INITIAL SAFETY FACTOR ASSESSMENT

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INITIAL SAFETY FACTOR ASSESSMENT

Bremo Power Station CCR Surface Impoundment: West Ash Pond

Dominion Energy℠

Submitted To: Bremo Power Station
1038 Bremo Bluff Road
Bremo Bluff, VA 23022

Submitted By: Golder Associates Inc.
2108 W. Laburnum Avenue, Suite 200
Richmond, VA 23227

April 2018 **Project No. 15-20347**

Golder Associates

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1.0 CERTIFICATION

This Initial Safety Factor Assessment for the Bremo Power Station's West Ash Pond was prepared by Golder Associates Inc. (Golder). The document and Certification/Statement of Professional Opinion are based on and limited to information that Golder has relied on from Dominion Energy and others, but not independently verified, as well as work products produced by Golder.

On the basis of and subject to the foregoing, it is my professional opinion as a Professional Engineer licensed in the Commonwealth of Virginia that this document has been prepared in accordance with good and accepted engineering practices as exercised by other engineers practicing in the same discipline(s), under similar circumstances, at the same time, and in the same locale. It is my professional opinion that the document was prepared consistent with the requirements in §257.73(e) of the United States Environmental Protection Agency's "Standards for the Disposal of Coal Combustion Residuals in Landfills and Surface Impoundments," published in the Federal Register on April 17, 2015, with an effective date of October 19, 2015 [40 CFR §257.73(e)], as well as with the requirements in §257.100 resulting from the EPA's "Hazardous and Solid Waste Management System: Disposal of Coal Combustion Residuals From Electric Utilities; Extension of Compliance Deadlines for Certain Inactive Surface Impoundments; Response to Partial Vacatur" published in the Federal Register on August 5, 2016 with an effective date of October 4, 2016 (40 CFR §257.100).

The use of the word "certification" and/or "certify" in this document shall be interpreted and construed as a Statement of Professional Opinion, and is not and shall not be interpreted or construed as a guarantee, warranty, or legal opinion.

Daniel McGrath
Print Name

Associate and Senior Consultant
Title

Daniel McGrath
Signature

4/13/18
Date

2.0 INTRODUCTION

This Initial Safety Factor Assessment was prepared for the Bremo Power Station's (Station) inactive Coal Combustion Residuals (CCR) surface impoundment, the West Ash Pond (WAP). This Initial Safety Factor Assessment was prepared in accordance with 40 CFR Part §257, Subpart D and is consistent with the requirements of 40 CFR §257.73(e) and 40 CFR §257.73(e)(3)(v).

The Station, owned and operated by Virginia Electric and Power Company d/b/a Dominion Energy Virginia (Dominion), is located in Fluvanna County at 1038 Bremo Road, east of Route 15 (James Madison Highway) and north of the James River. The Station includes an inactive CCR surface impoundment, the WAP, as defined by the Disposal of Coal Combustion Residuals from Electric Utilities; Final Rule and Direct Final Rule (40 CFR §257; the CCR rule). All elevations noted in this report are in feet relative to the North American Vertical Datum of 1988 (NAVD-88).

3.0 SAFETY FACTOR ASSESSMENT

A slope stability analysis of the dikes surrounding the WAP was conducted to determine whether the calculated factors of safety meet or exceed the minimum safety factors specified in 40 CFR §257.73(e)(1).

3.1 Methodology

Stability safety factors were evaluated using a general limit equilibrium (GLE) method and the computer program SLIDE 7.0 Version 7.031 (2018). Specifically, the method developed by Morgenstern and Price was used in SLIDE to evaluate the stability of potential failure surfaces. The factor of safety is calculated by dividing the resisting forces by the driving forces along the critical slip surface.

Stability was evaluated along three cross-sections of the WAP, as shown in Figure 1 in Appendix A. Subsurface stratigraphy at each cross-section and material properties for dike and foundation materials were taken from previous Golder investigations, analyses, and reports included in Golder's March 2017 Virginia Department of Conservation and Recreation (DCR) Impounding Structure Geotechnical Design Report Supporting Documents (Golder 2017). Table 1 below presents the material properties used for the steady-state stability analyses. The four loading scenarios required by the CCR rule are discussed in the following sections.

Table 1: Summary of Geotechnical Strength Properties (Golder 2017)

Summary of Geotechnical Strength Properties				
Material	***Total Unit Weight pcf)***	***Strength Properties***		
		Drained		***Undrained***
		Peak φ' (°)	**Cohesion (psf)**	**Su (tsf)**
Sluiced CCR	90	28	0	$Su = 0.22*\sigma'_v + 0.1$ (tsf)
Compacted CCR	110	34	0	N/A
Dike Fill Soils	125	31	50	N/A
Alluvium	115	28	50	N/A
Residuum	125	31	50	N/A
Disintegrated Rock	140	31	1000	N/A

3.2 Long-Term Maximum Storage Pool Conditions

The water level in the WAP for the maximum pool storage scenario is expected to remain at or below elevation 200 in the areas near the dikes. This is a pool elevation that considers the principal spillway to be out of service, as is the current condition.

3.3 Maximum Surcharge Pool Conditions

The peak water level calculated to exist within the WAP during the 1,000-year, 24-hour rain event was used to evaluate stability for this elevated (surcharge pool) water level. The maximum pool surcharge corresponds to a water level at elevation 205.6. For further details, refer to the hydraulic and hydrologic stormwater routing analysis included in Appendix B of the Inflow Design Flood Control System Plan.

3.4 Seismic Loading Conditions

Factors of safety for stability under seismic loading conditions were calculated based on the earthquake hazard corresponding to a probability of exceedance of 2% in 50 years (2,475-year return period). The displacement-based seismic slope stability screening method, as described in Bray and Travasarou (2009), was used to evaluate the seismic stability. For this method, a pseudo-static coefficient corresponding to an allowable displacement of six inches (15 centimeters) was used. The pseudo-static coefficient was calculated to be 0.063g. Details on the calculation of the pseudo-static coefficient are available in the Seismic Hazard Assessment presented in Appendix B.

3.5 Post-Seismic Liquefaction Loading Conditions

Golder evaluated the liquefaction susceptibility of the site soils, as presented in the Liquefaction Calculation Package included as Appendix C. The liquefaction susceptibility analysis indicates that the representative factor of safety for both foundation and dike soils is above 1.2. Thus, slope stability analyses evaluating the impact of liquefaction are not necessary. For more detail on the analysis, refer to Appendix C.

3.6 Results

The table below presents the results of the slope stability assessments of the dikes surrounding the WAP in its current condition for the analysis cases required in 40 CFR §257.73(e)(i) to (iv) of the CCR rule.

Table 2: Slope Stability Assessment Results

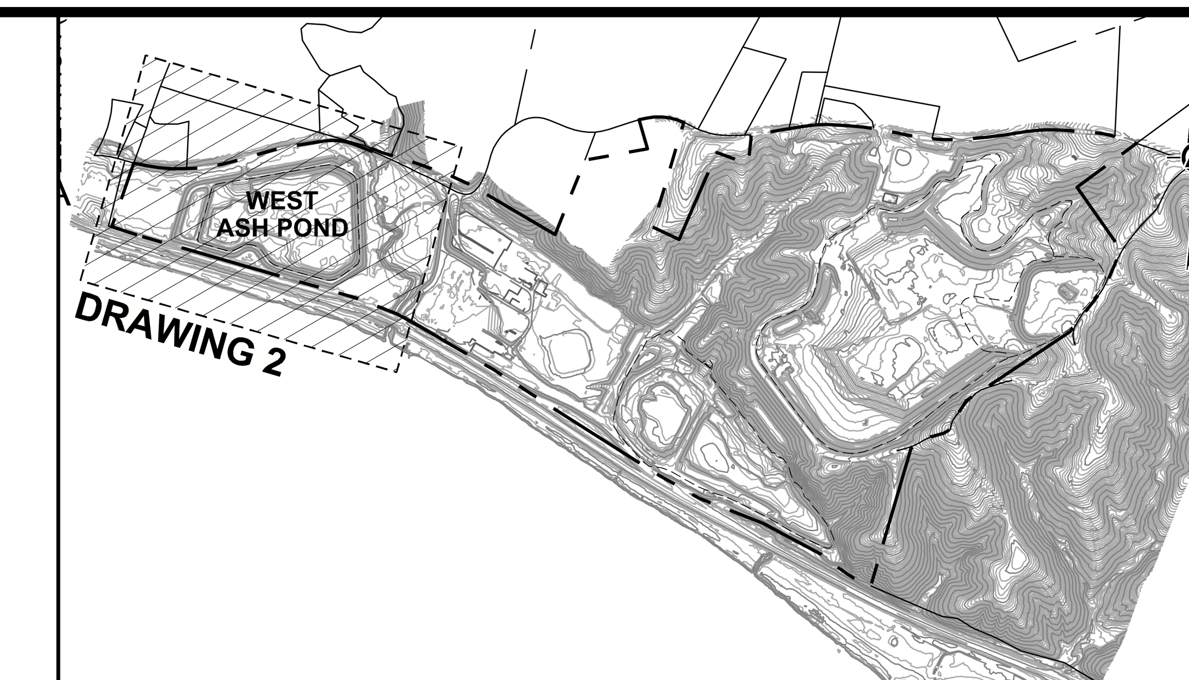
Analysis Case	Maximum Storage Pool	Maximum Surcharge Pool	Seismic	Post-Earthquake Liquefaction
Target Factor of Safety (FS)	1.5	1.4	1.0	1.2
Cross-Sections	**Factor of Safety**			
A-A (East)	1.6	1.6	1.4	Soils Calculated Not to Liquefy
B-B (North)	1.7	1.7	1.5	
B-B (South)	1.6	1.6	1.4	
C-C (North)	1.8	1.8	1.5	
C-C (South)	1.4	1.4	1.3	

For all cases analyzed, the calculated factors of safety are in excess of those target factors of safety presented in the CCR rule for all analyzed sections, with the exception of Section C-C (South). The calculated factor of safety for Section C-C (South) is below the target factor of safety for the normal storage pool scenario. For further details, see the stability figures in Appendix A.

In recognition of Section C-C (South) not meeting the target factor of safety, the water level in the WAP is kept pumped down and routine weekly inspections are conducted to observe any changes in the embankment. There are no plans to impound water or other material behind the WAP embankment, and monitoring will continue until the pond achieves final closure.

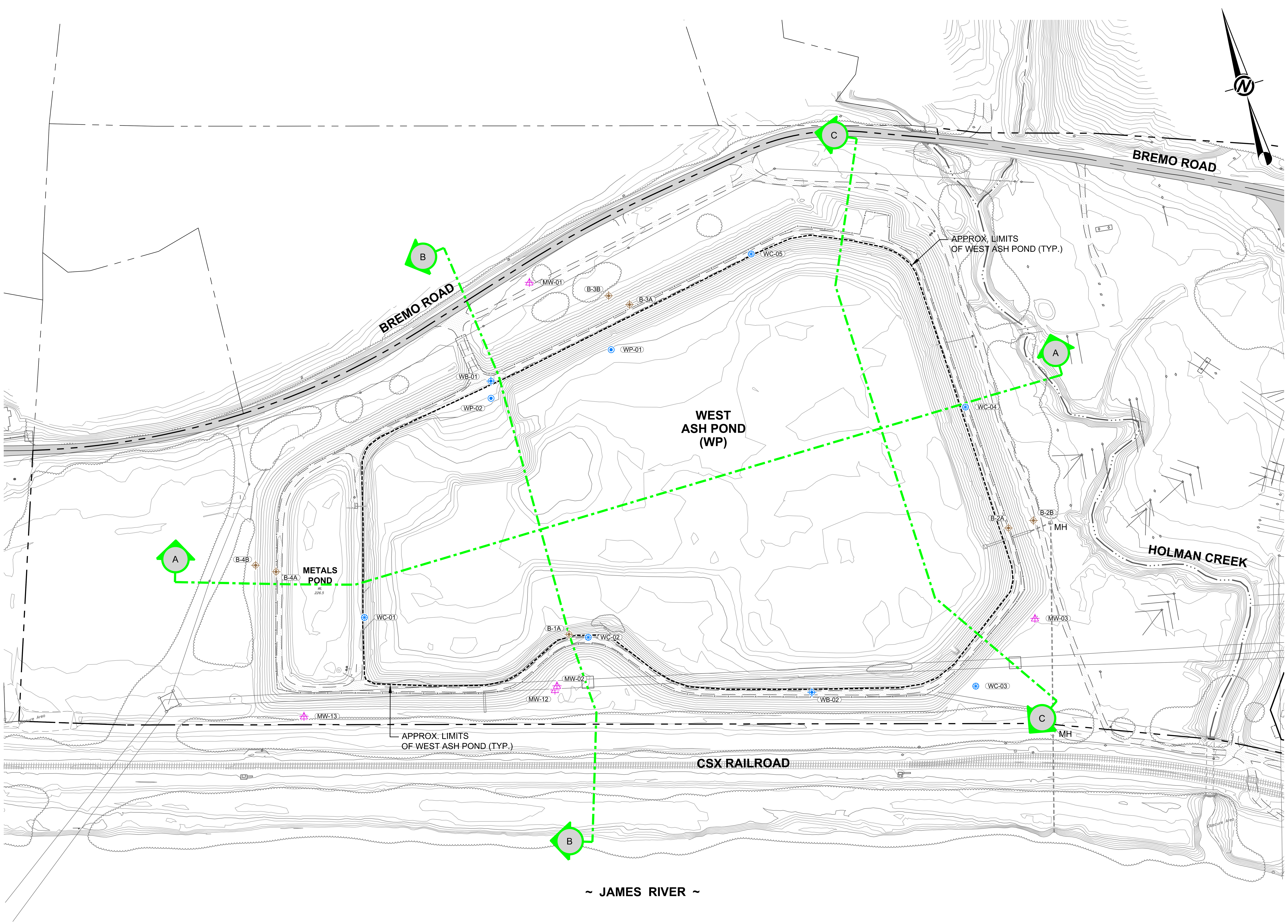
APPENDIX A-1

Stability Analysis Cross Section Location Plan



LEGEND

	DOMINION PROPERTY BOUNDARY
	ADJACENT PROPERTY BOUNDARY
	APPROXIMATE LIMITS OF EXISTING ASH PONDS
300	EXISTING TOPOGRAPHIC CONTOURS (2' INTERVALS)
220	DESIGN SURFACE CONTOURS (2' INTERVALS)
	EXISTING PAVED ROAD
	EXISTING RAILROAD
	CREEK CENTERLINE
	EXISTING FENCE
Obscure Area	DENOTES AREAS OF TOPOGRAPHY THAT DO NOT MEET MINIMUM ACCURACY STANDARDS FOR AERIAL SURVEYING
	GES MONITORING WELL (2013)
	HALEY AND ALDRICH BORING (2015)
	GOLDER BORING
	GOLDER PIEZOMETER
	GOLDER CONE PENETRATION TEST (CPT)
	GOLDER PROBE HOLE
	GOLDER HAND AUGER
	SLOPE STABILITY SECTIONS
	SLOPE STABILITY DRAWING LOCATIONS - SEE APPENDIX D



REFERENCES

1. TOPOGRAPHY DERIVED FROM THE MONTHLY EXCAVATION SURVEY PREPARED BY H&B SURVEYING AND MAPPING LLC., COLLECTED ON JANUARY 31, 2018.

REV	DATE	REVISION DESCRIPTION	DES	CADD	CHK	RVW
△	01/04/17	ADDED 2016 TOPO; UPDATED DESIGN GRADES, NOTATION, SECTION LOCATIONS	-	SEP	JGM	GLH

PROJECT
DOMINION
BREMO POWER STATION
CCR IMPOUNDMENT CLOSURE
FLUVANNA COUNTY, VIRGINIA

TITLE
INACTIVE POND DEMONSTRATION GEOTECHNICAL PLAN (WEST POND)

Golder Associates

PROJECT No.		15-20347	FILE No.	152034?AD00-02 INACTIVE POND DEMON
DESIGN	LJ	03/05/2018	SCALE	AS SHOWN
CADD	RMS	03/05/2018		
CHECK	JGM	03/05/2018		1
REVIEW	GLH	03/05/2018		

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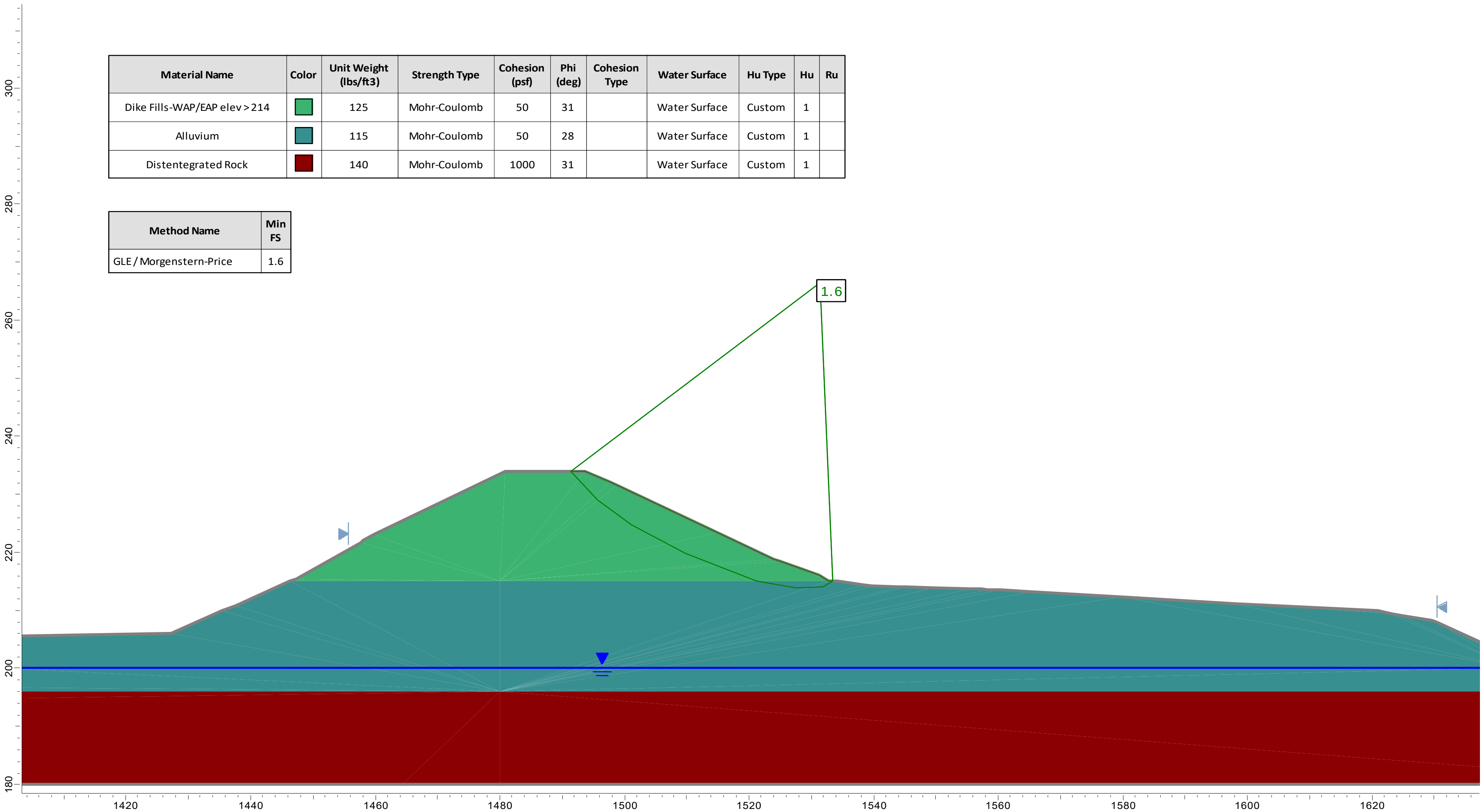
APPENDIX A-2

FIGURES 2A – 6C

Existing Conditions Stability Assessment Results



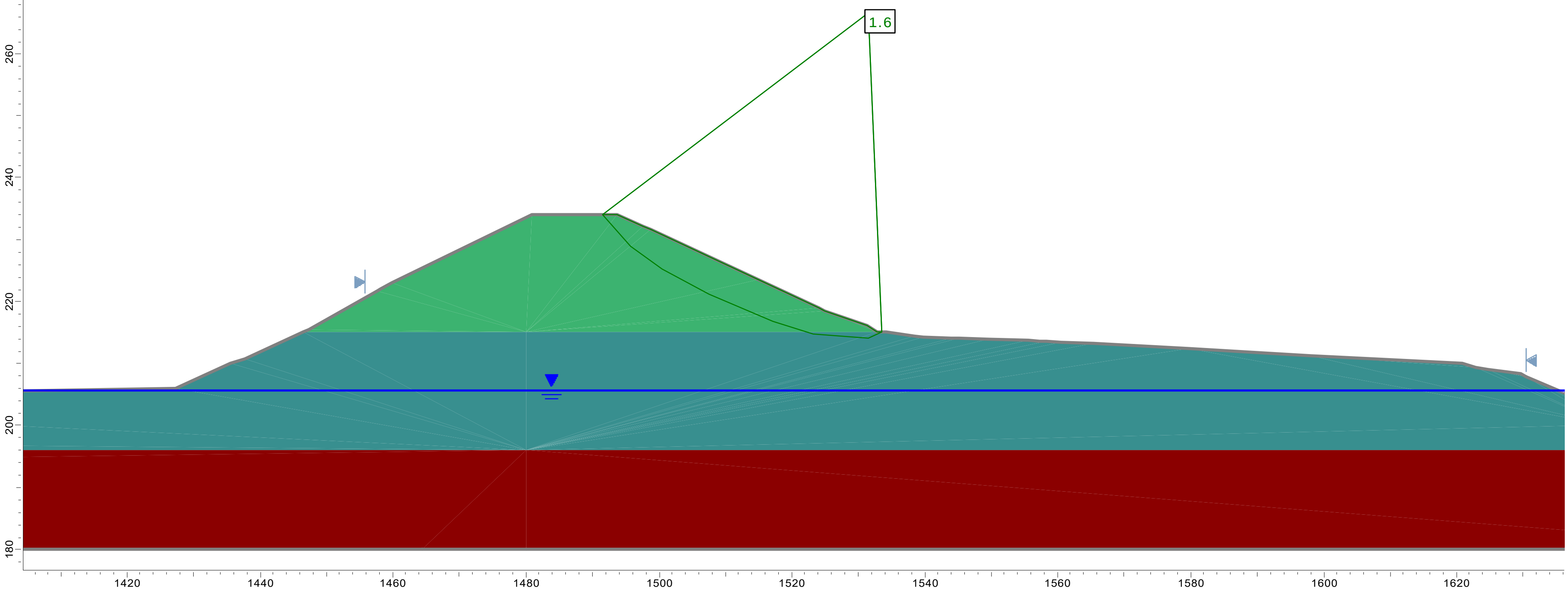
Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Cohesion Type	Water Surface	Hu Type	Hu	Ru
Dike Fills-WAP/EAP elev>214		125	Mohr-Coulomb	50	31		Water Surface	Custom	1	
Alluvium		115	Mohr-Coulomb	50	28		Water Surface	Custom	1	
Distentegrated Rock		140	Mohr-Coulomb	1000	31		Water Surface	Custom	1	

Method Name	Min FS
GLE / Morgenstern-Price	1.6

Golder Associates	SCALE: AS SHOWN	PROJECT	Bremo West Pond - Inactive Pond Demonstration
	DATE: Mar 2018	TITLE	Section A-A (East) Long Term, Normal Storage Pool
	MADE BY: LJ		
	CAD: -		
FILE: STABILITY	CHECK: JGM	CLIENT	Dominion Energy
PROJECT No. 1520347 / REV. 0	REVIEW: GLH	FIGURE	2(a)

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Cohesion Type	Water Surface	Hu Type	Hu	Ru
Dike Fills-WAP/EAP elev>214		125	Mohr-Coulomb	50	31		Water Surface	Custom	1	
Alluvium		115	Mohr-Coulomb	50	28		Water Surface	Custom	1	
Distentegrated Rock		140	Mohr-Coulomb	1000	31		Water Surface	Custom	1	

Method Name	Min FS
GLE / Morgenstern-Price	1.6

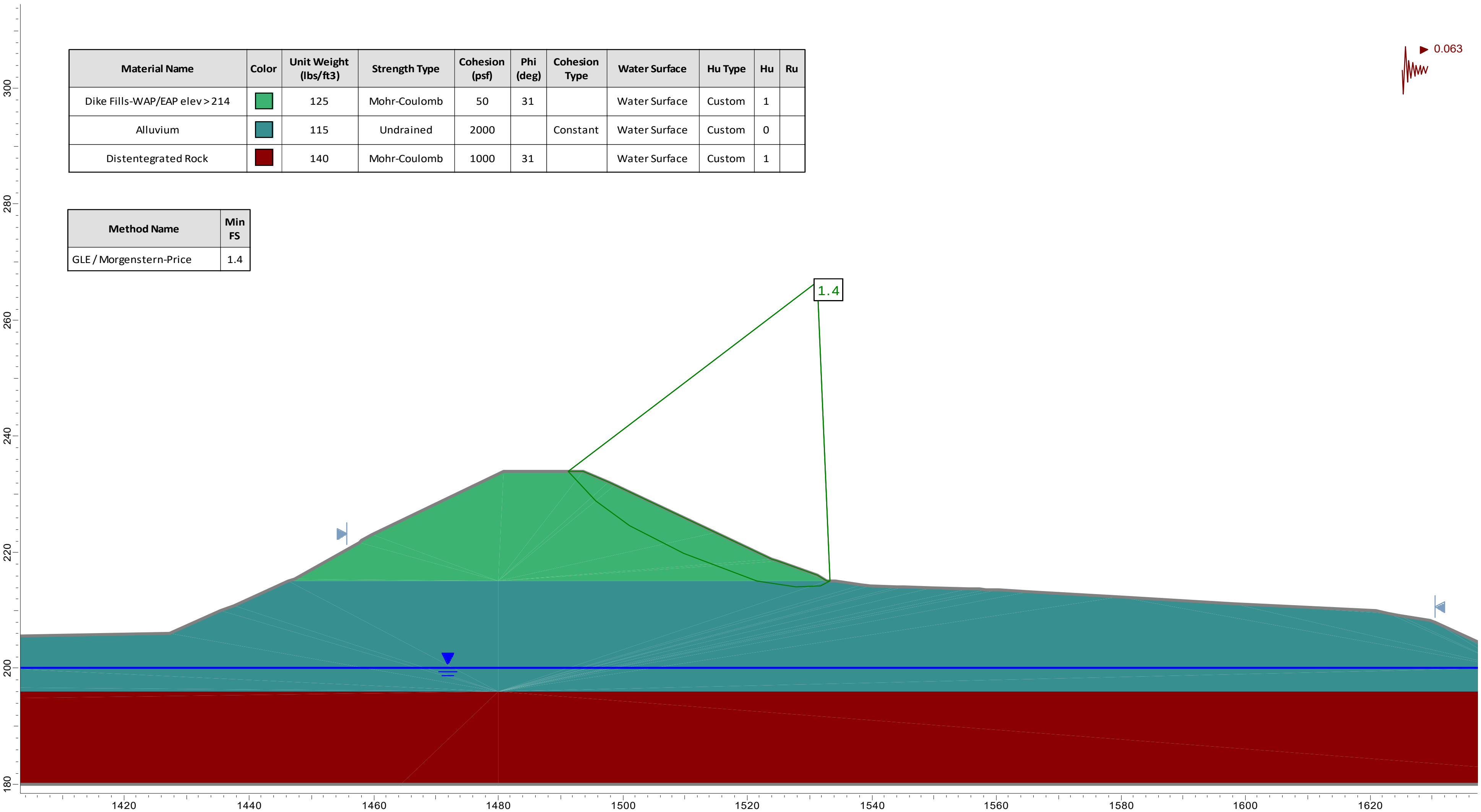


Golder Associates

SCALE	AS SHOWN	PROJECT	Bremo West Pond - Inactive Pond Demonstration
DATE	Mar 2018	TITLE	Section A-A (East) Maximum Surchage Pool
MADE BY	LJ		
CAD	-		
FILE	STABILITY	CLIENT	Dominion Energy
PROJECT No.	1520347	REV.	0
CHECK	JGM	FIGURE	2(b)
REVIEW	GLH		

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Cohesion Type	Water Surface	Hu Type	Hu	Ru
Dike Fills-WAP/EAP elev > 214		125	Mohr-Coulomb	50	31		Water Surface	Custom	1	
Alluvium		115	Undrained	2000		Constant	Water Surface	Custom	0	
Distentegrated Rock		140	Mohr-Coulomb	1000	31		Water Surface	Custom	1	

Method Name	Min FS
GLE / Morgenstern-Price	1.4



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DATE	Mar 2018
MADE BY	LJ
CAD	-
CHECK	JGM
REVIEW	GLH
FILE	STABILITY
PROJECT No.	1520347
REV.	0

PROJECT **Bremo West Pond - Inactive Pond Demonstration**

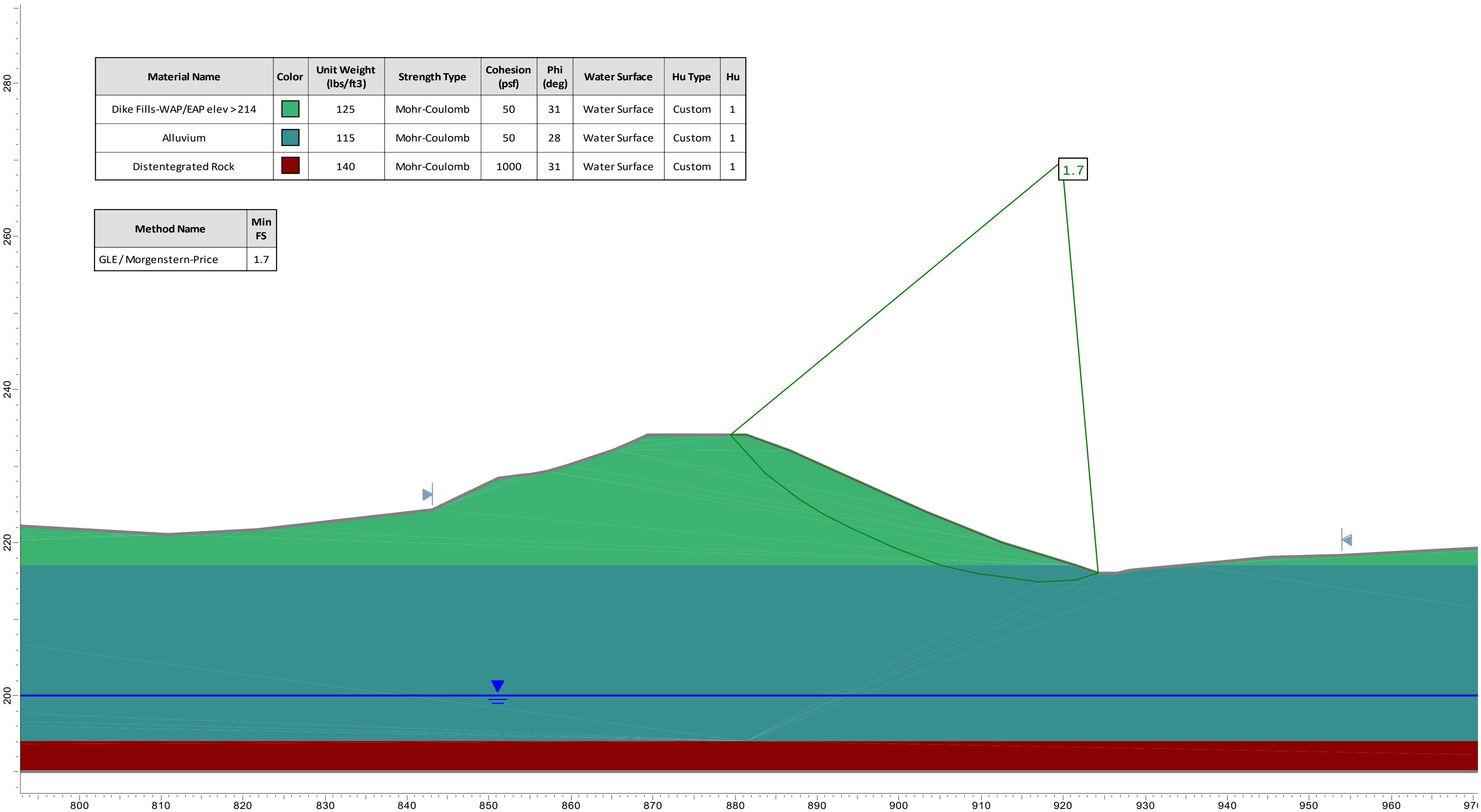
TITLE **Section A-A (East)**
Seismic Screening

CLIENT **Dominion Energy**

FIGURE **2(c)**

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Hu Type	Hu
Dike Fills-WAP/EAP elev >214		125	Mohr-Coulomb	50	31	Water Surface	Custom	1
Alluvium		115	Mohr-Coulomb	50	28	Water Surface	Custom	1
Distentegrated Rock		140	Mohr-Coulomb	1000	31	Water Surface	Custom	1

Method Name	Min FS
GLE / Morgenstern-Price	1.7



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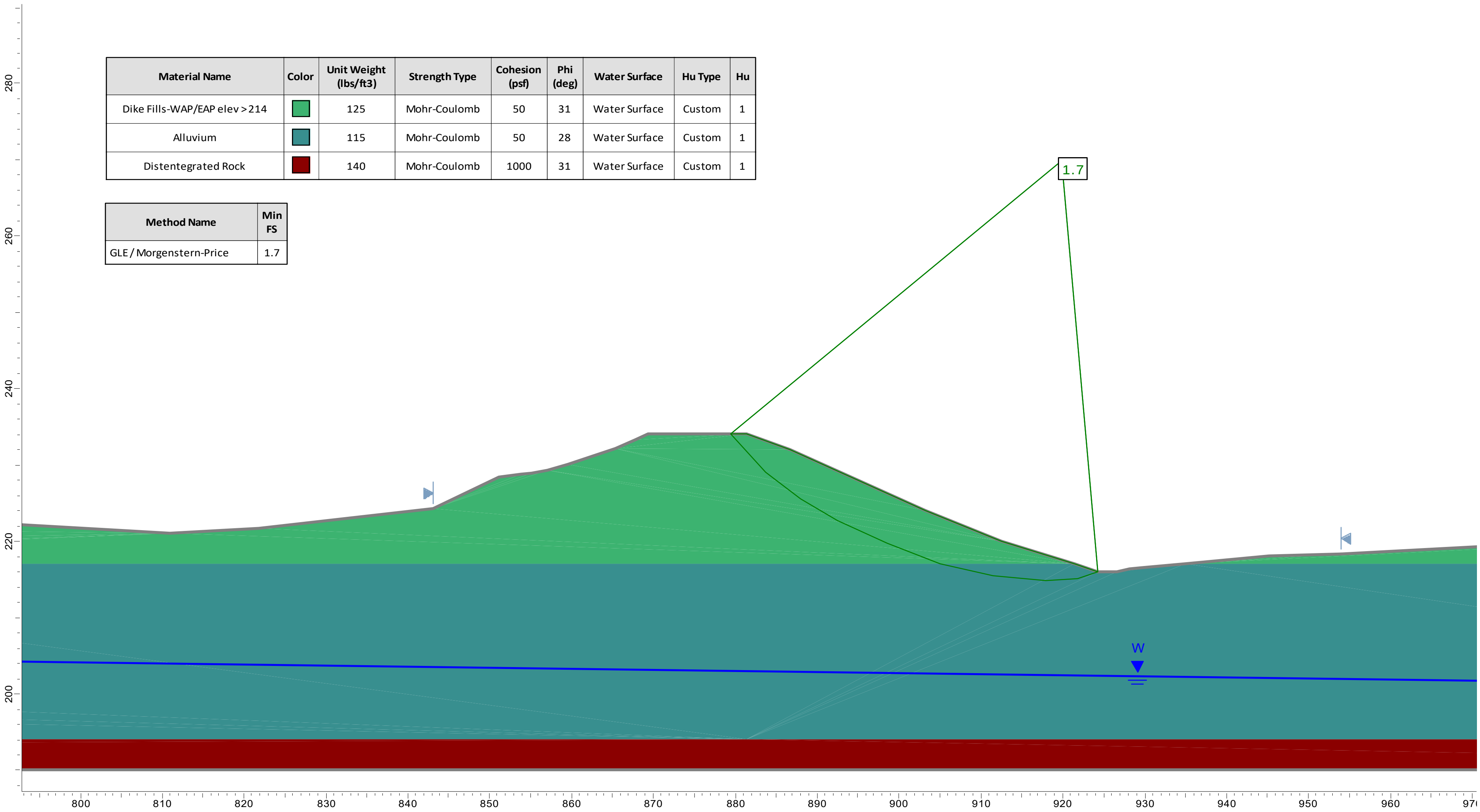
	DATE Mar 2018	TITLE	**Section B-B (North)** **Long Term, Normal Storage Pool**
	MADE BY LJ		
	CAD -		
FILE STABILITY	CHECK JGM	CLIENT **Dominion Energy**	FIGURE **3(a)**
PROJECT No. 1520347 REV. 0	REVIEW GLH		

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Hu Type	Hu
Dike Fills-WAP/EAP elev > 214		125	Mohr-Coulomb	50	31	Water Surface	Custom	1
Alluvium		115	Mohr-Coulomb	50	28	Water Surface	Custom	1
Distentegrated Rock		140	Mohr-Coulomb	1000	31	Water Surface	Custom	1

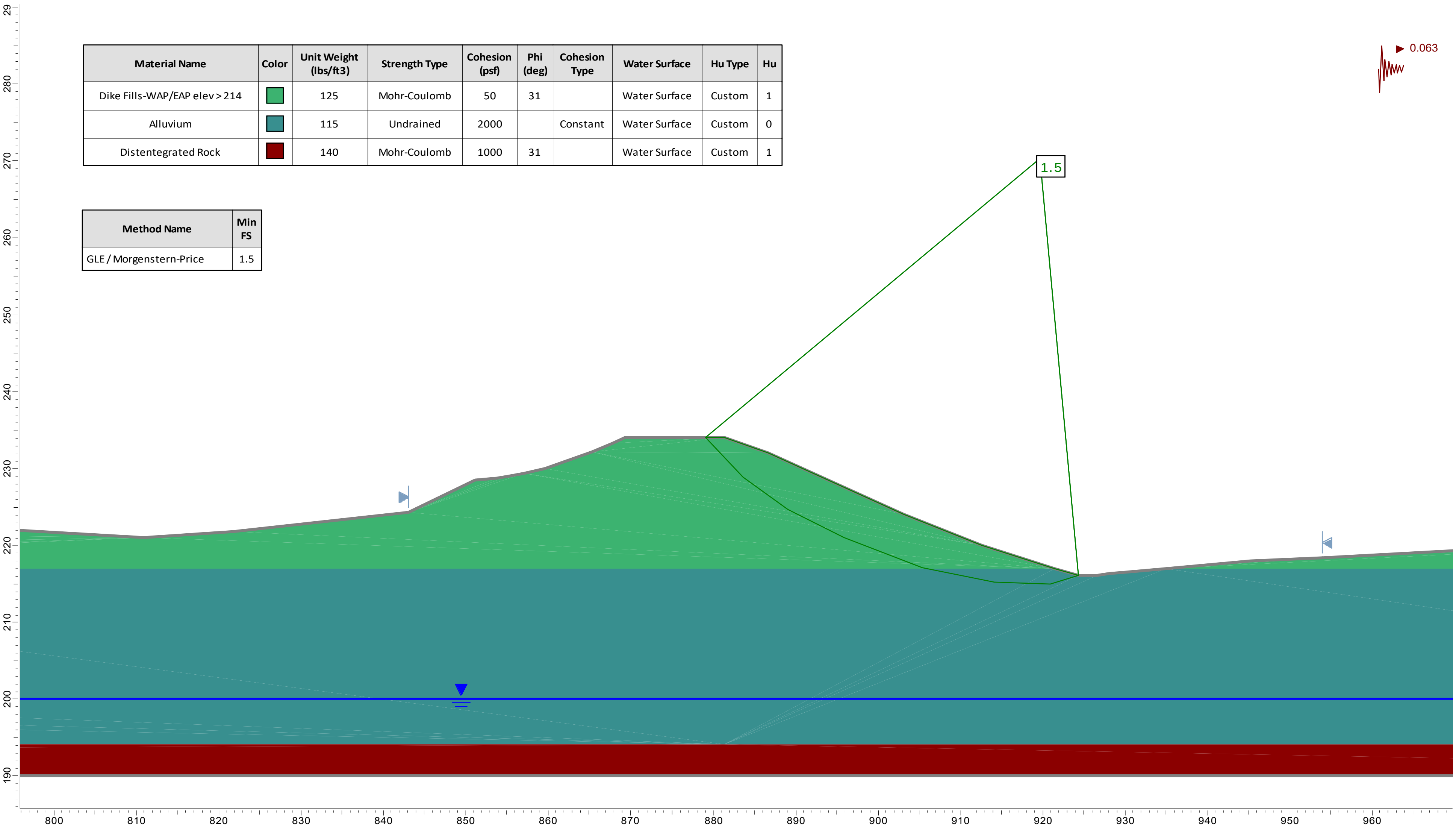
Method Name	Min FS
GLE / Morgenstern-Price	1.7



Golder Associates	SCALE AS SHOWN	PROJECT	**Bremo West Pond - Inactive Pond Demonstration**
	DATE Mar 2018	TITLE	**Section B-B (North)** **Maximum Surchage Pool**
	MADE BY LJ		
	CAD -		
FILE STABILITY	CHECK JGM	CLIENT	**Dominion Energy**
PROJECT No. 1520347 REV. 0	REVIEW GLH	FIGURE	3(b)

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Cohesion Type	Water Surface	Hu Type	Hu
Dike Fills-WAP/EAP elev > 214		125	Mohr-Coulomb	50	31		Water Surface	Custom	1
Alluvium		115	Undrained	2000		Constant	Water Surface	Custom	0
Distentegrated Rock		140	Mohr-Coulomb	1000	31		Water Surface	Custom	1

Method Name	Min FS
GLE / Morgenstern-Price	1.5



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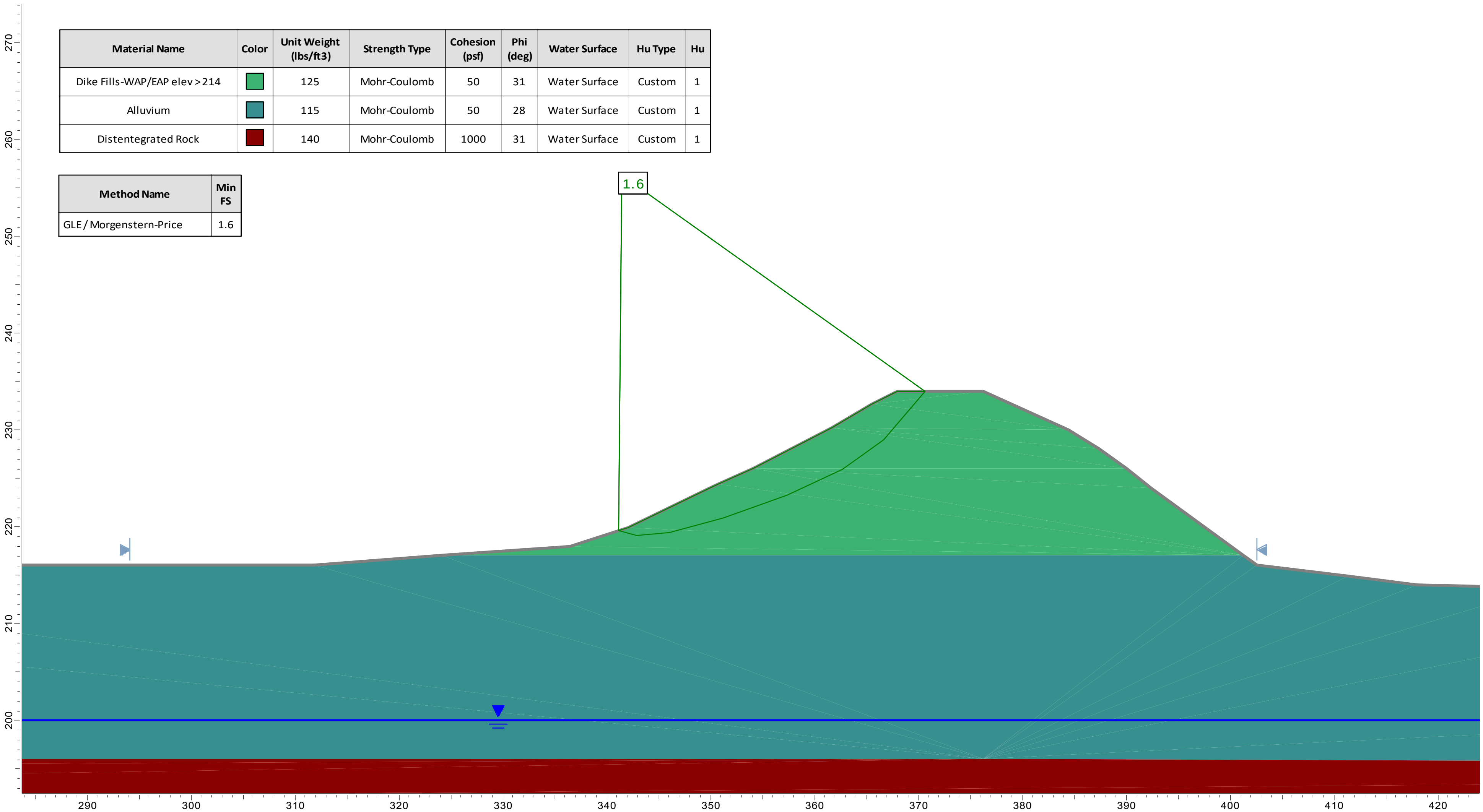
MADE BY	LJ		
CAD	-		
FILE	STABILITY	CHECK	JGM
PROJECT No.	1520347	REV.	0
REVIEW	GLH	CLIENT	Dominion Energy
FIGURE	3(c)		

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Hu Type	Hu
Dike Fills-WAP/EAP elev > 214		125	Mohr-Coulomb	50	31	Water Surface	Custom	1
Alluvium		115	Mohr-Coulomb	50	28	Water Surface	Custom	1
Distentegrated Rock		140	Mohr-Coulomb	1000	31	Water Surface	Custom	1

Method Name	Min FS
GLE / Morgenstern-Price	1.6



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CAD	-		
FILE	STABILITY		
CHECK	JGM	CLIENT	Dominion Energy
PROJECT No. 1520347	REV. 0	REVIEW	GLH
		FIGURE	4(a)

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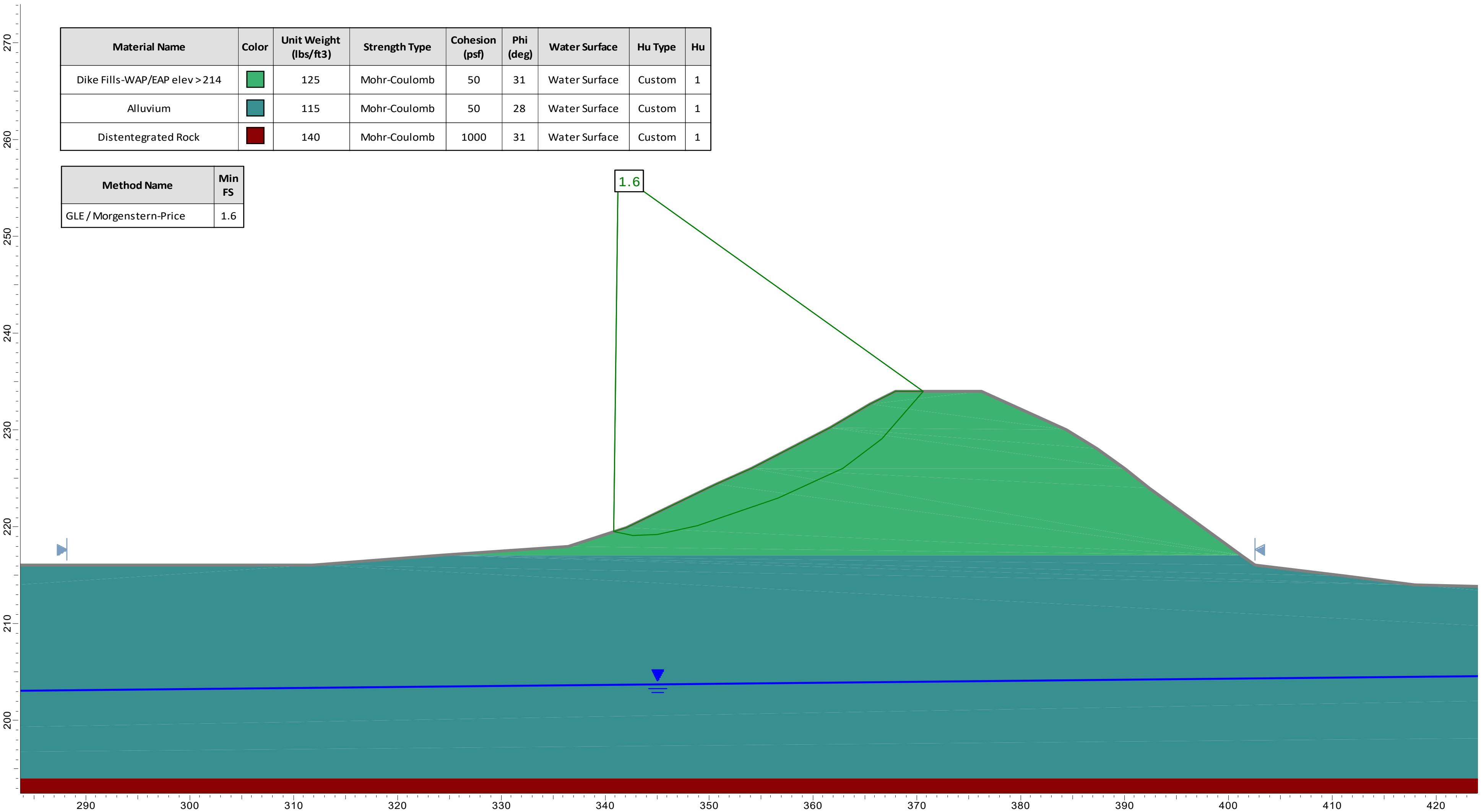
Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Hu Type	Hu
Dike Fills-WAP/EAP elev > 214		125	Mohr-Coulomb	50	31	Water Surface	Custom	1
Alluvium		115	Mohr-Coulomb	50	28	Water Surface	Custom	1
Distentegrated Rock		140	Mohr-Coulomb	1000	31	Water Surface	Custom	1

Method Name	Min FS
GLE / Morgenstern-Price	1.6



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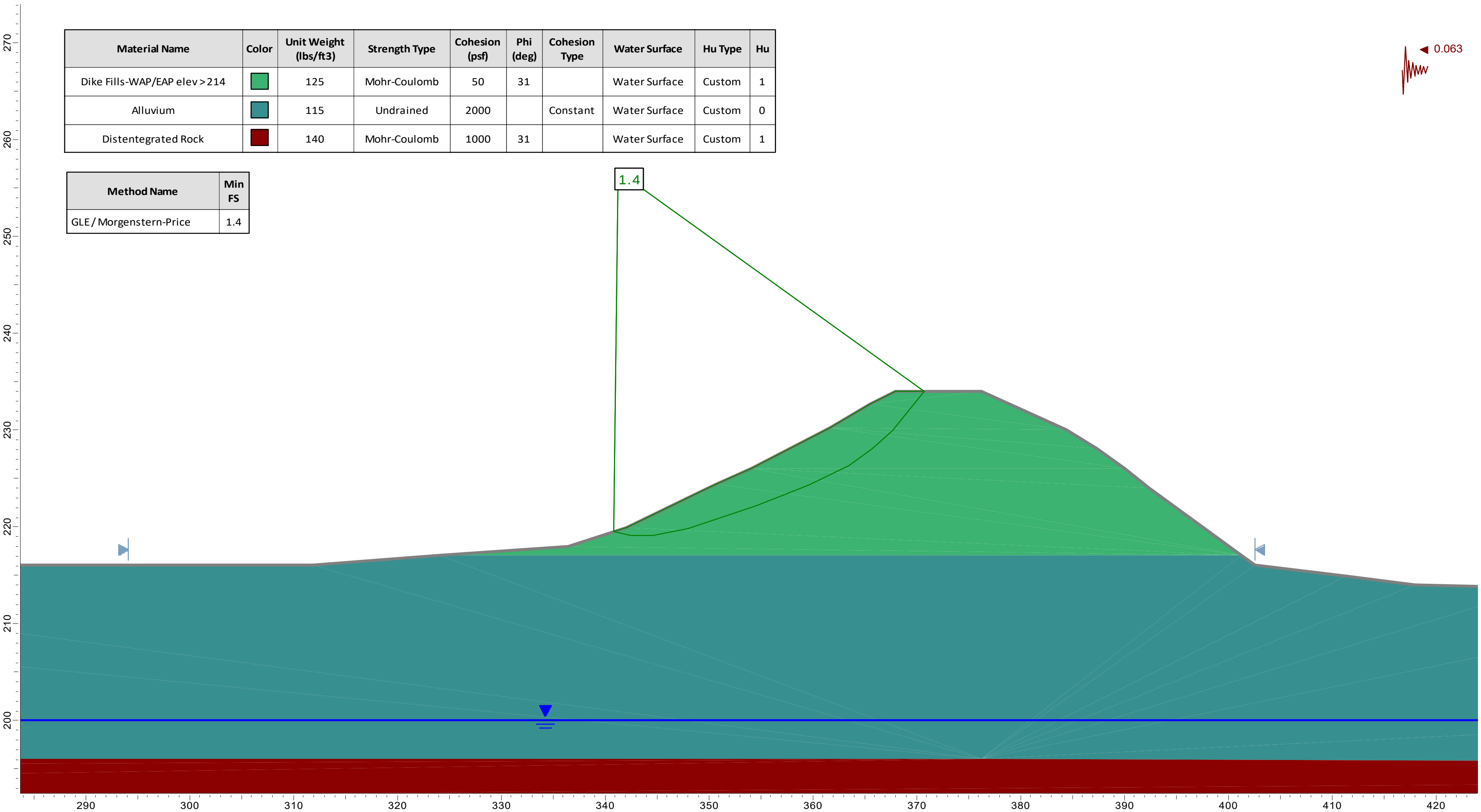
	CAD: -		
FILE: STABILITY	CHECK: JGM	CLIENT	Dominion Energy
PROJECT No. 1520347 REV. 0	REVIEW: GLH	FIGURE	4(b)



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Cohesion Type	Water Surface	Hu Type	Hu
Dike Fills-WAP/EAP elev>214		125	Mohr-Coulomb	50	31		Water Surface	Custom	1
Alluvium		115	Undrained	2000		Constant	Water Surface	Custom	0
Distentegrated Rock		140	Mohr-Coulomb	1000	31		Water Surface	Custom	1

Method Name	Min FS
GLE / Morgenstern-Price	1.4

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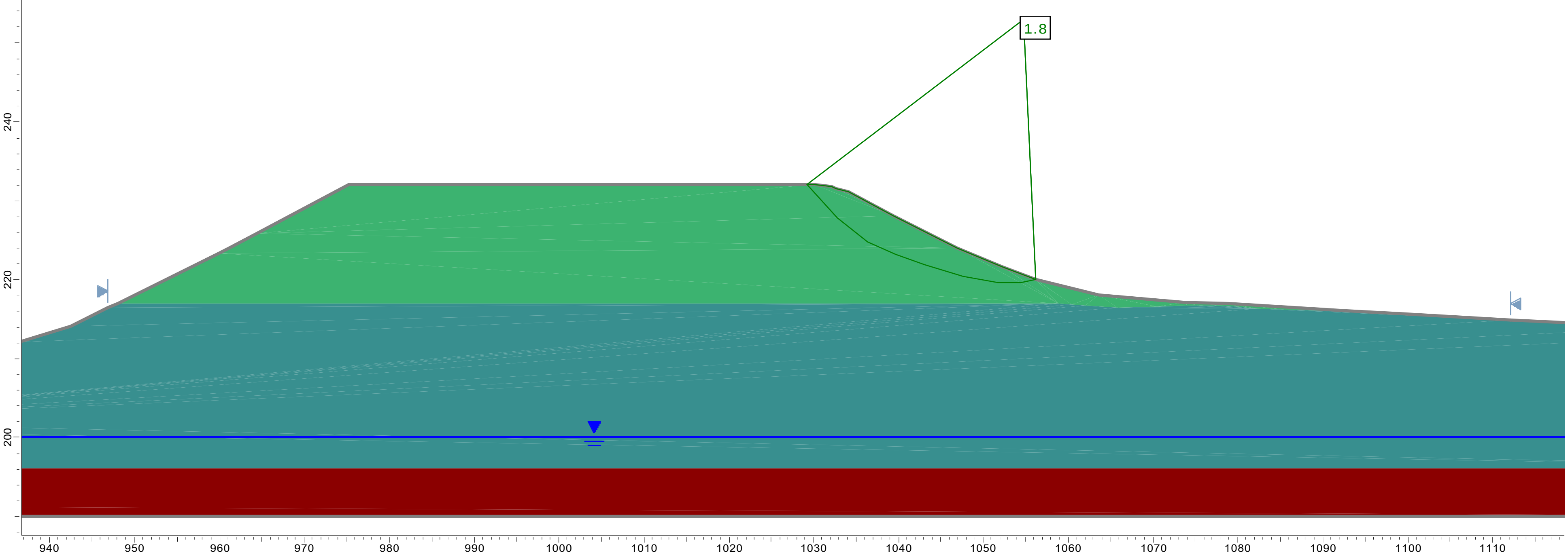
SCALE	AS SHOWN	PROJECT	Bremo West Pond - Inactive Pond Demonstration
DATE	Mar 2018	TITLE	Section B-B (South) Seismic Screening
MADE BY	LJ		
CAD	-		
FILE	STABILITY	CHECK	JGM
PROJECT No.	1520347	REV.	0
REVIEW	GLH	CLIENT	Dominion Energy
FIGURE	4(c)		

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Hu Type	Hu
Dike Fills-WAP/EAP elev>214		125	Mohr-Coulomb	50	31	Water Surface	Custom	1
Alluvium		115	Mohr-Coulomb	50	28	Water Surface	Custom	1
Distentegrated Rock		140	Mohr-Coulomb	1000	31	Water Surface	Custom	1

Method Name	Min FS
GLE / Morgenstern-Price	1.8



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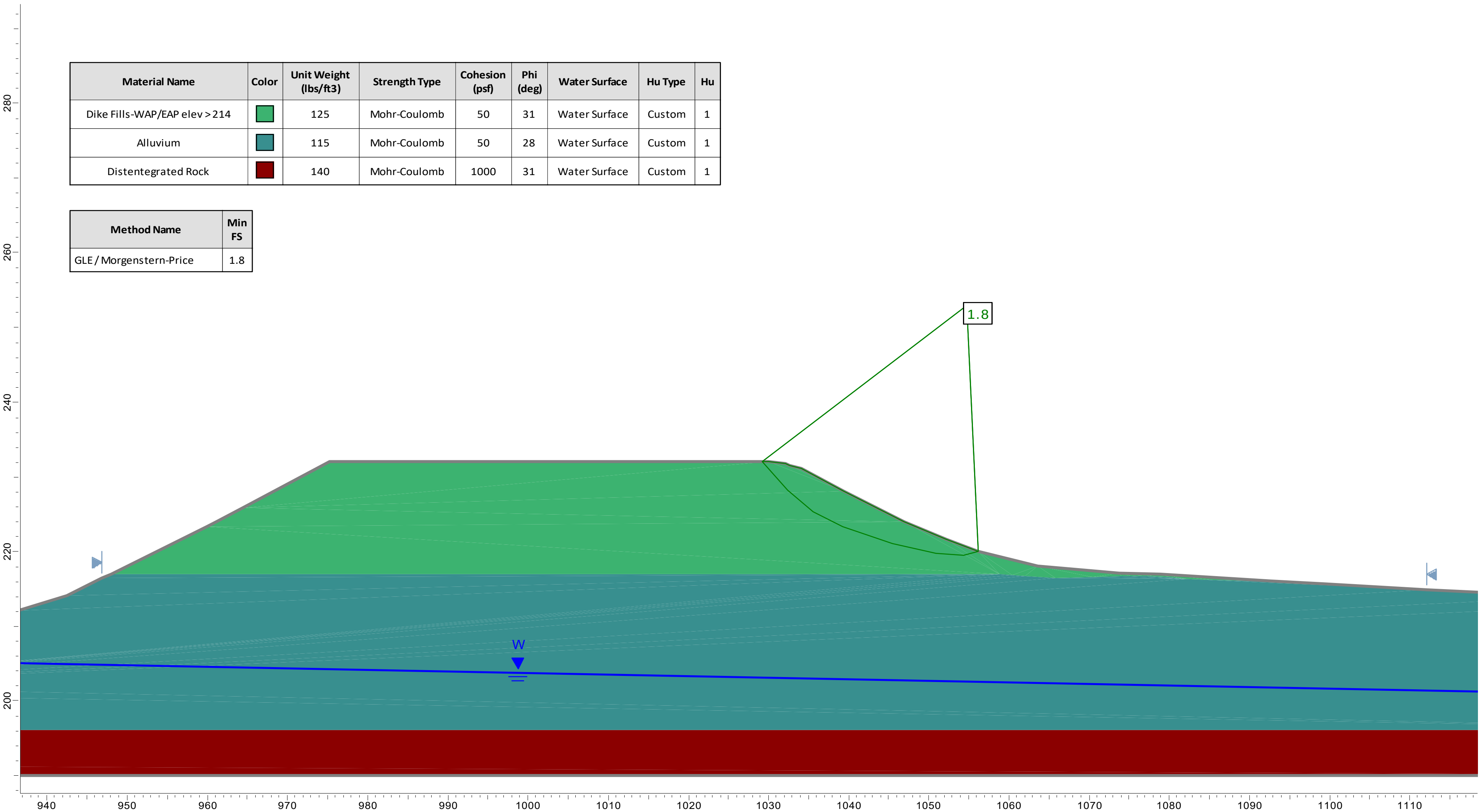
	DATE: Mar 2018	TITLE	Section C-C (North) Long Term, Normal Storage Pool
	MADE BY: LJ		
	CAD: -		
FILE: STABILITY	CHECK: JGM	CLIENT	Dominion Energy
PROJECT No. 1520347 / REV. 0	REVIEW: GLH	FIGURE	5(a)

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Hu Type	Hu
Dike Fills-WAP/EAP elev > 214		125	Mohr-Coulomb	50	31	Water Surface	Custom	1
Alluvium		115	Mohr-Coulomb	50	28	Water Surface	Custom	1
Distentegrated Rock		140	Mohr-Coulomb	1000	31	Water Surface	Custom	1

Method Name	Min FS
GLE / Morgenstern-Price	1.8



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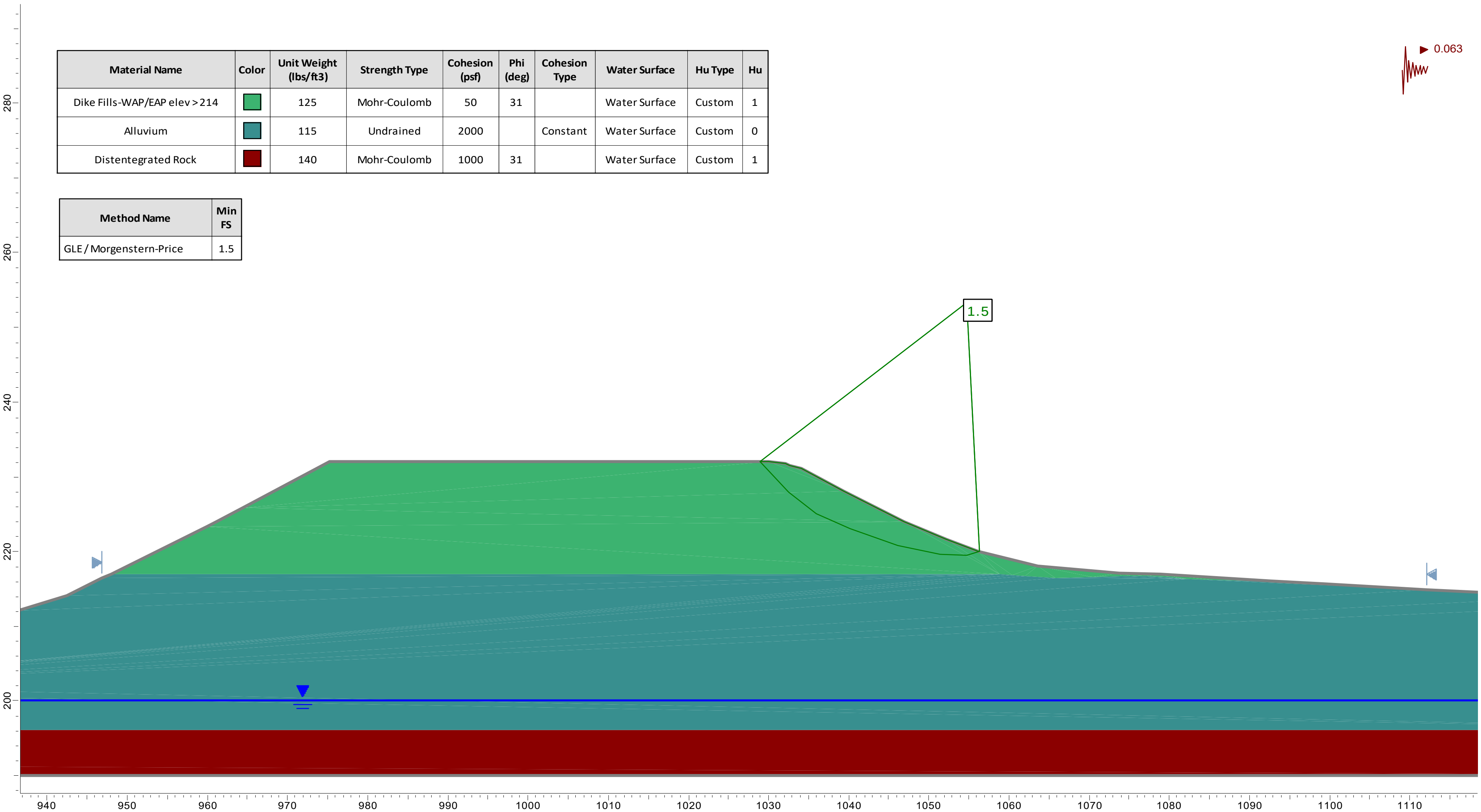
	DATE: Mar 2018	TITLE	Section C-C (North) Maximum Surchage Pool
	MADE BY: LJ		
	CAD: -		
FILE: STABILITY	CHECK: JGM	CLIENT: Dominion Energy	FIGURE: 5(b)
PROJECT No. 1520347 — REV. 0	REVIEW: GLH		

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Cohesion Type	Water Surface	Hu Type	Hu
Dike Fills-WAP/EAP elev > 214		125	Mohr-Coulomb	50	31		Water Surface	Custom	1
Alluvium		115	Undrained	2000		Constant	Water Surface	Custom	0
Distentegrated Rock		140	Mohr-Coulomb	1000	31		Water Surface	Custom	1

Method Name	Min FS
GLE / Morgenstern-Price	1.5



SCALE AS SHOWN	PROJECT	Bremo West Pond - Inactive Pond Demonstration	
DATE Mar 2018	TITLE	Section C-C (North) Seismic Screening	
MADE BY LJ			
CAD -			
FILE STABILITY	CHECK JGM	CLIENT	Dominion Energy	FIGURE 5(c)
PROJECT No. 1520347 REV. 0	REVIEW GLH		

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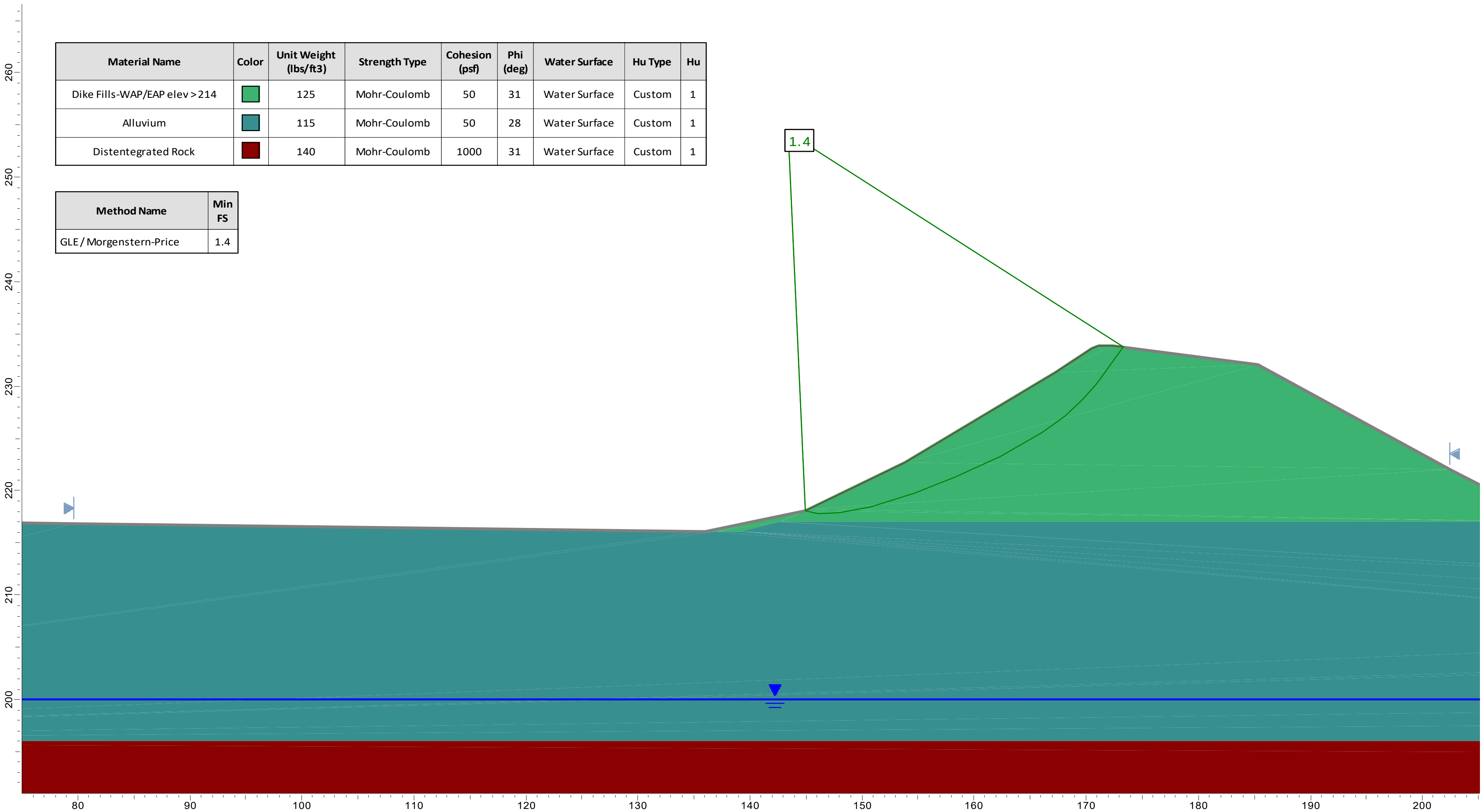
Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Hu Type	Hu
Dike Fills-WAP/EAP elev > 214		125	Mohr-Coulomb	50	31	Water Surface	Custom	1
Alluvium		115	Mohr-Coulomb	50	28	Water Surface	Custom	1
Distentegrated Rock		140	Mohr-Coulomb	1000	31	Water Surface	Custom	1

Method Name	Min FS
GLE / Morgenstern-Price	1.4



Golder Associates	SCALE AS SHOWN	PROJECT	Bremo West Pond - Inactive Pond Demonstration
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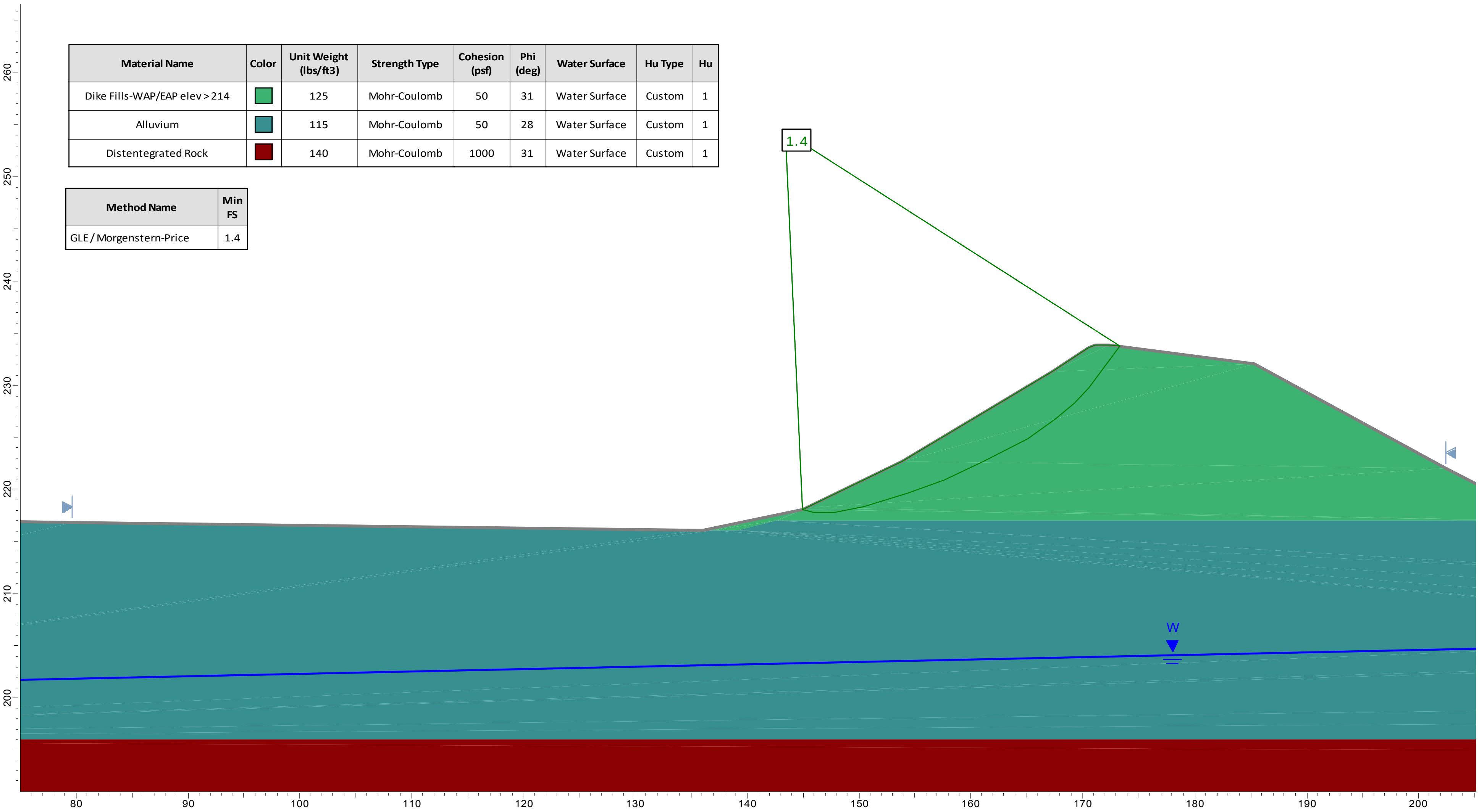
	MADE BY LJ		
	CAD -		
FILE STABILITY	CHECK JGM	CLIENT	Dominion Energy
PROJECT No. 1520347 REV. 0	REVIEW GLH	FIGURE	6(a)

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Hu Type	Hu
Dike Fills-WAP/EAP elev > 214		125	Mohr-Coulomb	50	31	Water Surface	Custom	1
Alluvium		115	Mohr-Coulomb	50	28	Water Surface	Custom	1
Distentegrated Rock		140	Mohr-Coulomb	1000	31	Water Surface	Custom	1

Method Name	Min FS
GLE / Morgenstern-Price	1.4



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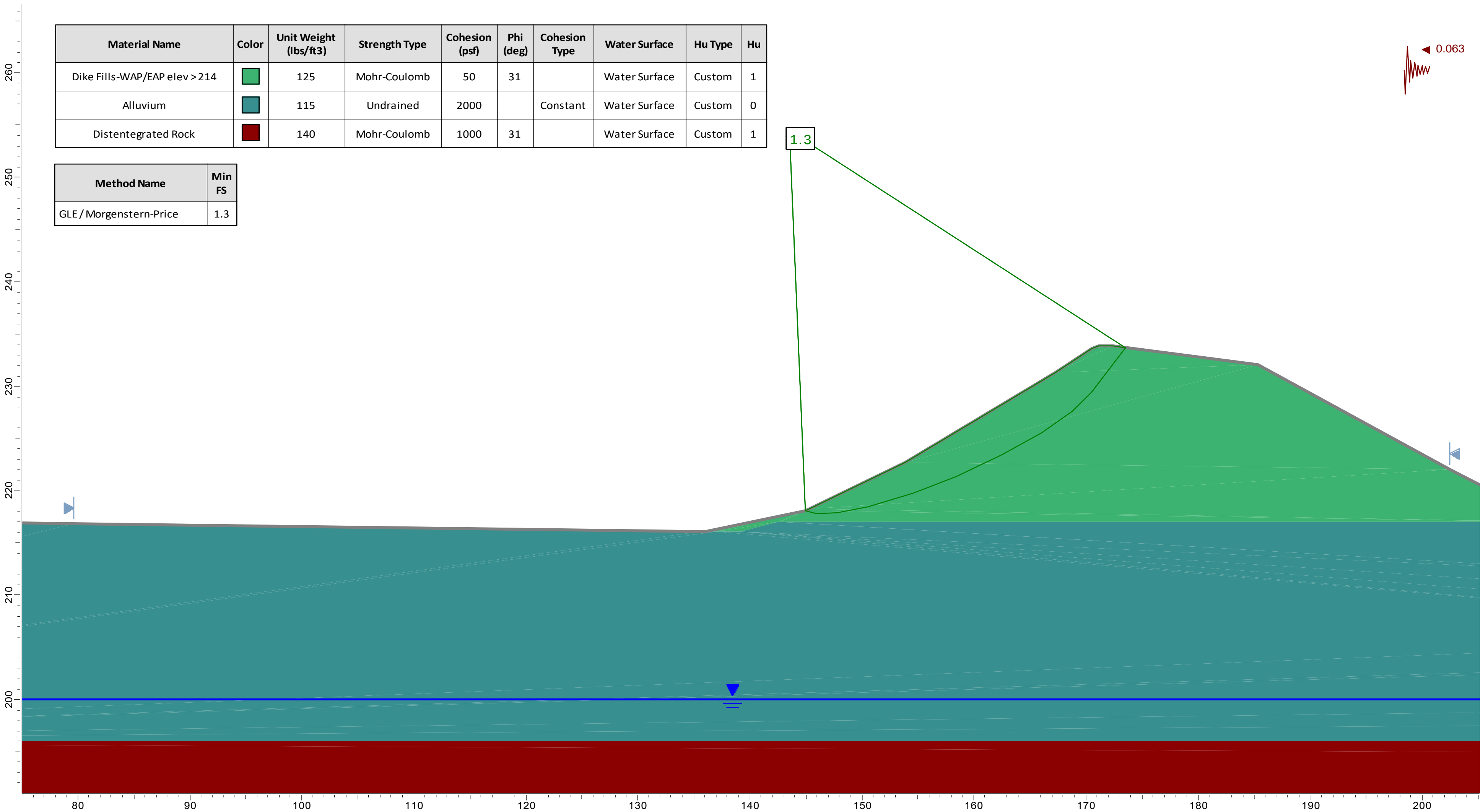
SCALE	AS SHOWN	PROJECT	Bremo West Pond - Inactive Pond Demonstration
DATE	Mar 2018	TITLE	Section C-C (South) Maximum Surchage Pool
MADE BY	LJ		
CAD	-		
CHECK	JGM	CLIENT	Dominion Energy
REVIEW	GLH	FIGURE	6(b)

FILE STABILITY

PROJECT No. 1520347 REV. 0

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Cohesion Type	Water Surface	Hu Type	Hu
Dike Fills-WAP/EAP elev > 214		125	Mohr-Coulomb	50	31		Water Surface	Custom	1
Alluvium		115	Undrained	2000		Constant	Water Surface	Custom	0
Distentegrated Rock		140	Mohr-Coulomb	1000	31		Water Surface	Custom	1

Method Name	Min FS
GLE / Morgenstern-Price	1.3



Golder Associates	SCALE: AS SHOWN	PROJECT	Bremo West Pond - Inactive Pond Demonstration
	DATE: Mar 2018	TITLE	**Section C-C (South)** **Seismic Screening**
	MADE BY: LJ		
	CAD: -		
FILE: STABILITY	CHECK: JGM	CLIENT	**Dominion Energy**
PROJECT No. 1520347 / REV. 0	REVIEW: GLH	FIGURE	6(c)

APPENDIX B

Seismic Hazard Assessment

CALCULATIONS

Date:	April 2018	**Made by:**	S. Secara
Project No.:	15-20347	**Checked by:**	L. Jin / G. Martin
Subject:	Seismic Hazard Assessment	**Reviewed by:**	G. Hebeler
Project:	**BREMO POWER STATION – WEST ASH POND**		

1.0 OBJECTIVE

This calculation package identifies and summarizes the seismic hazard at the project site located at 78.282°W and 37.707°N. The seismic hazard is necessary for geotechnical design evaluations of stability under earthquake loading and liquefaction susceptibility.

2.0 SEISMIC HAZARD SUMMARY

For ash pond closures, the United State Environmental Protection Agency's (USEPA) Coal Combustion Residuals (CCR) Rule has specified seismic analyses be completed for a seismic event with a 2% probability of exceedance in 50 years (2% / 50yr), equivalent to a return period of approximately 2,500 years, based on the United States Geological Survey (USGS) seismic hazard maps. The USGS has provided online tools associated with this hazard for its 2014 seismic hazard model. The sections below detail the use of these tools to obtain seismic hazard data for use in analyses.

3.0 PEAK GROUND AND SPECTRAL ACCELERATION

The peak ground acceleration (PGA) and spectral ground accelerations (S_a) corresponding to a range of spectral periods are necessary for many engineering analyses including slope stability analysis and liquefaction analysis. For a 2% PE in 50 years of the 2014 SHM, The USGS provides a reference PGA and spectral accelerations corresponding to a reference site on the border between the National Earthquake Reductions Hazard Program (NEHRP) site classes B and C with an average shear wave velocity in the upper 30 m (V_{s30}) of 760 m/s. These reference accelerations are often referenced with a BC subscript (e.g. PGA_{BC}) scaled as appropriate to match site conditions and analysis input requirements. Figure 1 below shows the project site on seismic hazard map for PGA_{BC}, and Figure 2 displays the uniform hazard response spectrum curve, which plots the reference spectral acceleration, or ground motion, for various spectral periods. The uniform hazard response spectrum curve is presented in tabular form in Table 1.

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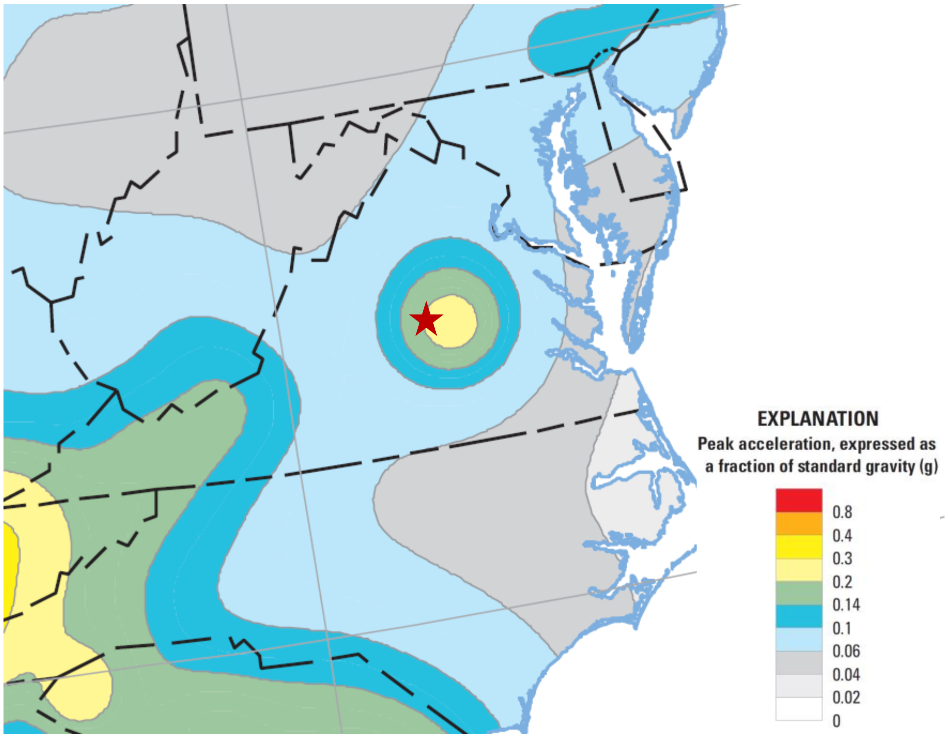


Figure 1: PGA_{BC} for the 2% PE in 50 years at the project site (red star). (USGS 2014).

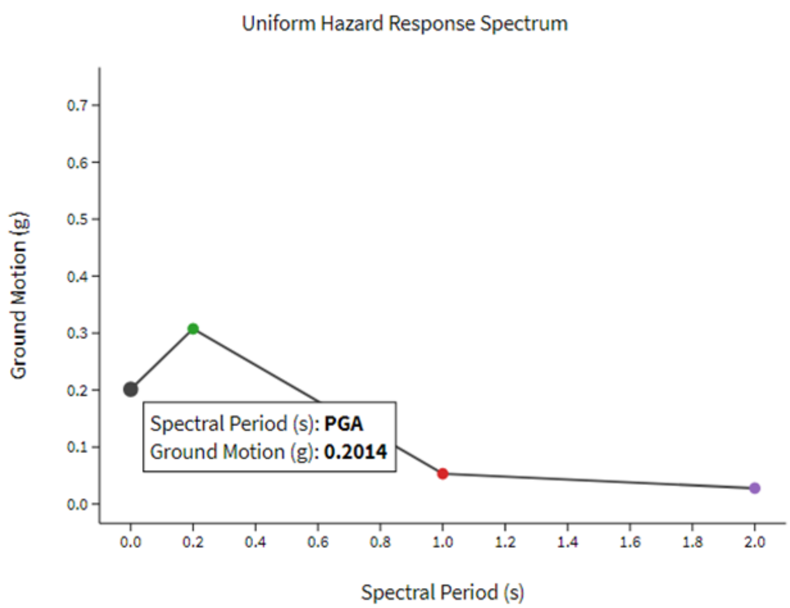


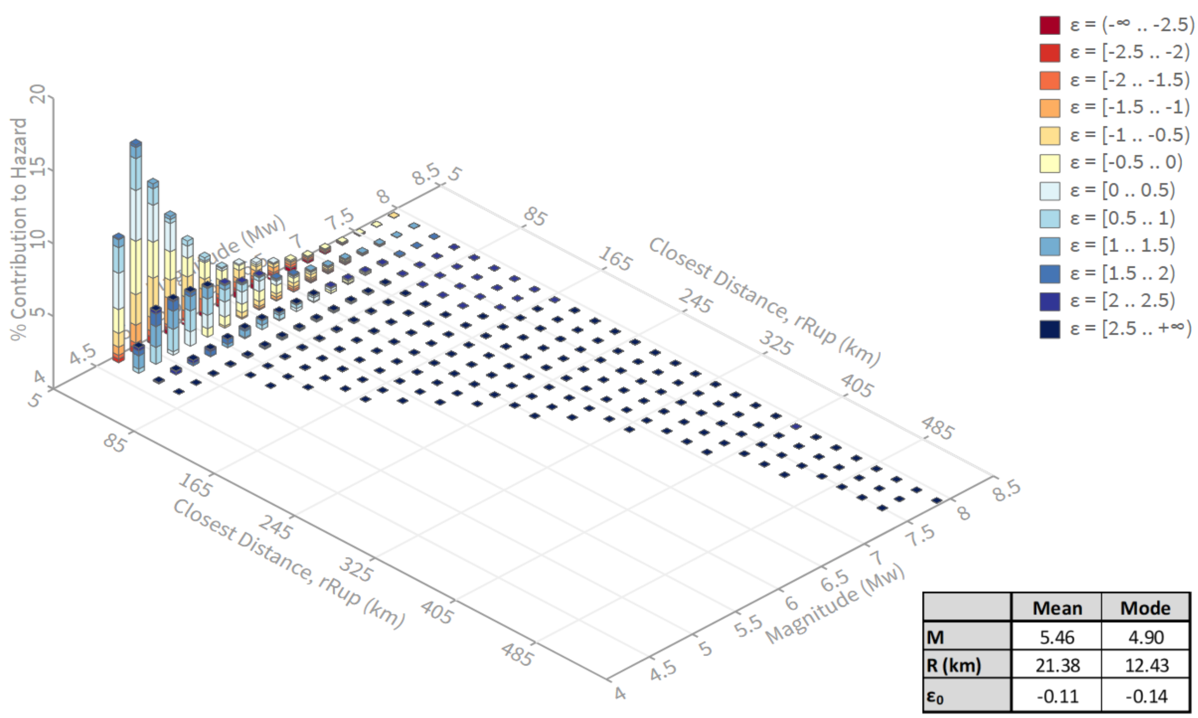
Figure 2: Uniform Hazard Response Spectrum for the 2% PE in 50 years Seismic Hazard at the Project Site (USGS 2014).

Table 1: Reference Site (BC) PGA and Spectral Acceleration for the 2% PE in 50 year Seismic Hazard at the Project Site (USGS 2014).

Spectral Period (s)	Acceleration, BC (g)
0 (PGA)	0.2014
0.2	0.3075
1.0	0.0531
2.0	0.0278

3.1 Seismic Hazard Deaggregation

The seismic hazard is compiled from multiple predictive models which consider many seismic sources of varying combinations of earthquake magnitude and distance from the project site. For each magnitude and distance pair, models predict the resulting accelerations and activity rates for the project site. The results of these predictive models are aggregated to produce the seismic hazard model for specified return periods. The seismic hazard model can be deaggregated to obtain the contribution to hazard percentage of magnitude and distance combinations. This information is necessary for analyses requiring earthquake magnitude (e.g. liquefaction susceptibility) or distance. Figure 3 below displays a deaggregation plot of the PGA_{BC} at the project site for a 2% PE in 50 years with descriptive statistics available through the USGS online tools.



	Mean	Mode
M	5.46	4.90
R (km)	21.38	12.43
ε_0	-0.11	-0.14

Figure 3: Deaggregation Plot of the PGA_{BC} at the Project Site for a 2% PE in 50 Years

3.2 Design Earthquake Magnitude

Some seismic analysis methods require a design earthquake magnitude as an input. One such analysis is the liquefaction screening method. Based on its application in the liquefaction screening, a design earthquake magnitude of 5.34 was selected. Additional details on the design earthquake magnitude are available in the Liquefaction Assessment Calculation Package, presented as Appendix C to the Initial Safety Factor Assessment. This selected design earthquake magnitude was used in other analyses requiring a design magnitude for consistency.

4.0 DETERMINATION OF SITE-SPECIFIC PEAK GROUND ACCELERATION

For the liquefaction analysis, the site-specific PGA at the surface, a_{max}, was calculated from the site reference peak ground acceleration (PGA_{BC}). The PGA_{BC} was multiplied by an amplification factor calculated from the average shear wave velocity in the upper 30 meters (Vs30) to obtain a representative a_{max}. A representative shear wave velocity was derived from correlations to CPT measurements in the East Ash Pond (EAP) and West Ash Pond (WAP) dikes. Data from both the WAP and EAP were analyzed together to obtain a representative shear wave velocity profile because the WAP and EAP dikes are constructed from the same materials and belong to the same general soil unit. CPTs refused on disintegrated rock, so a shear wave velocity of 1350 feet per second (ft/s) was assumed for materials below CPT refusal. Figure 4 shows the correlated shear wave velocities and the representative shear wave velocity profile. The Vs30 was calculated from the representative profile to be 898 ft/s.

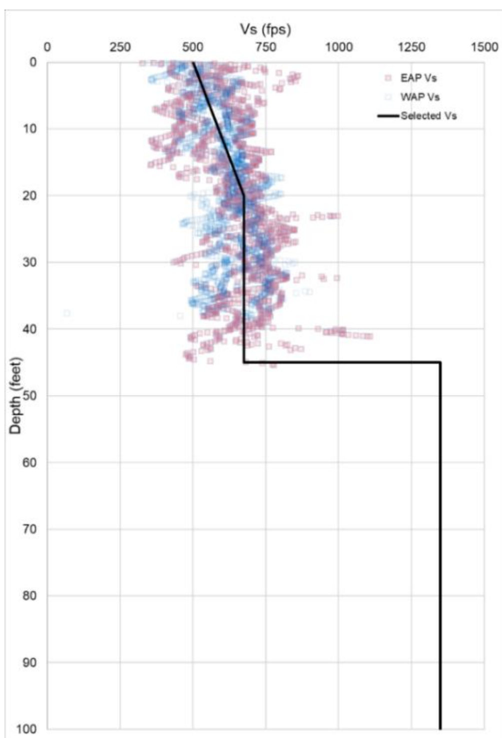


Figure 4. Shear Wave Velocity Profile for the East Ash Pond and West Ash Pond

Table 2: Representative Shear Wave Velocity in the Upper 30 m (Vs30)

Pond ID	Vs30 (ft/s)	Vs30 (m/s)
West Ash Pond	898	274

4.1 Determination of Site Coefficient F_a

An amplification factor was evaluated from two sources:

- Atkinson and Boore's 2006 publication on earthquake ground-motion prediction equations for Eastern North America
- the International Building Code (IBC, 2012)

Atkinson and Boore's publication provides a site response term which is used to amplify the PGA_{BC}, and the IBC provides a site coefficient F_a (amplification factor) as well. Amplification factors from these two sources were averaged to obtain a representative amplification factor.

Table 3: Site Coefficient F_a

Pond ID	Atkinson and Boore (2006)	IBC (2012)	Selected for Analysis
West	1.23	1.59	1.41

4.2 Site-Specific Peak Ground Acceleration a_{max}

$$a_{max} = PGA_{BC} * F_a = 0.2014g * 1.41 = 0.285\ g \quad (1)$$

With an amplification factor F_a of 1.41, Golder calculated the site-specific peak ground acceleration a_{max} to be 0.285 g for the considered seismic hazard.

Table 4: a_{max} at West Ash Pond

Pond ID	a_{max}
West Ash Pond	0.285 g

5.0 PSEUDOSTATIC COEFFICIENT

For slope stability analyses, Golder used the Bray and Travasarou (2009) screening method which models the seismic loading using a pseudostatic coefficient (k). This section details the calculation of the pseudostatic coefficient for the project site. Details on the slope stability analysis are available in a separate calculation package.

Stability under seismic conditions is calculated using the pseudo-static method to model horizontal seismic forces as the product of a seismic coefficient (k) and the weight of the sliding mass. Bray and Travasarou (2009) proposed screening methodology to determine the seismic coefficient k based on the degraded period of the sliding mass and an allowable seismic displacement threshold. The screening method includes an equation to calculate the pseudostatic coefficient for periods of 0.2 and 0.5 seconds, which encompasses the range of typical slope periods. A period of 0.2 s is more conservative, so for this analysis, Golder used the equation associated with a period of 0.2 s and an allowable seismic displacement of 15 cm:

$$\boldsymbol{k_{15\,cm}} = (\mathbf{0.036}\boldsymbol{M_w} - \mathbf{0.004})\boldsymbol{S_a} - \mathbf{0.030} > \mathbf{0.0},\ \boldsymbol{for\ S_a} = \boldsymbol{S_a}(\boldsymbol{T} = \mathbf{0.2}\ \boldsymbol{s}) < \mathbf{2.0}\ \mathrm{g} \qquad (2)$$

Where, k_{15cm} = pseudostatic coefficient

M_w = Design Earthquake Magnitude

S_a = Spectral acceleration at the base of the sliding mass

As noted in Table 1, the BC spectral acceleration at a period of 0.2 s is 0.492 g. This value is multiplied by an amplification factor to obtain the acceleration at the base of the sliding mass. Golder used an amplification factor of 1.6 as prescribed by the international building code (IBC 2012) for a site class D. The project site was classified as D according to the representative shear wave velocity in the upper 30 meters or 100 feet (Vs30). Thus, the spectral acceleration S_a used in the equation is 0.492 g (0.3075 g x 1.6). The pseudostatic coefficient was calculated to be 0.063 g as shown in the table below.

Table 5: $k_{15\,cm}$ at West Ash Pond

Pond ID	$k_{15\,cm}$
West Ash Pond	0.063 g

6.0 REFERENCE

Atkinson, G.M. and D.M. Boore (2006) “Earthquake Ground-Motion Prediction Equations for Eastern North America,” Bulletin of the Seismological Society of America, Vol. 96, No. 6, pp. 2181-2205.

Bray, J.D., and Travasarou, T. 2009. Pseudostatic Coefficient for Use in Simplified Seismic Slope Stability Evaluation. Journal of Geotechnical and Geoenvironmental Engineering, Vol. 135, No. 9: pp. 1336-1340.

United States Geologic Survey, Unified Hazard Tool. https://earthquake.usgs.gov/hazards/interactive/. Accessed January 9, 2018.

International Code Council, Inc. (2012), “2012 Insertional Building Code”, Section 1613.3

APPENDIX C

Liquefaction Calculation Package

CALCULATIONS

Date:	April 2018	**Made by:**	S. Secara
Project No.:	15-20347	**Checked by:**	L. Jin / G. Martin
Subject:	Liquefaction Calculation Package	**Reviewed by:**	G. Hebeler
Project:	**DOMINION ENERGY – WEST ASH POND**		

1.0 OBJECTIVE

The objective of this calculation package is to assess the liquefaction potential of the dikes and underlying foundation soils of the West Ash Pond (WAP) at Dominion Energy's Bremo Power Station.

This liquefaction assessment uses the screening-level assessment described in Youd et al. (2001). Cone Penetration Test (CPT) data is used to characterize soils for this assessment with updates suggested by Robertson (2009).

2.0 LIQUEFACTION ASSESSMENT METHODOLOGY

Seismically-induced liquefaction susceptibility was evaluated using the National Center for Earthquake Engineering Research (NCEER) simplified procedure with CPT data (Youd et al., 2001). The simplified procedure is an empirical method used to calculate the factor of safety against liquefaction. The factor of safety is defined as a ratio of the cyclic resistance ratio (CRR) to the cyclic stress ratio (CSR). The CRR is a measure of a soils' resistance to liquefaction and was estimated using CPT data. The CSR is a measure of the seismic demand on the soil and was estimated using seismic hazard assessment resources provided by the United States Geologic Survey (USGS) as described in Golder's Seismic Hazard Assessment package.

2.1 CSR Determination

The CSR is defined as:

$$CSR = \frac{\tau_{ave}}{\sigma'_v} = 0.65\left(\frac{a_{max}}{g}\right)\left(\frac{\sigma_v}{\sigma'_v}\right)r_d$$

where a_{max} is the peak horizontal acceleration at the ground surface, g is the acceleration due to gravity, σ_v is the total vertical overburden stress, σ'_v is the effective vertical overburden stress, and r_d is a depth-dependent stress reduction factor defined as:

$$r_d = 1.0 - 0.00765z \quad for\ z \leq 9.15\ m$$

$$r_d = 1.174 - 0.0267z \quad for\ 9.15\ m < z \leq 23\ m$$

$$r_d = 0.744 - 0.008z \quad for\ 23\ m < z \leq 30\ m$$

$$r_d = 0.50 \quad for\ z > 30\ m$$

where z is the depth in meters (m). The determination of the a_{max} (0.285 g) is provided in the Golder's Seismic Hazard Assessment presented as Appendix B to the Initial Safety Factor Assessment.

2.2 CRR Determination

The second major step in assessing the liquefaction susceptibility using the simplified approach is to estimate the CRR. Robertson and Wride (1998) developed the procedure for calculating CRR from the CPT as a function of the "clean sand" cone penetration resistance normalized to 1 atmosphere (atm; approximately 100 kilopascals; kPa) and given as $(q_{c1N})_{cs}$. The CRR is based on an earthquake magnitude of 7.5 and a magnitude scaling factor (MSF) adjusts the CRR for magnitudes other than 7.5.

The CRR for an earthquake magnitude (M) of 7.5 is given as:

$$(q_{c1N})_{cs} < 50 \quad CRR_{7.5} = 0.833\left[\frac{(q_{c1N})_{cs}}{1000}\right] + 0.05$$

$$50 \leq (q_{c1N})_{cs} < 160 \quad CRR_{7.5} = 93\left[\frac{(q_{c1N})_{cs}}{1000}\right]^3 + 0.08$$

where $(q_{c1N})_{cs}$ is the clean sand cone penetration resistance normalized to 1 atm (approximately 100 kPa or 1 ton per square foot; tsf).

The tip resistance (q_c) is normalized to obtain q_{c1N} as:

$$q_{c1N} = C_Q\left(\frac{q_c}{P_a}\right)$$

$$C_Q = \left(\frac{P_a}{\sigma'_v}\right)^n$$

where C_Q is the normalizing factor for cone penetration resistance, P_a is 1 atm of pressure, n is an exponent that is dependent on the soil type, and q_c is the cone tip penetration resistance (q_c is replaced by q_t the cone tip resistance corrected for geometric impacts of the pore pressure measurement in all instances).

The method adopted in this assessment calculates the exponent, n, according to a method developed by Robertson (2009) and represents a small modification from the standard NCEER approach. The exponent, n, is calculated as:

$$n = 0.381 I_c + 0.05\left(\frac{\sigma'_{vo}}{P_a}\right) - 0.15 \le 1.0$$

where

$$I_c = [(3.47 - logQ_{t1})^2 + (1.22 + logF_r)^2]^{0.5}$$

$$Q_{t1} = \left[\frac{q_c - \sigma_{vo}}{\sigma'_{vo}}\right]$$

$$F_r = \left[\frac{f_s}{q_c - \sigma_{vo}}\right] \times 100\%$$

2.2.1 Clean Sand Equivalent Cone Penetration Resistance $(q_{c1N})_{cs}$

According to the NCEER approach, the presence of fines affects the liquefaction resistance of soils. A correction factor, K_c, is applied to the normalized penetration resistance (q_{c1N}) to determine the clean sand equivalent $(q_{c1N})_{cs}$ where

$$(q_{c1N})_{cs} = K_c q_{c1N}$$

$$for\ I_c \le 1.64 \quad K_c = 1.0$$

$$for\ I_c > 1.64 \quad K_c = -0.403 I_c^4 + 5.581 I_C^3 - 21.63 I_c^2 + 33.75 I_c - 17.88$$

2.2.2 Magnitude Scaling Factor (MSF)

The magnitude scaling factor (MSF) adjusts the CRR for magnitudes other than 7.5 (Youd et al. 2001) where the factor of safety against liquefaction is calculated as

$$FS = \frac{CRR_{7.5}}{CSR} \times MSF$$

A number of different MSF values are discussed in the NCEER approach. The MSF values used in this assessment are the revised Idriss values (which are considered a lower bound set of values), and are calculated as:

$$MSF = \frac{10^{2.24}}{M^{2.56}}$$

Where M is the design earthquake magnitude.

A probabilistic seismic hazard analysis was used to estimate the ground acceleration, and while such an analysis includes the aggregate contributions of all possible combinations of magnitude and distance from all sources, a design earthquake magnitude is not specified in the probabilistic tools provided by the USGS.

The simplified approach requires the selection of a single earthquake magnitude. Since liquefaction is sensitive to ground motion duration, which is correlated to earthquake magnitude, this selection is an important issue in liquefaction assessments.

The selection of either the mean or modal magnitude produces inconsistent risks of liquefaction because the relationship between duration (represented by magnitude) and liquefaction potential is non-linear. Kramer (2008) suggests that the best way to handle this issue is to perform liquefaction calculations for all magnitudes and to weight the results according to the relative contribution of each magnitude.

Golder has implemented this approach by recognizing that the MSF is the only term in the simplified approach that is affected by the magnitude selection. Golder calculated a weighted-average MSF (weighted by the relative contribution of each magnitude) and then calculated the magnitude corresponding to that MSF.

Golder calculated the earthquake magnitude to be 5.34. This value is less than the mean magnitude (5.46), and is greater than the modal magnitude (4.90).

2.3 Factor of Safety Against Liquefaction

The factor of safety was calculated as:

$$FS = \frac{CRR_{7.5}}{CSR} \times MSF$$

The factor of safety was calculated for each CPT reading (every recorded CPT depth reading).

3.0 RESULTS AND CONCLUSIONS

The USEPA's 2015 Final Rule on the Disposal of Coal Combustion Residuals (CCR, EPA Rule) specifies a target factor of safety of 1.2 against liquefaction for pond impoundment structures in Section §257.73(e)(iv). Calculated factors of safety against liquefaction are in excess of 1.2 for all data analyzed except at select depths in three CPTs. These lower calculated factors of safety are limited to isolated zones no thicker than two feet. Thus, the liquefaction susceptibility analysis indicates that the representative factor of safety for both foundation and dike soils is above 1.2 for all CPTs.

4.0 REFERENCES

Atkinson, G.M. and D.M. Boore (2006) "Earthquake Ground-Motion Prediction Equations for Eastern North America," *Bulletin of the Seismological Society of America,* Vol. 96, No. 6, pp. 2181-2205.

Kramer, S.L. (2008). "Evaluation of Liquefaction Hazards in Washington State" Final Research report WA-RD 668.1, December 2008.

Robertson, P.K. and C.E. (Fear) Wride (1998) “Evaluating Cyclic Liquefaction Potential Using the Cone Penetration Test,” *Canadian Geotechnical Journal*, Vol. 35, pp. 442-459.

Youd, T.L. et al. (2001). “Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER and 1998 NCEER/NSF workshops on Evaluation of Liquefaction Resistance of Soils”, Journal of Geotechnical and Geoenvironmental Engineering, vol. 127, No. 4, April 2001.

Test Date:	3/21/2015	**Project:**	Bremo Ash Pond Closure	**Test Type:**	CPTU	**Water Table:**	11.5 ft	**2% PE in 50 years Seismic Hazard**	
Test ID:	WC-01	**Location:**	Bremo Bluff, VA	**Device:**	10 cm^2, Type 2 filter	**Golder Eng:**	S. Secara	**Magnitude:**	5.34
Latitude	37.71108	**Client:**	Dominion Energy	**Standard:**	ASTM D5778	**Check**	L. Jin / G. Martin	**a_{max}:**	0.285 g
Longitude	-78.29476	**Proj No.:**	1520347	**Push Co.:**	Mid Atlantic Drilling Inc.	**Review:**	G. Hebeler		
Elevation:	234.6 ft	**Termination:**	71.9 ft-bgs	**Operator:**	Cory Robison				

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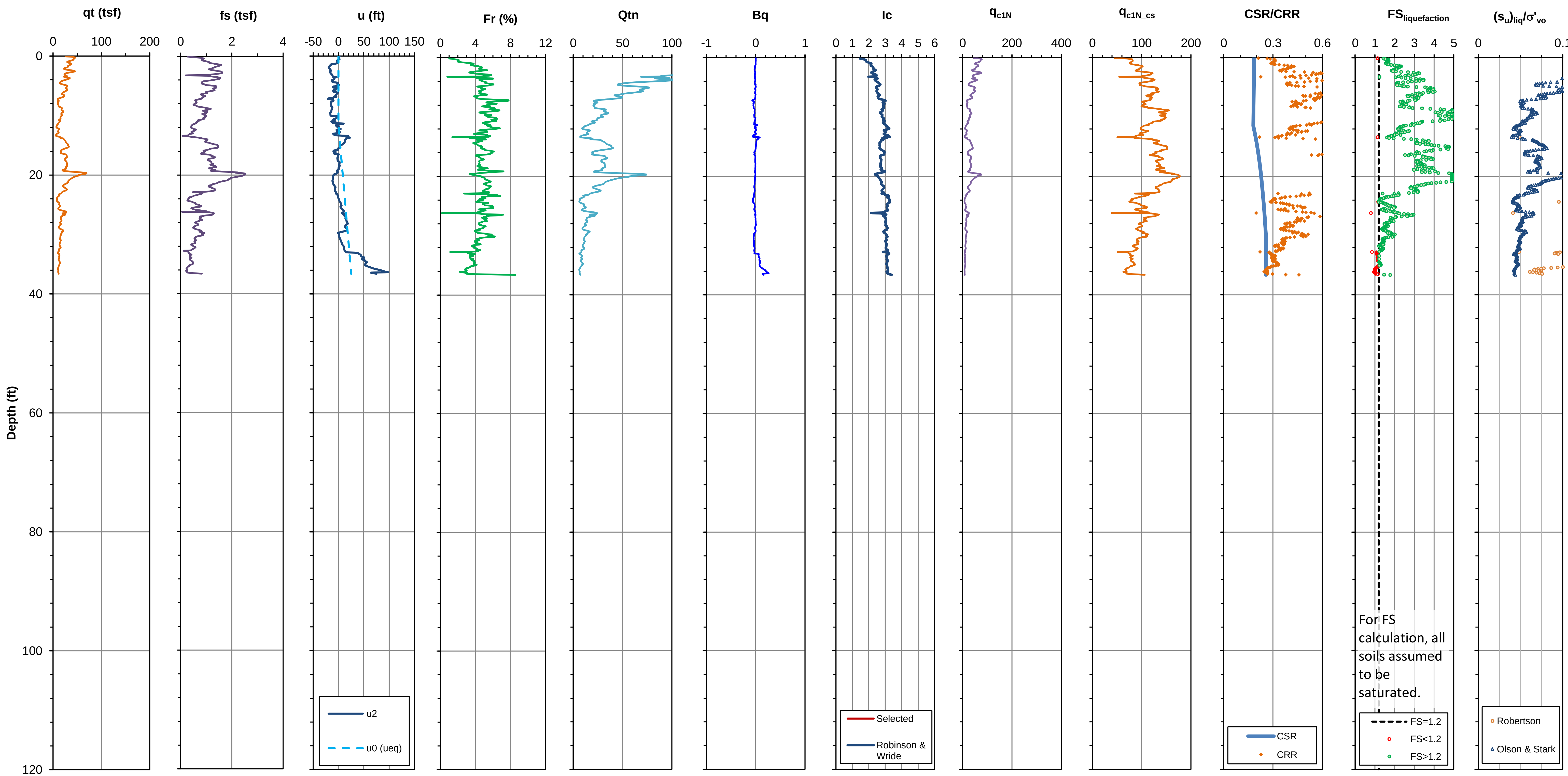

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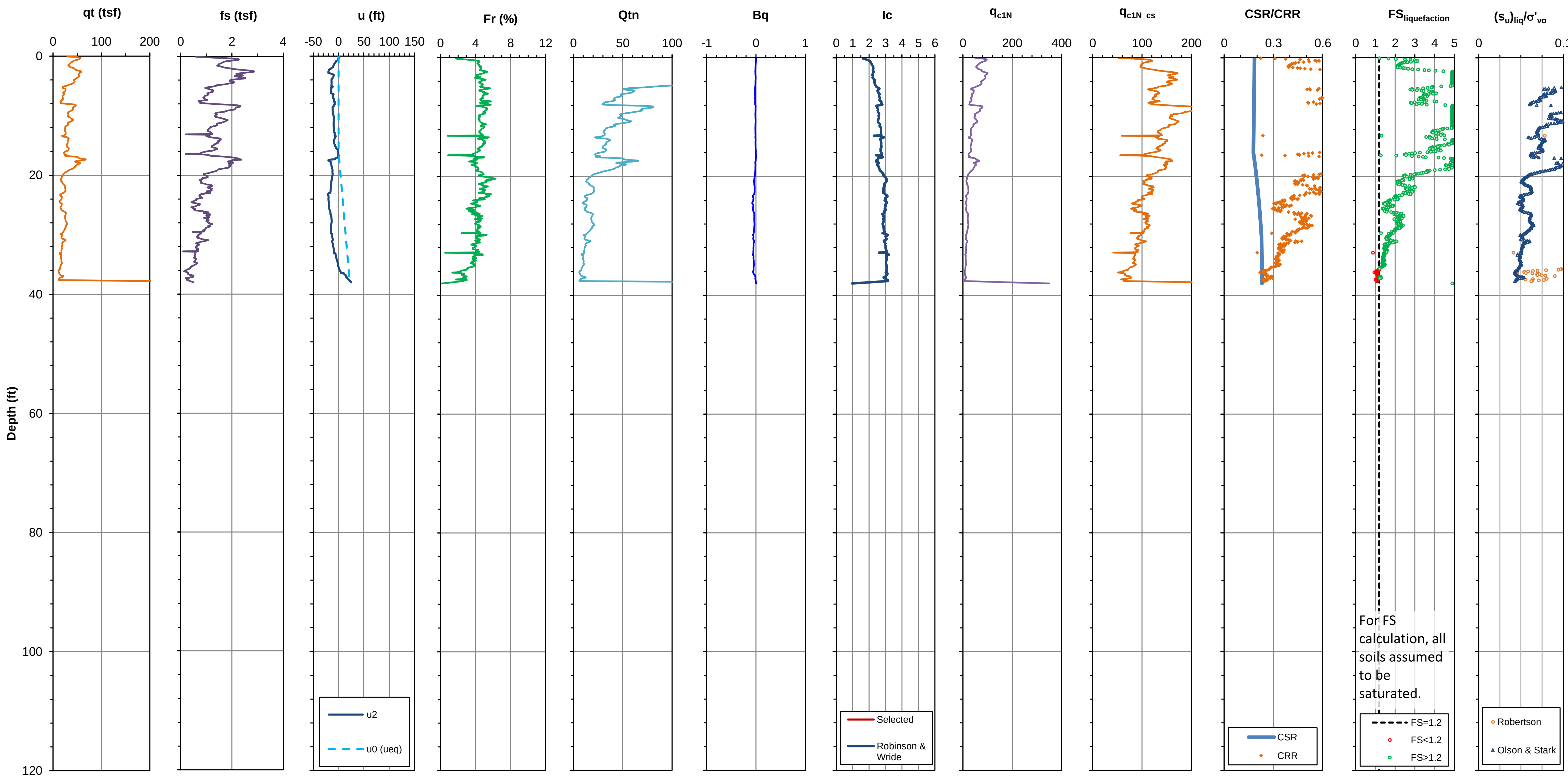
Test ID:	WC-02	**Location:**	Bremo Bluff, VA	**Device:**	10 cm^2, Type 2 filter	**Golder Eng:**	S. Secara	**Magnitude:**	5.34
Latitude	37.71067	**Client:**	Dominion Energy	**Standard:**	ASTM D5778	**Check**	L. Jin / G. Martin	**a_{max}:**	0.285 g
Longitude	-78.29344	**Proj No.:**	1520347	**Push Co.:**	Mid Atlantic Drilling Inc.	**Review:**	G. Hebeler		
Elevation:	233.9 ft	**Termination:**	71.9 ft-bgs	**Operator:**	Cory Robison				

Golder Associates



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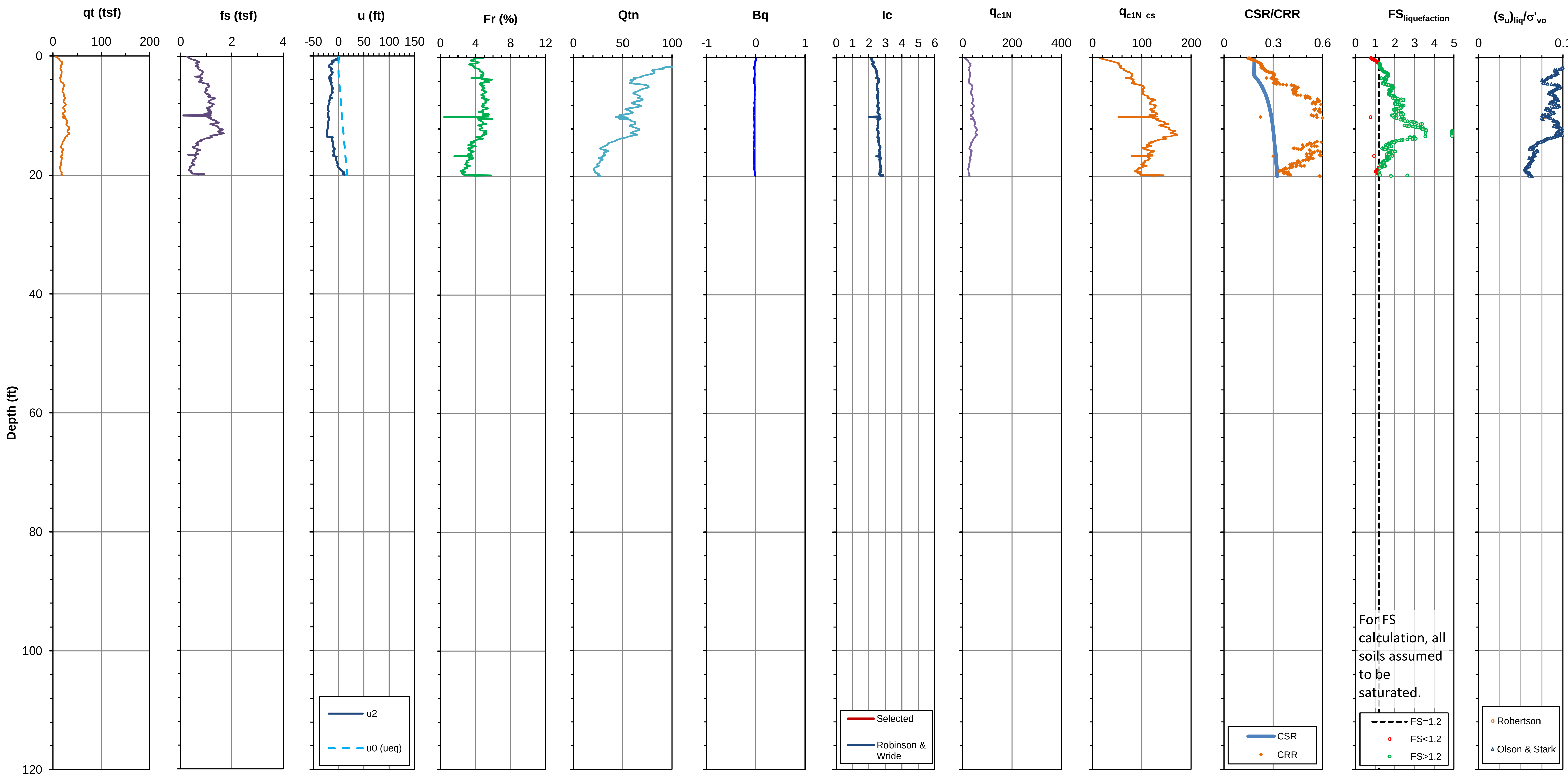
Test ID:	WC-03	**Location:**	Bremo Bluff, VA	**Device:**	10 cm^2, Type 2 filter	**Golder Eng:**	S. Secara
Latitude	37.70989	**Client:**	Dominion Energy	**Standard:**	ASTM D5778	**Check**	L. Jin / G. Martin
Longitude	-78.29118	**Proj No.:**	1520347	**Push Co.:**	Mid Atlantic Drilling Inc.	**Review:**	G. Hebeler
Elevation:	217.3 ft	**Termination:**	71.9 ft-bgs	**Operator:**	Cory Robison		

2% PE in 50 years Seismic Hazard
Magnitude: 5.34
a_{max}: 0.285 g



Test Date:	3/21/2015	**Project:**	Bremo Ash Pond Closure	**Test Type:**	CPTU	**Water Table:**	100.0 ft	**2% PE in 50 years Seismic Hazard**
Test ID:	WC-04	**Location:**	Bremo Bluff, VA	**Device:**	10 cm^2, Type 2 filter	**Golder Eng:**	S. Secara	**Magnitude:** 5.34
Latitude	37.71125	**Client:**	Dominion Energy	**Standard:**	ASTM D5778	**Check**	L. Jin / G. Martin	a_{max}: 0.285 g
Longitude	-78.29075	**Proj No.:**	1520347	**Push Co.:**	Mid Atlantic Drilling Inc.	**Review:**	G. Hebeler	
Elevation:	234.4 ft	**Termination:**	71.9 ft-bgs	**Operator:**	Cory Robison			

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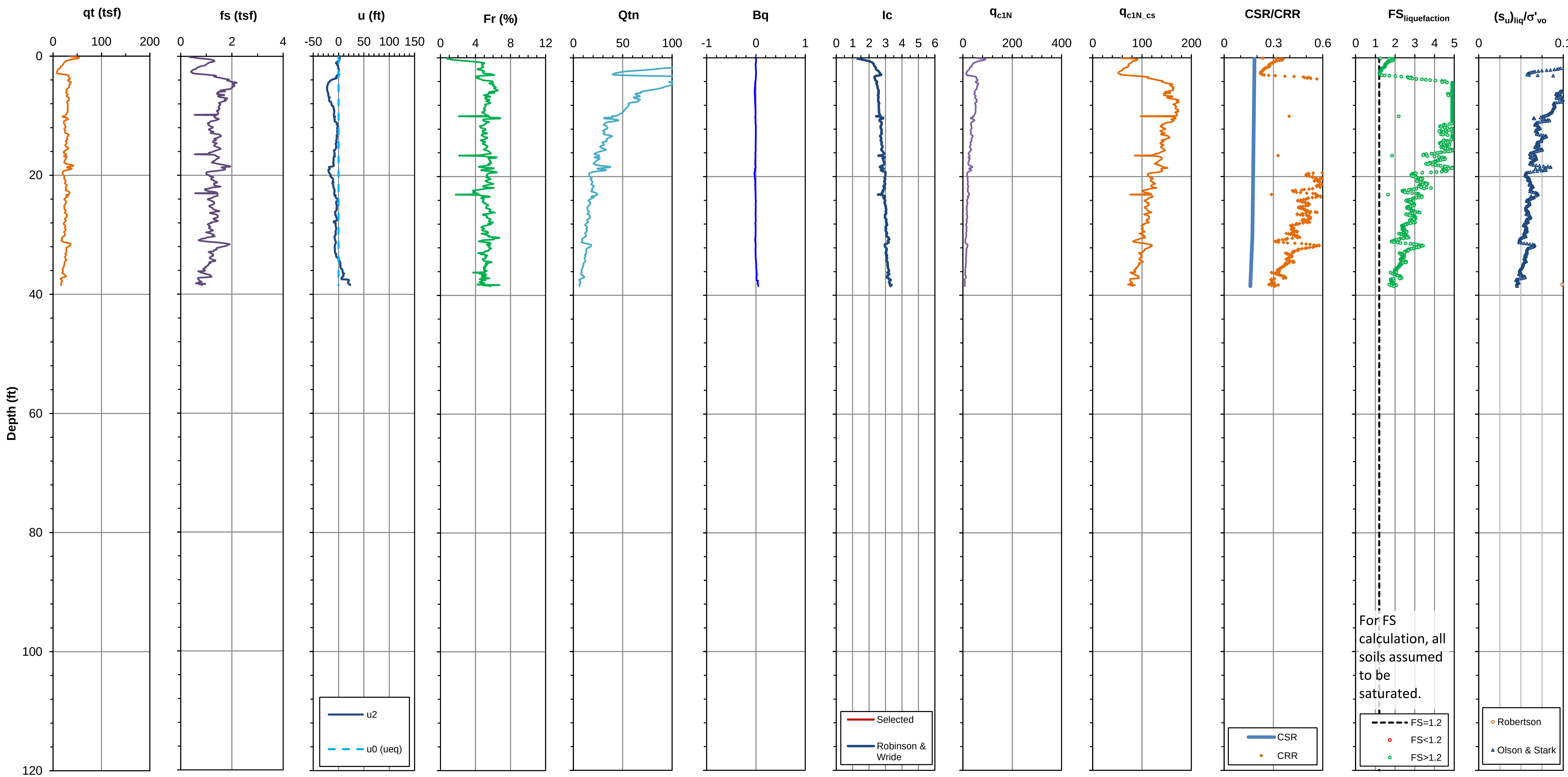

Test Date:	3/17/2015	**Project:**	Bremo Ash Pond Closure	**Test Type:**	CPTU	**Water Table:**	100.0 ft	**2% PE in 50 years Seismic Hazard**	
Test ID:	WC-05	**Location:**	Bremo Bluff, VA	**Device:**	10 cm^2, Type 2 filter	**Golder Eng:**	S. Secara	**Magnitude:**	5.34
Latitude	37.71228	**Client:**	Dominion Energy	**Standard:**	ASTM D5778	**Check**	L. Jin / G. Martin	**a_{max}:**	0.285 g
Longitude	-78.29177	**Proj No.:**	1520347	**Push Co.:**	Mid Atlantic Drilling Inc.	**Review:**	G. Hebeler		
Elevation:	233.1 ft	**Termination:**	71.9 ft-bgs	**Operator:**	Cory Robison				

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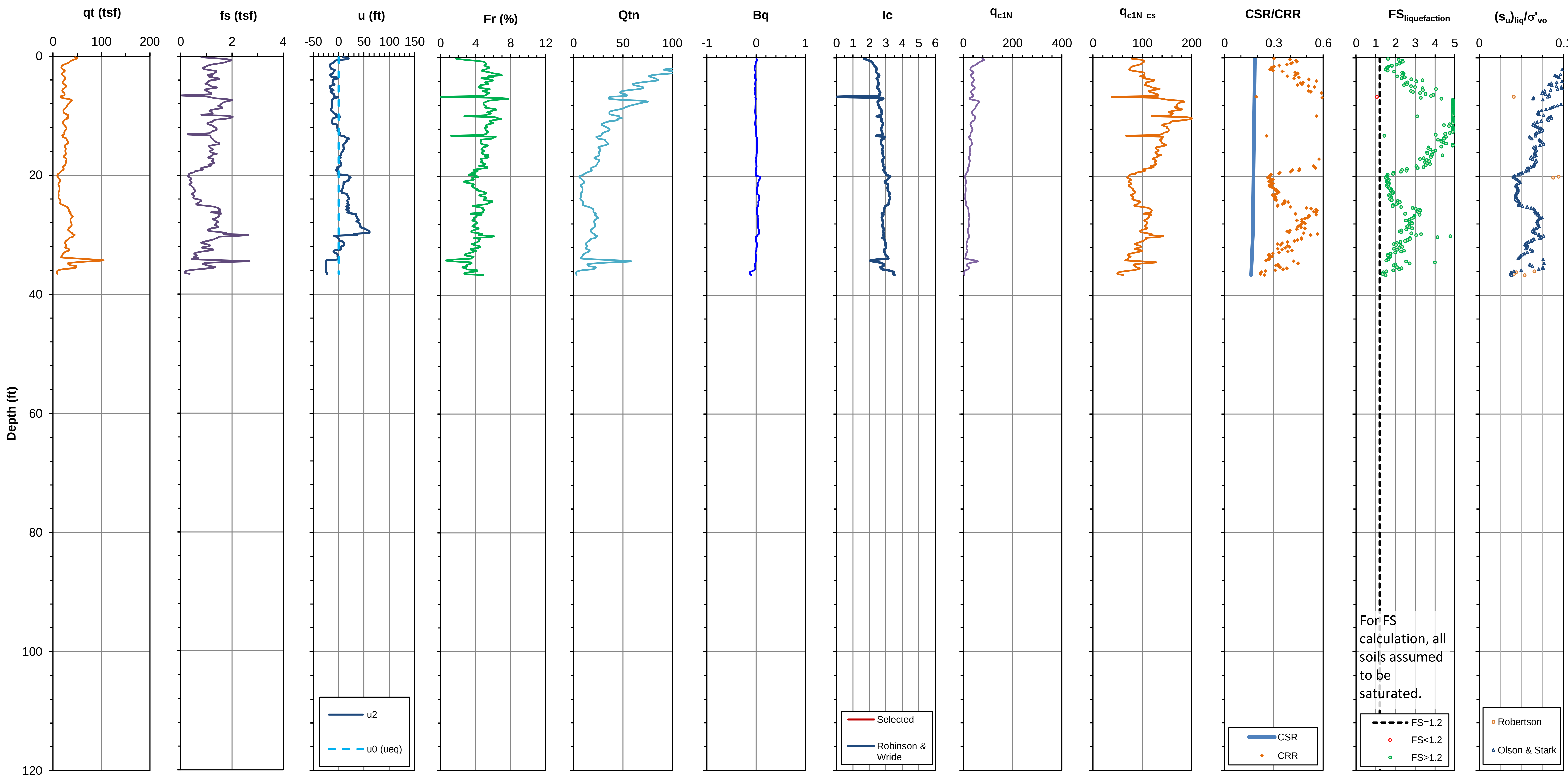

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