GOLDER
MEMBER OF WSP

October 8, 2021 21465697

Mr. George McKenzie, PE
Consumers Energy Company
1945 West Parnall Road
Jackson, Michigan 49201

PERIODIC STRUCTURAL STABILITY AND SAFETY FACTOR ASSESSMENT REPORT
JH CAMPBELL GENERATING FACILITY CLOSED POND A
CONSUMERS ENERGY COMPANY
WEST OLIVE, MICHIGAN

Dear Mr. McKenzie:

Golder Associates Inc. (Golder) has prepared this letter report to summarize the periodic structural stability assessment and safety factor assessment for the closed Pond A surface impoundment (Pond A) at the Consumers Energy Company (CEC) JH Campbell Generating Facility (JH Campbell). This report has been prepared pursuant to §257.73(d) and §257.73(e) of the Coal Combustion Residual (CCR) Rule[1].

The CCR Rule requires that existing CCR surface impoundments meeting the requirements of §257.73(b) conduct initial and periodic (every 5 years) structural stability assessments in accordance with §257.73(d) and safety factor assessments in accordance with §257.73(e).

SITE DESCRIPTION AND BACKGROUND

JH Campbell is a coal-fired power generation facility located near West Olive, Michigan. Pond A is located along the southern side of the JH Campbell ash disposal area (Figure 1). Pond A is a certified closed former CCR surface impoundment which received commingled CCRs and low-volume miscellaneous wastewaters and served as a detention basin to settle suspended solids and CCRs until they could be mechanically removed to maintain storage capacity.

Pond A was closed with CCR in place and capped with a final cover system over the former CCR surface impoundment area in accordance with §257.102(d). Pond A closure construction is documented in the Pond A – Construction Documentation Report (Golder, 2019c[2]) and the closure was approved by the Michigan Department of Environment, Great Lakes and Energy (EGLE). Prior to construction of the final cover system. Pond A was dewatered by actively pumping standing water downstream in accordance with applicable federal, state and local

[1] 40 Code of Federal Regulations Part 257 (40 CFR 257), Subpart D – Standards for the Disposal of Coal Combustion Residuals in Landfills and Surface Impoundments, Published in Federal Register, Vol. 80, No. 74, April 17, 2015.

[2] Golder 2019c. J.H. Campbell Generating Facility Pond A – Construction Documentation Report, Golder Associates Inc., October 1, 2019.

rules and regulations. After dewatering activities were complete, influent and effluent piping was permanently abandoned or removed. Once the CCR materials in Pond A were sufficient to provide a stable surface to support fill materials, excavated CCR materials from Bottom Ash Ponds 1-2 and Bottom Ash Pond 3 were used to backfill Pond A to provide adequate positive drainage to prevent the impounding of water and meet closure design subgrades. Backfilled CCR materials were placed in 14- to 16-inch thick lifts and compacted until no excessive rutting or yielding was observed. The Pond A final cover system is comprised of the following components:

- CCR backfill compacted and graded to maintain positive drainage,
- 40-mil high density polyethylene (HDPE) geomembrane,
- 10 ounce per square yard nonwoven geotextile,
- 6-inch diameter perforated drainage piping,
- 24-inch thick protective cover (sand) layer, and
- 6-inch thick topsoil/vegetative support layer.

Closure construction began on June 20, 2018 with dewatering operations and was completed August 2, 2019 with final seeding and mulching. Pond A was reclassified as a low hazard potential CCR surface impoundment pursuant to §257.73(a) since it is no longer capable of impounding water (Golder 2019b[3]).

STRUCTURAL STABILITY ASSESSMENT

The CCR Rule requires a periodic structural stability assessment be conducted to document whether the design, construction, operation, and maintenance are consistent with recognized and generally accepted good engineering practices for the maximum volume of CCR and CCR wastewater that can be impounded therein. The following sections provide documentation for the periodic stability assessment and rely on the initial Pond A Structural Stability and Safety Factor Assessment Report (Golder, 2016[4]), Pond A Closure Plan (Golder, 2019a[5]), annual inspections performed at Pond A and routine inspections performed by CEC. The most recent annual inspection was completed by Golder in May 2021. The summary inspection checklist is included in **Appendix A**.

Foundations and Abutments [§257.73(d)(1)(i)]

Certified issued for construction (IFC) drawings were available on the original design of the Pond A embankments from 1979. The foundation soils consist of native sand soils. There has been no indication of foundational or abutment instability or movement in recent or historic site inspections. The foundation soils and abutments are considered stable.

Slope Protection [§257.73(d)(1)(ii)]

The embankment slopes for Pond A are protected from erosion and deterioration by establishment of vegetative cover. Embankment slopes are routinely inspection for signs of erosion, seepage, animal burrows, sloughing, and unwanted vegetation. The May 2021 inspection did not identify items relating to slope protection that required

[3] Golder 2019b. Consumers Energy Company JH Campbell Generating Facility, Pond A Hazard Potential Classification Assessment, Golder Associates Inc., April 10, 2019.

[4] Golder 2016. J.H. Campbell Generating Facility, Pond A Structural Stability and Safety Factor Assessment Report, Golder Associates Inc., October 14, 2016.

[5] Golder 2019a. J.H. Campbell Generating Facility, Pond A Closure Plan, Golder Associates Inc., January 31, 2019.

investigation or repair. The embankment slopes are not subjected to wave or sudden drawdown effects. The slope protection measures are considered adequate.

Dikes (Embankment) [§257.73(d)(1)(iii)]

Based on the IFC drawings and subsurface investigations, it is understood that the perimeter dike was constructed with standard earthwork equipment and consists of compacted sand fill. Based on the relative density of the materials encountered during subsurface investigations, inspections, and results of the recent stability analyses; the embankment dikes are considered sufficient to withstand the range of loading conditions for Pond A.

Vegetated Slopes [§257.73(d)(1)(iv)]

The vegetative cover requirement on surface impoundment dikes be maintained at no more than 6-inches was vacated by EPA. Proposed rules on vegetative cover are still pending.

Spillways [§257.73(d)(1)(v)]

There are no spillways on Pond A, the pond is closed.

Hydraulic Structures [§257.73(d)(1)(vi)]

Pond A influent and effluent pipes were removed and/or abandoned in-place during closure construction. The stormwater management system for Pond A includes two 36-inch diameter reinforced concrete pipe (RCP) culverts that convey stormwater through the southern perimeter berm to armored down chutes which connect to an existing ditch that conveys flow to the recirculation pond. The Class IV precast RCP culverts met closure construction specifications and were installed in the southwest and southeast corners of Pond A. During installation and subsequent inspections, the culverts were free of deterioration, deformation, distortion, bedding deficiencies, sedimentation and debris which may negatively affect operation.

Downstream Slopes Adjacent to Water Body [§257.73(d)(1)(vii)]

The downstream slopes of Pond A are not adjacent to water bodies.

Structural Stability Deficiencies [§257.73(d)(2)]

No structural stability deficiencies were noted during recent inspections or in this periodic assessment.

SAFETY FACTOR ASSESSMENT

Pursuant to §257.73(e)(1), the safety factor assessment must document the calculated factor of safety for the dike slopes under the following scenarios:

i) Maximum Pool Storage – defined as the long-term, maximum storage pool elevation and equal to the upstream outlet elevation; static factor of safety must equal or exceed 1.50.

ii) Maximum Pool Surcharge – defined as the temporary raised pond level above the maximum pool storage elevation due to an inflow design flood; static factor of safety must equal or exceed 1.40.

iii) Seismic Loading Conditions – seismic factor of safety must equal or exceed 1.00.

iv) Liquefaction Potential – necessary only of dikes constructed of soils that have a susceptibility to liquefaction; factor of safety must equal or exceed 1.20.

Pond A is no longer capable of impounding CCRs and liquids with the completion of the closure construction; therefore, conditions (i) and (ii) are no longer applicable to the unit.

Stability Analysis

A stability analysis was performed for the closed Pond A grades in the Pond A Closure Plan (Golder, 2019a). No new stability analysis was deemed necessary as the conditions have not changed since closure of Pond A. Undrained material strength properties were used to evaluate short-term stability under seismic loading conditions and drained material strength properties were used to evaluation long-term stability. The calculation excerpts from the Pond A Closure Plan (Golder, 2019a) stability analysis are provided in **Appendix B**.

The stability analysis results indicate that the closed Pond A slopes provide adequate factors of safety:

Table 1: Summary of Stability Analysis Results

Analysis	Minimum Calculated Factor of Safety	Required Factor of Safety
Short-Term, Pseudo-Static,	1.4	1.00
Long-Term, Static	1.7	1.50

A veneer stability analysis was conducted to assess the final cover stability for various scenarios including equipment forces during construction, seepage forces, and seismic conditions. Veneer stability analysis is also provided in **Appendix B**.

Liquefaction Potential

A screening of embankment and foundation soils for seismically-induced liquefaction susceptibility was performed in the initial Pond A Structural Stability and Safety Factor Assessment. The screening-level results indicated that the embankment and foundation soils for Pond A are not susceptible to seismically-induced liquefaction. The liquefaction screening results are provided in Appendix C of the initial Pond A Structural Stability and Safety Factor Assessment Report (Golder, 2016).

SUMMARY

No structural stability deficiencies were identified for the closed Pond A during this assessment.

The calculated factors of safety applicable to the closed Pond A meet or exceed applicable minimum values.

Golder Associates Inc.

Samuel F. Stafford, PE
Senior Engineer

Tiffany D. Johnson, PE
Senior Consultant and Principal

SFS/TDJ/

Attachments: Figure 1
Appendix A – Annual Inspection Checklist
Appendix B – Excerpts from the 2019 Closure Plan Stability Analysis

https://golderassociates.sharepoint.com/sites/145646/project files/6 deliverables/5-yr stability report/campbell/jh campbell pond a stability eval.docx

CERTIFICATION

Professional Engineer Certification Statement [§257.73(d)(3) and §257.73(e)(2)]

I hereby certify that this Periodic Structural Stability and Safety Factor Assessment Report has been prepared in accordance with good engineering practices, including the consideration of applicable industry standards, and in accordance with the applicable requirements of §257.73(d) periodic structural stability assessments and §257.73(e) periodic safety factor assessments.

Golder Associates Inc.

Signature

October 8, 2021
Date of Report Certification

Samuel F. Stafford, PE
Name

6201308939
Professional Engineer Certification No.

STATE OF MICHIGAN
SAMUEL FORREST STAFFORD
ENGINEER
No.
6201308939
LICENSED PROFESSIONAL ENGINEER

Samuel F Stafford
This item has been electronically signed and sealed by Samuel F. Stafford, PE using a Digitial Signature. Printed copies of this document are not considered signed and sealed and the signature must be verified on any electronic copies.
2021.10.08 15:58:51 -04'00'

LEGEND

NOTE(S)

1. ALL PHOTO LOCATIONS SHOWN ARE APPROXIMATE AND BASED ON HAND HELD GPS LATITUDE AND LONGITUDE COORDINATES ACQUIRED DURING SITE INSPECTION. SOME PHOTO LOCATIONS HAVE BEEN MANUALLY ADJUSTED TO BETTER MATCH ACTUAL PHOTO LOCATIONS.
2. SITE INSPECTION PERFORMED ON MAY 20, 2020
3. AERIAL IMAGERY SHOWN IS REPRESENTATIVE ONLY AND MAY NOT REFLECT CURRENT SITE CONDITIONS.
4. THIS FIGURE IS SIZED FOR 11"X17" ANSI-B-PAPER AND ALL SCALES ASSOCIATED MUST BE VERIFIED.
5. THIS FIGURE ORIGINAL PRINTED IN COLOR. ANY REPRODUCTION IN BLACK AND WHITE MAY RESULT IN LOSS OF INFORMATION.

REFERENCE(S)

1. COORDINATE SYSTEM: NAD 1983 STATEPLANE MICHIGAN SOUTH FIPS 2113 FEET
2. IMAGERY SOURCE: ESRI, MAXAR, GEOEYE, EARTHSTAR GEOGRAPHICS, CNES/AIRBUS DS, USDA, USGS, AEROGRID, IGN, AND THE GIS USER COMMUNITY

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Feet

CLIENT
CONSUMERS ENERGY COMPANY

Consumers Energy

PROJECT
PERIODIC STRUCTURAL STABILITY AND
SAFETY FACTOR ASSESSMENT
J.H. CAMPBELL GENERATING FACILITY

TITLE
CLOSED POND A SITE LAYOUT

CONSULTANT
GOLDER

YYYY-MM-DD	2021-08-30
DESIGNED	NRL
PREPARED	SMS
REVIEWED	SS
APPROVED	TJ

PROJECT NO.	CONTROL	REV.	FIGURE
21465697	A016	0	1

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B

APPENDIX A

Annual Inspection Checklist

CCR LANDFILL VISUAL INSPECTION CHECKLIST

Facility Name: J.H. Campbell Dry Ash Landfill

Owner: Consumers Energy Company (CEC)

Purpose of Facility: Dry Ash Disposal

County, State: Ottawa County, Michigan

Inspected By: Samuel Stafford and Scott Fulmer **Inspection Date:** May 20, 2021

Weather: 70-degrees F, Cloudy

.

ITEM	Acceptable	Monitor/Maintain	Investigate	Repair	REMARKS
1. General Conditions					
a. Current volume of CCR					Total Airspace Consumed: 5,471,450 cys Volume of leachate drainage layer from Cells 1 through 5 construction: 140,355 cys Volume of CCR: 5,331,095 cys (as of March 25, 2021)
b. Alterations	X				
c. Grass cover	X				
d. Settlement / misalignment / cracks	X				None observed.
e. Leachate Collection	X				
2. Landfill Slope					
a. Erosion – liner exposed?	X				
b. Rodent burrows		X			Burrows observed on final cover benches, adjacent to downchutes, and near toe of slope, see note 3.
c. Vegetation	X				
d. Cracks/settlement	X				None observed.

ITEM	Acceptable	Monitor/Maintain	Investigate	Repair	REMARKS
e. Riprap/other erosion protection	X				
f. Slide, Slough, Scarp	X				None observed.
g. Benches		X			Areas of low spots inside the benches, water could stage prior to draining to the downchutes, see note 3.
h. Final Cover		X			Equipment damage to cover vegetation/soils noted on west, north, and east sides, see note 3.
i. Downchutes	X				
3. Crest					
a. Soil condition	X				
b. Comparable to design width or previous inspection	X				
c. Vegetation	X				NA
d. Rodent burrows	X				
e. Exposed to heavy traffic	X				
f. Damage from vehicles / machinery		X			Equipment damage noted to cover vegetation/soils, see note 3.
4. Toe					
a. Vegetation	X				
b. Rodent burrows		X			Small animal burrows observed near toe of slope, see note 3.
c. Settlement	X				None observed.
d. Drainage conditions	X				
e. Seepage	X				None observed.

Notes:

1) Leachate collection system inspection was limited by visual observation of surficial components of the system, i.e. condition of riser pipes.

2) Maintain erosion controls per the SMP. This is not a deficiency or release as classified under 40 CFR 257.84(b)(5).

3) Features observed and documented in this checklist were not considered a deficiency or release as classified under 40 CFR 257.84(b)(5) and required no immediate action beyond periodic inspection in accordance with the SMP and typical maintenance.

APPENDIX B

Excerpts from the 2019 Closure Plan Stability Analysis

	SUBJECT:	Stability Analyses - Closure Plan J.H. Campbell Pond A	
Golder Associates	Job No.:	1667572.0003.02	Prepared: MJ
	Ref.:	Consumers/Campbell Pond A Closure/MI	Checked: JRP
	Date:	Aug-16-2018	Reviewed: DL

Slope Stability Analyses for the Proposed Closure Plan of J.H. Campbell Pond A

in Ottawa County, Michigan

Objective:

Analyze the short term psuedo-static and long term static stability of the proposed closure conditions for Consumers Energy Corporation (Consumers) J.H. Campbell Pond A in Ottawa County, Michigan.

Analysis Methods:

The static stability of the proposed closure conditions for J.H. Campbell Pond A in Ottawa County, Michigan was evaluated using the computer program SLIDE 2018 Version 8.016 (Rocscience, 2018). Generalized limit equilibrium method of stability analysis developed by Morgenstern and Price (Abramson et al., 2002) was utilized for the analysis. Block and circular search patterns were utilized to find failure surfaces that resulted in the minimum calculated factor of safety. Depending on the analyzed section, block search patterns were used to search for slip surfaces within a specific layer (e.g. CCR, sand-clay interface).

Minimum required factors of safety (FoS) for this analysis were taken as 1.5 for permanent loading conditions (long-term, drained) and 1.0 for temporary loading conditions (end of construction, undrained, seismic). A groundwater elevation of 600.7 feet was assumed within the pond area decreasing to an elevation of 594 feet at the exterior southern drainage channel to account for mounded water during short term conditions at end of construction. During long term conditions, groundwater was assumed at the historic grounwater elevation of 590 feet. All elevations presented are based on plant datum (NGVD29).

Global slip surfaces or those impacting the crest of the slope were considered "Critical" surfaces that may compromise the stability of the impoundment. Shallow or surficial slip surfaces along the slope surface (i.e., not global or impacting the crest of the slope) with factors of safety lower than the "Critical" surface were often generated during the analyses; the shallow slip surfaces were considered "Non-Critical" and issues that could likely be addressed by maintenance (e.g. local regrading, riprap armoring, etc.). Both "Critical" and "Non-Critical" surfaces (as required) are shown on the stability output figures.

Analysis Sections:

Two (2) cross-sections were selected to evaluate the stability of the entire area of Pond A. Section B was considered the most critical and was utilized for this analysis. Figure 1 provides an overview of the section locations.

Analysis Cases:

The following stability cases were analyzed for the current analysis:

- Proposed Fill Conditions - Short-term Strength Parameters (Undrained Conditions with Seismic)
- Proposed Fill Conditions - Long-term Strength Parameters (Drained Conditions)

Material Properties:

The material properties used for this analysis are provided in the table below.

Material	Unit Weight (pcf)		Strength Properties		
	Dry	Saturated	Peak ϕ′ (°)	Cohesion (psf)	Undrained Shear Strength (psf)
Cover Material	115	120	28	-	-
CCR	75	100	28	-	-
Fill Sand	110	115	36	-	-
Native Sand	105	120	34	-	-
Native Clay	115	125	27	-	1950

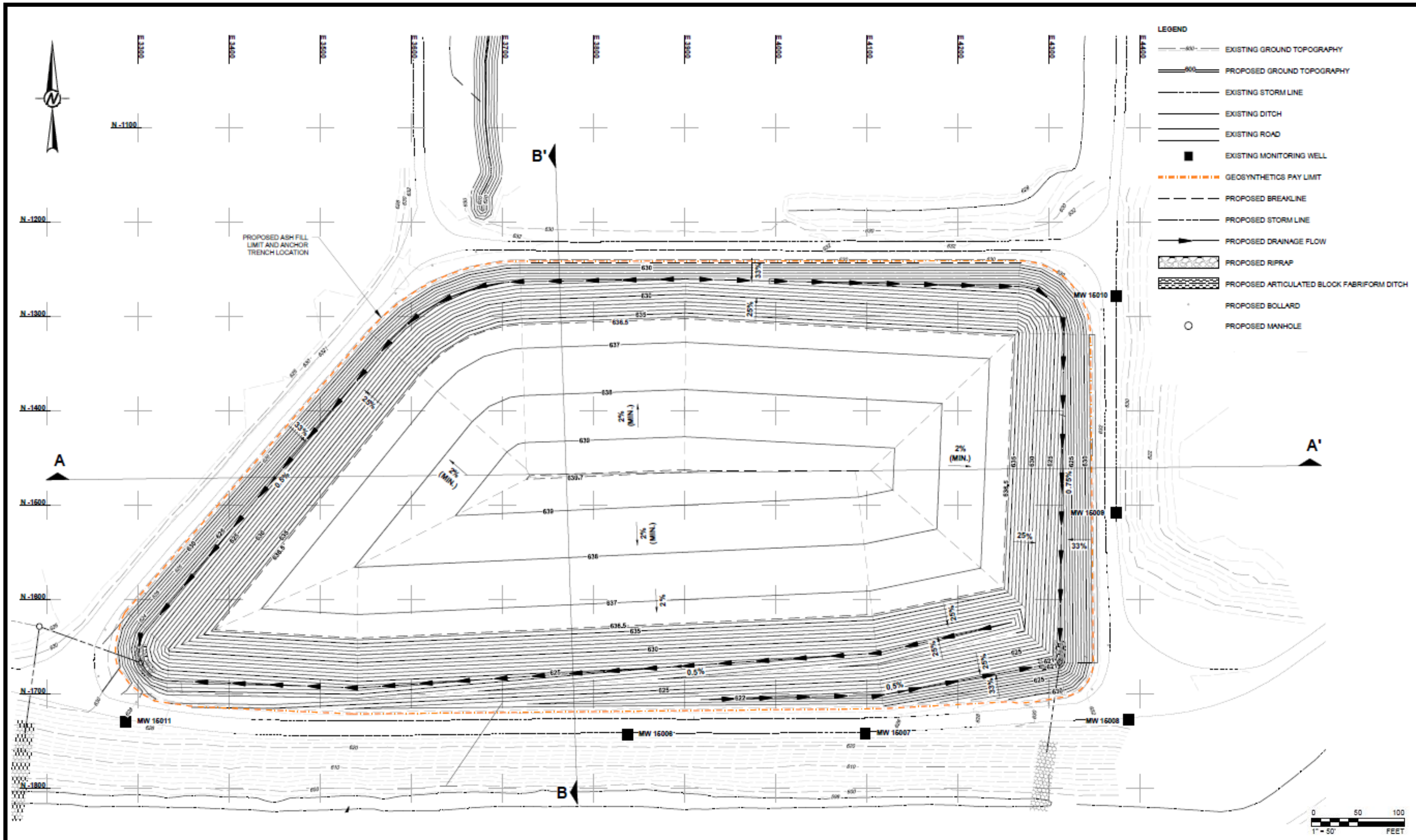
Summary of Stability Analyses Results

Cross-Section B-B

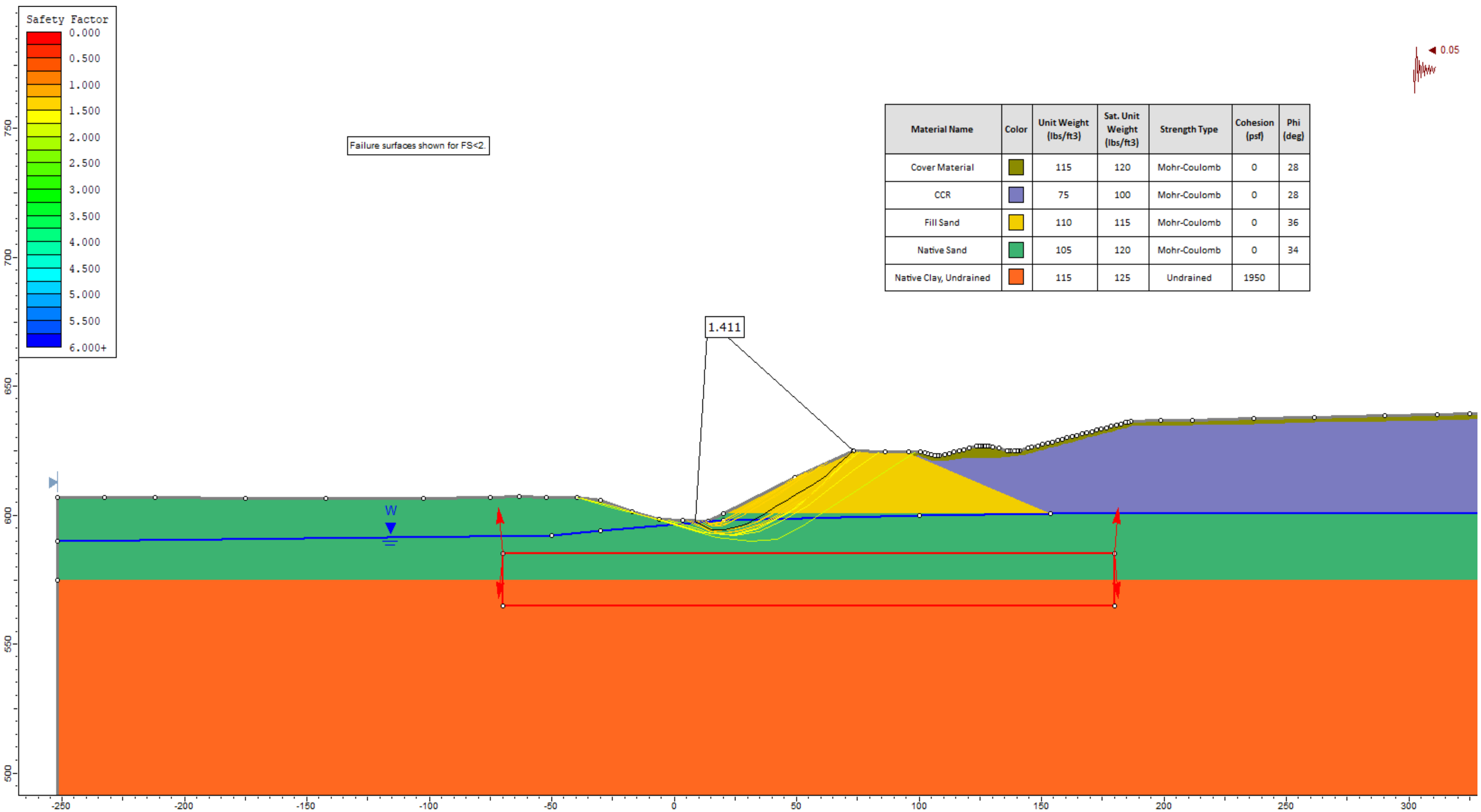
Analysis	Method	Calculated Value	Required FoS	Evaluation	Figure
PROPOSED CONDITIONS - Pond A with 1:3 side slopes (18.43 degrees)					
Pseudo-Static, Short-Term	Block	1.4	1.0	OK	1A
	Circular	2.2	1.0	OK	1B
Static, Long-Term	Block	1.7	1.5	OK	1C
	Circular	4.7	1.5	OK	1D

References:

1. Rocscience (2018), SLIDE 2018 Version 8.016
2. Abramson, L.W., T.S. Lee, S. Sharma, and G.M. Boyce (2002), Slope Stability and Stabilization Methods, 2nd edition, John Wiley & Sons, New York.



Golder Associates Inc.	SCALE: AS SHOWN	TITLE	
	DATE: Aug 2018	**Stability Cross-Section Location Plan**	
	MADE BY: MJ		
	CAD: DS		
FILE: STABILITY	CHECK: JRP	Consumers Energy Corporation	FIGURE: 1
PROJECT No. 1667572.0003 REV. 2	REVIEW: DL		



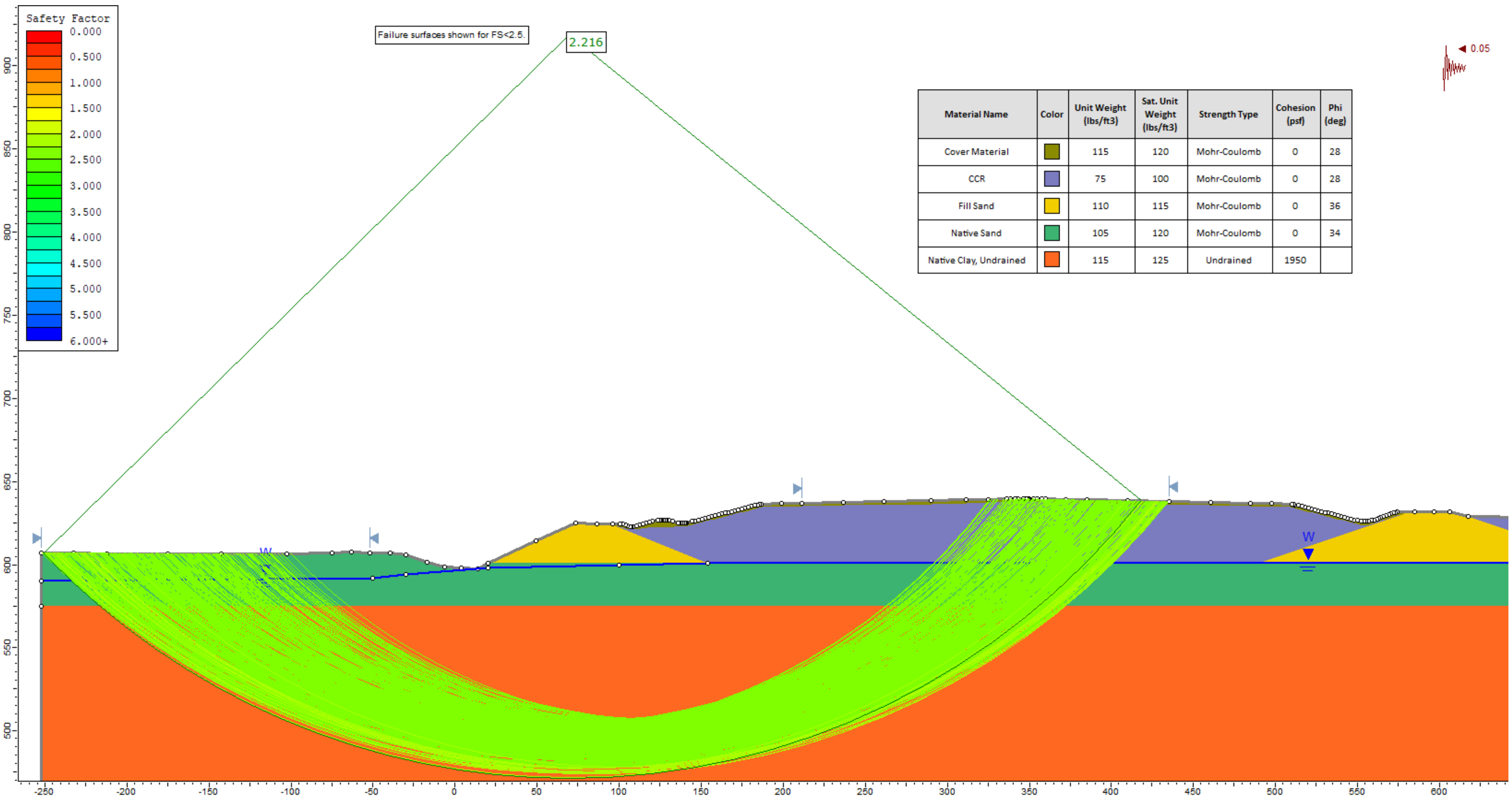
Material Name	Color	Unit Weight (lbs/ft3)	Sat. Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Cover Material		115	120	Mohr-Coulomb	0	28
CCR		75	100	Mohr-Coulomb	0	28
Fill Sand		110	115	Mohr-Coulomb	0	36
Native Sand		105	120	Mohr-Coulomb	0	34
Native Clay, Undrained		115	125	Undrained	1950	

Golder Associates Inc.

SCALE	AS SHOWN	TITLE	
DATE	Aug 2018	**Cross-Section B-B - Pseudo-Static, Short-Term, End of Construction Condition - Block Failure Search**	
MADE BY	MJ		
CAD	DS		
CHECK	JRP	**Consumers Energy Corporation**	FIGURE **1A**
REVIEW	DL		

FILE: STABILITY

PROJECT No. 1667572.0003 | REV. 2



Material Name	Color	Unit Weight (lbs/ft3)	Sat. Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Cover Material		115	120	Mohr-Coulomb	0	28
CCR		75	100	Mohr-Coulomb	0	28
Fill Sand		110	115	Mohr-Coulomb	0	36
Native Sand		105	120	Mohr-Coulomb	0	34
Native Clay, Undrained		115	125	Undrained	1950	

Golder Associates

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SCALE	AS SHOWN
DATE	Aug 2018
MADE BY	MJ
CAD	DS
CHECK	JRP
REVIEW	DL

FILE STABILITY

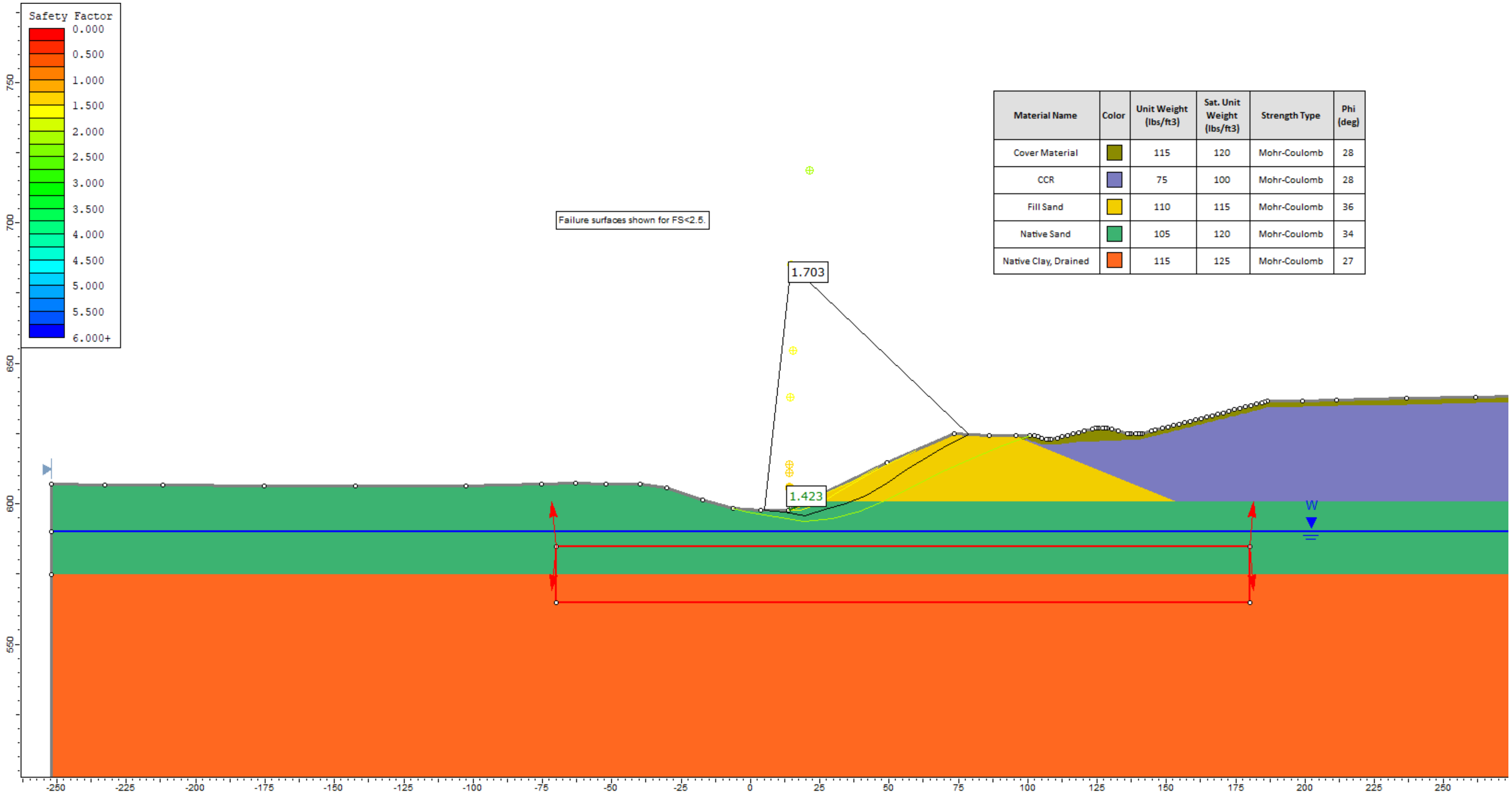
PROJECT No. 1667572.0003 REV. 2

TITLE

Cross-Section B-B - Pseudo-Static, Short-Term, End of Construction Condition - Circular Failure

Consumers Energy **Consumers Energy Corporation**

FIGURE **1B**



Material Name	Color	Unit Weight (lbs/ft3)	Sat. Unit Weight (lbs/ft3)	Strength Type	Phi (deg)
Cover Material		115	120	Mohr-Coulomb	28
CCR		75	100	Mohr-Coulomb	28
Fill Sand		110	115	Mohr-Coulomb	36
Native Sand		105	120	Mohr-Coulomb	34
Native Clay, Drained		115	125	Mohr-Coulomb	27

Golder Associates
Golder Associates Inc.

SCALE	AS SHOWN
DATE	Aug 2018
MADE BY	MJ
CAD	DS
CHECK	JRP
REVIEW	DL

FILE STABILITY

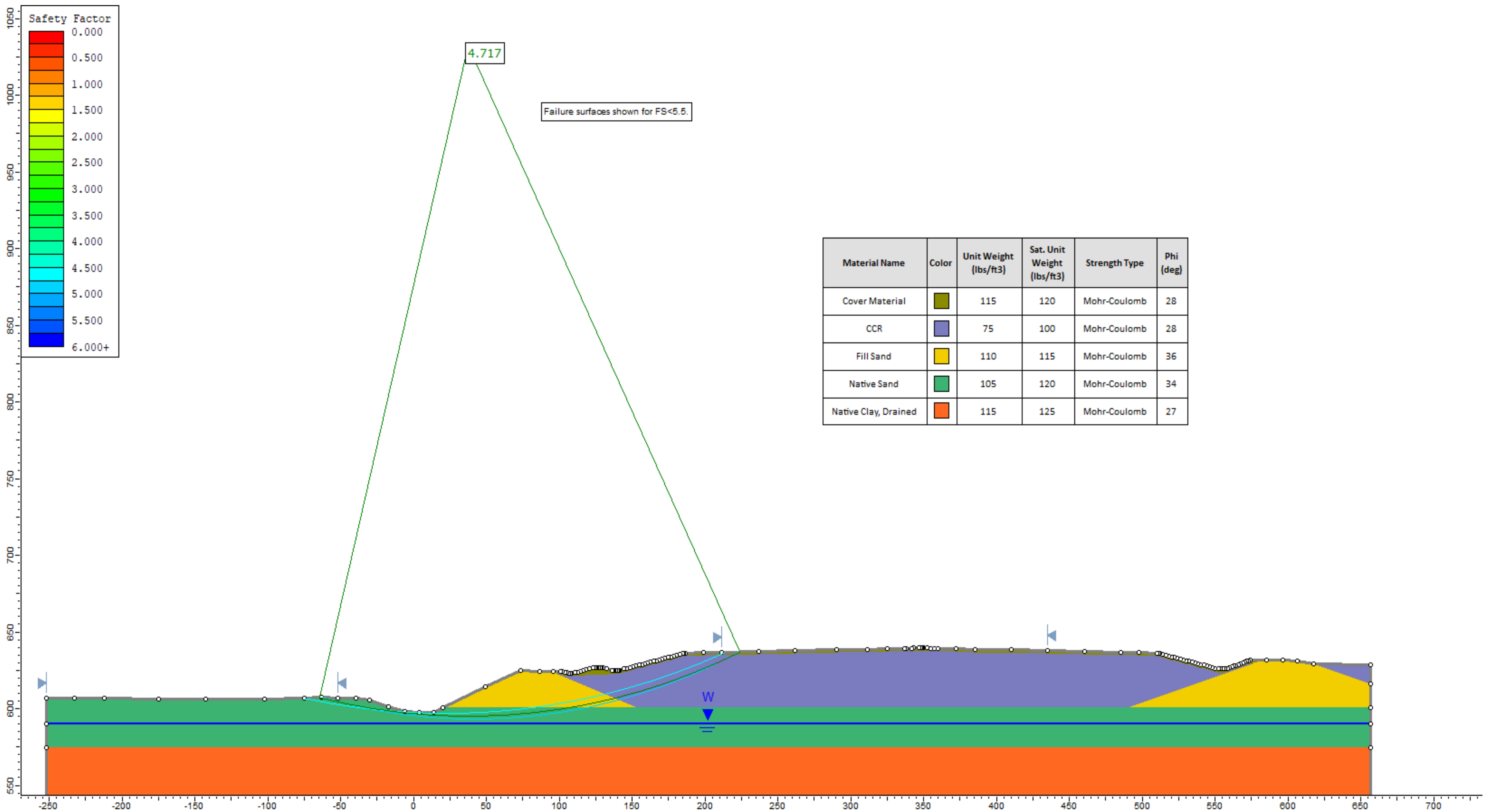
PROJECT No. 1667572.0003 REV. 2

TITLE

Cross-Section B-B - Static, Long-Term Condition - Block Failure Search

Consumers Energy **Consumers Energy Corporation**

FIGURE **1C**



Material Name	Color	Unit Weight (lbs/ft3)	Sat. Unit Weight (lbs/ft3)	Strength Type	Phi (deg)
Cover Material		115	120	Mohr-Coulomb	28
CCR		75	100	Mohr-Coulomb	28
Fill Sand		110	115	Mohr-Coulomb	36
Native Sand		105	120	Mohr-Coulomb	34
Native Clay, Drained		115	125	Mohr-Coulomb	27

Golder Associates
Golder Associates Inc.

SCALE	AS SHOWN
DATE	Aug 2018
MADE BY	MJ
CAD	DS
CHECK	JRP
REVIEW	DL
FILE	STABILITY
PROJECT No.	1667572.0003
REV.	2

TITLE

Cross-Section B-B - Static, Long-Term Condition - Circular Failure

Consumers Energy **Consumers Energy Corporation**

FIGURE **1D**

FINAL COVER VENEER STABILITY CALCULATIONS

Golder Associates

CALCULATIONS

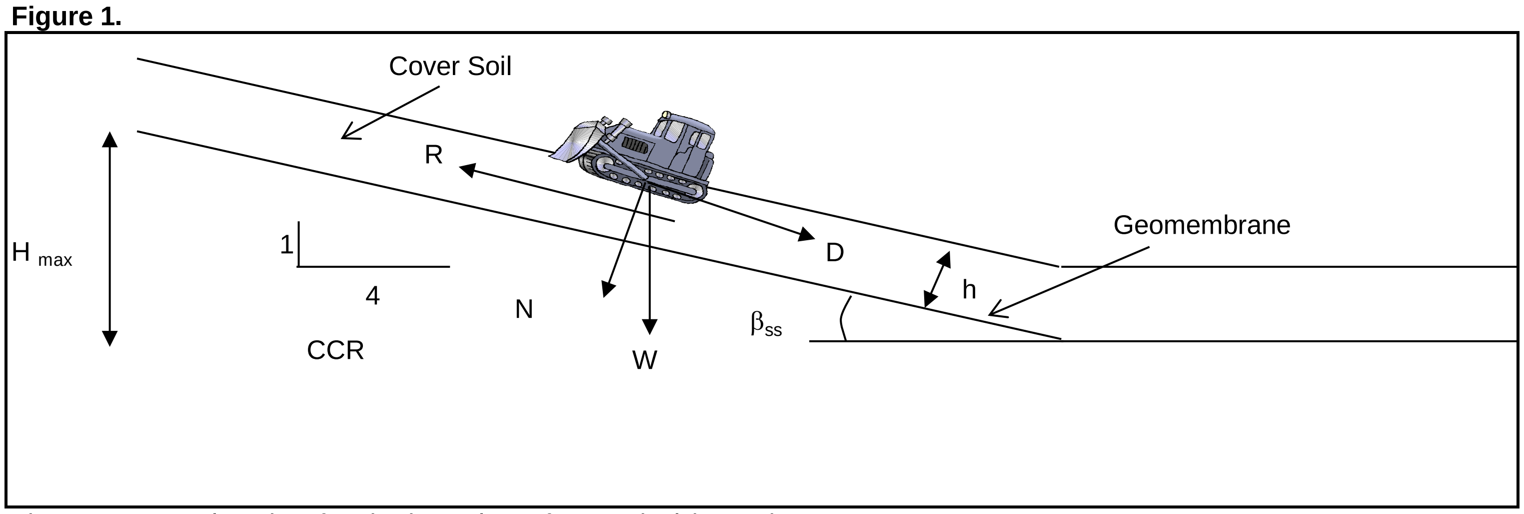
Date:	Aug-18	**Made by:**	MMJ
Project No.:	1667572.0003	**Checked by:**	JRP
Subject:	**3H:1V FINAL COVER STABILITY - SHORT TERM WITH EQUIPMENT FORCES**	**Reviewed by:**	DL
Project Short Title:	JH Campbell Pond A Closure Plan		

1.0 OBJECTIVE

Analyze the short-term static stability of the cap system at JH Campbell Pond A, considering peak low normal load shear strengths with regards to wedge/block failure and sliding due to equipment forces and considering water within the protective cover and topsoil layer.

2.0 GEOMETRY

Figure 1.



The worst case slope is 3 feet horizontal to 1 foot vertical (3H:1V)

2.0 ASSUMPTIONS

1.) The proposed Final Cover system consists of (from top to bottom):

6-inch (in) topsoil layer
24-in protective cover
10 ounce per square yard (oz/sy) 100-mil thick nonwoven geotextile (GT)
40-mil thick High Density Polyethylene (HDPE) textured geomembrane (TGM).

2.) Material Properties used for the analysis are shown in Table 1 along with assumptions used to clarify estimated properties of materials where applicable.

3.) The final cover slopes are designed to be a maximum 3 horizontal to 1 vertical (3H:1V) along the perimeter ditch.

4.) Maximum slope length along the 3H:1V slope is approximately 31.5 feet (ft).

5.) This calculation is valid for equipment moving up the slope only.

3.0 METHODS

1.) **Use method outlined in R.M. Koerner and T. Soong's method, Reference 2. Please see Figure 1 for Equations and Parameter definitions for the calculations performed below.**

2.) Allow a minimum interim factor of safety of 1.3, when saturated conditions are considered, and peak interface friction angles are used.

3.) Interface friction angles were taken as averages of representative lab data for similar materials, residual strengths. (These friction angles are conservative and for design purposes. The owner may choose to purchase materials with interface friction angles greater than those used in the design.)

Golder Associates

CALCULATIONS

Date:	Aug-18	**Made by:**	MMJ
Project No.:	1667572.0003	**Checked by:**	JRP
Subject:	**3H:1V FINAL COVER STABILITY - SHORT TERM WITH EQUIPMENT FORCES**	**Reviewed by:**	DL
Project Short Title:	JH Campbell Pond A Closure Plan		

4.0 CALCULATIONS

Calculate Factor of Safety using Koerner's Method for short term stability with equipment loads;
(See attached Reference 2, GRI Report #18, for method)

Uniform Cover Soil Thickness with the Incorporation of Equipment Loads

thickness of cover soil =	h =	2.5	ft				
soil slope angle beneath the geomembrane =	β =	18.43	degrees	Slope = 3H : 1V			
length of slope measured along the geosynthetics =	L =	31.5	ft	Maximum slope length			
unit wt. of cover soil =	γ =	120	pcf	Assume saturated conditions			
friction angle of cover soil =	ϕ =	28	degrees				
cohesion of cover soil =	c =	0	psf		C =	0	lb
interface frict. between GT and 40-mil TGM =	δ =	25	***degrees peak low normal load***				
adhesion between GT and 40-mil TGM =	ca =	0	psf		Ca =	0.00	lb

Dozer Specifications		(Ref 3)	
D6R LGP Track- type tractor	39,222	lb	
Track	128	inches long	
	33	inches wide	

thickness of cover soil =	h =	2.5	ft	b/h=	1.1	
equipment ground pressure (=wt. of equip./(2*w*b)) =	q =	668.56	psf	We = q*w*I =	6824.6	lb/ft
length of equipment track =	w =	10.67	ft	Ne = Wecosβ =	6474.6	lb/ft
width of equipment track =	b =	2.75	ft	Fe=We*a/g*I=	457.2	lb
influence factor at Geotextile interface =	I =	0.96	See Ref 2, Fig 7.			
acceleration of bulldozer =	a =	0.07	g	Assume Cat D6R LGP dozer accelerating to 3 mph in approx. 2 sec. (accel. = 0.07 g)		

W_A	7,074.39	lb
N_A	6,711.55	lb
W_p	1,250.29	lb

$$FS = \frac{R}{D} = \frac{-b + \sqrt{b^2 - 4ac}}{2a}$$

a	4,602.48
b	-7,313.71
c	1,033.60

FS	**1.43**

Golder Associates

CALCULATIONS

Date:	Aug-18	**Made by:**	MMJ
Project No.:	1667572.0003	**Checked by:**	JRP
Subject:	**3H:1V FINAL COVER STABILITY - SHORT TERM WITH EQUIPMENT FORCES**	**Reviewed by:**	DL

Project Short Title: JH Campbell Pond A Closure Plan

4.0 CALCULATIONS CONT.

Uniform Cover Soil Thickness
Seepage Forces with Parallel-to-Slope Buildup

(See attached Figure 1 depicting seepage forces with parallel-to-slope buildup)

1) Assume maximum 100-mil of head on geotextile.

thickness of cover soil =	h =	2.5	ft	
soil slope angle beneath the geomembrane =	β =	18.43	degrees	Slope = 3H : 1V
length of slope measured along the geosynthetics =	L =	31.5	ft	Maximum slope length
vertical height of slope measured from toe =	*H =*	*10*	ft	
depth of water over geomembrane =	h_w =	0.01	ft	100-mil
parallel submergence ratio =	*PSR =*	*4.00E-03*		PSR = depth of water on TGM / thickness of cover soil
dry unit wt. of cover soil =	γ_d =	115	pcf	
saturated unit wt. of cover soil =	γ_{sat} =	120	pcf	
unit wt. of water =	γ_w =	62.4	pcf	
friction angle of drainage soil =	ϕ =	28	degrees	
interface frict. between GT and 40-mil TGM =	δ =	25	***degrees peak low normal load***	

W_A	7,859.6	lb
Un	18.6	lb
Uh	0.0	lb
N_A	7,437.9	lb
W_p	1,198.2	lb
Uv	0.0	lb

$$FS = \frac{-b + \sqrt{b^2 - 4ac}}{2a}$$

a	2,357.3
b	-4,345.2
c	583.0

FS	**1.70**

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5.0 CONCLUSIONS

The evaluation of this short-term condition considering equipment forces and water within the protective layer and topsoil layer is found to be acceptable with the Factors of Safety being greater than 1.3. Since it was a short-term condition, peak low normal load shear strengths were applied.

6.0 REFERENCES

1.) Koerner, R.M., *Designing with Geosynthetics* , Prentice Hall, New Jersey, 1998.

2.) Koerner, R.M. and Soong, T., "Analysis and design of veneer cover soils" Geosynthetics International, 2005, 12, No.1.

3.) Ritchiespecs, Specification Summary, D6N LGP Crawler Tractor.

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CALCULATIONS

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1.0 OBJECTIVE

Analyze a "worst case" scenario and determine the long-term stability of the final cover system considering long term normal load shear strengths with regards to wedge/block failure and sliding due to water seepage forces within the protective layer and topsoil layer while considering seismic forces.

2.0 ASSUMPTIONS

1.) The proposed Final Cover system consists of (from top to bottom):

6-inch (in) topsoil layer
24-in protective layer
10 ounce per square yard (oz/sy) 100-mil thick nonwoven geotextile (GT)
40-mil thick High Density Polyethylene (HDPE) textured geomembrane (TGM).

2.) Material Properties used for the analysis are shown in Table 1 along with assumptions used to clarify estimated properties of materials where applicable.

3.) The worst case final cover slopes are designed to be a maximum 3 horizontal to 1 vertical (3H:1V) along the perimeter ditch.

4.) Maximum slope length along the 3H:1V slope is approximately 31.5 feet (ft).

5.) The peak interface friction angle has been used because settlement of the CCR will be negligible and HDPE geomembrane will be used.

3.0 METHODS

1.) **Use method outlined in R.M. Koerner and T. Soong's method, Reference 2. Please see Figure 1 for Equations and Parameter definitions for the calculations performed below.**

2.) Allow a minimum interim factor of safety of 1.1, with seismic when saturated conditions are considered, and residual interface friction angles are used and calculate the maximum safe slope length for each condition.

3.) Interface friction angles were taken as averages of representative lab data for similar materials, residual strengths. (These friction angles are conservative and for design purposes. The owner may choose to purchase materials with interface friction angles greater than those used in the design.)

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CALCULATIONS

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4.0 CALCULATIONS

Calculate Factor of Safety using Koerner's Method for long term stability with wet conditions (i.e. water on the liner); (See attached GRI Report #18)

Uniform Cover Soil Thickness
Seismic and Seepage Forces with Parallel-to-Slope Buildup

(See attached Figure 1 depicting seepage forces with parallel-to-slope buildup)

1) Assume maximum 100-mil of head (geotextile thickness)

thickness of cover soil =	h =	2.5	ft	
soil slope angle beneath the geomembrane =	β =	18.43	degrees	Slope = 3H : 1V
length of slope measured along the geosynthetics =	L =	31.5	ft	Length between drainage outfalls.
vertical height of slope measured from toe =	*H =*	*10*	ft	
depth of water over geotextile =	h_w =	0.01	ft	Assume 100 mil of head (GT thickness)
parallel submergence ratio =	*PSR =*	*4.00E-03*		PSR = depth of water on TGM / thickness of cover soil
dry unit wt. of cover soil =	γ_d =	115	pcf	
saturated unit wt. of cover soil =	γ_{sat} =	120	pcf	
unit wt. of water =	γ_w =	62.4	pcf	
friction angle of cover soil =	ϕ =	28	degrees	
peak interface frict. between GT and 40-mil TGM =	δ =	25	***degrees peak low normal load***	

2) Determine seismic coefficient following FHWA (2011) and AASHTO (2009) guidelines. Pond A classifies as site class D - "Stiff Soil". See USGS Design Map Summary Report (Reference 6) for site factors and seismic design values used below.

AASHTO peak ground acceleration site factor =	F_{pga} =	1.6		
USGS mapped acceleration coefficient =	PGA =	0.023	g	
maximum possible seismic coefficient =	k_{max} =	0.037	g	$k_{max} = F_{pga}$*PGA
spectral acceleration at 1 second for site class B =	S_1 =	0.026	g	
AASHTO site factor for the spectral acceleration at 1 second =	F_v =	2.4		
	B =	1.70		$B = F_v*S_1/k_{max}$
slope height reduction factor =	α =	0.985		α =1+0.01*H(0.5B-1)
average peak acceleration	k_{av} =	0.036	g	$k_{av} = \alpha*k_{max}$
seismic coefficient =	Cs =	0.018	g	$C_s = 0.5*k_{av}$

W_A	7,859.6	lb
Un	18.6	lb
Uh	0.0	lb
N_A	116.5	lb
W_p	1,198.2	lb
Uv	0.0	lb

With Seismic

W_A (lb)	142.43
W_P (lb)	21.71

$$FS = \frac{-b+\sqrt{b^2-4ac}}{2a}$$

a	42.7
b	-70.6
c	9.1

FS	**1.5**

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5.0 CONCLUSIONS

Considering the use of seismic loading, peak low normal load shear strengths, and saturated conditions, the long-term "worst case" stability evaluation results are considered acceptable with a factor of safety = 1.1.

6.0 REFERENCES

1.) Koerner, R.M., *Designing with Geosynthetics* , Prentice Hall, New Jersey, 1998.

2.) Koerner, R.M. and Soong, T., "Analysis and design of veneer cover soils" Geosynthetics International, 2005, 12, No.1.

3.) Ritchiespecs, Specification Summary, D6N LGP Crawler Tractor.

4.) FHWA, "LRFD Seismic Analysis and Design of Transportation Geotechnical Features and Structural Foundations", 2011.

5.) AASHTO, "Guide Specifications for LRFD Seismic Bridge Design", 2009.

6.) USGS, Design Map Summary Report for JH Campbell Pond A, generated from http://earthquake.usgs.gov/designmaps/us/application.php on January 18, 2017.

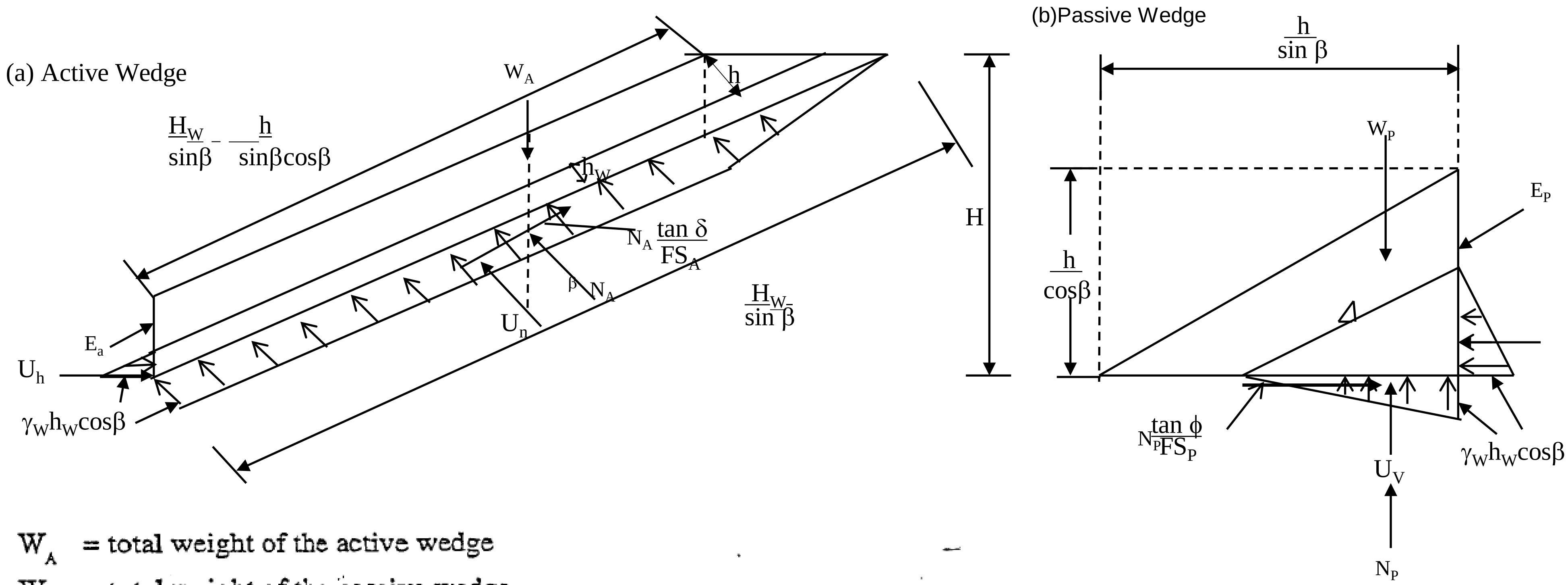
TABLE 1 - Material Properties

Symbol	Definition and assumptions for the purpose of this calculation
h =	*Thickness of the cover soil* - In all cases the protective cover will be 2.0 feet thick and the topsoil will be 0.5 feet thick for a total of 2.5 feet.
β =	*Soil slope angle beneath the geomembrane* - A 3H:1V slope exhibits an angle of soil beneath the geomembrane of 18.43°. This slope is present on the side slopes and represents a "worst case" scenario.
L =	*Length of slope measured along the geomembrane* - The maximum 3H:1V slope length anticipated is 31.5 feet.
γ_d =	*Weighted dry unit weight of final cover soil* - The protective cover and topsoil are both assumed to contain a mix of sandy soils with varying amounts of fines. In place unit weight is assumed to be 115 pounds per cubic foot (pcf).
ϕ =	*Minimum friction angle of final cover soil* - A friction angle of 28 degrees is assumed for protective cover and topsoil materials for this calculation.
c =	*Cohesion of the cover soil* - Cohesion is assumed to be zero because cover soils may be sand.
δ =	*Critical Interface friction angle within the final cover system* - The critical interface will be between a 40 mil textured HDPE geomembrane and 100-mil, 10oz/sy geotextile. The estimated peak friction angle between these materials is 25 degrees. The estimated residual friction angle between these materials is 17 degrees.
ca =	*Adhesion between cover soil of the active wedge and the geomembrane* - Adhesion is assumed to be zero because cover soils may be sand.
γ_{sat} =	*Saturated unit weight of final cover soil* - The unit weight of saturated final cover soils is assumed to be 120 pcf for this calculation.
Cs =	*Average seismic coefficient* - The average horizontal component seismic coefficient for the Ottawa County area is 0.018 gravity. Calculation shown on page 6.
I =	*Influence factor at geocomposite interface* - The influence factor at the geomembrane interface and width of the dozer track divided by the thickness of cover soil show I = 0.96 for this case (Reference 2, Figure 7).

FIGURE 1

Uniform Cover Soil Thickness
Seepage Forces with Parallel-to-Slope Buildup

JAB
JBF



W_A = total weight of the active wedge
W_P = total weight of the passive wedge
N_A = effective force normal to the failure plane of the active wedge
N_P = effective force normal to the failure plane of the passive wedge
γ = unit weight of the cover soil
h = thickness of the cover soil
L = length of slope measured along the geomembrane
β = soil slope angle beneath the geomembrane
φ = friction angle of the cover soil
δ = interface friction angle between cover soil and geomembrane
C_a = adhesive force between cover soil of the active wedge and the geomembrane
c_a = adhesion between cover soil of the active wedge and the geomembrane

C = cohesive force along the failure plane of the passive wedge
c = cohesion of the cover soil
E_A = interwedge force acting on the active wedge from the passive wedge
E_P = interwedge force acting on the passive wedge from the active wedge
FS = factor-of-safety against cover soil sliding on the geomembrane

$$W_A = \gamma h^2 \left(\frac{L}{h} \cdot \frac{1}{\sin 2\beta} - \frac{1}{2\tan\beta}\right)$$

$$a(FS)^2 + b(FS) + c = 0$$

$$N_A = W_A \cos\beta$$

$$a = (W_A - N_A\cos\beta)\cos\beta$$

$$W_P = \frac{\gamma h^2}{\sin 2\beta}$$

$$b = -[(W_A - N_A\cos\beta)\sin\beta\tan\phi + (N_A\tan\delta + C_a)\sin\beta\cos\beta + \sin\beta(C + W_P\tan\phi)]$$

$$N_p = W_P + E_P\sin\beta$$

$$c = (N_A\tan\delta + C_a)\sin^2\beta\tan\phi$$

$$C = \frac{(c)(h)}{\sin\beta}$$

AND:

$$E_P\cos\beta = \frac{C + N_P\tan\phi}{FS}$$

$$FS = \frac{-b + \sqrt{b^2 - 4ac}}{2a}$$