAVARRO & WRIGHT
CONSULTING ENGINEERS, INC.

By: WNB
Checked By: dsc

Ultimate Bearing Capacity
Using Semi-Empirical Method

Mineral Spring Road Rockery Wall

Use Empirical Bearing Capacity, see DM-4, Section 10.6.3.2.2

Applicable Core Borings------------	B-1 and B-2
Average RQD% below Bottom of Footing Elevation (BFE)-------------	47%
Rock Strength, from lab testing, in TSF-	741
RMR Value for Rock, from attached worksheet------------	57

Coefficient for Estimation of Ultimate Bearing Capacity, based on RMR valu
see DM-4, Table 10.6.3.2.2-1
and attached chart.

Use N_{ms}= 0.145 Category B Rock

Resistance Factor for Bearing Capacity, see DM-4, Table 10.5.5.2.2-1

Φ= 0.5

Ultimate Bearing Capacity

$Q_{ult}=N_{ms}*C_o$

Q_{ult}= 107.45 TSF

Factored Bearing Resistance

$Q_{fact}=Q_{ult}*\Phi$

Q_{fact}= 53.7 TSF

Greater than Allowable Bearing Pressure, Design is Valid for Rock

Calculation Sheet

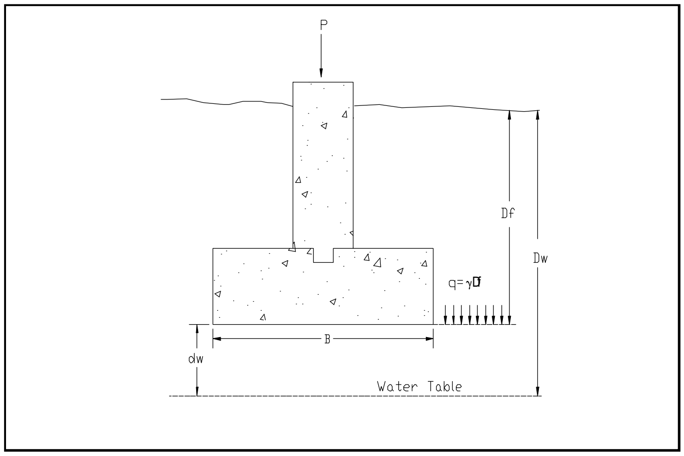
PROJECT NAME: Loyalsock State Forest Flood Repairs, Area 6, Site 20
PROJECT NUMBER 1712RE802-20
By: WNB
Reviewed By: dsc

Bearing Capacity Analysis By Terzaghi Equation:

Footing Type:	Equation:
Continuous	qult = cNc + q'Nq + 0.5γBNγ
Square	qult = 1.3cNc + q'Nq + 0.4γBNγ
Round	qult = 1.3cNc + q'Nq + 0.3γBNγ

Input:

B (ft):	6
Footing Type:	continuous
Df (ft):	6
Dw (ft):	6
γ (pcf):	125
Cohesion, c (psf):	0
Friction Angle, φ:	36
(See Table 1) Nc:	65.53
(See Table 1) Nq:	47.16
(See Table 1) Nγ:	54.36



Φ, deg	Nc	Nq	N_γ	Kp
0	5.7	1.0	0.0	10.8
5	7.3	1.6	0.5	12.2
10	9.6	2.7	1.2	14.7
15	12.9	4.4	2.5	18.6
20	17.7	7.4	5.0	25.0
25	25.1	12.7	9.7	35.0
30	37.2	22.5	19.7	52.0
34	52.6	36.5	36.0	
35	57.8	41.4	42.4	82.0
40	95.7	81.3	100.4	141.0
45	172.3	173.3	297.5	298.0
48	258.3	287.9	780.1	
50	347.5	415.1	1153.2	800.0

Calculation Sheet

PROJECT NAME:	Loyalsock State Forest Flood Repairs, Area 6, Site 20
PROJECT NUMBER:	1712RE802-20
By:	WNB
Reviewed By:	dsc

Ultimate Bearing Capacity, qult (psf):

Step 1: Determine effect of water table

Surcharge Pressure, q (psf):
(Note: q is effective weight; therefore if Dw is less than Df, calculate effective weight.)

Dw (ft) = 6 Conservatively Assume Bottom of Footing
Df (ft) = 6

therefore,
q' = 750 (psf)
q'*Nq = 35,370 (psf)

H, Depth of Footing Wedge Zone:
**(Note: When the water table is below the wedge zone (H), the water table can be ignored.
If the water table lies within H, the effective weight should be calculated.)**

H (ft) = 5.9
Dw (ft) = 6
dw (ft) = 0.0
therefore,
γ' = 62.6 (pcf)
and,
γ'*B*Nγ = 20,418 (psf)

Step 2: Calculate component of bearing capacity due to cohesion

c*Nc = 0 (psf)

Step 3: Calculate ultimate bearing capacity

Footing type: continuous

qu = 45,579 (psf)

Step 4: Calculate net allowable bearing capacity assuming a factor of safety of 3.0

qa = 15,193 psf =

NAVARRO & WRIGHT GEOTECHNICAL LABORATORY
Unit Weight

PROJECT: World End State Park	**Date: September 3, 2019**
JOB No: 1712RE802-23	**Tested By: DFP**

Boring No.	Sample No.	Depth (ft.)	Diameter (in.)	Length (in.)	Unit Weight pcf (dry)	Water Content (%)
B-2	S-1	0-2	2.5	1.0	106.6	10.6%
B-5	S-5	8-10	2.5	1.0	122.1	11.1%

For Rockery Wall Design, conservatively utilize
Moist Unit Weight = 106.6(1+.106) =125 pcf

For slope stability design, conservatively
utilize Moist Unit Weight = 135 pcf

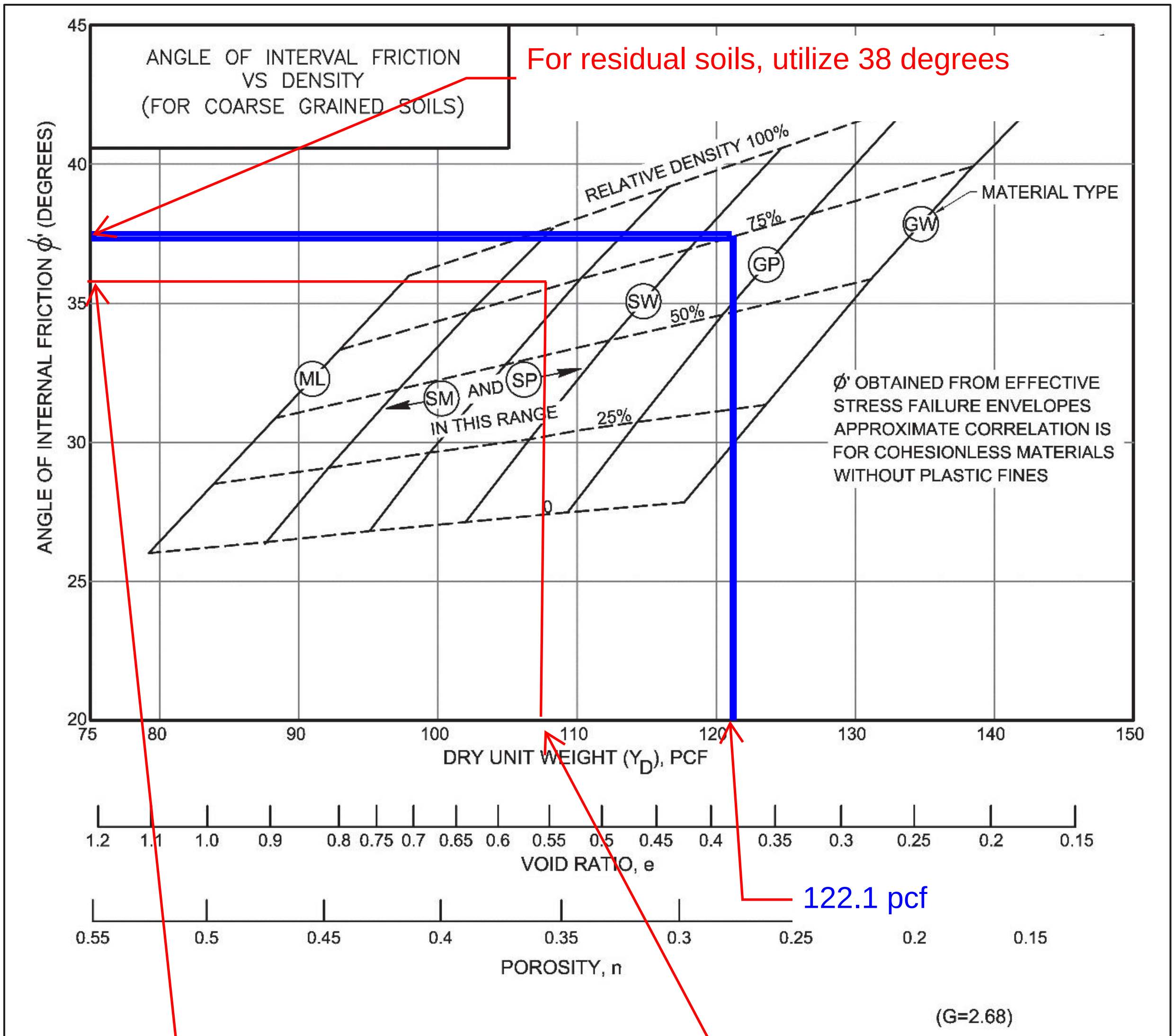


Figure 5.5.3.1.1-1 – Correlations of Effective Angle of Friction
with Index Properties for Granular Soils

106.6 pcf

Notes: 1. Reference: NAVFAC DM 7.01, 1986

For Rockery Wall Design,
Utilize Friction Angle = 36 degrees

re must be taken when using correlations when SPT is
se gravel, cobbles and boulders. These "large" materials can
ative density) and result in an overestimation of the internal

Cone penetrometer testing (CPT) can also be used to estimate the internal angle of friction of granular soil, although CPT is mainly appropriate for sands since the presence of gravel can cause erroneously high results. Similar to SPT N-values, there are correlations between CPT tip resistance and internal angle of friction. If CPT data are obtained, it is recommended that FHWA Geotechnical Engineering Circular No. 5 be consulted for correlation to internal angle of friction.

Date: 11/13/19
Project: 1712RE802
Mineral Springs Road, Worlds End State Park

By:___WNB____
Checked By: dsc

Shear Strength of Rock Mass

- Use Eq. 10.4.6.4-1, DM-4 2007
- Average unconfined compressive strength of intact rock core:

Qu = 327.8 tsf, or 655.6 KSF (Value obtained from lab testing)

- Dimensionless constants

m = 0.4657
s = 0.000762948 (Refer to attached Table 10.4.6.4-4)

- For Effective Normal Stress, assume:

d = 6 ft. (Excavation Depth estimated from groundline and BCE information)

1 125 pcf (Density determined from attached reference chart)

$\sigma'_n = \gamma_m d$

$\sigma'_n =$ 0.75 KSF

- Dimensionless Factor:

$$h = 1 + \frac{16(m\sigma'_n + sQ_u)}{3m^2 Q_u} = \boxed{1.02}$$

- Instantaneous friction angle of the rock mass:

$$\emptyset'_i = \tan^{-1}\{4h\cos^2[30 + 0.33\sin^{-1}(h^{-3/2})] - 1\}^{-1/2}$$

$= \boxed{58.58 \text{ degrees}}$

- Shear Strength of the Rock Mass

$$\tau = (\cot\emptyset'_i - \cos\emptyset'_i)m\frac{Q_u}{8}$$

τ = 7.75 KSF

Date: 11/13/19
Project: 1712RE802
Mineral Springs Road, Worlds End State Park

By:___WNB____
Checked By: dsc

		A = Carbonate rocks with well developed crystal cleavage - *dolomite, limestone and marble* B = Lithified argrillaceous rocks - *mudstone, silstone, shale and slate (normal to cleavage)* C = Arenaceous rocks with strong crystals and poorly developed crystal cleavage - *sandstone and quartzite* D = Fine grained plyminerallic igneous crystalline rocks - *andesite, dolerite, diabase and rhyolite* E = Coarse grained polyminerallic igneous & metamorphic crystalline rocks - *amphibolite, gabbro gneiss, granite, norite, quartz-diorite*				
		A	B	C	D	E
INTACT ROCK SAMPLES Laboratory size specimens free from discontinuities CSIR rating: *RMR* = 100	*m* *s*	7.00 1.00	10.00 1.00	15.00 1.00	17.00 1.00	25.00 1.00
VERY GOOD QUALITY ROCK MASS Tightly interlocking undisturbed rock with unweathered joints at 900-3000 mm {3-10 ft.} CSIR rating: *RMR* = 85	*m* *s*	2.40 0.082	3.43 0.082	5.14 0.082	5.82 0.082	8.567 0.082
GOOD QUALITY ROCK MASS Fresh to slightly weathered rock, slightly disturbed with joints at 900-3000 mm {3-10 ft.} CSIR rating: *RMR* = 65	*m* *s*	0.575 0.00293	0.821 0.00293	1.231 0.00293	1.395 0.00293	2.052 0.00293
FAIR QUALITY ROCK MASS Several sets of moderately weathered joints spaced at 300-900 mm {1-3 ft.} CSIR rating: *RMR* = 44	*m* *s*	0.128 0.00009	0.183 0.00009	0.275 0.00009	0.311 0.00009	0.458 0.00009
POOR QUALITY ROCK MASS Numerous weathered joints at 50-300 mm {2-12 in.}; some goute. Clean compacted waste rock. CSIR rating: *RMR* = 23	*m* *s*	0.029 3×10^{-6}	0.041 3×10^{-6}	0.061 3×10^{-6}	0.069 3×10^{-6}	0.102 3×10^{-6}
VERY POOR QUALITY ROCK MASS Numerous heavily weathered joints spaced <50 mm {2 in.} with gouge. Waste rock with fines. CSIR rating: *RMR* = 3	*m* *s*	0.007 1×10^{-7}	0.010 1×10^{-7}	0.015 1×10^{-7}	0.017 1×10^{-7}	0.025 1×10^{-7}

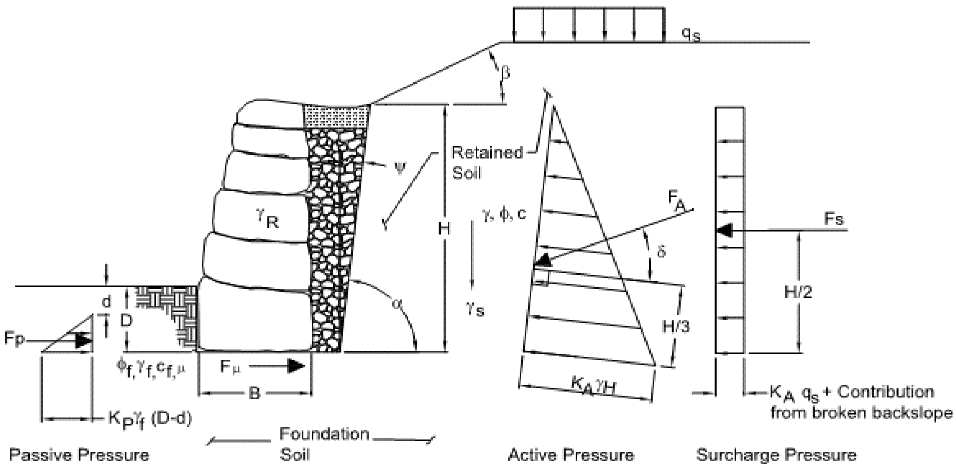
Taken From AASHTO LRFD Bridge Design Specs (2010)

Calculated by interpretation of exponential graph

Project Name: **Mineral Springs State Park Slide Repair at Worlds End State Park**
Structure: **Rockery Wall**
N&W Project No. **1712RE802-23**

Subject: **Rockery Wall Design**

Reference: **FHWA Rockery Design and Construction Guidelines**



*From FHWA Rockery Design and Construction Guidelines, Chapter 4, Recommended Rockery Design Guidelines

Inputs:

Parameter	Value	Unit	Description
D =	6	feet	Depth of Embedment
$\gamma_{s=}$	125	pcf	Unit weight of retained soil
Φ=	36	°	Friction angle of retained soil
C=	0	pcf	Cohesion of retained soil, conservatively assumed to be zero
δ=	24	°	*Coulomb Interface Friction Angle = 2/3phi to phi
φ	30	°	Allowable back cut angle of crushed aggregate
ß	20	°	Ground surface inclination
γ_s	120	pcf	Unit weight of soil above retained soil layer
γ_R	145	pcf	*Unit Weight of rockery wall
H=	18	feet	Height of Retained Soil Layer (Includes embedment)
L=	25	feet	Length of Rockery
q_s	240	psf	*Utilized 240 psf

Project Name: **Mineral Springs State Park Slide Repair at Worlds End State Park**
Structure: **Rockery Wall**
N&W Project No. **1712RE802-23**

Subject: Rockery Wall Design

$$K_A = \frac{\cos^2(\psi+\phi)}{\cos^2(\psi)\cdot\cos(\delta-\psi)\cdot\left[1+\sqrt{\frac{\sin(\phi+\delta)\cdot\sin(\phi-\beta)}{\cos(\delta-\psi)\cdot\cos(-\psi-\beta)}}\right]^2}$$

Figure 31. Equation. Determination of lateral earth pressure coefficient, K_A, using the Coulomb method.

Convert degrees to radians

Φ=	36 ° =	0.628	radians
δ=	24 ° =	0.418667	radians
φ=	30 ° =	0.523333	radians
ß=	20 ° =	0.348889	radians

K_A = 0.137669

All force and moment calculations performed for one (1) Unit Foot of length of Rockery Wall.

Calculate Surcharge load from soil above retained soil layer

q_s = (Unit Weight of soil above retained soil layer)(Height of soil above retained soil layer)

q_s = 240 psf

Calculate Horizontal Force on Back of Rockery

$$F_H = F_{A,H} + F_S = \tfrac{1}{2}\gamma_S K_A H^2 \cos(\delta-\psi) + q_S K_A H$$

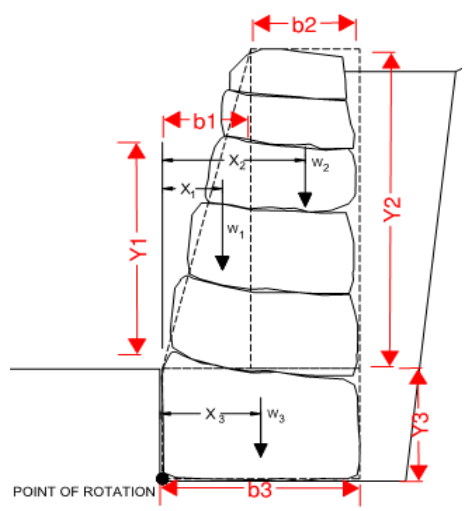
Figure 32. Equation. Horizontal force on back of rockery, equal to the sum of the lateral earth pressure and any surcharge loads.

F_H= 3367.251 lb

Geometry and Weight of Rockery

b_1=	2 ft	Y1=	9.6 ft
b_2=	4 ft	Y2=	12 ft
b_3=	6 ft	Y3=	6 ft

w_1= 2784 lb
w_2= 6960 lb
w_3= 5220 lb
Total Weight = 14964 lb
= 14.964 kips



Project Name: **Mineral Springs State Park Slide Repair at Worlds End State Park**
Structure: **Rockery Wall**
N&W Project No. **1712RE802-23**

Subject: Rockery Wall Design

Calculate Friction Force Resisting Sliding

$$F_{\mu} = \mu \cdot (W + F_{A,V}) = \mu \cdot \left(\sum_i W_i + \tfrac{1}{2}\gamma_S K_A H^2 \sin(\delta - \psi) \right)$$

Figure 34. Equation. Computation of frictional resistance along the base of the rocker

Table 7. Typical friction factors for determination of FS_{SL}.

Base Rock Texture	Foundation Material	Estimated Ultimate Friction Factor, μ
Rough	Dense, medium-grained sand ϕ=36°	0.7
Smooth, angular rocks with flat faces	Stiff silt or clay ϕ=30°	0.4
Rough	Moderately weathered bedrock ϕ=36°	0.6
Rough	300 mm thick layer of crushed rock ϕ=40°	0.8
Smooth, angular rocks with flat faces	300 mm thick layer of "foundation fill" with 100% passing 50 mm sieve, 6% maximum passing 75 μm sieve ϕ=35°	0.7

μ= 0.6
F_{μ}= 8803.557711 lb

Calculate Rankine Passive Pressure

$$F_P = \tfrac{1}{2}\gamma_S K_P (D - d)^2, \text{ where}$$

$$K_P = \frac{\tan^2\left(45° + \frac{\phi_F}{2}\right)}{FS}$$

Figure 35. Equation. Evaluation of passive resistance at the rockery toe.

Φ_F= 36 Degrees

FS = 1.5
*d= 1 ft
K_p= 2.560828612
F_p= 4001.294707 lb

Factor of Safety against Sliding

$$FS_{SL} = \frac{F_{\mu} + F_P}{F_H}$$

Figure 36. Equation. Expression for factor of safety against sliding (FS_{SL}).

FS_{sl}= 3.802760947

FSsl > 1.5 Yes

Project Name: Mineral Springs State Park Slide Repair at Worlds End State Park
Structure: Rockery Wall
N&W Project No. 1712RE802-23

Subject: Rockery Wall Design

Determine Overturning Moment about Toe of Rockery

$$M_o = \tfrac{1}{2}\gamma_S K_A H^2 \cos(\delta - \psi)\left(\frac{H}{3}\right) + q_S K_A H\left(\frac{H}{2}\right)$$

Figure 37. Equation. Determination of overturning moments about the toe of the rockery.

M_o= 21987.69698 lb-ft

Determine Resisting Moment about Toe of Rockery

$$M_r = \sum_i W_i x_i + \tfrac{1}{2}\gamma_S K_A H^2 \sin(\delta - \psi)\left(\frac{H}{3}\cdot\tan(\psi) + B\right) + \cancel{\tfrac{1}{2}\gamma_S K_P (D-d)^2\left(\frac{D-d}{3}\right)}$$

Figure 38. Equation. Determination of resisting moments about the toe of the rockery

Conservatively Ignore Passive Resistance

x_1 =	$(2/3)b_1$=	1.3333333
x_2 =	$b_1+(0.5*b_2)$=	4
x_3 =	$(0.5)b_3$ =	3

M_r= 50856.19621 lb-ft

Determine Factor of Safety against Overturning

$FS_{ot} > 2.0$ 2.312938743

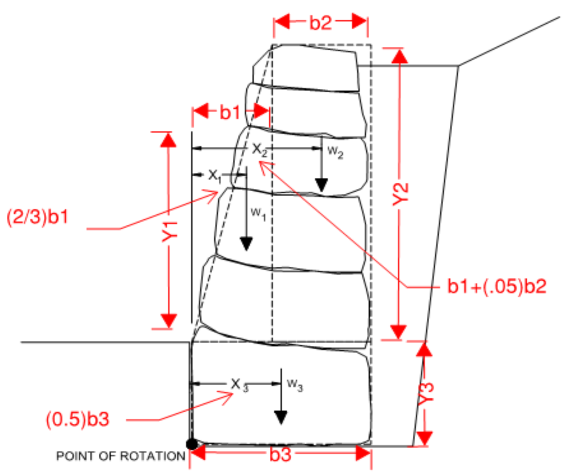


Figure 33. Graphic. Estimation of rockery weight and centroidal distances.

Project Name: Mineral Springs State Park Slide Repair at Worlds End State Park
Structure: Rockery Wall
N&W Project No. 1712RE802-23

Subject: Rockery Wall Design

Check for Internal Overturning at 2/3 Height

H' =	12	ft
H-H'=	6	ft
x_1=	0.9	ft
x_2=	3	ft
W_1=	565.5	lb
W_2=	2784	lb

Determine Overturning Moment about P'

$$M_{o\_int} = \tfrac{1}{2}\gamma_S K_A (H-H')^2 \cos(\delta-\psi)\left(\frac{H-H'}{3}\right) + q_S K_A (H-H')\left(\frac{H-H'}{2}\right)$$

Figure 40. Equation. Calculation of internal overturning moment at a distance H' from the base of the rockery.

M_{o_int}= 1210.845 lb-ft

Determine Resisting Moment about P'

$$M_{r\_int} = \sum_i W_{i\_top}(x_i - x') + \tfrac{1}{2}\gamma_S K_A (H-H')^2 \sin(\delta-\psi)\left(\frac{H-H'}{3}\cdot\tan(\psi) + B'\right)$$

Figure 41. Equation. Calculation of internal resisting moment at a distance H' from the base of the rockery, with outermost bearing distance x' from the face of rockery.

M_{r_int}= 7003.111 lb-ft

Fs_{int_OT}= 5.783654 >2.0

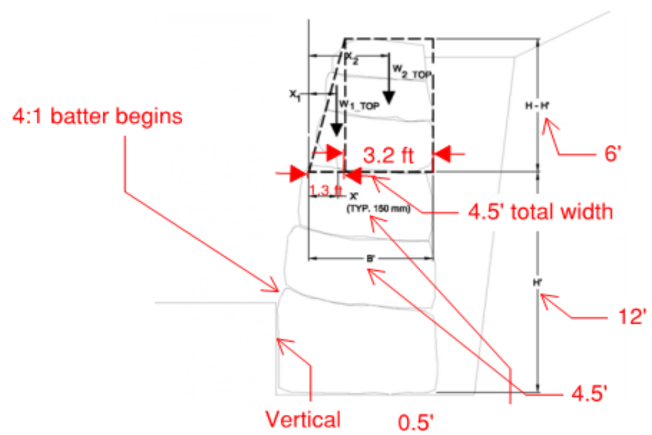


Figure 42. Graphic. Geometric relationships for determination of internal stability.

Project Name: Mineral Springs State Park Slide Repair at Worlds End State Park
Structure: Rockery Wall
N&W Project No. 1712RE802-23

Subject: Rockery Wall Design

Determine eccentricity about Center of a Base Rock of Width B

$$e = \frac{B}{2} - \frac{M_r - M_O}{W + \frac{1}{2}\gamma_S K_A H^2 \sin(\delta - \psi)}$$

Figure 43. Equation. Determination of eccentricity, e, about the center of a base rock of width B.

e= 1.0

$$q_{max} = \frac{W + \frac{1}{2}\gamma_S K_A H^2 \sin(\delta - \psi)}{B} \cdot \left(1 + \frac{6e}{B}\right)$$

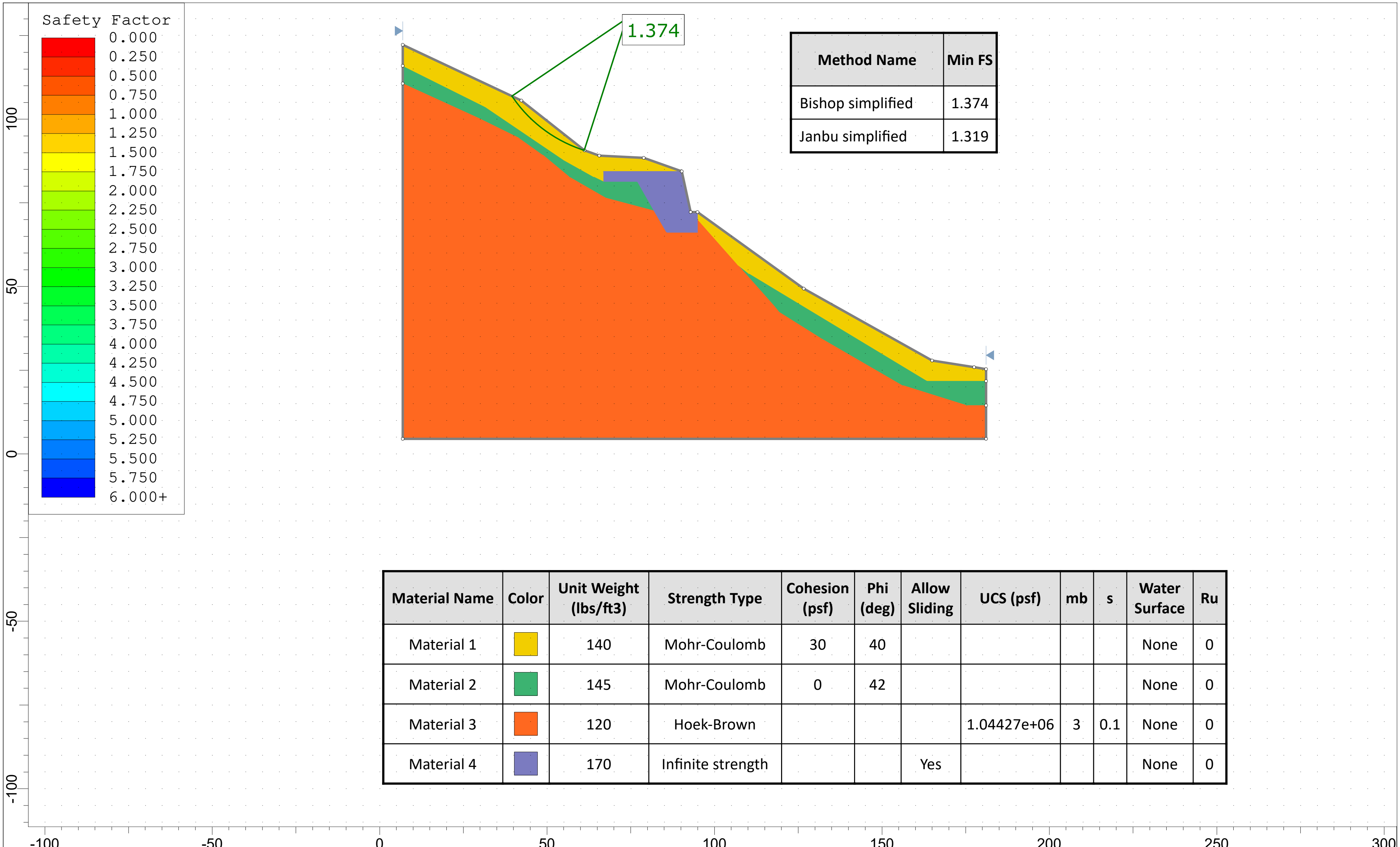
Figure 44. Equation. Determination of maximum bearing pressure (q_{max}) applied at the toe of the base rock.

q_{max}= 4970.314 psf

Ultimate Bearing Capacity = q_u = 45,579 psf

Allowable Bearing Capacity, FS = 3.0, = q_a = 15193 (From Bearing Capacity Calculation)

$q_a > q_{max}$; Design is valid



Method Name	Min FS
Bishop simplified	1.374
Janbu simplified	1.319

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Allow Sliding	UCS (psf)	mb	s	Water Surface	Ru
Material 1		140	Mohr-Coulomb	30	40					None	0
Material 2		145	Mohr-Coulomb	0	42					None	0
Material 3		120	Hoek-Brown				1.04427e+06	3	0.1	None	0
Material 4		170	Infinite strength			Yes				None	0

rocscience

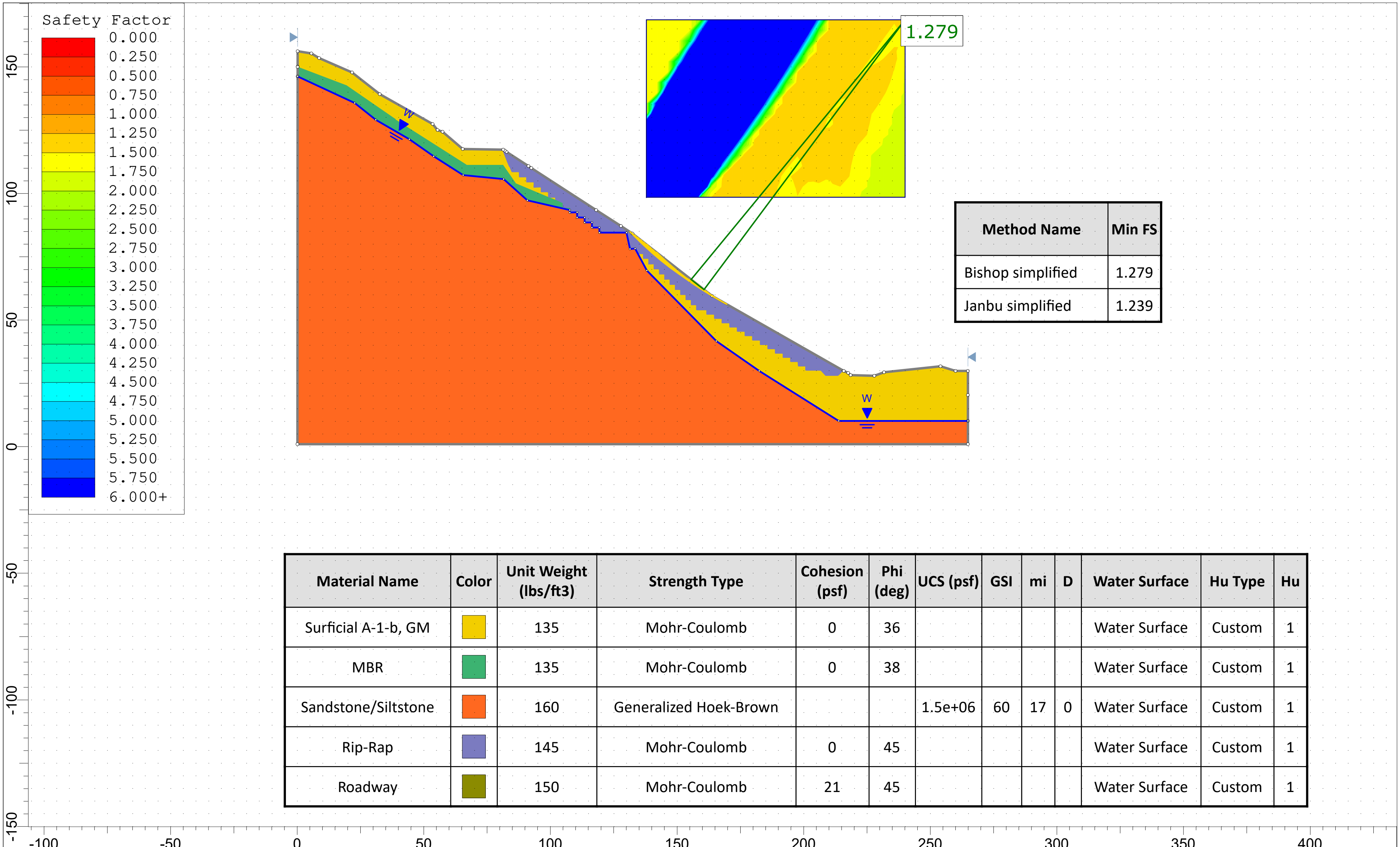
SLIDEINTERPRET 8.014

Project SLIDE - An Interactive Slope Stability Program

Analysis Description

Drawn By | *Scale* 1:476 | *Company*

Date 10/23/2019, 9:52:49 AM | *File Name* Site-1.slmd



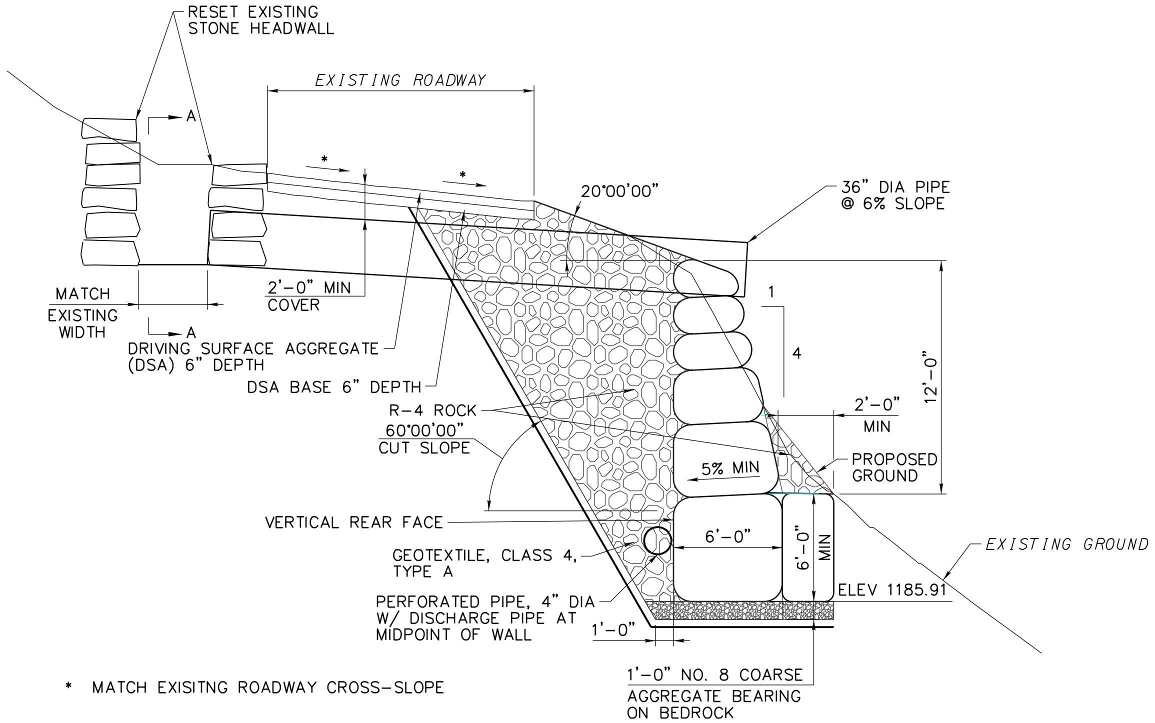
Method Name	Min FS
Bishop simplified	1.279
Janbu simplified	1.239

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	UCS (psf)	GSI	mi	D	Water Surface	Hu Type	Hu
Surficial A-1-b, GM		135	Mohr-Coulomb	0	36					Water Surface	Custom	1
MBR		135	Mohr-Coulomb	0	38					Water Surface	Custom	1
Sandstone/Siltstone		160	Generalized Hoek-Brown			1.5e+06	60	17	0	Water Surface	Custom	1
Rip-Rap		145	Mohr-Coulomb	0	45					Water Surface	Custom	1
Roadway		150	Mohr-Coulomb	21	45					Water Surface	Custom	1

rocscience

SLIDEINTERPRET 8.014

Project	SLIDE - An Interactive Slope Stability Program
Analysis Description	
Drawn By	
Scale	1:629
Company	
Date	10/31/2019, 9:27:30 AM
File Name	Site2.slmd



* MATCH EXISITNG ROADWAY CROSS-SLOPE

TYPICAL SLIDE REPAIR – SITE 1

STA 10+75.00 TO STA 11+09.00
NOT TO SCALE

ROCKERY DESIGN SCHEDULE							
MAX HEIGHT H (FT)	MIN ROCK BASE WIDTH B (FT)	MIN CUT SLOPE BATTER	MAX EQUIVALENT BACKSLOPE	MIN ROCK WEIGHT: CAP ROCK	MIN ROCK WEIGHT: BASE ROCK	DITCH TYPE	SURCHARGE
12	6	30°	20°	200 LB	200 LB	OUTLET PIPES	240 PSF

ROCKERY DESIGN DATA:

FRICION ANGLE | = 36°
COHESION, c = 0
BULK UNIT WEIGHT, Y = 145 PSF
ALLOWABLE BEARING PRESSURE = 15,193 PSF

NOTE:

CONSTRUCT ROCKERY AND PLACE BASE, FACING, AND CAP ROCKS ACCORDING TO THE CONTACT SPECIFICATIONS. PLACE EACH ROCK INDIVIDUALLY BY EQUIPMENT SUITABLE FOR LIFTING, MANIPULATING, AND PLACING ROCKS OF THE SIZE AND SHAPE SPECIFIED. ENSURE THAT EACH ROC IS FIRMLY SET AND SUPPORTED BY UNDERLYING MATERIALS AND ADJACENT ROCKS. REPOSITION OR REPLACE LOOSE ROCKS.

A MAXIMUM TOLERANCE OF 0.5' MAY BE APPLIED TOWARD THE TOTAL BASE ROCK WIDTH. USE ROCK WITH MINIMUM LENGTH OF 5.5'. WHEN LENGTH EXCEEDS 5.5', TWO APPROXIMATELY EQUAL SIZE BASE ROCKS MAY BE USED, PROVIDED ROCKS ARE IN CONTACT AT TWO POINTS OR MORE. DO NOT CONSECUTIVELY PLACE BASE ROCKS WITH WIDTHS LESS THAN B.

PLACE ROCK IN FRONT OF THE BASE ROCK, WITH A MINIMUM OF 2.0' IN WIDTH AND 2.0' IN LENGTH AND EMBEDMENT EQUAL TO 6.0' TO ENGAGE PASSIVE RESISTANCE AT TOE. A MAXIMUM TOLERANCE OF 0.5' MAY BE APPLIED TOWARD THE TOTAL ROCK WIDTH. USE ROCK WITH A MINIMIMUM LENGTH OF 3.0'. WHEN LENGTH EXCEEDS 3.0', TWO APPROXIMATELY EQUAL SIZE BASE ROCKS MAY BE USED, PROVIDED ROCKS ARE IN CONTACT AT TWO POINTS OR MORE. DO NOT CONSECUTIVELY PLACE ROCKS WITH WIDTHS LESS THAN 2.0'.

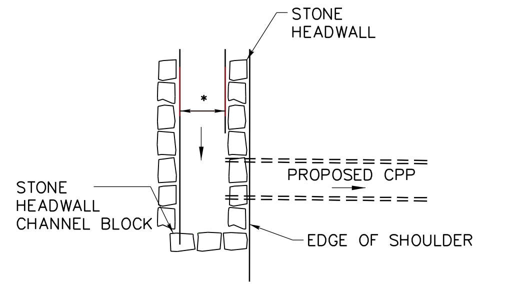
PLACE BASE, FACING, AND CAP ROCKS SO THAT THEIR HEIGHT DIMENSION IS NOT GREATER THAN THEIR WIDTH. THE LONGEST DIMENSION OF THE BASE, FACING, AND CAP ROCKS IS PERPENDICULAR TO FACE OF ROCKERY.

DISCHARGE OUTLET PIPES TO EXISTING RIP RAP SLOPE AT LOW POINT IN THE ROCKERY AND AT 100 FT MAX SPACING.

STABILITY OF TEMPORARY CUT SLOPES IS THE RESPONSIBILITY OF THE CONTRACTOR.

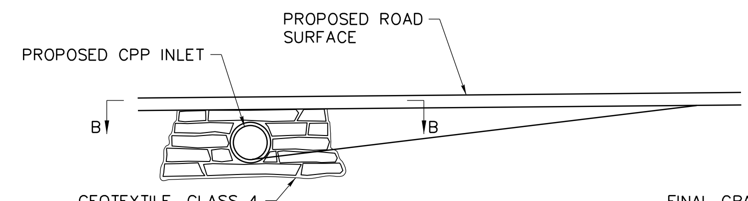
DO NOT CONSTRUCT ROCKERY OR SLOPES EXCEEDING THE HEIGHTS SHOWN ON THE ROCKERY DESIGN SCHEDULE WITHOUT PRIOR WRITTEN APPROVAL BY THE ENGINEER.

CONSTRUCT ROCKERY PARALLEL TO ROADWAY UNLESS OTHERWISE NOTED.



SECTION B-B

* MATCH EXISTING WIDTH



SECTION A-A

HEADWALL NOTES:
1. USE ROCKS OF UNIFORM THICKNESS, FLAT ON TWO OR THREE SIDES THAT CAN BE HANDLED BY ONE PERSON ARE IDEAL.
2. WALLS SHOULD EXTEND 2 TIMES THE DIAMETER BEYOND THE PIPE OPENING.
3. GEOTEXTILE TO BE INSTALLED UNDER, BEHIND, AND ALONG SIDES OF WALL.
4. PLACE A LARGER FLAT STONE UNDER THE PIPE OPENING. BASE STONES SHOULD BE THE LARGEST AVAILABLE AND STAGGER JOINTS AS THE WALL IS CONSTRUCTED. THE BASE WIDTH SHOULD BE EQUAL TO THE WALL HEIGHT. CANT THE FACE OF THE WALL TOWARDS THE ROAD AT A RATE OF 2" PER FOOT OF HEIGHT. BACKFILL AND COMPACT LAYERS AS THE WALL IS CONSTRUCTED. PLACE A LARGER STONE OVER THE PIPE TO BRIDGE BOTH SIDES OF THE WALL.

GENERAL NOTES

HORIZONTAL CONTROL IS TIED TO PA STATE PLANE COORDINATE SYSTEM (NORTH ZONE), NORTH AMERICAN DATUM (NAD) 1983 ESTABLISHED BY GPS (OBSERVATION).

VERTICAL CONTROL IS BASED ON NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD 1988) (GEOID 12B).

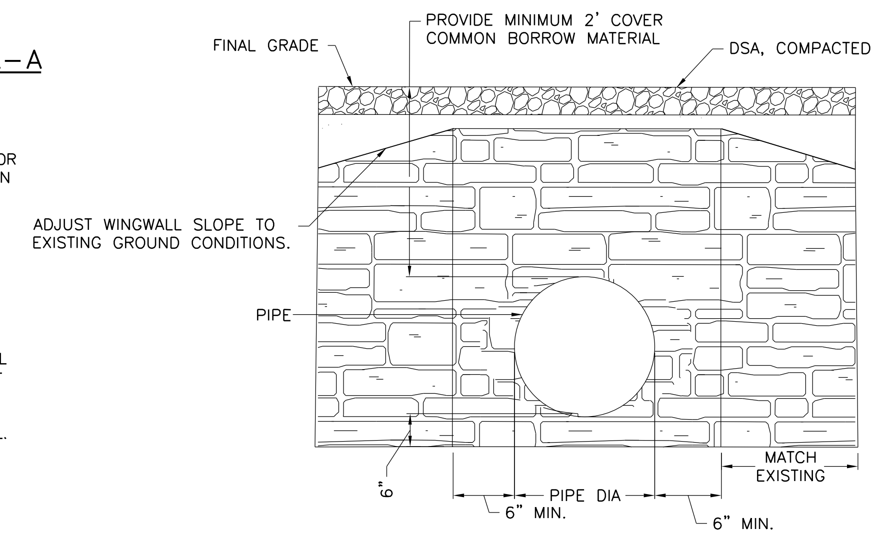
AVERAGE COMBINED SCALE FACTOR:

CONSTRUCT PROJECT IN ACCORDANCE WITH PROJECT SPECIFICATIONS, AS SUPPLEMENTED BY PENNSYLVANIA DEPARTMENT OF TRANSPORTATION PUBLICATION 408 SPECIFICATIONS, DATED 2016 AND CURRENT INTERIMS.

THREE WORKING DAYS PRIOR TO EXCAVATION THE CONTRACTOR MUST CONTACT THE ONE-CALL SYSTEM INC., 1-800-242-1776.

DETAILS, OTHER THAN THOSE INDICATED, ARE ON THE FOLLOWING STANDARD DRAWINGS FROM THE DEPARTMENT OF TRANSPORTATION, PUBLICATIONS 72M, 111M, AND 219M:

RC-10M	CLASSIFICATION OF EARTHWORK	JUNE 1, 2010
RC-30M	SUBSURFACE DRAINS	FEBRUARY 8, 2019
RC-40M	SLOPE PROTECTION	FEBRUARY 8, 2019
RC-70M	PERIMETER CONTROL DEVICE	FEBRUARY 8, 2019
RC-72M	INLET AND OUTLET PROTECTION	FEBRUARY 8, 2019
RC-73M	CHANNEL AND SLOPE PROTECTION	FEBRUARY 8, 2019
RC-77M	ROCK CONSTRUCTION ENTRANCE	JUNE 1, 2010



HEADWALL

NOT TO SCALE

CALL BEFORE YOU DIG

PENNSYLVANIA LAW REQUIRES 3 WORKING DAYS NOTICE FOR CONSTRUCTION PHASE AND 10 WORKING DAYS IN DESIGN STAGE-STOP CALL

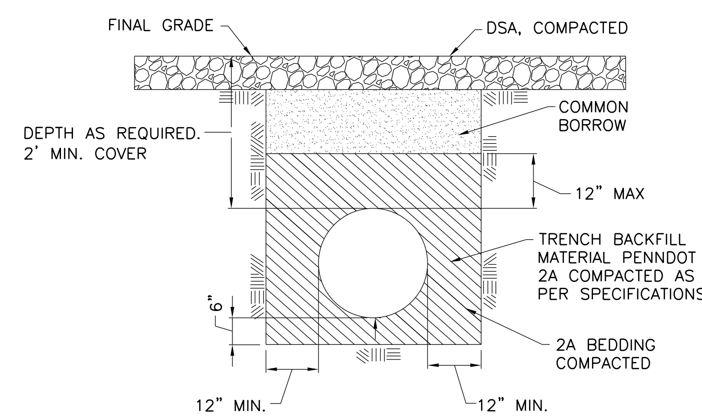
POCS SERIAL NUMBERS:

20193111180 (FORKS TOWNSHIP)
CONTRACTOR SHALL NOTIFY THE ONE CALL SYSTEM 3 DAYS PRIOR TO EXCAVATION AT 1-800-242-1776.

UTILITY LISTING NOTES:

1. DATA CONCERNING EXISTING UTILITIES HAS BEEN OBTAINED FROM AVAILABLE INFORMATION. ACCURACY OF THIS DATA IS NOT GUARANTEED.

2. CONTRACTOR SHALL COMPLY WITH ACT 287 OF THE GENERAL ASSEMBLY, AS AMENDED (ACT 172), WHICH DEFINES THE PROCEDURES FOR NOTIFICATION TO THE PUBLIC UTILITIES PRIOR TO EXCAVATION, DRILLING, OR DEMOLITION WORK USING POWER EQUIPMENT OR EXPLOSIVES.



NOTE:
1. STABILIZE DISTURBED AREAS ADJACENT TO THE ROAD SURFACE WITH ROCK LINING OR SEED AND MULCH.
2. THIS DETAIL SHALL BE USED FOR PIPE INSTALLATIONS WHICH ARE NOT CONVEYING WATERS OF A STREAM.
3. DO NOT DEPRESS PIPE INVERT BELOW CHANNEL BOTTOM.

PIPE (FOR STORMWATER)

NOT TO SCALE

DETAILS PREPARED BY
LARSON DESIGN GROUP
1000 COMMERCE PARK DRIVE
WILLIAMSPORT, PA 17701

12/10/2019

N:_2017\1712RE802 DCNR W023_WorldsEnd_CADD\MicroStation\Details.dgn

NAVARRO & WRIGHT CONSULTING ENGINEERS, INC.
151 Reno Avenue
New Cumberland, PA 17070
(717) 441-2216 (Telephone)
(717) 441-6408 (Fax)

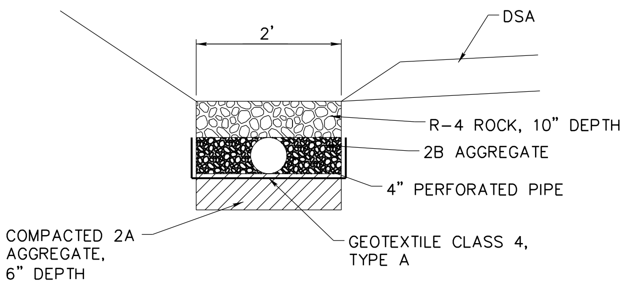
Mineral Spring Road Rehabilitation

Worlds End State Park
Site 1 and Site 2
Forks Township, Sullivan County, Pennsylvania

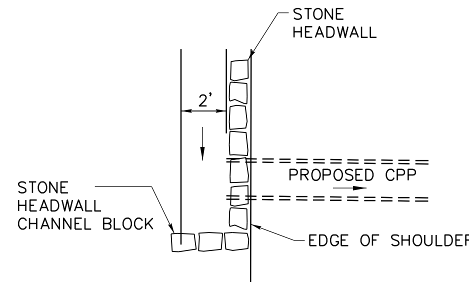
Source:
Detail source file provided by Larson Design Group

Job number: 1712RE802
Drawn by: SRF
Checked by: WB
Scale: N.T.S.
Date: 12/2/2019

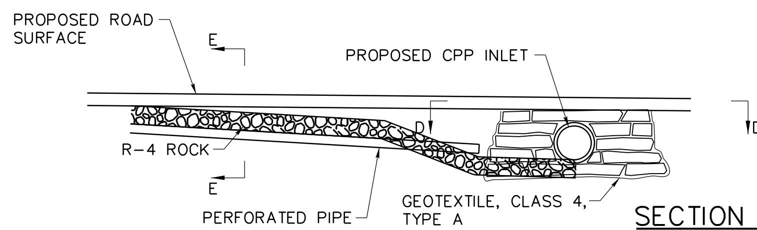
Figure:
1



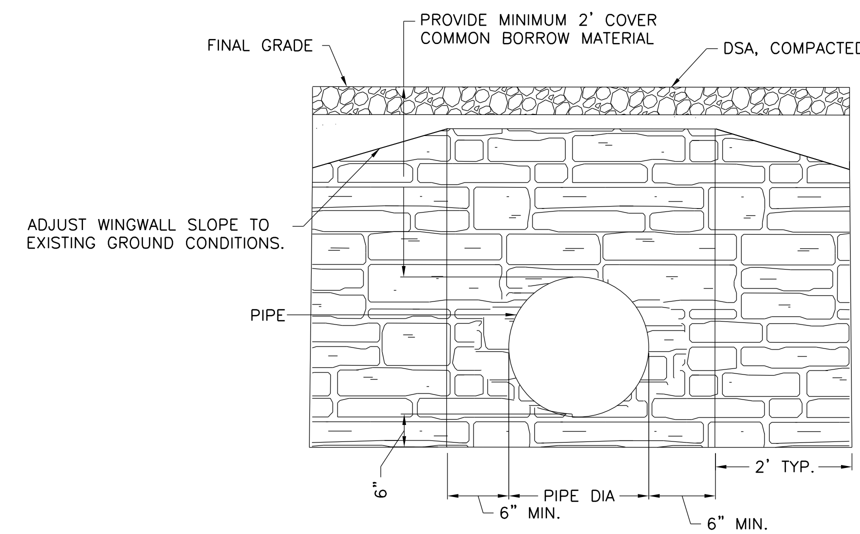
SECTION E-E



SECTION D-D



SECTION C-C



HEADWALL
NOT TO SCALE

HEADWALL NOTES:
1. USE ROCKS OF UNIFORM THICKNESS, FLAT ON TWO OR THREE SIDES THAT CAN BE HANDLED BY ONE PERSON ARE IDEAL.
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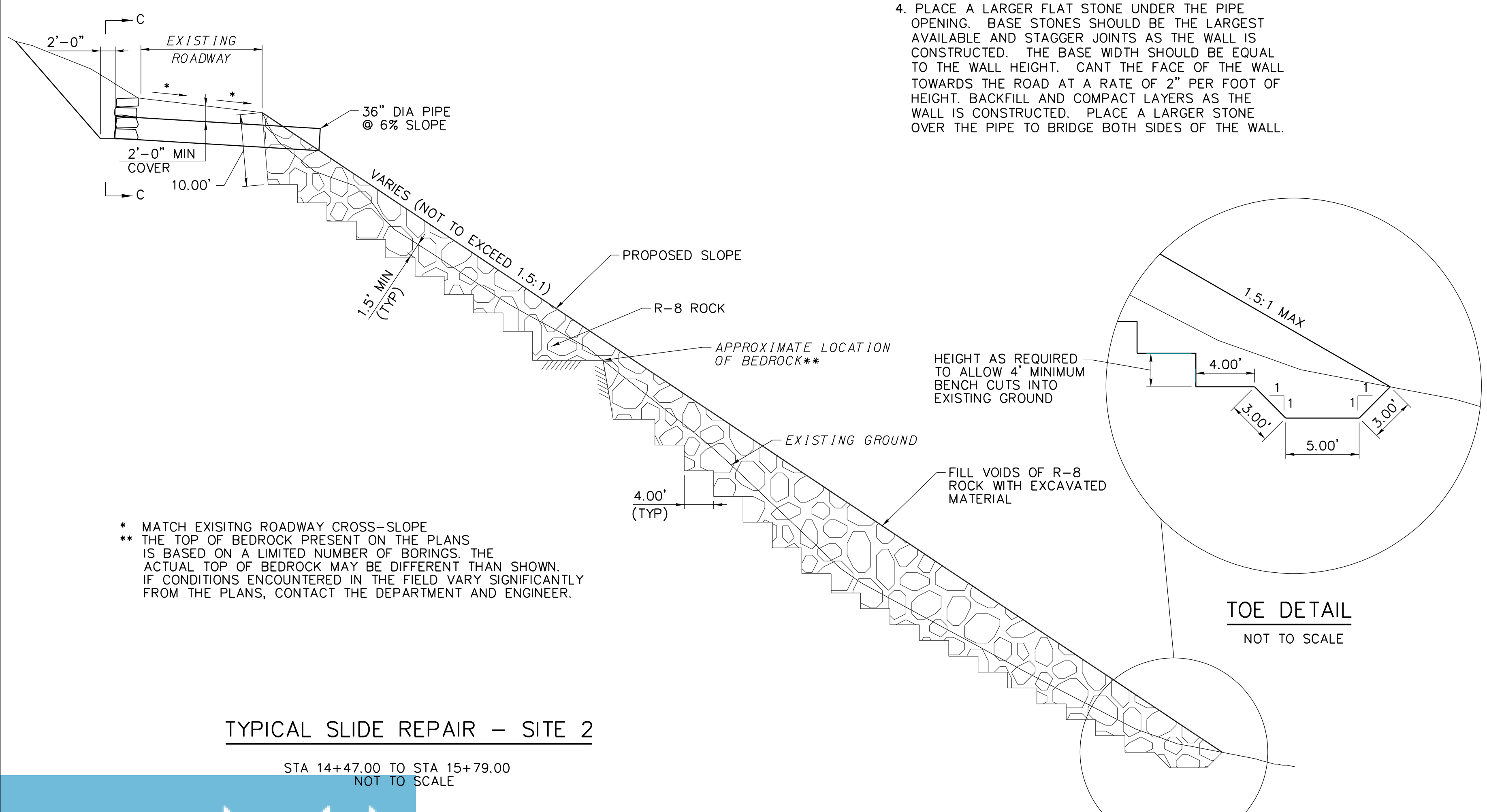

* MATCH EXISITNG ROADWAY CROSS-SLOPE
** THE TOP OF BEDROCK PRESENT ON THE PLANS IS BASED ON A LIMITED NUMBER OF BORINGS. THE ACTUAL TOP OF BEDROCK MAY BE DIFFERENT THAN SHOWN. IF CONDITIONS ENCOUNTERED IN THE FIELD VARY SIGNIFICANTLY FROM THE PLANS, CONTACT THE DEPARTMENT AND ENGINEER.

TOE DETAIL
NOT TO SCALE

TYPICAL SLIDE REPAIR - SITE 2
STA 14+47.00 TO STA 15+79.00
NOT TO SCALE

ALL DIMENSIONS AND EXISTING CONDITIONS SHALL BE CHECKED AND VERIFIED BY CONTRACTOR AT THE SITE.

DETAILS PREPARED BY
LARSON DESIGN GROUP
1000 COMMERCE PARK DRIVE
WILLIAMSPORT, PA 17701

NAVARRO & WRIGHT CONSULTING ENGINEERS, INC.
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Mineral Spring Road Rehabilitation
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Figure:
2

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12/10/2019