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
CLOSED PONDS 1 AND 2
FORMER JR WHITING GENERATING FACILITY
CONSUMERS ENERGY COMPANY
ERIE, 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 Ponds 1 and 2 surface impoundment (Ponds 1 and 2) at the Consumers Energy Company (CEC) former JR Whiting Generating Facility (JR Whiting). 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

JR Whiting is a former coal-fired power generation facility located in Erie, Michigan that ceased electrical generation in 2016. Ponds 1 and 2 are located east of the former JR Whiting facility (Figure 1). Ponds 1 and 2 are a closed former CCR surface impoundment which received bottom ash, plant process water, and occasionally sluiced fly ash.

The Ponds 1 and 2 surface impoundment 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). Ponds 1 and 2 closure construction is documented in the Ponds 1 and 2 – Construction Documentation Report (Golder, 2020[2]). Prior to construction of the final cover system, Ponds 1 and 2 were dewatered by actively pumping standing water downstream in accordance with applicable federal, state and local rules and regulations. After dewatering

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[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 2020. J.R. Whiting Generating Facility, Ponds 1 and 2 – Construction Documentation Report, Golder Associates Inc., February 24, 2020.

activities were complete, influent and effluent piping was permanently abandoned or removed and the subgrade areas were assessed by the construction team to determine if they were suitable for regrading or if bridging layers were required. Areas with soft or unsuitable subgrade soils identified were bridged with a 10 ounce/square yard woven geotextile beneath a single 3-foot lift of bottom ash or with onsite vegetation. Areas were accepted for fill placement when no rutting or pumping was observed in excess of 1-inch. Compaction of the regraded materials was achieved with standard earthwork equipment until no rutting or pumping was observed in excess of 1-inch. Onsite materials were graded to establish a uniform grade capable of supporting structural fill and final cover materials. Structural fill materials were placed in lifts of approximately 9-inches, graded and compacted to achieve closure design grades. The Ponds 1 and 2 and final cover system is comprised of the following components:

- In-place CCR materials and structural fill compacted and graded to maintain positive drainage,
- 40-mil high density polyethylene (HDPE) geomembrane,
- 8 ounce per square yard nonwoven geotextile,
- 4-inch diameter perforated drainage piping with sock,
- 28-inch thick protective cover (sand) layer, and
- 6-inch thick vegetated topsoil layer.

Closure construction began on May 7, 2019 with dewatering operations and was completed November 25, 2019 with final seeding and mulching. Approval for the Ponds 1 and 2 closure was provided by the Michigan Department of Environment, Great Lakes and Energy (EGLE).

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 Structural Stability Assessment Report (Mannik Smith, 2016a[3]), Safety Factor Assessment Report (Mannik Smith, 2016b[4]), Ponds 1 and 2 Closure Plan (Golder, 2017[5]), annual inspections performed at Ponds 1 and 2 and routine inspections performed by CEC. The most recent annual inspection was completed by Golder in May 2021.

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

No certified documents were available on the original design or construction of the Ponds 1 and 2 embankments. Subsurface investigations have revealed that the foundation soils consist of stable native clay 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.

[3] Mannik Smith 2016a. Structural Stability Assessment Report, Ponds 1 & 2, JR Whiting Plant, Mannik and Smith Group, October 13, 2016.

[4] Mannik Smith 2016b. Safety Factor Assessment Report, Ponds 1 & 2, JR Whiting Plant, Mannik and Smith Group, October 14, 2016

[5] Golder 2017. J.R. Whiting Generating Facility, Ponds 1 and 2 Closure Plan, Golder Associates Inc., December 18, 2017.

Slope Protection [§257.73(d)(1)(ii)]

The embankment slopes for Ponds 1 and 2 are protected from erosion and deterioration by establishment of vegetative cover and the eastern embankment along Lake Erie is lined with improved riprap (primarily consisting of concrete debris). 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 investigation or repair. The slope protection measures are considered adequate against surface erosion, wave action, and sudden drawdown effects.

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

No certified documents were available on the original design or construction of the Ponds 1 and 2 embankments. Relative densities observed during past subsurface investigations indicate that the perimeter dike was likely constructed with standard earthwork equipment and compacted and/or proof rolled in lifts. 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 Ponds 1 and 2.

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 Ponds 1 and 2.

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

There are no active hydraulic structures underlying the base of Ponds 1 and 2 or passing through the perimeter dike. The only remaining hydraulic structures are above-cap drainage piping that outlets on the west side of Ponds 1 and 2.

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

The east side of Ponds 1 and 2 is adjacent to Lake Erie. The south side of Ponds 1 and 2 is adjacent to the former discharge channel. The top of the embankment along Lake Erie was constructed at an elevation of approximately 588 feet and the western perimeter was constructed at an elevation of approximately 581 feet. Peak flood stages in the vicinity of Ponds 1 and 2 from FEMA National Flood Insurance Maps[6] are at elevations ranging from 577 feet to 580 feet. On that basis, it is anticipated that Lake Erie flood elevations will not inundate Ponds 1 and 2. Past stability assessments indicate that the downstream slope along Lake Erie has adequate safety factors under extreme water conditions including low lake levels (Mannik Smith, 2016b).

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

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

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[6] FEMA, National Flood Insurance Program, Flood Insurance Rate Map, Monroe County, Michigan, Panel 387 of 525, Version 2.3.2.4, Map Number 26115CO387F, Revised June 19, 2020.

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.

Ponds 1 and 2 are 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 Ponds 1 and 2 grades in the Ponds 1 and 2 Closure Plan (Golder, 2017). No new stability analysis was deemed necessary. 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 Ponds 1 and 2 Closure Plan (Golder, 2017) stability analysis are provided in **Appendix A**.

The stability analysis results indicate that the closed Ponds 1 and 2 slopes provide adequate factors of safety:

Table 1: Summary of Stability Analysis Results

Analysis	Minimum Calculated Factor of Safety	Required Factor of Safety
Cross-Section A-A' Short-Term, Pseudo-Static,	1.5	1.00
Cross-Section A-A' Long-Term, Static	2.2	1.50
Cross-Section B-B' Short-Term, Pseudo-Static,	1.5	1.00
Cross-Section B-B' Long-Term, Static	4.2	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 A**.

Liquefaction Potential

A screening of embankment and foundation soils for seismically-induced liquefaction susceptibility was performed in the initial Ponds 1 and 2 Safety Factor Assessment Report (Mannik Smith Group, 2016b). The screening-level results indicated that the embankment and foundation soils for Ponds 1 and 2 are not susceptible to seismically-induced liquefaction. The liquefaction potential assessment calculation are provided in Appendix B of the initial Safety Factor Assessment Report (Mannik Smith Group, 2016b).

SUMMARY

No structural stability deficiencies were identified for the closed Ponds 1 and 2 during this assessment.

The calculated factors of safety applicable to the closed Pond 1 and 2 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 - Excerpts from the 2017 Closure Plan Stability Analysis

https://golderassociates.sharepoint.com/sites/145646/project files/6 deliverables/5-yr stability report/whiting/jr whting pond 1-2 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

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 15:59:22 -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 27, 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

DRAFT

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Feet

CLIENT
CONSUMERS ENERGY COMPANY

Consumers Energy

PROJECT
PERIODIC STRUCTURAL STABILITY AND SAFETY FACTOR ASSESSMENT
J.R. WHITING GENERATING FACILITY

TITLE
CLOSED PONDS 1 AND 2 SITE LAYOUT.

CONSULTANT

GOLDER

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

PROJECT NO.	CONTROL	REV.	FIGURE
21465697	A001	0	1

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

APPENDIX A

Excerpts from the 2017 Closure Plan Stability Analysis

CALCULATIONS

Date:	August, 2017	**Made by:**	AK
Project No.:	1667572	**Checked by:**	SAM
Subject:	Global Stability Analyses - Closure Plan J.R. Whiting Ponds 1 and 2	**Reviewed by:**	TDJ
Project Short Title:	**JR WHITING PONDS 1 AND 2 CLOSURE**		

1.0 OBJECTIVE

To analyze the stability of the proposed closure design for Consumers Energy Corporation (Consumers) J.R. Whiting Ponds 1 and 2, located in Erie, Michigan.

2.0 ANALYSIS METHODS

The static and pseudo-static stability of the proposed closure design for J.R. Whiting Ponds 1 and 2 were evaluated using the computer program SLIDE Version 7.017 (Rocscience, 2016). 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 surfaces were analyzed to find failure surfaces that resulted in the minimum calculated factor of safety (FOS) for each critical cross section analyzed.

Per the US Environmental Protection Agency (EPA) Coal Combustion Residual (CCR) regulations (40 CFR 257.73) (see Reference 3), the minimum FOS results for this analysis are 1.5 for permanent loading conditions (long-term, drained) and 1.0 for seismic conditions (undrained). A seismic coefficient of 0.05 times the acceleration due to gravity at Earth's surface was used for pseudo-static analysis, as discussed in Appendix F. Global failure surfaces or those impacting the crest of the cover slopes were considered "Critical" surfaces that may compromise the stability of the closed ponds. Shallow or surficial slip surfaces along the slope surface (i.e., not global or impacting the cover system) with factors of safety lower than the "Critical" surfaces were often generated during the analyses. The shallow slip surfaces were considered "Non-Critical" erosion related issues that could likely be addressed by maintenance (e.g. local regrading, riprap armoring, etc.). Veneer stability of the proposed closure cover system is presented in a separate calculation.

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15851 South US 27, Suite 50
Lansing, MI 48906 USA
Tel: (517) 482-2262 Fax: (517) 482-2460 www.golder.com

3.0 ANALYSIS SECTIONS:

Two critical sections were selected to evaluate the stability of the designed closure of Ponds 1 and 2. Sections A and B were considered the most critical and were utilized for this analysis because they are located in areas with the steepest slopes, or highest amount of fill. Figure 1 provides an overview of the section locations.

4.0 ANALYSIS CASES:

The following stability cases were analyzed for the current analysis:

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

5.0 MATERIAL PROPERTIES:

The material properties used for this analysis are provided in Appendix F. For pseudo-static analyses, a strength reduction factor of 0.8 has been applied to undrained shear strength parameters per Hynes-Griffin and Franklin (1984) method (Reference 4).

Table 1: Summary of Stability Analyses Results

Cross-Section A-A'

Analysis	Method	Calculated Value	Required FoS	Evaluation	Figure
Static, Long-Term	Block	2.2	1.5	OK	1A
	Circular	2.2	1.5	OK	1B
Pseudo-Static, Short-Term	Block	1.5	1.0	OK	1C
	Circular	1.5	1.0	OK	1D

Cross-Section B-B'

Analysis	Method	Calculated Value	Required FoS	Evaluation	Figure
Static, Long-Term	Block	1.5	1.5	OK	1E
	Circular	1.5	1.5	OK	1F
Pseudo-Static, Short-Term	Block	4.2	1.0	OK	1G
	Circular	4.2	1.0	OK	1H

6.0 REFERENCES:

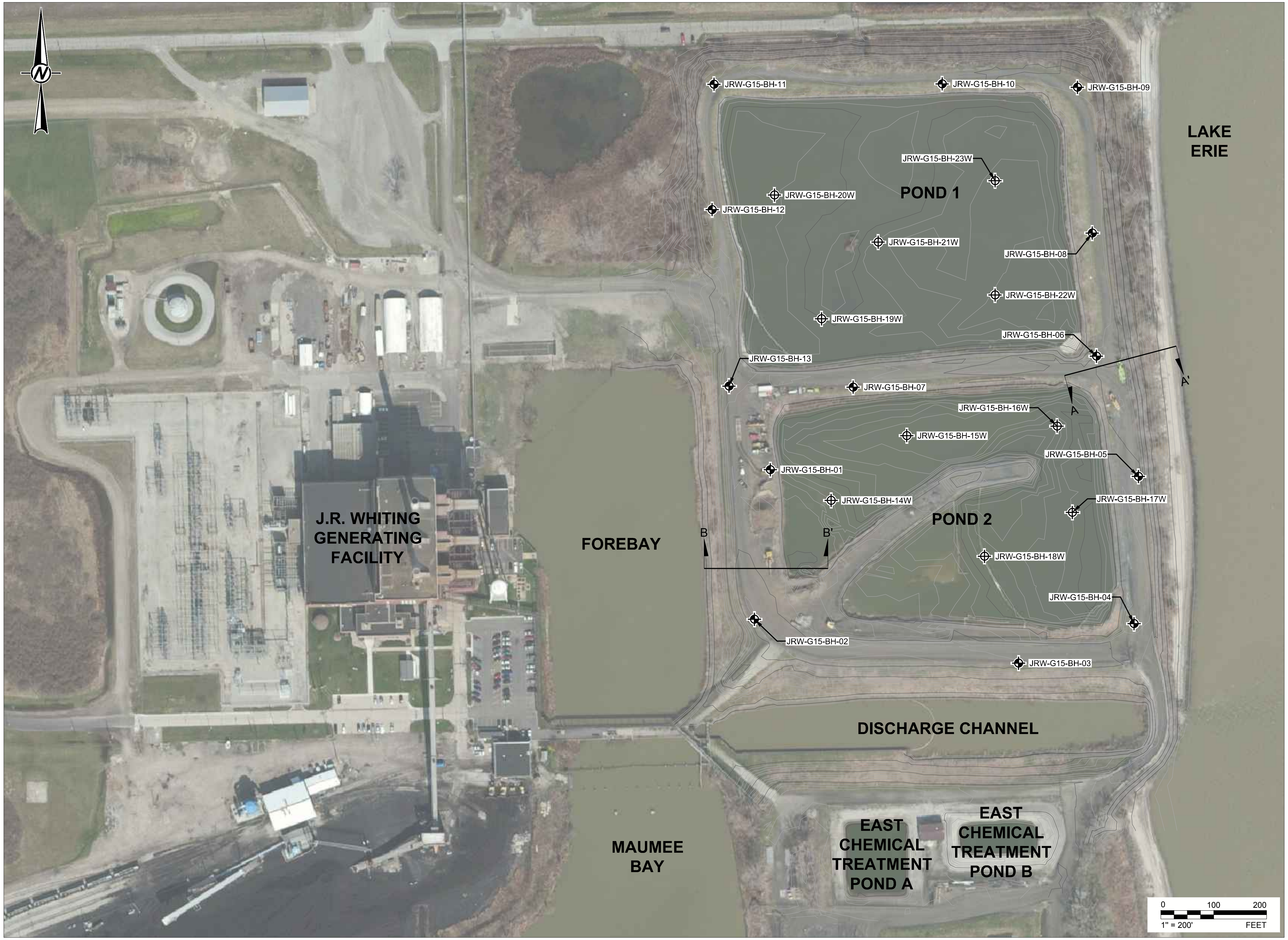
1. Rocscience (2016), SLIDE Version 7.017

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.

3. US Environmental Protection Agency (EPA) Resource Conservation and Recovery Act (RCRA) "Disposal of Coal Combustion Residuals from Electric Utilities; Final Rule" (Rule, 40 Code of Federal (CFR) Part 257), April 2015.

4. Hynes-Griffin, M.E., Franklin, A.G., 1984. Rationalizing the seismic coefficient method. U.S. Army Corps of Engineers Waterways Experiment Station, Miscellaneous Paper GL-84-13, 37 pp

5. Golder Associates Inc., 2017. J.R. Whiting Ash Ponds 1 and 2 Closure Plan, Appendix F, Table1: Global Material Properties Used for Calculations.



LEGEND

JRW-G15-BH-## 2015 LAND BOREHOLE LOCATION (GOLDER, 2016)

JRW-G15-BH--##W 2015 OVER-WATER BOREHOLE LOCATION (GOLDER, 2016)

EXISTING GROUND MAJOR CONTOUR (5' INTERVAL)

EXISTING GROUND MINOR CONTOUR (1' INTERVAL)

NOTES

1. ALL BOREHOLE LOCATIONS SHOWN ARE APPROXIMATE.
2. SCALE OF AERIAL IMAGERY IS APPROXIMATE.
3. AERIAL IMAGE IS SHOWN FOR GENERAL REFERENCE ONLY AND CURRENT SITE CONDITIONS MAY VARY FROM THE IMAGE SHOWN ON THIS FIGURE.
4. NO DIMENSIONS OR QUANTITIES ARE TO BE SCALED OR DEVELOPED FROM THIS FIGURE.
5. THIS FIGURE IS SIZED FOR 11"X17" ANSI-B PAPER AND ALL SCALES ASSOCIATED MUST BE VERIFIED.
6. 2015 OVER-WATER BOREHOLE LOCATIONS WERE LOCATED HORIZONTALLY BY GOLDER USING A HAND HELD GPS (TRIMBLE).
7. 2015 LAND BOREHOLE LOCATIONS WERE STAKED OUT AND DOCUMENTED ON 2015-10-19 HORIZONTALLY AND VERTICALLY BY MUXLOW SURVEY COMPANY.
8. 2016 MANNIK AND SMITH GROUP (MSG) BOREHOLE LOCATIONS ARE APPROXIMATE, BASED ON BOREHOLE LOCATION SKETCH PROVIDED BY IBRAHEEM SHUNNAR (MSG) TO GEORGE L. MCKENZIE II (CEC) VIA EMAIL ON JANUARY 27, 2017. NO SURVEY OR GPS LOCATIONS HAVE BEEN PROVIDED.
9. BOREHOLES DRILLED BY SME IN 1976 AND 1977 (SME, 1977) AND LOCATIONS HAVE BEEN ESTIMATED FROM TEST BORING LOCATION PLAN - POND #1, 2, AND 6; NTH, 2011.

REFERENCES

1. AERIAL IMAGERY SOURCE: ESRI, DIGITALGLOBE, GEOEYE, I-CUBED, EARTHSTAR GEOGRAPHICS, CNES/AIRBUS DS, USDA, USGS, AEX, GETMAPPING, AEROGRID, IGN, IGP, SWISSTOPO, AND THE GIS USER COMMUNITY.
2. HORIZONTAL DATUM: NAD 1983 STATE PLANE COORDINATES, MICHIGAN SOUTH ZONE, INTERNATIONAL FEET.
3. VERTICAL DATUM: NGVD 29.
4. GROUND SURFACE SURVEY DATED NOVEMBER 2015 PROVIDED BY CEC TO GOLDER VIA DWG FILE. PER ELEVATION BASIS NOTE ON DRAWING NO SF-19884, SHEET 34 PROVIDED BY SHERIDAN SURVEYING CO. ELEVATIONS WERE LOWERED 0.90' TO OBTAIN NAVD 88 ELEVATIONS.
5. PONDS SURVEY COMPLETED IN MARCH 2015, ADDITIONAL SURVEY PERFORMED IN OCTOBER AND NOVEMBER 2015 PER SHERIDAN SURVEYING CO. DRAWING.

CLIENT
CONSUMERS ENERGY COMPANY
4525 E. ERIE ROAD
ERIE, MICHIGAN

CONSULTANT

Golder Associates

YYYY-MM-DD	2017-07-05
DESIGNED	AK
PREPARED	DJC
REVIEWED	SAM
APPROVED	

PROJECT
J.R. WHITING GENERATING FACILITY
ASH PONDS 1 & 2 AND EAST CHEMICAL TREATMENT PONDS CLOSURE

TITLE
SLOPE STABILITY CROSS-SECTION LOCATION PLAN

PROJECT NO.	CONTROL	REV.	FIGURE
1667572	1667572E001.dwg	0	1

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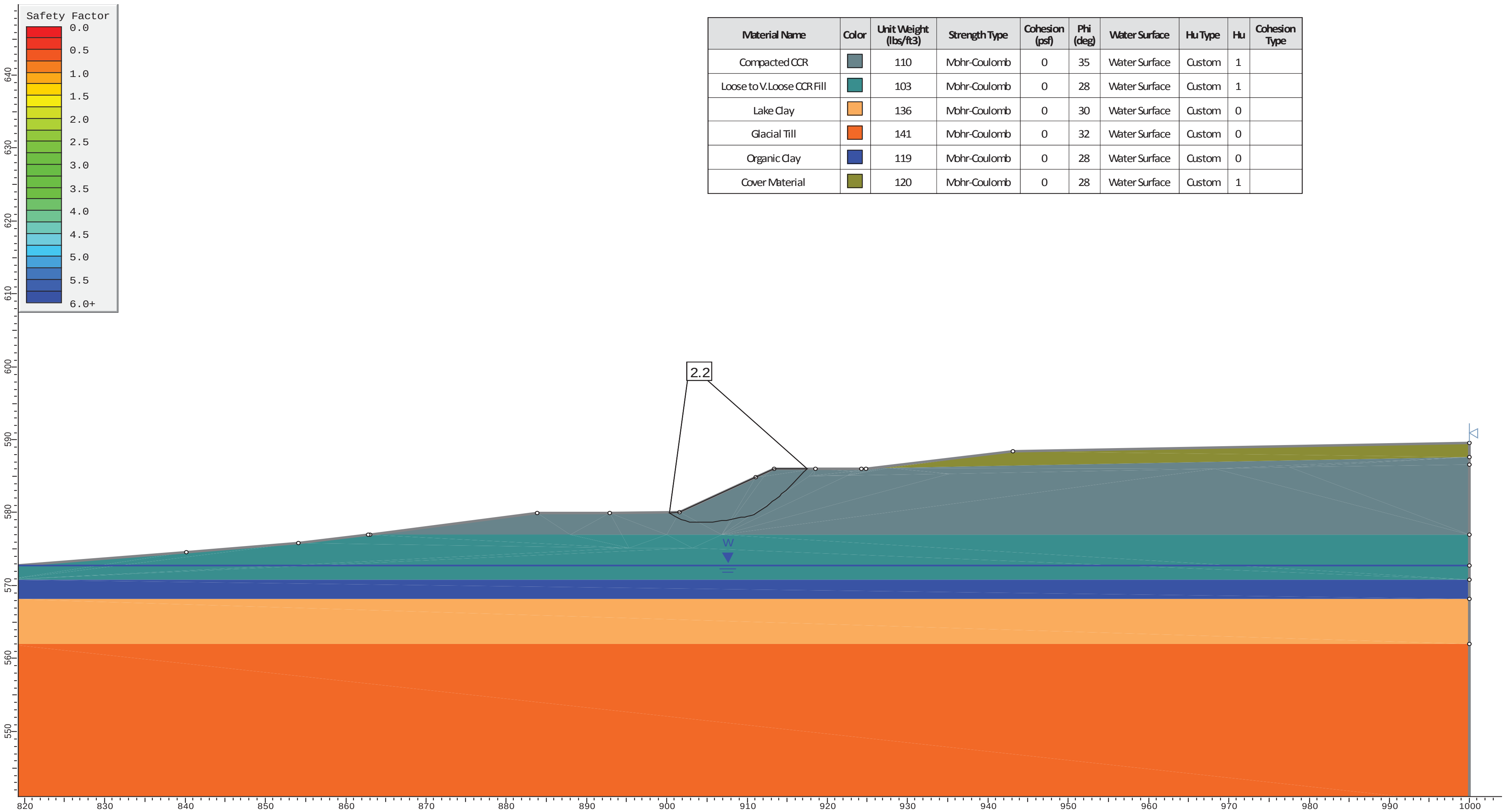
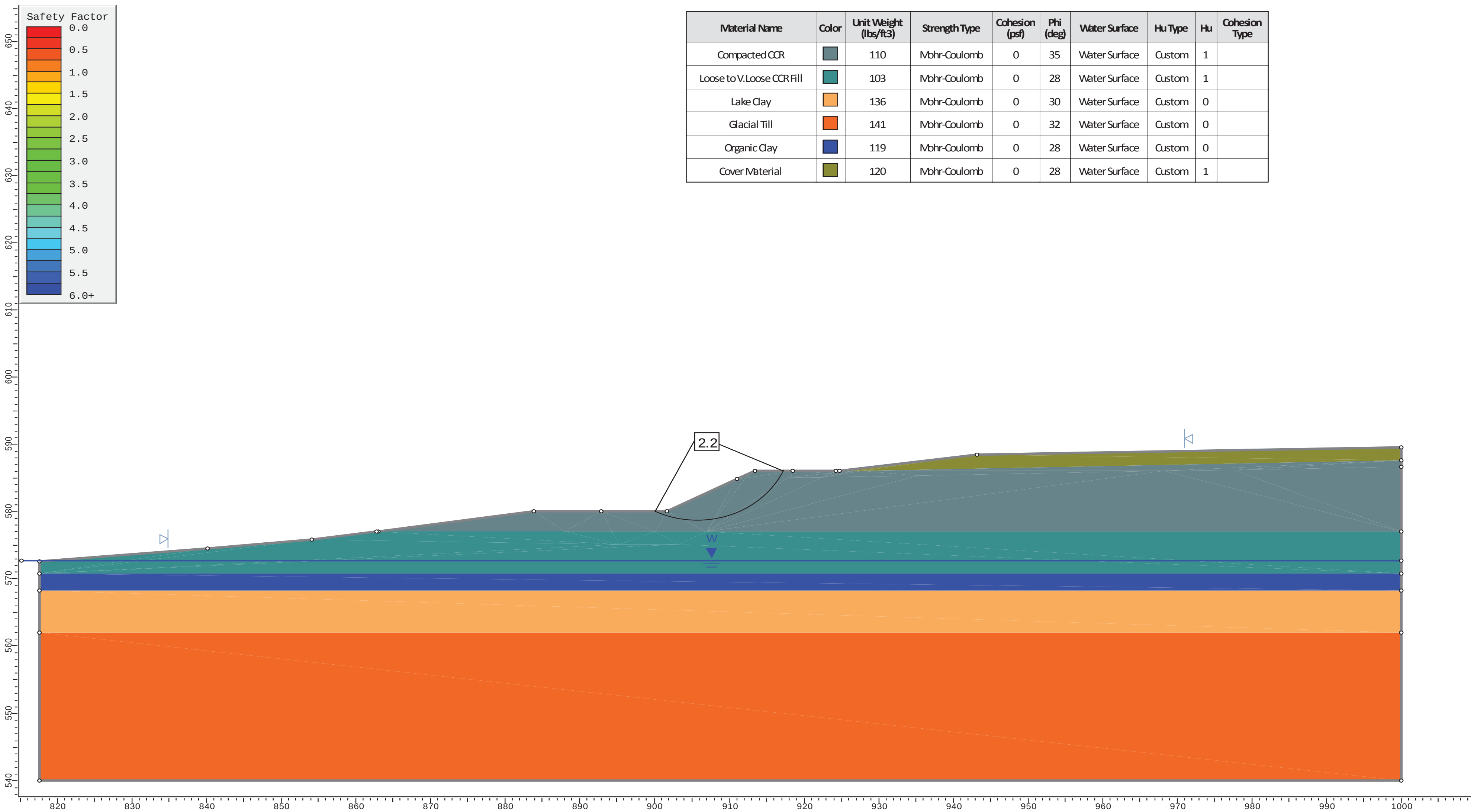
1 in

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Hu Type	Hu	Cohesion Type
Compacted CCR		110	Mohr-Coulomb	0	35	Water Surface	Custom	1	
Loose to V.Loose CCR Fill		103	Mohr-Coulomb	0	28	Water Surface	Custom	1	
Lake Clay		136	Mohr-Coulomb	0	30	Water Surface	Custom	0	
Glacial Till		141	Mohr-Coulomb	0	32	Water Surface	Custom	0	
Organic Clay		119	Mohr-Coulomb	0	28	Water Surface	Custom	0	
Cover Material		120	Mohr-Coulomb	0	28	Water Surface	Custom	1	



Golder Associates	SCALE: AS SHOWN	PROJECT	J.R. Whiting Ash Ponds 1 & 2 Closure
	DATE: Aug 2017	TITLE	Cross-Section A-A' Static, Long-Term Condition-Block Failure
	MADE BY: AK		
	CAD: DJC		
FILE: STABILITY	CHECK: SAM	CLIENT	Consumers Energy Company
PROJECT No. 1667572 / REV. 0	REVIEW: TDJ	FIGURE	1A



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Hu Type	Hu	Cohesion Type
Compacted CCR		110	Mohr-Coulomb	0	35	Water Surface	Custom	1	
Loose to V.Loose CCR Fill		103	Mohr-Coulomb	0	28	Water Surface	Custom	1	
Lake Clay		136	Mohr-Coulomb	0	30	Water Surface	Custom	0	
Glacial Till		141	Mohr-Coulomb	0	32	Water Surface	Custom	0	
Organic Clay		119	Mohr-Coulomb	0	28	Water Surface	Custom	0	
Cover Material		120	Mohr-Coulomb	0	28	Water Surface	Custom	1	

Golder Associates

SCALE	AS SHOWN
DATE	Aug 2017
MADE BY	AK
CAD	DJC
CHECK	SAM
REVIEW	TDJ

FILE STABILITY

PROJECT No. 1667572 REV. 0

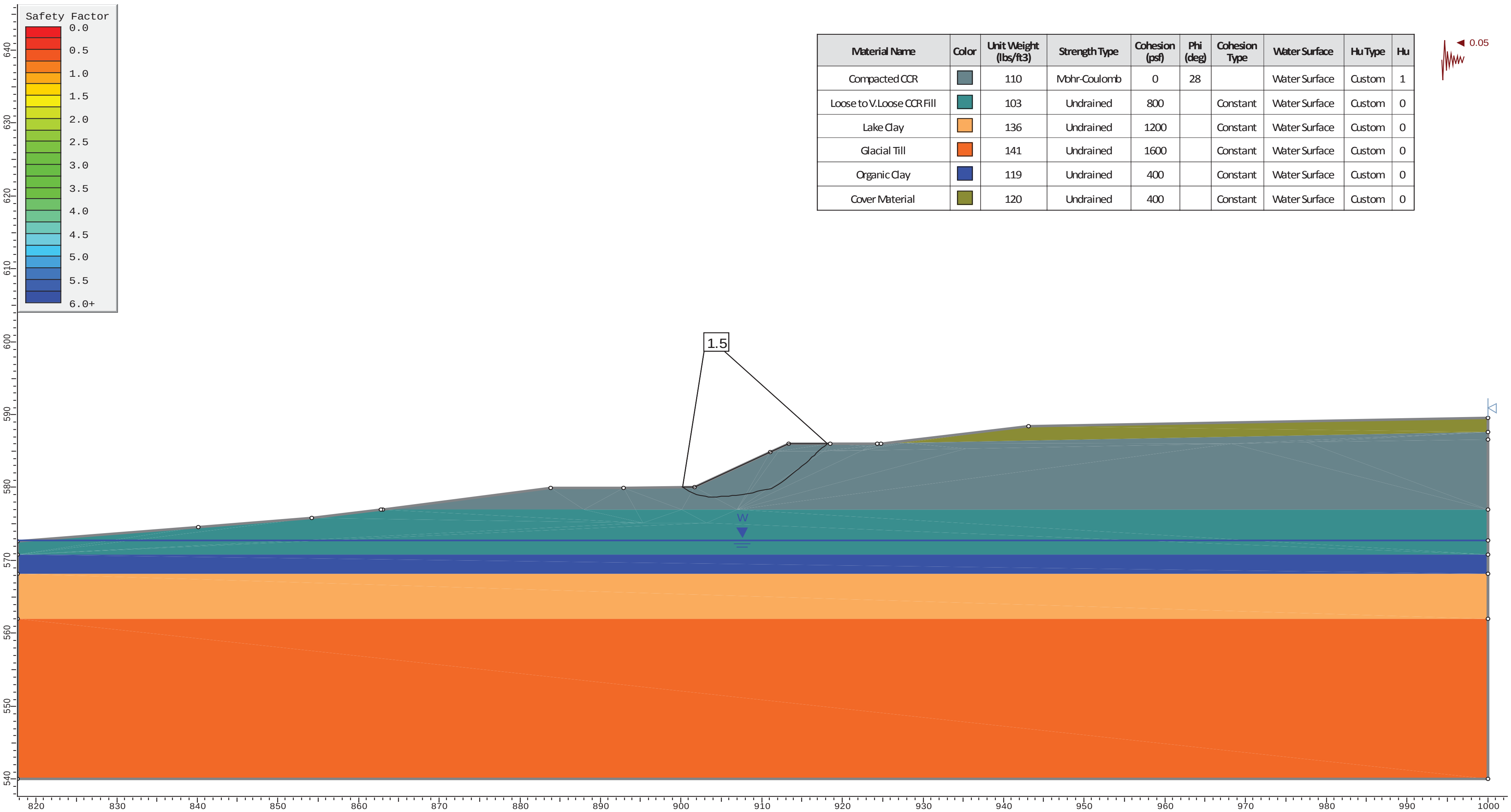
PROJECT **J.R. Whiting Ash Ponds 1 & 2 Closure**

TITLE **Cross-Section A-A' Static, Long-Term Condition-Circular Failure**

CLIENT **Consumers Energy Company**

FIGURE **1B**

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Cohesion Type	Water Surface	Hu Type	Hu
Compacted CCR		110	Mohr-Coulomb	0	28		Water Surface	Custom	1
Loose to V.Loose CCR Fill		103	Undrained	800		Constant	Water Surface	Custom	0
Lake Clay		136	Undrained	1200		Constant	Water Surface	Custom	0
Glacial Till		141	Undrained	1600		Constant	Water Surface	Custom	0
Organic Clay		119	Undrained	400		Constant	Water Surface	Custom	0
Cover Material		120	Undrained	400		Constant	Water Surface	Custom	0

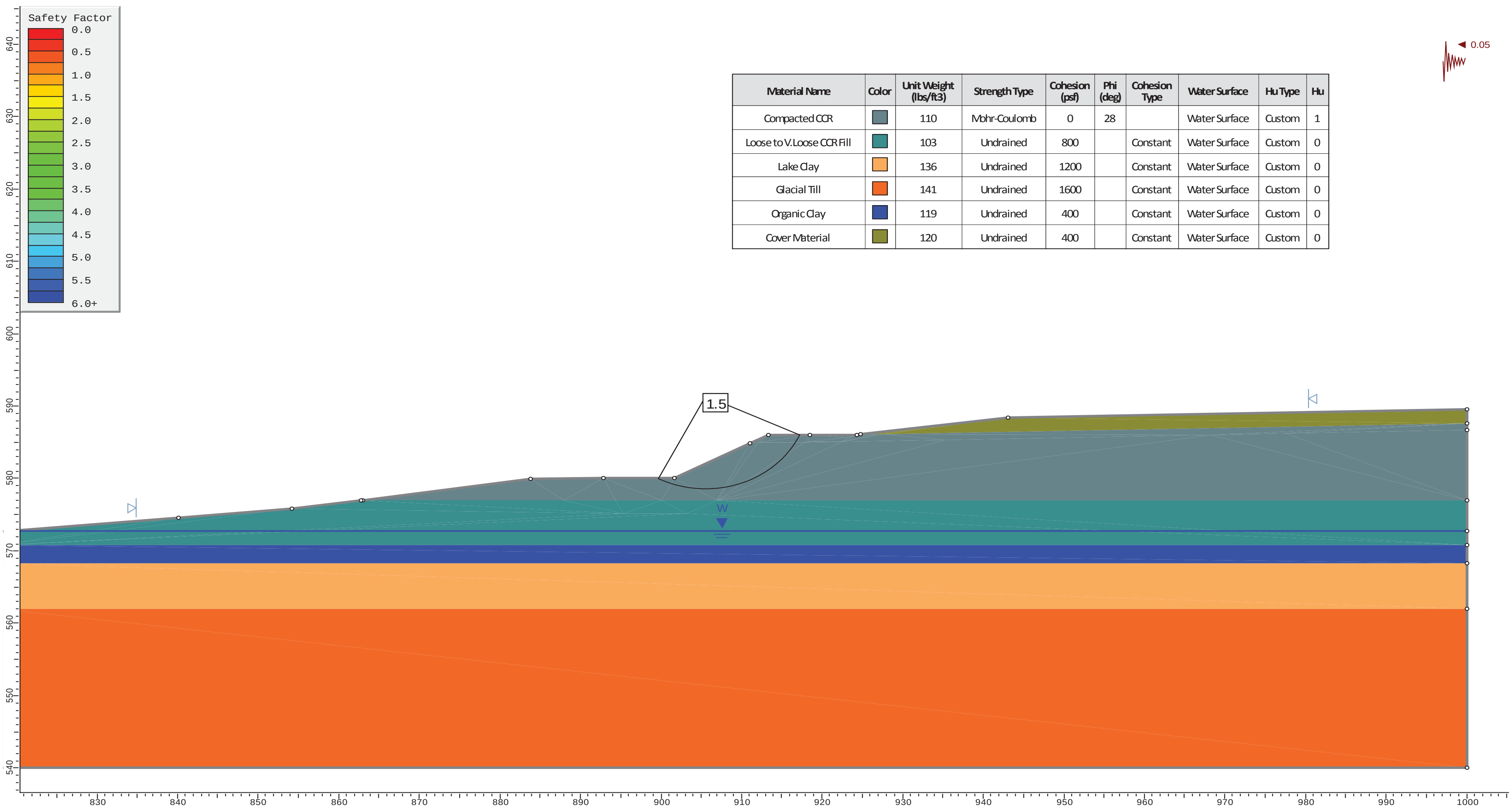


Golder Associates

SCALE	AS SHOWN	PROJECT	J.R. Whiting Ash Ponds 1 & 2 Closure
DATE	Aug 2017	TITLE	Cross-Section A-A' Pseudo-Static, Short-Term Condition-Block Failure
MADE BY	AK		
CAD	DJC		
CHECK	SAM	CLIENT	Consumers Energy Company
REVIEW	TDJ	FIGURE	1C

FILE STABILITY

PROJECT No. 1667572 REV. 0



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Cohesion Type	Water Surface	Hu Type	Hu
Compacted CCR		110	Mohr-Coulomb	0	28		Water Surface	Custom	1
Loose to V.Loose CCR Fill		103	Undrained	800		Constant	Water Surface	Custom	0
Lake Clay		136	Undrained	1200		Constant	Water Surface	Custom	0
Glacial Till		141	Undrained	1600		Constant	Water Surface	Custom	0
Organic Clay		119	Undrained	400		Constant	Water Surface	Custom	0
Cover Material		120	Undrained	400		Constant	Water Surface	Custom	0

Golder Associates

SCALE	AS SHOWN
DATE	Aug 2017
MADE BY	AK
CAD	DJC
CHECK	SAM
REVIEW	TDJ

FILE STABILITY

PROJECT No. 1667572 REV. 0

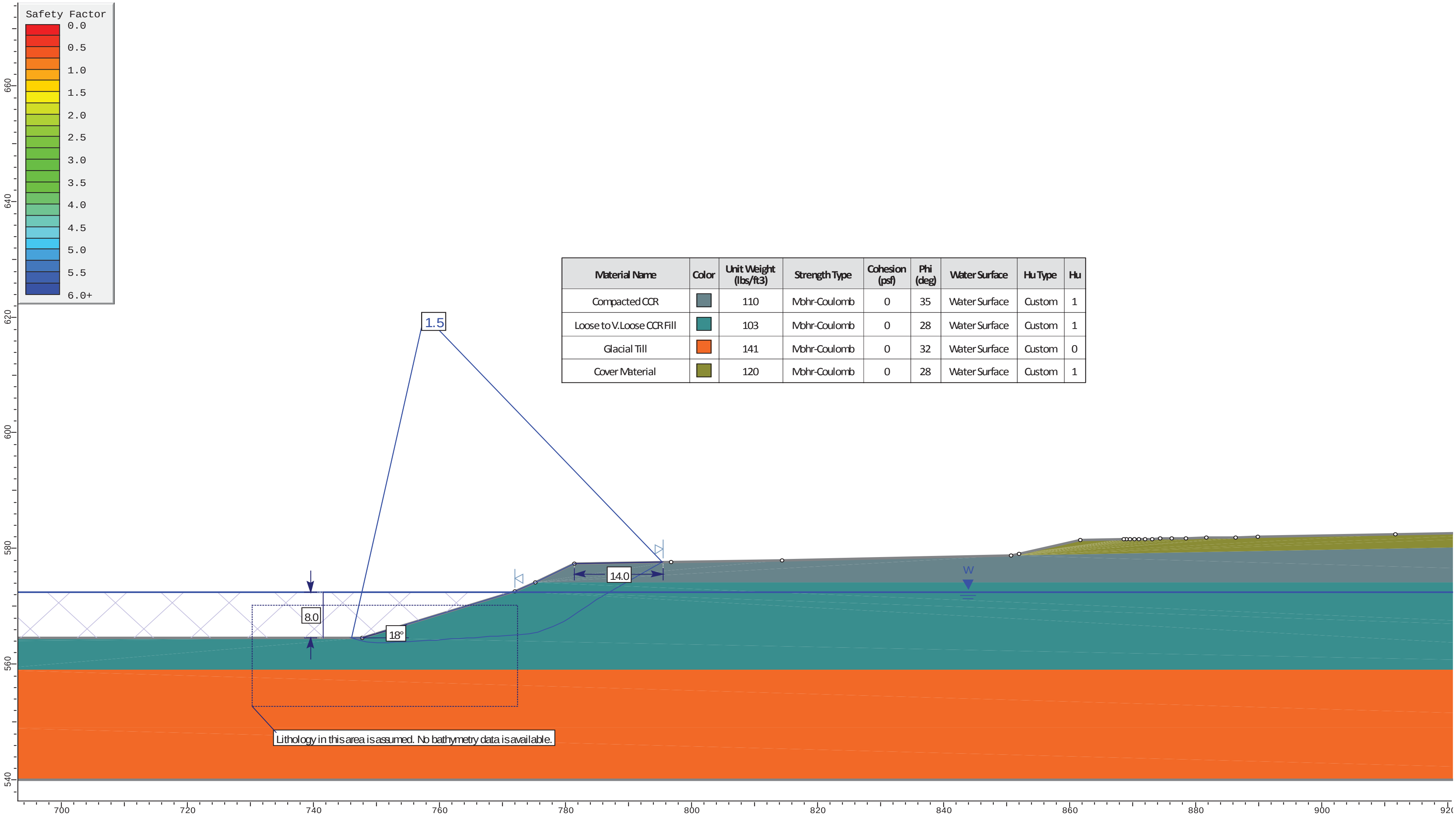
PROJECT **J.R. Whiting Ash Ponds 1 & 2 Closure**

TITLE

Cross-Section A-A'
Pseudo-Static, Short-Term Condition-Circular Failure

CLIENT **Consumers Energy Company**

FIGURE **1D**



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Hu Type	Hu
Compacted CCR		110	Mohr-Coulomb	0	35	Water Surface	Custom	1
Loose to V.Loose CCR Fill		103	Mohr-Coulomb	0	28	Water Surface	Custom	1
Glacial Till		141	Mohr-Coulomb	0	32	Water Surface	Custom	0
Cover Material		120	Mohr-Coulomb	0	28	Water Surface	Custom	1

Golder Associates

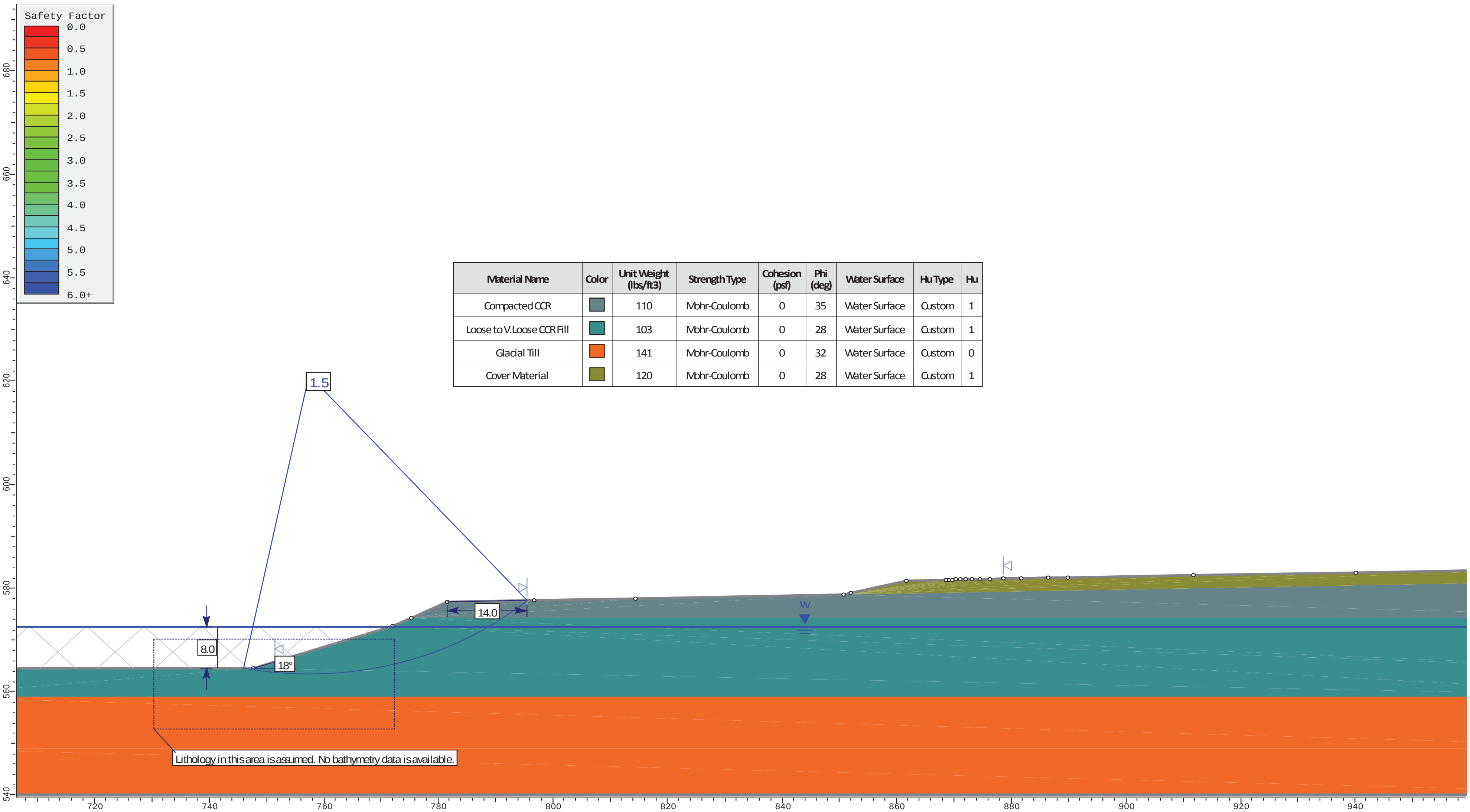
SCALE	AS SHOWN
DATE	Aug 2017
MADE BY	AK
CAD	DJC
CHECK	SAM
REVIEW	TDJ
FILE	STABILITY
PROJECT No.	1667572
REV.	0

PROJECT **J.R. Whiting Ash Ponds 1 & 2 Closure**

TITLE **Cross-Section B-B'**
Static, Long-Term Condition-Block Failure

CLIENT **Consumers Energy Company**

FIGURE **1E**



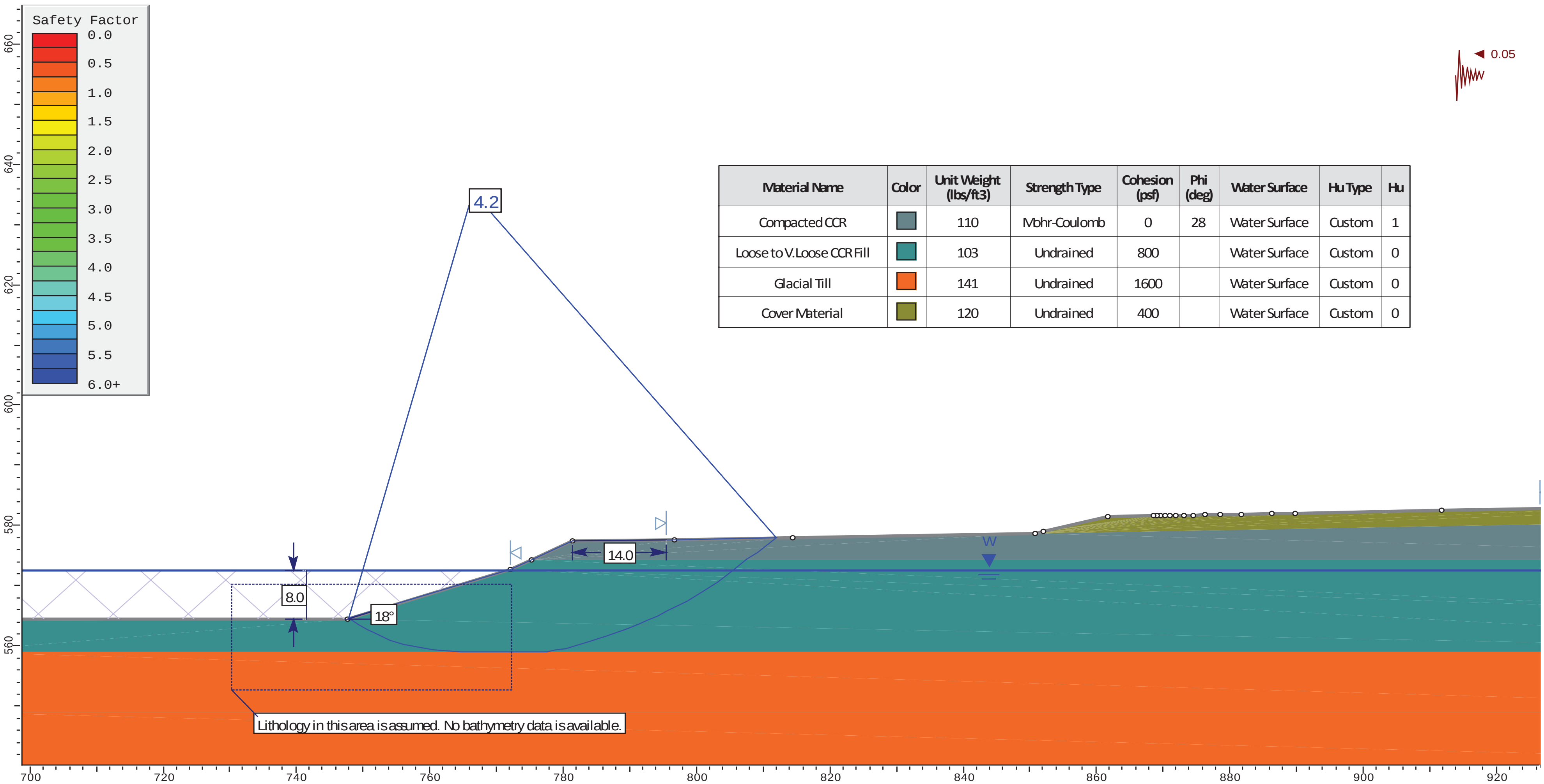
Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Hu Type	Hu
Compacted CCR		110	Mohr-Coulomb	0	35	Water Surface	Custom	1
Loose to V.Loose CCR Fill		103	Mohr-Coulomb	0	28	Water Surface	Custom	1
Glacial Till		141	Mohr-Coulomb	0	32	Water Surface	Custom	0
Cover Material		120	Mohr-Coulomb	0	28	Water Surface	Custom	1

Golder Associates

SCALE	AS SHOWN	PROJECT	J.R. Whiting Ash Ponds 1 & 2 Closure
DATE	Aug 2017	TITLE	Cross-Section B-B' Static, Long-Term Condition-Circular Failure
MADE BY	AK		
CAD	DJC		
CHECK	SAM	CLIENT	Consumers Energy Company
REVIEW	TDJ	FIGURE	1F

FILE STABILITY

PROJECT No. 1667572 REV. 0



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Hu Type	Hu
Compacted CCR		110	Mohr-Coulomb	0	28	Water Surface	Custom	1
Loose to V.Loose CCR Fill		103	Undrained	800		Water Surface	Custom	0
Glacial Till		141	Undrained	1600		Water Surface	Custom	0
Cover Material		120	Undrained	400		Water Surface	Custom	0

Golder Associates

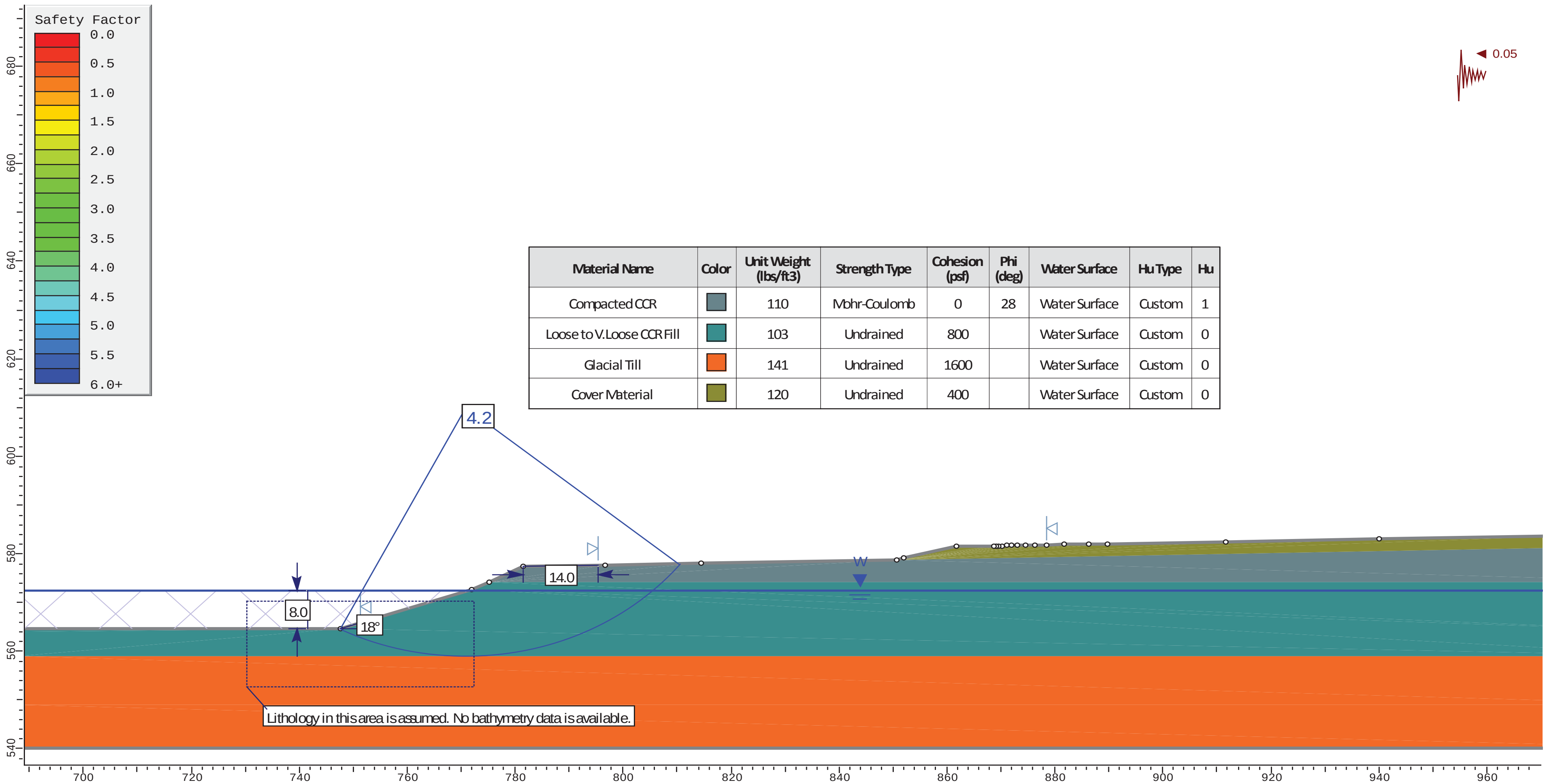
SCALE	AS SHOWN
DATE	Aug 2017
MADE BY	AK
CAD	DJC
CHECK	SAM
REVIEW	TDJ
FILE	STABILITY
PROJECT No.	1667572
REV.	0

PROJECT **J.R. Whiting Ash Ponds 1 & 2 Closure**

TITLE **Cross-Section B-B' Pseudo-Static, Short-Term Condition-Block Failure**

CLIENT **Consumers Energy company**

FIGURE **1G**



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Hu Type	Hu
Compacted CCR		110	Mohr-Coulomb	0	28	Water Surface	Custom	1
Loose to V.Loose CCR Fill		103	Undrained	800		Water Surface	Custom	0
Glacial Till		141	Undrained	1600		Water Surface	Custom	0
Cover Material		120	Undrained	400		Water Surface	Custom	0

Golder Associates

SCALE	AS SHOWN
DATE	Aug 2017
MADE BY	AK
CAD	DJC
CHECK	SAM
REVIEW	TDJ
FILE	STABILITY
PROJECT No.	1667572
REV.	0

PROJECT **J.R. Whiting Ash Ponds 1 & 2 Closure**

TITLE **Cross-Section B-B'**
Pseudo-Static, Short-Term Condition-Circular Failure

CLIENT **Consumers Energy Company**

FIGURE **1H**

FINAL COVER VENEER STABILITY CALCULATIONS

CALCULATIONS

Date:	July-2017	**Made by:**	BAB
Project No.:	1667572	**Checked by:**	SAM
Subject:	STABILITY - SHORT TERM WITH EQUIPMENT FORCES	**Reviewed by:**	TDJ

Project Short Title: JR Whiting Pond 1 & 2 Closure

1.0 OBJECTIVE

To analyze and determine the short-term static stability of the final cover system considering peak low normal load shear strengths with regards to wedge/block failure and sliding due to equipment forces.

30"

2.0 ASSUMPTIONS

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

Erosion Protection Layer 0.5 feet (ft) thick (Topsoil)
Protective Cover Soil, 1.5 ft thick
8-ounce per square yard (oz/sy) Nonwoven Needle-Punched Geotextile
Geomembrane Liner, 40-mil Smooth High Density Polyethylene (HDPE)
Smooth drum rolled liner subgrade soils

2.) Material Properties:
See attached Table 1: Definitions and Assumptions
See Appendix F for material properties and references.

3.) The final cover will be constructed with a 2-percent (2%) slope.

4.) Maximum slope length along the 2.0% slope is 850 ft.

5.) Bulk Density of cover soil borrow material ~120 pounds per cubic foot (pcf) (reference 3).

6.) 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 8. 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. Peak interface friction is appropriate for HDPE geomembranes that will not experience significant settlement.

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

Date:	July-2017	**Made by:**	BAB
Project No.:	1667572	**Checked by:**	SAM
Subject:	STABILITY - SHORT TERM WITH EQUIPMENT FORCES	**Reviewed by:**	TDJ

Project Short Title: JR Whiting Pond 1 & 2 Closure

4.0 CALCULATIONS

Calculate Factor of Safety using Koerner's Method for short term stability with equipment loads;
(See attached "Analysis and design of veneer cover soils" (reference 8) for method)

Uniform Cover Soil Thickness with the Incorporation of Equipment Loads

Total thickness of cover soils =	h =	2	ft	
Cover slope=	β =	1.15	degrees	Slope = 2.0%
Length of slope measured along the geotextile =	L =	850	ft	
Unit wt. of soil (reference 3) =	γ_t =	120	pcf	
Friction angle of soil =	φ =	28	degrees	(see reference 3)
Cohesion of soil =	c =	0	psf	C = 0 lb
Interface friction between geotextile and 40-mil HDPE liner=	δ =	11	***degrees peak low normal load (see reference 3)***	
Adhesion between geotextile and 40-mil HDPE liner=	c_a =	0	psf	Ca = 0.00 lb

Notes:
c_a is conservatively assumed to be zero.
psf = pounds per square foot
lb = pounds

From CAT Handbook		(reference 4)
D6T LGP Track- type tractor	45,400	lb
Track	128	inches long
	36	inches wide

Total thickness of cover soils =	h =	2	ft	b/h= 1.5
Equipment ground pressure (=wt. of equip./(2*w*b)) =	q =	709.38	psf	We = q*w*I = 7491.0 lb/ft
Length of equipment track =	w =	10.67	ft	Ne = We*cosb = 7489.5 lb/ft
Width of equipment track =	b =	3.00	ft	Fe=We*a/g*I= 506.7 lb
Influence factor at geotextile interface =	I =	0.99		*Conservatively overestimated (reference 1)
Acceleration of bulldozer =	a =	0.07	g	*Assume Cat D6T dozer accelerating to 3 miles per hour in approx. 2 sec. (acceleration. = 0.07 g)

Note: g = acceleration due to gravity at Earth's surface (32.2 feet per second squared)

W_A	180,083.6	lb	(calculated per Figure 1)
N_A	180,047.4	lb	(calculated per Figure 1)
W_p	11,960.6	lb	(calculated per Figure 1)

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

a	4,270.44	(calculated per equation (22) on Figure 1)
b	-42,851.27	(calculated per equation (22) on Figure 1)
c	389.01	(calculated per equation (22) on Figure 1)

Factor of Safety (FS):	**10.0**

5.0 CONCLUSIONS

Using low peak normal load shear strengths, the evaluation of this short-term condition of a 2% sloped surface considering equipment forces is found to be acceptable with a Factor of Safety greater than 1.3.

6.0 REFERENCES

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

2.) Koerner, R.M. and Soong, T., "Cover Soil Slope Stability Involving Geosynthetic Interfaces", GRI Report #18, December 1996.

3.) Golder Associates Inc., 2017. J.R. Whiting Ash Ponds 1 and 2 Closure Plan, Appendix F, Table 1: Global Material Properties Used for Calculations.

4.) Caterpillar, Specification Summary, D6N LGP Track-type Tractor.

5.) NAVFAC, "Section IV. Specific-Gravity-of-Solids Determination (ASTM D 854-92)", March 2017

6.) Coduto, Donald P., "Geotechnical Engineering: Principles and Practices", Prentice Hall, New Jersey, 1999.

7.) Qian, Xuede, Koerner, R.M, Gray, D.H, Geotechnical Aspects of Landfill Design and Construction, Prentice Hall, New Jersey, 2002.

8.) Koerner, R.M. and Soong, T., "Analysis and Design of Veneer Cover Soils", Geosynthetics International, 2005, 12, No. 1.

CALCULATIONS

Date:	July-2017	**Made by:**	BAB
Project No.:	1667572	**Checked by:**	SAM
Subject:	FINAL COVER STABILITY - Long Term Seepage Forces	**Reviewed by:**	TDJ
Project Short Title:	JR Whiting Pond 1 & 2 Closure		

1.0 OBJECTIVE

To analyze a "worst case" scenario and determine the long-term stability of the final cover system considering peak low normal load shear strengths with regards to wedge/block failure and sliding due to water seepage forces within the lateral drainage layer.

30"

2.0 ASSUMPTIONS

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

Erosion Protection Layer 0.5 feet (ft) thick (Topsoil)
Protective Cover Soil, 1.5 ft thick
8-ounce per square yard (oz/sy) Nonwoven Needle-Punched Geotextile
Geomembrane Liner, 40-mil Smooth High Density Polyethylene (HDPE)
Smooth drum rolled liner subgrade soils

2.) Material Properties:
See attached Table 1: Definitions and Assumptions
See Appendix F for material properties and references.

3.) The final cover will be constructed with a 2-percent (2%) slope.

4.) Maximum slope length along the 2.0% slope is 850 ft.

5.) Bulk Density of cover soil borrow material ~120 pounds per cubic foot (pcf) (reference 3).

3.0 METHODS

1.) **Use the methods outlined in Xuede Qian, R.M. Koerner, and D.H. Gray's *Geotechnical Aspects of Landfill Design and Construction*, see Reference 7 for Equations and Parameter definitions.**

2.) Allow a minimum interim factor of safety of 1.3, when saturated conditions are considered and peak interface friction angles are used. Peak interface friction is appropriate for HDPE geomembranes that will not experience significant settlement.

3.) Interface friction angles were taken as averages of representative lab data for similar materials. (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.)

Date:	July-2017	**Made by:**	BAB
Project No.:	1667572	**Checked by:**	SAM
Subject:	FINAL COVER STABILITY - Long Term Seepage Forces	**Reviewed by:**	TDJ
Project Short Title:	JR Whiting Pond 1 & 2 Closure		

4.0 CALCULATIONS

Calculate Factor of Safety for long term stability with
wet conditions (i.e. water on the liner); (See Reference 7)

Uniform Cover Soil Thickness
Seepage Forces Horizontal-to-Slope Buildup

1) Conservatively assume 4 inches of head over the HDPE liner (depth equal to the diameter of the on-cap drain pipes).
2) Assume cover soil will have a uniform average unit weight (see reference 3)

Total thickness of cover soils =	h =	2	ft	
Cover slope=	β =	1.15	degrees	Slope= 2.0%
Length of slope measured along the geotextile =	L =	850	ft	
Vertical height of slope measured from toe =	*H =*	*17*	ft	
Depth of water over 40-mil HDPE liner =	h_w =	0.3333	ft	
Parallel submergence ratio =	*PSR =*	*0.167*		PSR = depth of water on FML / thickness of cover soil
Composite moist unit wt. of cover soil (reference 3) =	γ_{moist} =	120	pcf	
Composite saturated unit wt. of cover soil =	γ_{sat} =	125	pcf	(see reference 6)
Unit wt. of water =	γ_w =	62.4	pcf	
Friction angle of cover soil =	φ =	28	degrees	(see reference 3)
Interface friction. between Geotextile and 40-mil HDPE liner=	δ =	11	***degrees peak low normal load (see reference 3)***	

W_A	191,707.1	pounds (lb)
Un	17,503.7	lb
Uh	3.5	lb
N_A	174,164.9	lb
W_p	12,459.0	lb
Uv	172.7	lb

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

a	3,846.8
b	-40,421.1
c	361.3

Factor of Safety (FS):	**10.5**

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CALCULATIONS

Date:	July-2017	**Made by:**	BAB
Project No.:	1667572	**Checked by:**	SAM
Subject:	FINAL COVER STABILITY - Long Term Seepage Forces	**Reviewed by:**	TDJ
Project Short Title:	JR Whiting Pond 1 & 2 Closure		

4.0 CALCULATIONS (Continued)

Uniform Cover Soil Thickness

Seepage Forces Parallel-to-Slope Buildup

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

1) Conservatively assume 4 inches of head over the HDPE liner (depth equal to the diameter of the on-cap drain pipes).
2) Assume cover soil will have a uniform average unit weight (see reference 3)

Total thickness of cover soils =	h =	2	ft	
Cover slope=	β =	1.15	degrees	Slope= 2.0%
Length of slope measured along the geotextile =	L =	850	ft	
Vertical height of slope measured from toe =	*H* =	*17*	ft	
Depth of water over 40-mil HDPE liner =	h_w =	0.3333	ft	
Parallel submergence ratio =	*PSR* =	*0.167*		PSR = depth of water on FML / thickness of cover soil
Composite moist unit wt. of cover soil (reference 3) =	γ_{moist} =	120	pcf	
Composite saturated unit wt. of cover soil =	γ_{sat} =	125	pcf	(see reference 6)
Unit wt. of water =	γ_w =	62.4	pcf	
Friction angle of cover soil =	φ =	28	degrees	(see reference 3)
Interface friction. between Geotextile and 40-mil HDPE liner=	δ =	11	***degrees peak low normal load (see reference 3)***	

W_A	193,442.2	lb
Uh	3.5	lb
W_p	11,974.4	lb
UAN	17,503.8	lb
UPN	172.7	lb

a	3,881.6
b	-40,501.1
c	364.9

Factor of Safety (FS):	**10.4**

5.0 CONCLUSIONS

Considering low peak normal load shear strengths and saturated conditions, the long-term "worst case" stability evaluations for the lateral drainage layer option are considered acceptable with factors of safety greater than 1.3.

6.0 REFERENCES

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

2.) Koerner, R.M. and Soong, T., "Cover Soil Slope Stability Involving Geosynthetic Interfaces", GRI Report #18, December 1996.

3.) Golder Associates Inc., 2017. J.R. Whiting Ash Ponds 1 and 2 Closure Plan, Appendix F, Table 1: Global Material Properties Used for Calculations.

4.) Caterpillar, Specification Summary, D6N LGP Track-type Tractor.

5.) NAVFAC, "Section IV. Specific-Gravity-of-Solids Determination (ASTM D 854-92)", March 2017

6.) Coduto, Donald P., "Geotechnical Engineering: Principles and Practices", Prentice Hall, New Jersey, 1999.

7.) Qian, Xuede, Koerner, R.M, Gray, D.H, Geotechnical Aspects of Landfill Design and Construction, Prentice Hall, New Jersey, 2002.

8.) Koerner, R.M. and Soong, T., "Analysis and Design of Veneer Cover Soils", Geosynthetics International, 2005, 12, No. 1.

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CALCULATIONS

Date:	July-2017	**Made by:**	BAB
Project No.:	1667572	**Checked by:**	SAM
Subject:	FINAL COVER STABILITY - Long Term Seismic	**Reviewed by:**	TDJ
Project Short Title:	JR Whiting Pond 1 & 2 Closure		

1.0 OBJECTIVE

To analyze a "worst case" scenario and determine the long-term stability of the final cover system considering peak low normal load shear strengths with regards to seismic forces.

30"

2.0 ASSUMPTIONS

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

Erosion Protection Layer 0.5 feet (ft) thick (Topsoil)
Protective Cover Soil, 1.5 ft thick
8-ounce per square yard (oz/sy) Nonwoven Needle-Punched Geotextile
Geomembrane Liner, 40-mil Smooth High Density Polyethylene (HDPE)
Smooth drum rolled liner subgrade soils

2.) Material Properties:
See attached Table 1: Definitions and Assumptions
See Appendix F for material properties and references.

3.) The final cover will be constructed with a 2-percent (2%) slope.

4.) Maximum slope length along the 2.0% slope is 850 ft.

5.) Bulk Density of cover soil borrow material ~120 pounds per cubic foot (pcf) (reference 3).

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 1.0, when seismic conditions, and peak interface friction angles are considered (per the US Environmental Protection Agency (EPA) Coal Combustion Residual (CCR) regulations (40 CFR257.73). Peak interface friction is appropriate for HDPE geomembranes that will not experience significant settlement.

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

Date:	July-2017	**Made by:**	BAB
Project No.:	1667572	**Checked by:**	SAM
		Reviewed by:	TDJ
Subject:	FINAL COVER STABILITY - Long Term Seismic		
Project Short Title:	JR Whiting Pond 1 & 2 Closure		

4.0 CALCULATIONS

Calculate Factor of Safety using Koerner's Method for long term stability (See attached GRI Report #18).

Uniform Cover Soil Thickness with Seismic Forces

1) Assume cover soil will have a uniform average unit weight (see reference 3)

Total thickness of cover soils =	h =	2	ft			
Cover slope=	β =	1.15	degrees	Slope= 2.0%		
Length of slope measured along the geotextile =	L =	850	ft			
Vertical height of slope measured from toe =	*H* =	*17*	ft			
Composite moist unit wt. of cover soil (reference 3) =	γ_{moist} =	120	pcf			
Unit wt. of water =	γ_w =	62.4	pcf			
Friction angle of cover soil =	φ =	28	degrees	(see reference 3)		
Interface friction. between Geotextile and 40-mil HDPE liner=	δ =	11	***degrees peak low normal load (see reference 3)***			
Seismic coefficient =	Cs =	0.05	g			
Cohesion of soil =	c =	0	psf		C =	0
Adhesion between geotextile and 40-mil HDPE liner=	ca =	0	psf		Ca =	0.00

Notes:

c_a is conservatively assumed to be zero.

psf = pounds per square foot

g = acceleration due to gravity at Earth's surface (32.2 feet per second squared)

tan β =	0.02
tan φ =	0.53
tan δ =	0.19
sin β =	0.02
cos β =	1.00

W_A	180,083.6	pounds (lb)
N_A	180,047.4	lb
W_p	11,960.6	lb

With Seismic

Cs * W_A (lb)	9,004.18
Cs * W_P (lb)	598.03

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

a	13,213.1
b	-41,476.5
c	373.4

Factor of Safety (FS):	**3.1**

5.0 CONCLUSIONS

Considering the use of seismic loading and low peak normal load shear strengths, the long-term "worst case" stability evaluation is considered acceptable with a factor of safety greater than 1.0.

Date:	July-2017	**Made by:**	BAB
Project No.:	1667572	**Checked by:**	SAM
Subject:	FINAL COVER STABILITY - Long Term Seismic	**Reviewed by:**	TDJ
Project Short Title:	JR Whiting Pond 1 & 2 Closure		

6.0 REFERENCES

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

2.) Koerner, R.M. and Soong, T., "Cover Soil Slope Stability Involving Geosynthetic Interfaces", GRI Report #18, December 1996.

3.) Golder Associates Inc., 2017. J.R. Whiting Ash Ponds 1 and 2 Closure Plan, Appendix F, Table 1: Global Material Properties Used for Calculations.

4.) Caterpillar, Specification Summary, D6N LGP Track-type Tractor.

5.) NAVFAC, "Section IV. Specific-Gravity-of-Solids Determination (ASTM D 854-92)", March 2017

6.) Coduto, Donald P., "Geotechnical Engineering: Principles and Practices", Prentice Hall, New Jersey, 1999.

7.) Qian, Xuede, Koerner, R.M, Gray, D.H, Geotechnical Aspects of Landfill Design and Construction, Prentice Hall, New Jersey, 2002.

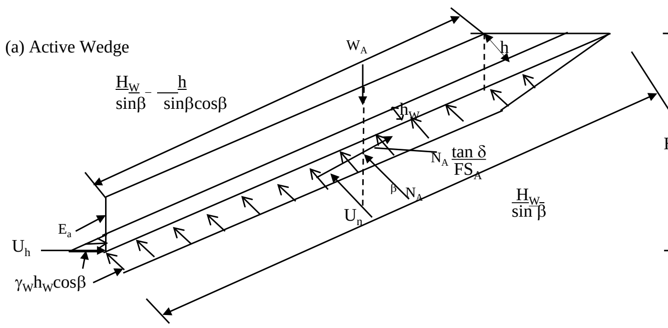
8.) Koerner, R.M. and Soong, T., "Analysis and Design of Veneer Cover Soils", Geosynthetics International, 2005, 12, No. 1.

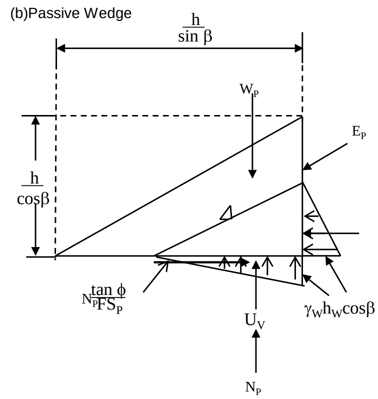
TABLE 1 - Definitions and Assumptions

Symbol	Definitions and assumptions
h =	*Thickness of the soil layer -* The protective cover will be 1.5 feet thick and the erosion protection layer will be 0.5 feet thick, for a total of 2.0 feet of cover soil.
β =	*Soil slope angle beneath the geomembrane -The* slope exhibits an angle beneath the geomembrane of 2.0%.
L =	*Length of slope measured along the geomembrane -* The maximum slope length anticipated is 850 feet.
γ_t =	*Unit weight of final cover soil* - The cover is assumed to be composed of 0.5 foot sandy clay erosion protection layer, and 1.5 feet of silty clay loam protective cover.
ϕ =	*Minimum friction angle of final cover soil*
c =	*Cohesion of the cover soil -* Cohesion is assumed to be zero because the cover soils are granular.
δ =	*Critical Interface friction angle within the final cover system -* The critical interface occur between the 40-mil Smooth HDPE Geomembrane Liner and the NW-NP Geotextile.
ca =	*Adhesion between cover soil of the active wedge and the geomembrane -* Adhesion is assumed to be zero because the cover soils are granular.
γ_{sat} =	*Saturated unit weight of final cover soils -* The unit weights of the saturated protective cover soil and erosion protection soil.
Cs =	*Average seismic coefficient -* The average horizontal component seismic coefficient for the the State of Michigan.
I =	*Influence factor at the geotextile interface -* The influence factor at the geomembrane interface and width of the dozer track divided by the thickness of the soil layer of interest. (Reference 2)

FIGURE 1

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





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

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

$$N_A = W_A \cos\beta$$

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

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

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

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

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

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

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

$$\begin{aligned} a &= [(W_A + W_e)\sin\beta + F_e]\cos\beta \\ b &= -\{[(N_e + N_A)\tan\delta + C_a]\cos\beta \\ &\quad + [(W_A + W_e)\sin\beta + F_e]\sin\beta\tan\phi \\ &\quad + (C + W_P\tan\phi)\} \\ c &= [(N_e + N_A)\tan\delta + C_a]\sin\beta\tan\phi \end{aligned} \quad (22)$$

$$\left.\begin{aligned} a &= W_A\sin\beta\cos\beta - U_h\cos^2\beta + U_h \\ b &= -W_A\sin^2\beta\tan\phi + U_h\sin\beta\cos\beta\tan\phi \\ &\quad - N_A\cos\beta\tan\delta - (W_P - U_V)\tan\phi \\ c &= N_A\sin\beta\tan\delta\tan\phi \end{aligned}\right\} \quad (31)$$

AND:

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

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