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Coal Combustion Residuals Unit
2023 Periodic Factor of Safety Assessment

Richmond Power & Light
Whitewater Valley Station
Surface Impoundment
Wayne County, Indiana

GAI Project Number: C151119.25

April 2023

RICHMOND POWER & LIGHT

Prepared by: GAI Consultants, Inc.
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385 East Waterfront Drive
Homestead, Pennsylvania 15120-5005

Prepared for: Richmond Power & Light
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P.O. Box 908
Richmond, Indiana 47374

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Certification/Statement of Professional Opinion

This 2023 5-year Periodic Factor of Safety Assessment (Assessment) for the Whitewater Valley Power Station (Station) was prepared by GAI Consultants, Inc. (GAI). The Assessment may contain findings and determinations that are based on certain information that, other than for information GAI originally prepared, GAI has relied on, but not independently verified. This Certification/Statement of Professional Opinion is therefore limited to the information available to GAI at the time the Assessment was written. On the basis of and subject to the foregoing, it is my professional opinion as a Professional Engineer licensed in the State of Indiana that the Assessment 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 Assessment was prepared consistent with the requirements of § 257.73(e)(1) 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 Subpart D), and meeting the provisions of the "Extension of Compliance Deadlines for Certain Inactive Surface Impoundments: Response to Partial Vacatur," effective October 4, 2016.

The use of the words "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.

GAI Consultants, Inc.

Charles Straley

Charles F. Straley, P.E.
Senior Engineering Manager

Date Apr 13, 2023

CHARLES F. STRALEY
REGISTERED
PE10708581
4-13-23
STATE OF INDIANA
PROFESSIONAL ENGINEER

Acronyms

Assessment	Coal Combustion Residuals 2023 Periodic Factor of Safety Assessment
CCR	Coal Combustion Residuals
CCR Rule	"Standards for the Disposal of Coal Combustion Residuals in Landfills and Surface Impoundments" 40 CFR 257 Subpart D (2015)
CFR	Code of Federal Regulations
EPA	United States Environmental Protection Agency
GAI	GAI Consultants, Inc.
Impoundment	Surface Impoundment
IN	Indiana
RP&L	Richmond Power & Light
Station	Whitewater Valley Power Station
USGS	United States Geological Survey

1.0 Introduction

The Whitewater Valley Power Station (Station) is owned by Richmond Power & Light (RP&L) and is located in Richmond, Indiana (IN). The station includes a Surface Impoundment (Impoundment), which is used for the long term storage of coal combustion residuals (CCR).

The Impoundment is located on RP&L property at the Whitewater Valley Power Station in Wayne County, Indiana (coordinates 39° 48' 12.9" North and 84° 53' 54.8" West). The Impoundment is located in the northwestern corner of the property.

The Impoundment is currently inactive and is regulated as an existing CCR surface impoundment under the United States Environmental Protection Agency's (EPA's) "Standards for the Disposal of Coal Combustion Residuals in Landfills and Surface Impoundments" [40 CFR 257 Subpart D] published in the Federal Register on April 17, 2015 with an effective date of October 19, 2015 (CCR Rule), and meeting the provisions of the "Extension of Compliance Deadlines for Certain Inactive Surface Impoundments: Response to Partial Vacatur," effective October 4, 2016.

2.0 Purpose

The 2023 Periodic Factor of Safety Assessment was performed according to § 257.73(e)(1) of the CCR Rule [40 CFR § 257.73(e)(1)]. In accordance with 40 CFR § 257.73(f), this assessment must be completed every five years.

3.0 Factor of Safety Assessment Requirements

In accordance with § 257.73(e)(1), a CCR surface impoundment owner or operator "must conduct initial and periodic safety factor assessments for each CCR unit and document whether the calculated factors of safety for each CCR unit achieve the minimum safety factors for the critical cross sections of the embankment."

§ 257.73(e)(1) requires that safety assessments be conducted for the following conditions of the impoundment and that the safety factor assessments be supported by appropriate engineering calculations:

- The calculated static factor of safety under the long-term, maximum storage pool loading condition must equal or exceed 1.50;
- The calculated static factor of safety under the maximum surcharge pool loading condition must equal or exceed 1.40;
- The calculated seismic factor of safety must equal or exceed 1.00; and
- For dikes constructed of soils that are susceptible to liquefaction, the calculated liquefaction factor of safety must equal or exceed 1.20.

This Assessment will document the factors of safety for the Impoundment as required by the CCR Rule.

4.0 Factor of Safety Assessment

The material underlying the Impoundment, comprising the embankment foundation, is discussed in the History of Construction (GAI Consultants, 2018a). The current configuration of the Impoundment is that it is filled with CCR material and generally graded to drain and not impound water. Thus, pooling of water within the Impoundment will be temporary. The critical sections for the stability analyses are located along the west embankment of the Impoundment due to their height and slope steepness. Under the maximum pool from the 1,000-year design storm event (GAI Consultants, 2018b), the critical sections are not adjacent to ponded water, and do not overtop.

The initial 2018 assessment analyzed static and seismic conditions using the simplified Bishop method which is an equilibrium method that satisfies moment equilibrium but ignores interslice shear forces. The stability analyses have been revised for the 2023 periodic 5-year assessment using the Morgenstern and Price method. The Morgenstern and Price Method satisfies both force and moment equilibrium by considering both shear and normal interslice forces. The critical section with the lowest factors of safety against slope failure was located at the Northwest Corner of the Impoundment. The minimum factors of safety against slope failure calculated for each condition are summarized in Table 1. Calculations are included in Appendix A.

Table 1
Calculated Factors of Safety

Factor of Safety Condition	Minimum Target Factor of Safety	Calculated Minimum Factor of Safety
Long-term, maximum storage pool loading	1.50	1.91
Maximum surcharge pool loading	1.40	1.91
Seismic factor of safety	1.00	1.59
Liquefaction factor of safety	1.20	≥1.20

Strength parameters used in the initial 2018 assessment were developed using blow count correlations, laboratory test data, and engineering judgment. The strength parameters were revised upon a review of all available information including the initial assessment and subsequent subsurface explorations performed in December 2021 and January 2023. Further explanation on the revisions made to the strength parameters is outlined in the Calculation Brief included in Appendix A.

4.1 Long-Term Maximum Storage Pool Loading Condition

Pursuant to the CCR Rule, the maximum storage pool loading is "the maximum water level that can be maintained that will result in full development of a steady-state seepage condition." Additionally, "the maximum storage pool loading needs to consider a pool elevation in the CCR unit that is equivalent to the lowest elevation of the invert of the spillway, i.e., the lowest overflow point of the perimeter of the embankment."

Since no long term pool is developed, the calculated static factors of safety for the long-term, maximum storage pool loading condition is based on the existing topographic conditions with a phreatic surface set to the measured groundwater level.

The calculated factor of safety is 1.91 for the embankment is greater than the minimum of 1.50 required by the CCR Rule.

4.2 Maximum Surcharge Pool Loading Conditions

Since pooling within the Impoundment will be temporary, and the topographic configuration of the Impoundment precludes pooling near the critical section, the calculated static factors of safety for the maximum surcharge pool loading condition is equivalent to that under long-term maximum storage pool loading condition. The calculated static factor of safety is greater than the minimum of 1.40 required by the CCR Rule.

4.3 Seismic Factor of Safety

The seismic factor of safety is calculated with a seismic loading event with a 2 percent probability of exceedance in 50 years, based on the United States Geological Survey (USGS) seismic hazard maps. A peak ground acceleration of 0.075g (acceleration of gravity) was used in the initial 2018 analysis. Using the more recent ASCE-7-22 code, GAI determined the PGA_m as 0.11g for the 2023 periodic assessment. The calculated factor of safety is 1.53 is greater than the minimum of 1.00 required by the CCR Rule.

4.4 Liquefaction Factor of Safety

Based on the soils of the Geotechnical Report (GAI Consultants, August 2016), the Impoundment embankments are generally composed of sandy lean clay. In order for liquefaction to occur, the embankment material would need to be saturated. The long term groundwater level is located below the base of the embankment; therefore, the embankment material should not be subject to liquefaction.

GAI, however, performed a liquefaction analysis to determine if the soils in the embankment are susceptible to liquefaction in 2016. Liquefaction analysis using the "Simplified Procedure" (Idriss and Boulanger 2008) was performed for the site. To determine the potential for liquefaction using this approach, SPT blow counts were used in conjunction with a design earthquake event. The initial liquefaction analysis performed in 2016 used a design earthquake with a magnitude of 6.1. This earthquake magnitude was obtained from 2008 USGS Interactive Deaggregation Tool (Reference 5). Using the current USGS Deaggregation tool (Reference 7), GAI determined the design earthquake as having a magnitude of 5.9. However, GAI concluded that the calculations did not need to be revised since the recent design earthquake magnitude is less than the magnitude used in the initial liquefaction analysis. Reference 2 was used during the initial 2016 liquefaction analysis to determine the depth of bedrock for Site Class determination. The bedrock in the vicinity of embankment varied between 14 and 68 ft, and an average depth of 60 ft was assumed for the site. The average blow count over the depth of 100 ft, assuming bedrock at 60 ft were calculated, and equations provided in ASCE 7-2010 were used to determine the site class as "D" using N-values from all 12 borings. During the 2021 and 2023 subsurface explorations, the depth to bedrock, when encountered, varied from approximately 15 to 40 feet below the ground surface. Since bedrock was not encountered in all the borings, the same average depth of 60 ft was assumed for the site, which resulted in the same Site Class (D) designation as before. During the initial 2016 analyses, the maximum acceleration for the analysis was determined from Reference 6 to be 0.11g based on Site Class D. Using the more recent ASCE 7-22 code (Reference 8), GAI determined the modified PGA value at 0.1g for the 2023 periodic assessment. However, GAI concluded that 2016 calculations did not need to be revised since the recent PGA is approximately equal to the design PGA used in the initial 2016 analyses.

GAI performed additional liquefaction analyses for the critical borings using the data from 2021 and 2023 investigations. The calculated liquefaction safety factors for these borings also met or exceeded the minimum of 1.20 stated in the CCR Rule. The liquefaction calculations are included in Appendix A.

5.0 Conclusion

Based on the analyses conducted for the conditions outlined in the CCR Rule, the Whitewater Valley Station Surface Impoundment meets or exceeds the required factors of safety.

6.0 References

1. GAI Consultants. *Geotechnical Summary Report*. August 2016.
2. GAI Consultants. *Groundwater Characterization Report.* September 2016.
3. GAI Consultants. 2018a. *History of Construction*. April 2018.
4. GAI Consultants. 2018b. *Inflow Design Flood Control System Plan*. April 2018.
5. United States Geological Survey (USGS) 2008 Interactive Deaggregation Tool (http://geohazards.usgs.gov/deaggint/2008/)
6. United States Geological Survey (USGS) Seismic Design Maps and Tools derived from Design Code Reference Document 2010 ASCE 7 (w/March 2013 errata) (http://earthquake.usgs.gov/designmaps/us/application.php)
7. United States Geological Survey (USGS) Interactive Deaggregation Tool (http://earthquake.usgs.gov/hazards/interactive/)
8. American Society of Civil Engineering (ASCE) ASCE 7 Hazard Tool (Code Reference Document 2022 ASCE 7 (http://asce7hazardtool.online)

APPENDIX A
Calculations

OBJECTIVE:

Perform the 2023 5-year periodic assessment and to evaluate deep-seated rotational failure surfaces under static and seismic conditions for the existing dike of the Surface Impoundment at the Richmond Power and Light (RP-L) Whitewater Valley Station located in Richmond, Wayne County, Indiana. The 2023 periodic Structural Stability Assessment (Assessment) was performed according to § 257.73(d) of the CCR Rule [40 CFR § 257.73(d)]. In accordance with 40 CFR § 257.73(f), this assessment must be completed every five years.

METHODOLOGY:

Stability will be evaluated under both static and seismic conditions using two-dimensional limit equilibrium analysis with the design software Slope/W by GeoStudio 2022, version 11.4.2.250. The target factors of safety for static and seismic conditions are outlined in 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. (CCR Rule), §257.73(e)(1) (Reference 1).

REFERENCES:

1. United States Environmental Protection Agency, 2015. *40 CFR Parts 257 and 261 Hazardous and Solid Waste Management System; Disposal of Coal Combustion Residuals from Electric Utilities; Final Rule*. April 17, 2015.
2. U.S. Geological Society. Earthquake Hazards Program. Lower 48 Maps and Data. Web. 2 Apr. 2018
3. U.S. Department of Transportation Federal Administration, Publication No. FHWA NHI-06-088, Soils and Foundations Reference Manual Volume I, December 2006.
4. "Geotechnical Summary Report" Whitewater Valley Station, GAI Consultants, August 2016

BACKGROUND:

RP-L is proposing the closure of the Surface Impoundment located at the Whitewater Valley Station in Wayne County, Indiana. The closure will be achieved by leaving the majority of the CCR material in place.

The analysis will analyze the stability of the existing conditions of the west dike. A static and seismic analysis will be performed to determine if the existing conditions of the west dike achieve the minimum target factors of safety Values. Target factors of safety values are outlined in §257.73(e)(1) of Reference 1. The static analysis will be the calculated static factor of safety under the long-term, maximum storage pool loading condition. The seismic analysis will be the calculated seismic factor of safety. The calculated static factor of safety under the maximum surcharge pool loading condition was not included in this calculation since the impoundment does not have water impounding capabilities.

ANALYSIS:

Long-term static and seismic stability analyses were performed along the west dike of the Surface Impoundment to evaluate the stability of the existing conditions of the dike. Three (3) cross-sections were selected to represent the critical and typical case slope conditions. Location of these sections are shown as Attachment 1, Figure 1. A plan drawing showing all borings drilled from 2015 to 2023 is also included in Attachment 1. Additionally, detailed information regarding the cross section geometry of each section is included in the slope stability software output presented as Attachment 3.

The material properties selected for the in-place CCR material were obtained from laboratory testing performed on in-situ samples obtained from the Surface Impoundment in September 2015. The material properties used to represent the in-place dike soils were also obtained from sampling completed during September 2015. Phi angles were based on relationships between plasticity index and phi. Values for cohesion were determined using the information presented in Reference 4. The analysis was completed using drained parameters for CCR material and the dike soils.

Soil strength parameters used in the initial assessment were based on the data from 2015 geotechnical investigation. Results from the SPT borings performed in December 2021 and January 2023 were compared to the initial 2015 SPT borings to confirm the use of the strength parameters outlined in the 2018 initial assessment, and to refine them if needed. Strength parameters for the Sandy, Lean Clay material at the western embankment were revised and the cohesion value was updated to 150 pounds per square foot (psf) based on the reviewed information. It was also noted that previously total strength parameters were conservatively used for long term analyses for the CCR material. However, upon review of the available field and laboratory data to date, it was noted that Consolidated Undrained (CU) Triaxial tests were performed on the undisturbed CCR material in 2015 which estimated both total and drained strength parameters. Therefore, soil strength parameters for the CCR material have now been revised to represent its strength properties more accurately; by using effective (drained) strength parameters for long-term static conditions, and total strength parameters for seismic loading. The soil parameters used in the slope stability analyses are summarized in Attachment 2 of this Appendix. The piezometric surface used in the initial 2018 analyses was confirmed for use in the 2023 periodic assessment through subsequent potentiometric surface readings taken from September 2020 to September 2022.

Based on the data obtained from subsurface explorations performed in 2015, 2021, and 2023, CCR material was encountered below soil fill in the borings drilled in the vicinity of the impoundment dike. This indicates that the impoundment may have been increased in size in the past by raising the impoundment dike by placing soil fill, at least partially, on top of previously placed CCR material.

<u>Seismic Conditions</u> – The existing facility is located in Wayne County, which is an area of low to moderate seismic activity and risk. A peak ground acceleration of 0.075g (acceleration of gravity) was used in the initial 2018 analysis. Using the more recent ASCE-7-22 code, GAI determined the PGA_m as 0.11g for the 2023 periodic assessment.

SUMMARY:

Stability analyses performed for the existing dike are summarized in Attachment 3. The initial 2018 assessment analyzed static and seismic conditions using the simplified Bishop method which is an equilibrium method that satisfies moment equilibrium but ignores interslice shear forces. The stability analyses have been revised for the 2023 periodic 5-year assessment using the Morgenstern and Price method. The Morgenstern and Price Method satisfies both force and moment equilibrium by considering both shear and normal interslice forces. A large number of deep-seated failure surfaces were generated and the most critical failure surface for each analysis section was isolated to determine the minimum factor of safety. Seismic analyses were performed for each static stability analysis and these included updated seismic coefficient equal to 0.11g.

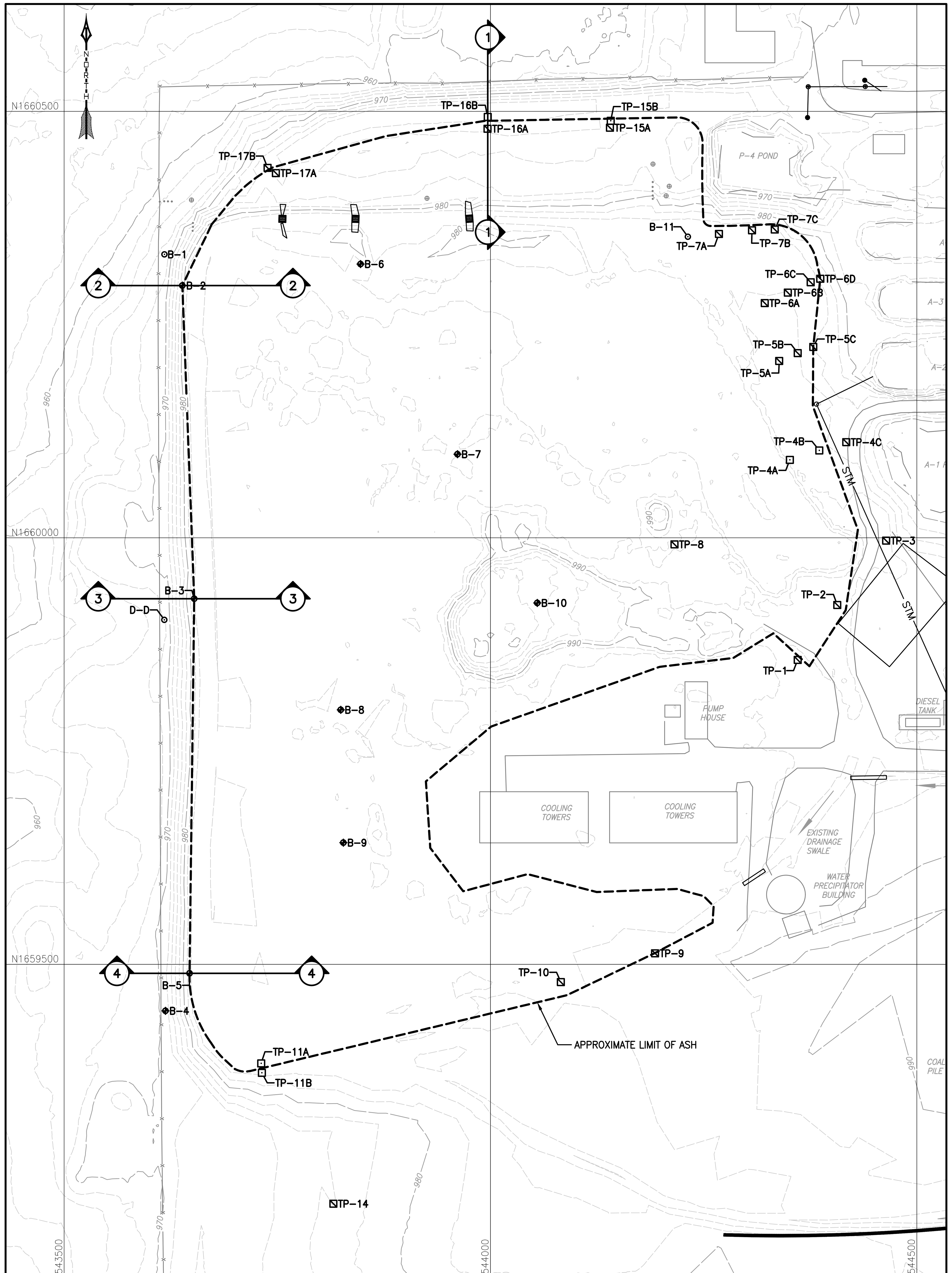
The following table summarizes the results of static and seismic slope stability analyses considering drained conditions for CCR material and dike soils.

Section	Condition Analyzed	Minimum Target Factor of Safety	Calculated Factor of Safety
Section 2-2 NW Corner	Static	1.50	1.91
	Seismic	1.00	1.59
Section 3-3 Mid Alignment	Static	1.50	2.23
	Seismic	1.00	1.78
Section 4-4 SW Corner	Static	1.50	2.20
	Seismic	1.00	1.93

As shown in the summary table above and in the SLOPE/W software output presented in Attachment 3, the resulting minimum factors of safety calculated for static and seismic conditions for the existing geometry of the dike are equal to or greater than the target values of 1.50 and 1.00, respectively.

ATTACHMENT 1

SLOPE STABILITY CROSS-SECTIONS



PLAN VIEW

SCALE: 1" = 80'

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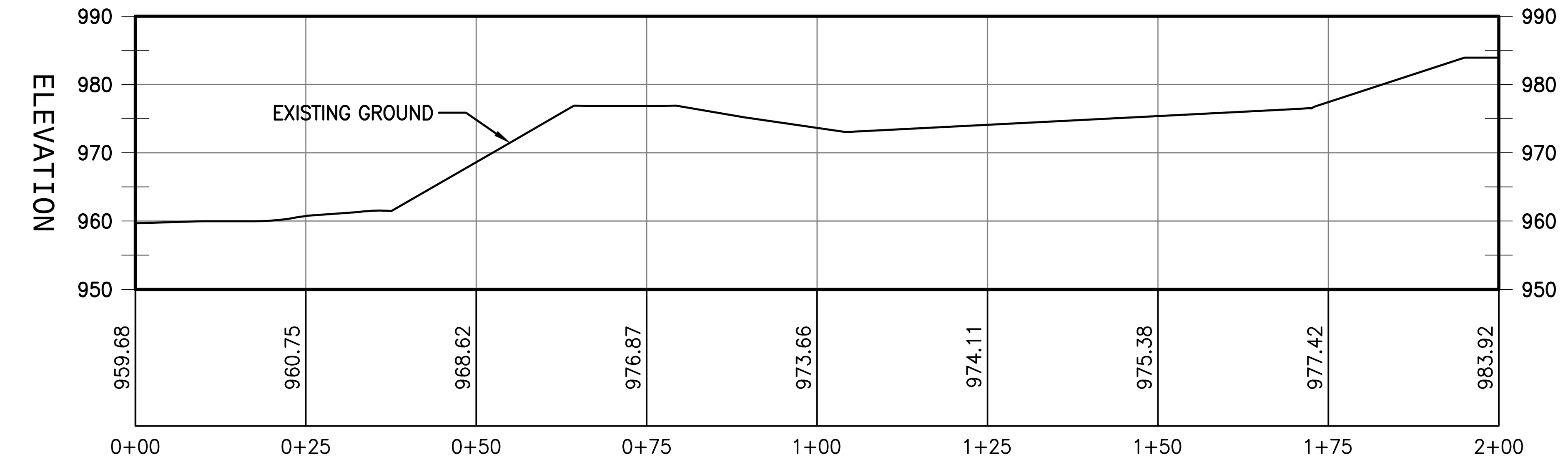

SECTION 1

SCALE: 1" = 20'

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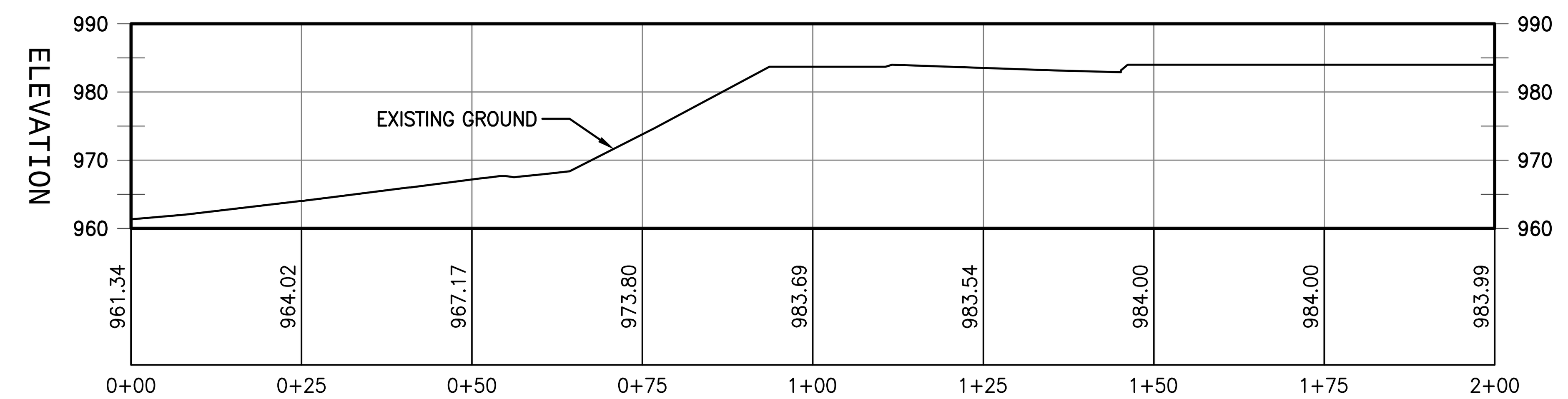

SECTION 2

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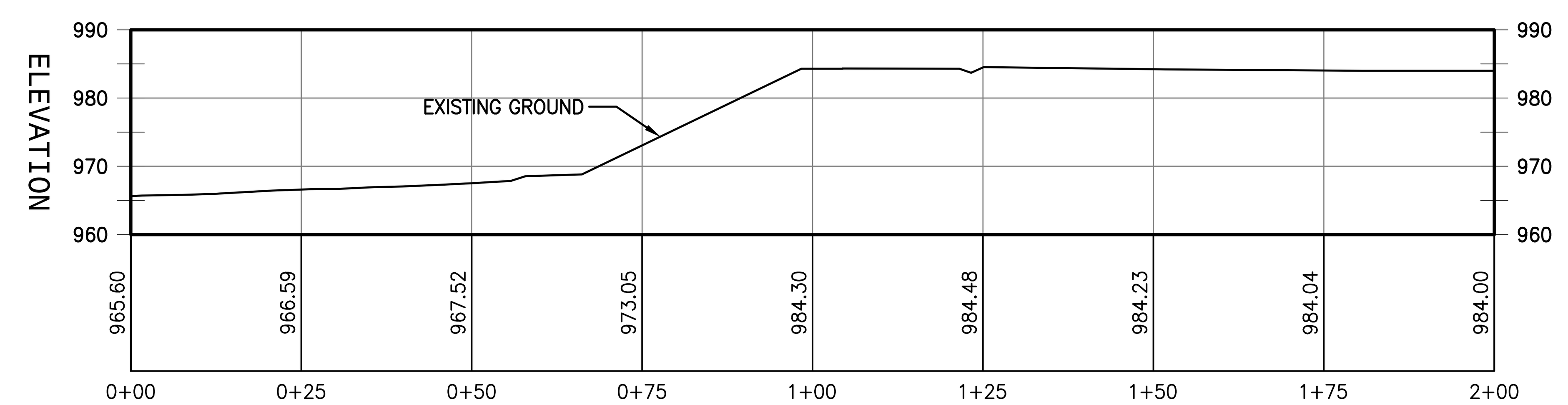

SECTION 3

SCALE: 1" = 20'

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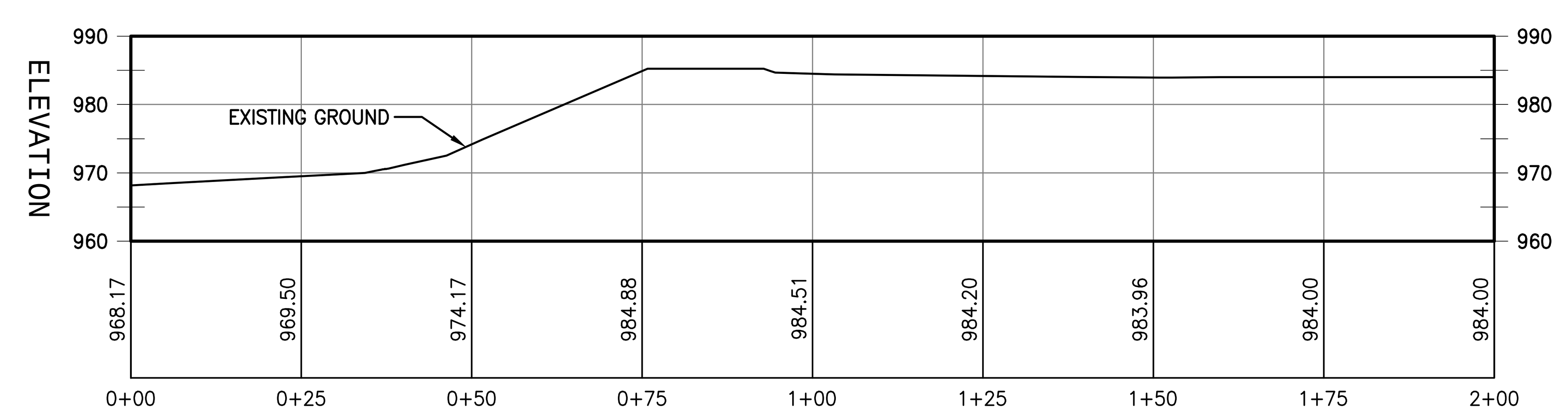

SECTION 4

SCALE: 1" = 20'

20 0 20 40

REFERENCE:
2012 INDIANA STATEWIDE IMAGERY AND LIDAR PROGRAM
1-FOOT PIXEL RESOLUTION ORTHOIMAGERY; AND
2-FOOT CONTOUR INTERVALS LINES DEVELOPED FROM 1.5 METER NPS BARE EARTH LIDAR.

SURVEY PROVIDED BY BEALS-MOORE & ASSOCIATES,INC. DATED JANUARY 17TH 2016

NOTE:

1. TP-12 AND TP-13 ARE LOCATED IN THE SOLAR FIELD SOUTH OF THE COAL PILE.
2. SECTION # CORRESPONDS TO BORING # AND THERE IS NO SECTION 1, 2, OR 4.

LEGEND:

- APPROXIMATE LIMIT OF ASH
- TP-2 SURVEYED TEST PIT LOCATION
- TP-11 APPROXIMATE TEST PIT LOCATION
- B-3 SURVEYED BORING LOCATION
- B-1 APPROXIMATE BORING LOCATION

DRAWING TITLE
FIGURE 1 - SLOPE CROSS SECTIONS AND PLAN VIEW

PROJECT
CCR RULE COMPLIANCE-RP&L
WHITEWATER VALLEY STATION
WAYNE COUNTY
RICHMOND, INDIANA 47374

CLIENT
RICHMOND POWER AND LIGHT
RICHMOND, INDIANA

gai consultants

ISSUING OFFICE: Murrysville | 4200 Triangle Lane, Export, PA 15632-1358

This drawing was produced with computer aided drafting technology and is supported by electronic drawing files. Do not revise this drawing via manual drafting methods.

NO.:	DATE:	DWN:	CHK:	APV:	DESCRIPTION:

REVISION RECORD

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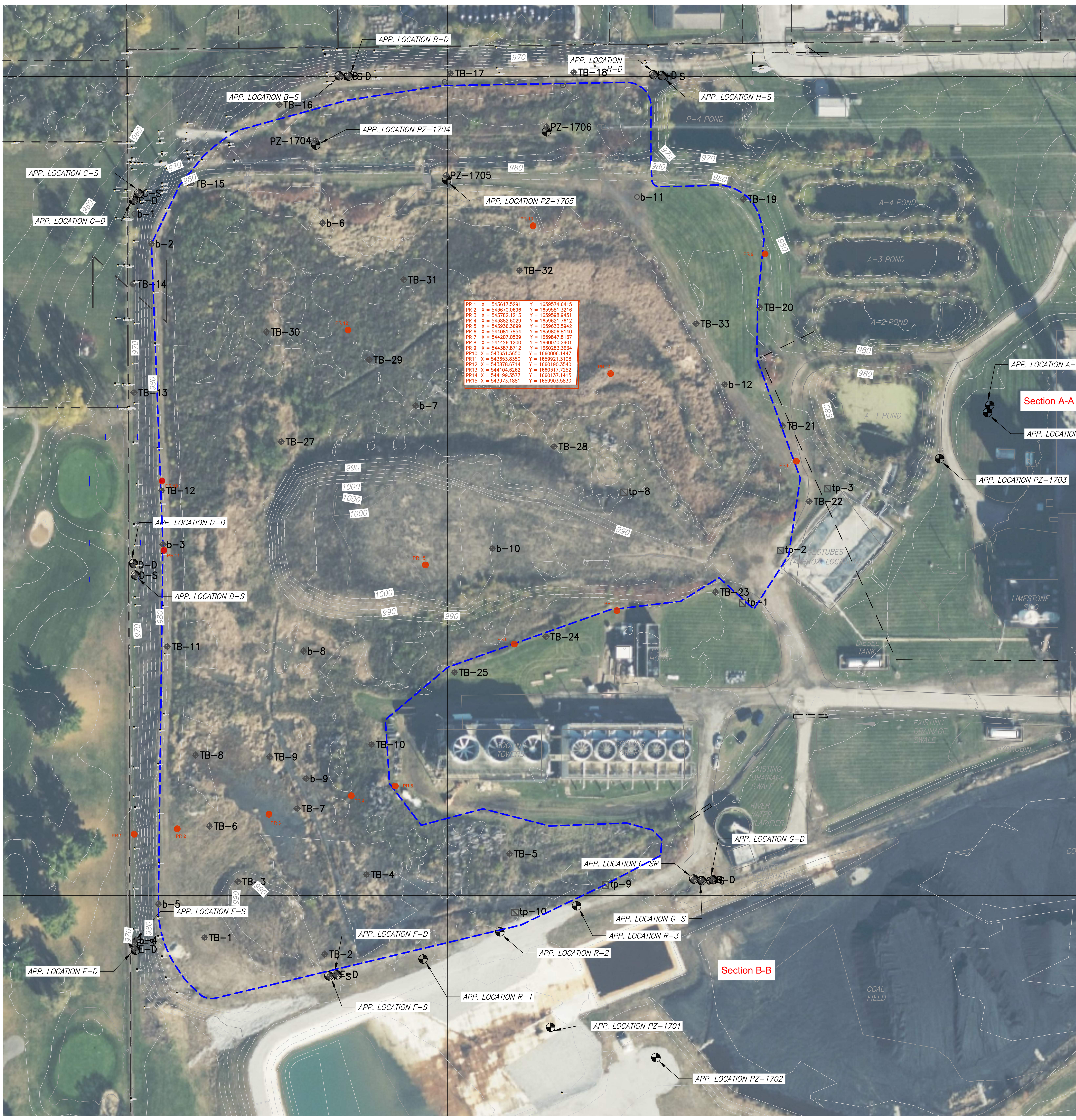
DRAWN BY:	CHECKED BY:	APPROVED BY:
SLODOJD		
DWG TYPE:	SCALE:	ISSUE DATE:
CIVIL	AS SHOWN	04/02/2018

GAI DRAWING NUMBER:
D1-001



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PR 4	X = 543882.6029	Y = 1659621.7612
PR 5	X = 543936.3699	Y = 1659633.5942
PR 6	X = 544081.7854	Y = 1659806.8140
PR 7	X = 544207.0539	Y = 1659847.8137
PR 8	X = 544426.1200	Y = 1660030.2901
PR 9	X = 544387.8712	Y = 1660283.3634
PR10	X = 543651.5650	Y = 1660006.1447
PR11	X = 543653.8350	Y = 1659921.3108
PR12	X = 543878.6714	Y = 1660190.3540
PR13	X = 544104.6262	Y = 1660317.7252
PR14	X = 544199.3577	Y = 1660137.1415
PR15	X = 543973.1881	Y = 1659903.5830

ATTACHMENT 2

SOIL PARAMETERS

By: RRJ 4/12/2023
Checked: AB 4/12/2023

Summary Stability Analysis Design Parameters

RP&L Whitewater Valley Station

Surface Impoundment Closure

Material	Total Unit Weight (pcf)	Drained Shear Strength	
		Cohesion (psf)	Friction Angle (deg)
Sandy Lean Clay	130.0	150.0	28.0
Silty Sand	125.0	0.0	28.0
CCR Material	90.0	0.0/500[1]	32.0/19.0[1]

Note 1: Denotes total strength parameters

ATTACHMENT 3

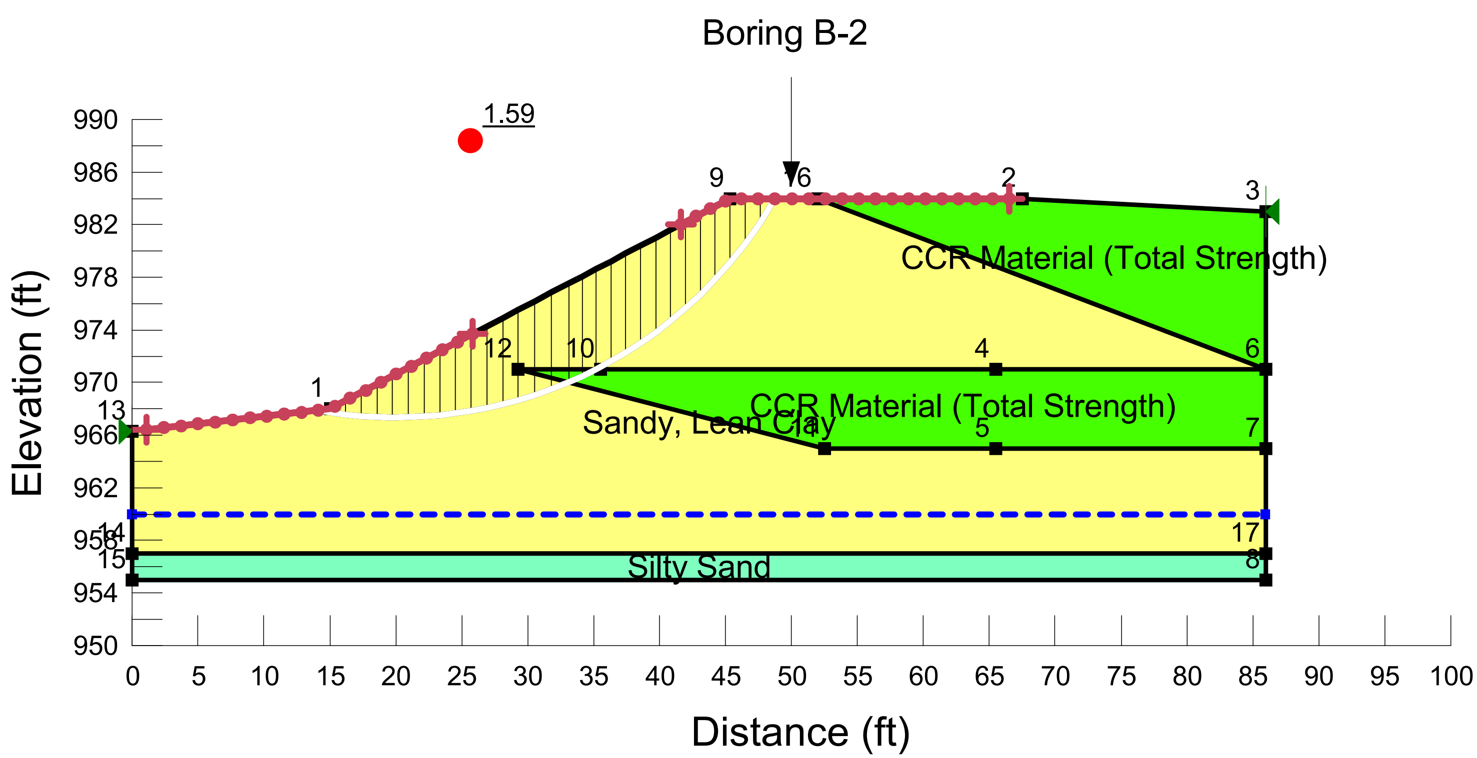
SLOPE STABILITY ANALYSIS RESULTS

By: RRJ 4/10/2023
Checked: AB 4/12/23

Proj No.: C151119.25

RP-L Surface Impoundment Existing Conditions - CCR Rule Factor of Safety
Section 2-2 - Northwest Dike
Drained - Horz Seismic Coef.: 0.11

Color	Name	Slope Stability Material Model	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Piezometric Surface
	CCR Material (Total Strength)	Mohr-Coulomb	90	500	19	1
	Sandy, Lean Clay	Mohr-Coulomb	130	150	28	1
	Silty Sand	Mohr-Coulomb	125	0	28	1

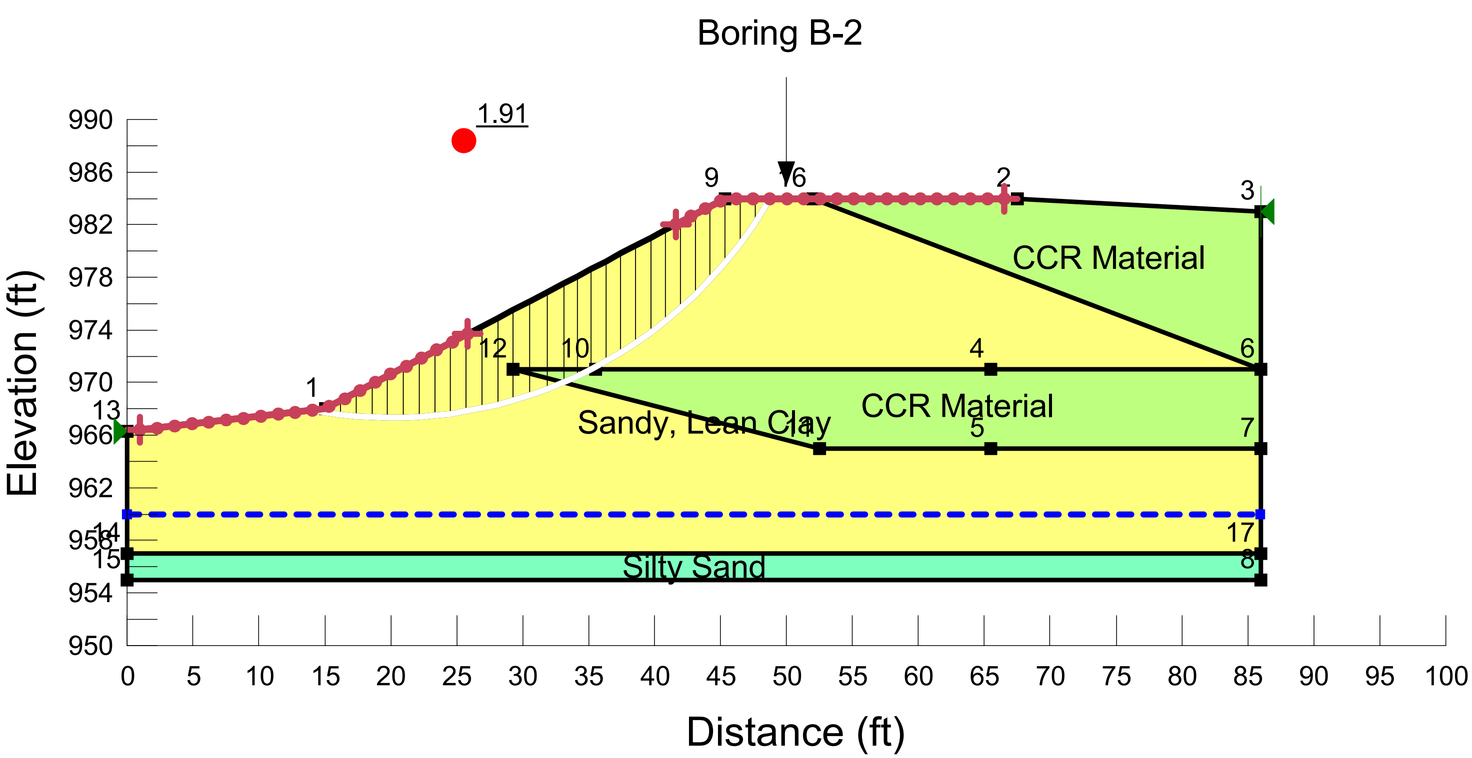


By: RRJ 4/10/2023
Checked: AB 4/12/23

Proj No.: C151119.25

RP-L Surface Impoundment Existing Conditions - CCR Rule Factor of Safety
Section 2-2 - Northwest Dike
Drained - Horz Seismic Coef.: 0

Color	Name	Slope Stability Material Model	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Piezometric Surface
	CCR Material	Mohr-Coulomb	90	0	32	1
	Sandy, Lean Clay	Mohr-Coulomb	130	150	28	1
	Silty Sand	Mohr-Coulomb	125	0	28	1

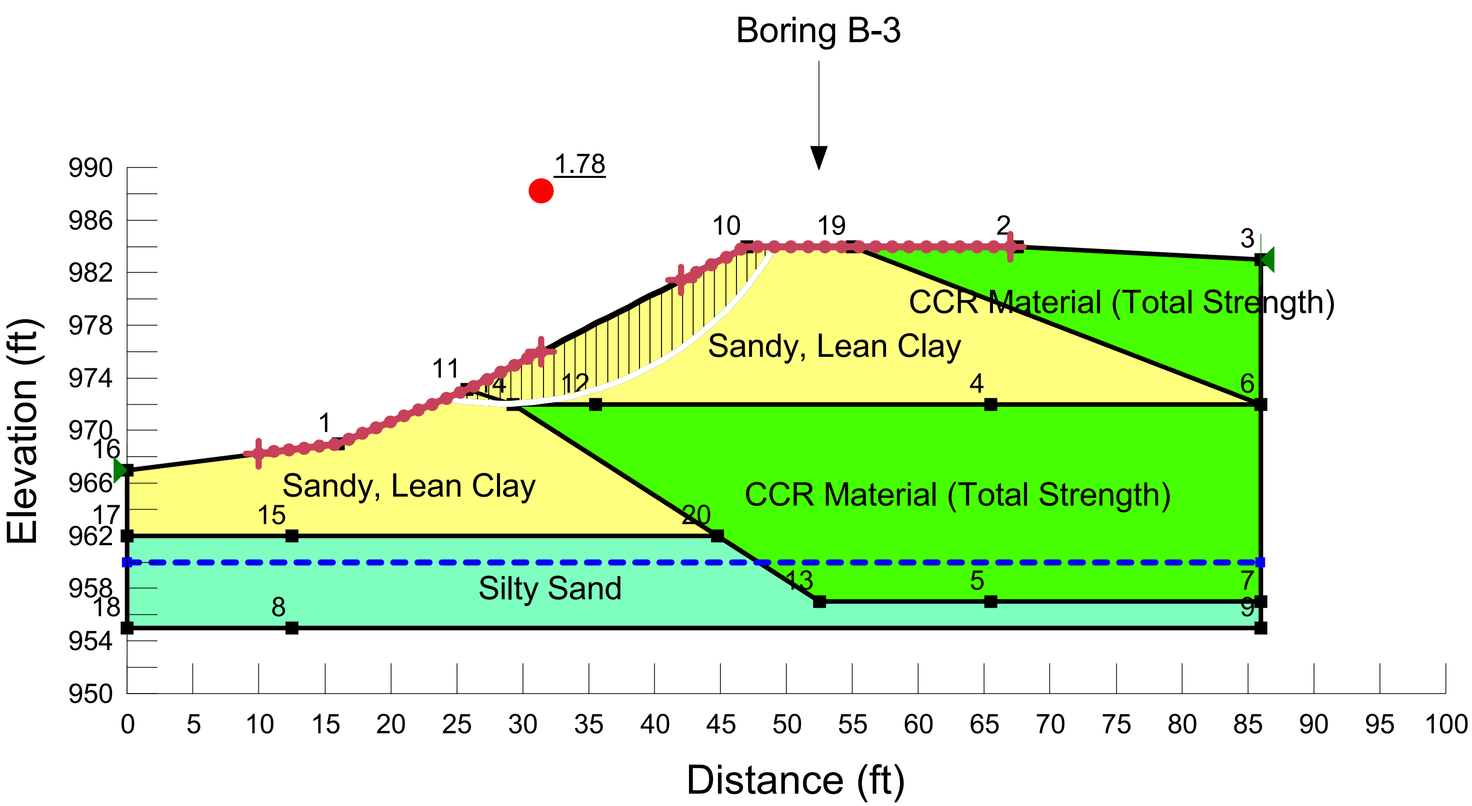


By: RRJ 4/10/2023
Checked: AB 4/12/23

Proj No.: C151119.25

RP-L Surface Impoundment Existing Conditions - CCR Rule Factor of Safety
Section 3-3 - Center West Dike
Drained - Horz Seismic Coef.: 0.11

Color	Name	Slope Stability Material Model	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Piezometric Surface
	CCR Material (Total Strength)	Mohr-Coulomb	90	500	19	1
	Sandy, Lean Clay	Mohr-Coulomb	130	150	28	1
	Silty Sand	Mohr-Coulomb	125	0	28	1

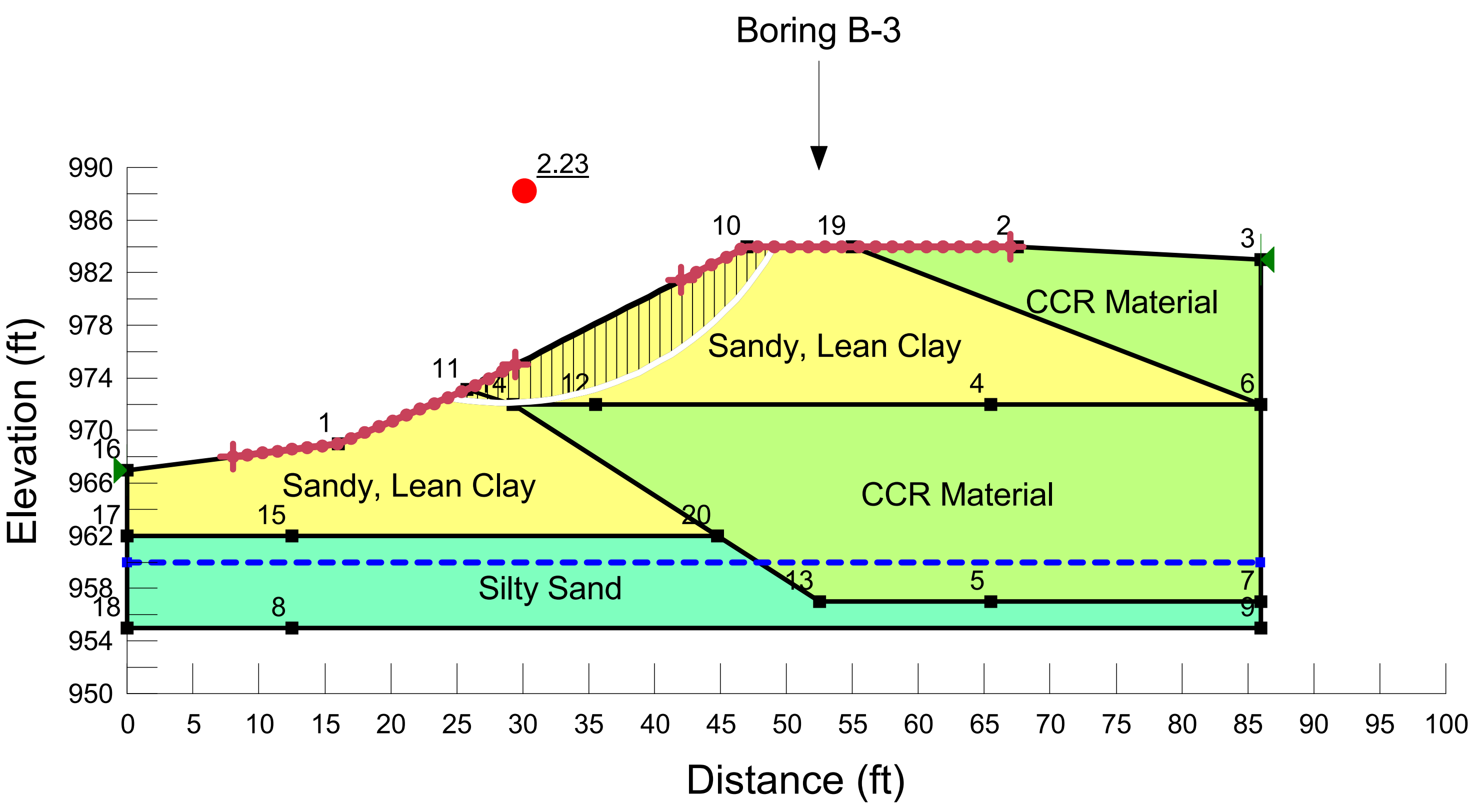


By: RRJ 4/10/2023
Checked: AB 4/12/23

Proj No.: C151119.25

RP-L Surface Impoundment Existing Conditions - CCR Rule Factor of Safety
Section 3-3 - Center West Dike
Drained - Horz Seismic Coef.: 0

Color	Name	Slope Stability Material Model	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Piezometric Surface
	CCR Material	Mohr-Coulomb	90	0	32	1
	Sandy, Lean Clay	Mohr-Coulomb	130	150	28	1
	Silty Sand	Mohr-Coulomb	125	0	28	1

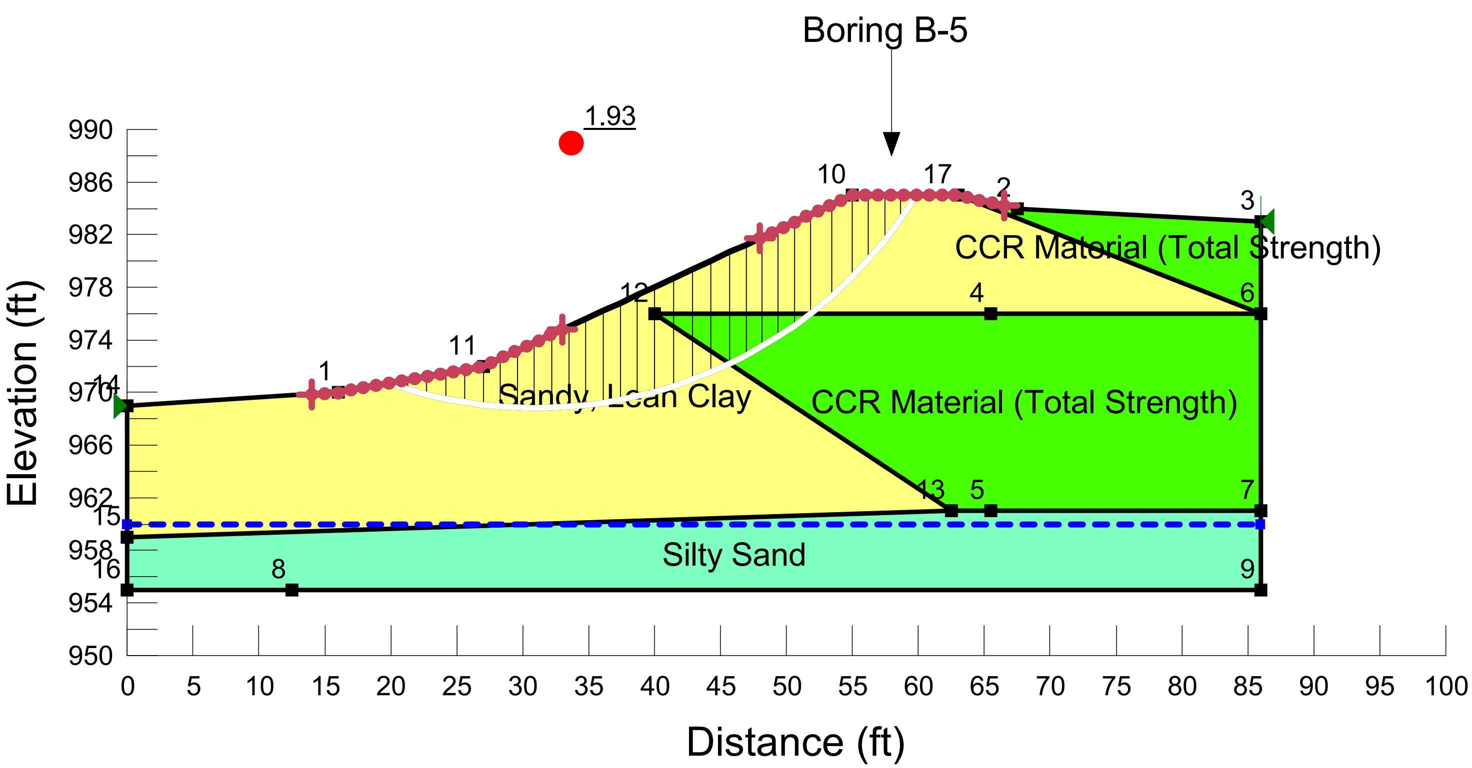


Proj No.: C151119.25

By: RRJ 4/10/2023
Checked: AB 4/12/23

RP-L Surface Impoundment Existing Conditions - CCR Rule Factor of Safety
Section 4-4 - Southwest Dike
Drained - Horz Seismic Coef.: 0.11

Color	Name	Slope Stability Material Model	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Piezometric Surface
	CCR Material (Total Strength)	Mohr-Coulomb	90	500	19	1
	Sandy, Lean Clay	Mohr-Coulomb	130	150	28	1
	Silty Sand	Mohr-Coulomb	125	0	28	1

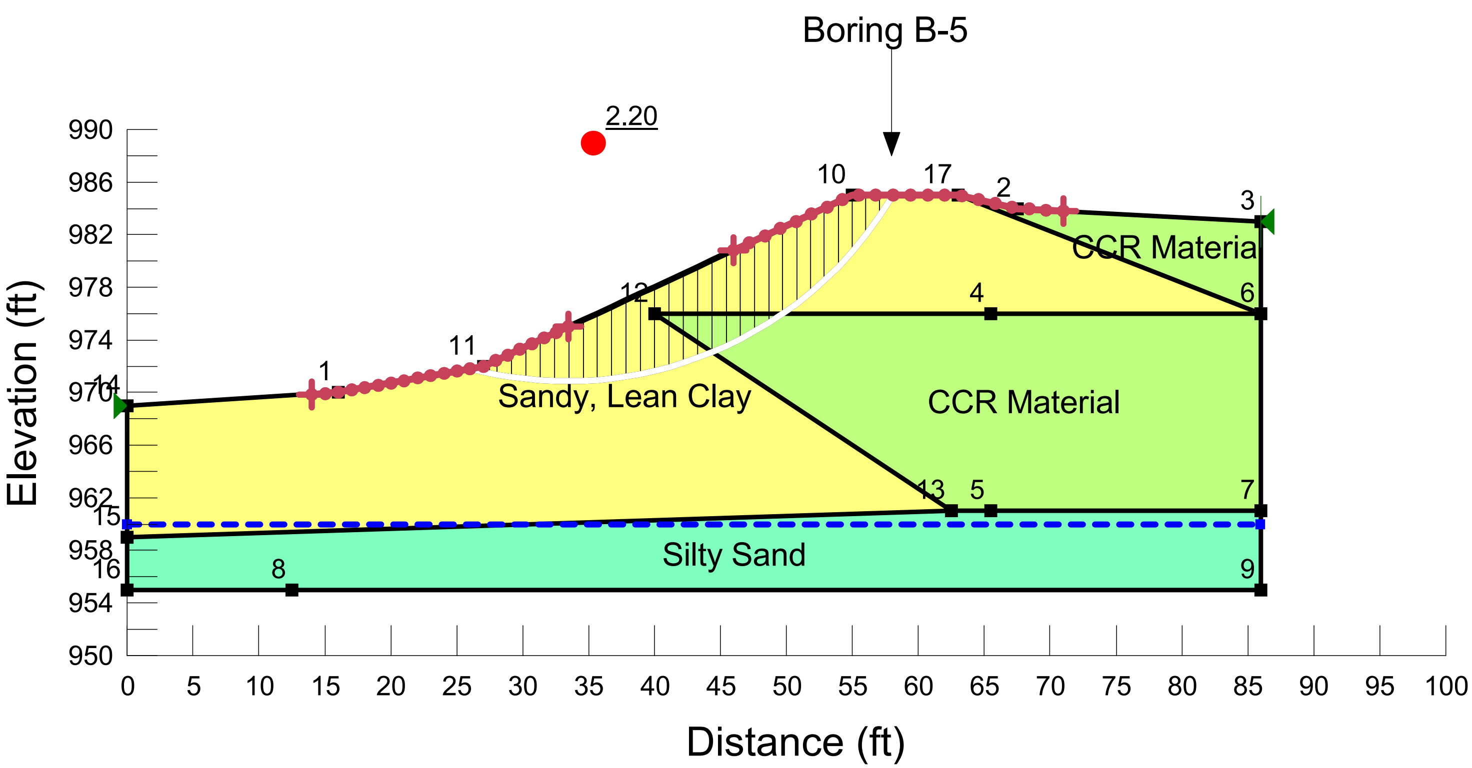


Proj No.: C151119.25

By: RRJ 4/10/2023
Checked: AB 4/12/23

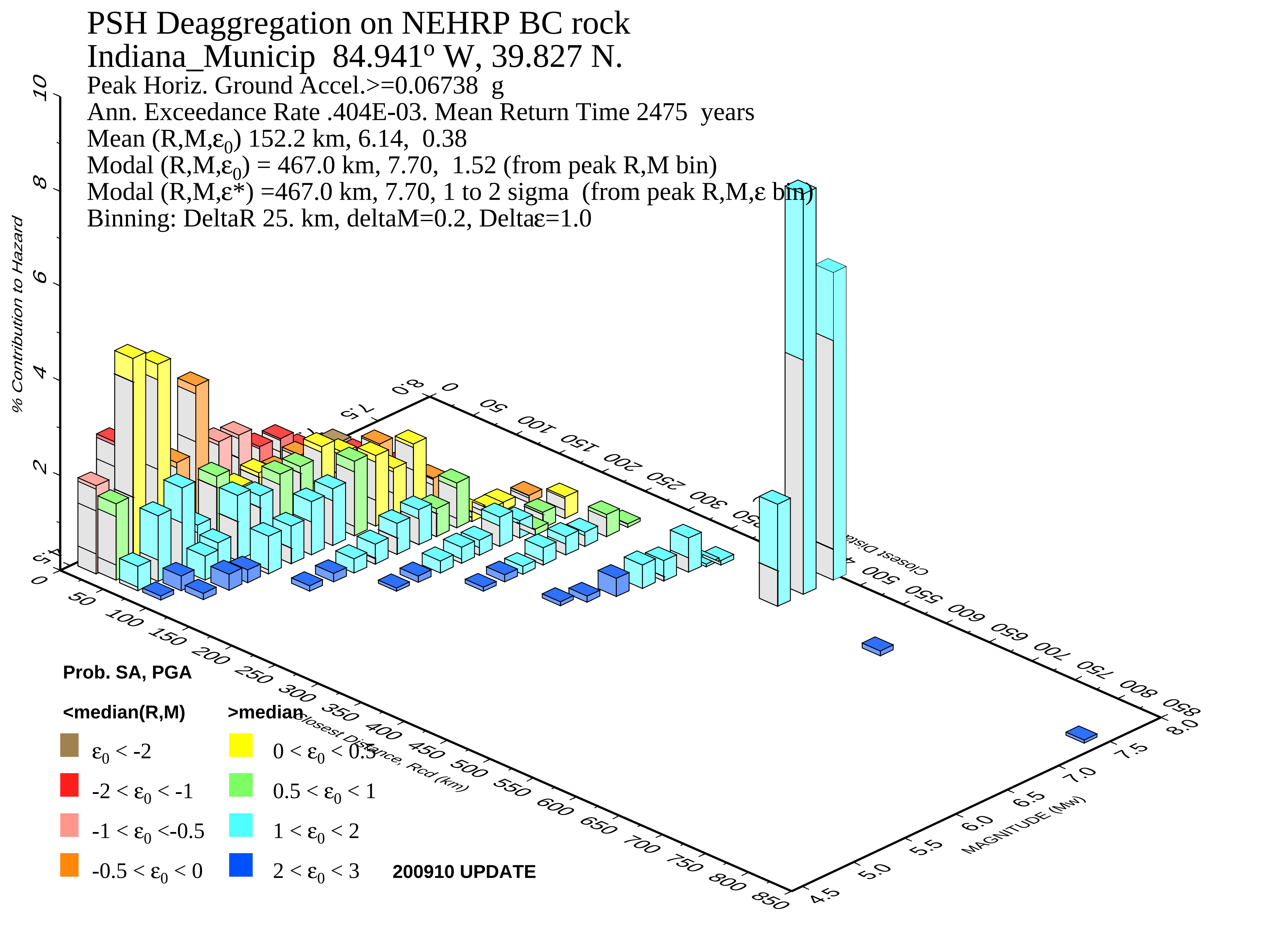
RP-L Surface Impoundment Existing Conditions - CCR Rule Factor of Safety
Section 4-4 - Southwest Dike
Drained - Horz Seismic Coef.: 0

Color	Name	Slope Stability Material Model	Unit Weight (pcf)	Effective Cohesion (psf)	Effective Friction Angle (°)	Piezometric Surface
	CCR Material	Mohr-Coulomb	90	0	32	1
	Sandy, Lean Clay	Mohr-Coulomb	130	150	28	1
	Silty Sand	Mohr-Coulomb	125	0	28	1



ATTACHMENT 4

USGS EARTHQUAKE GROUND ACCELERATION
&
LIQUEFACTION ANALYSIS

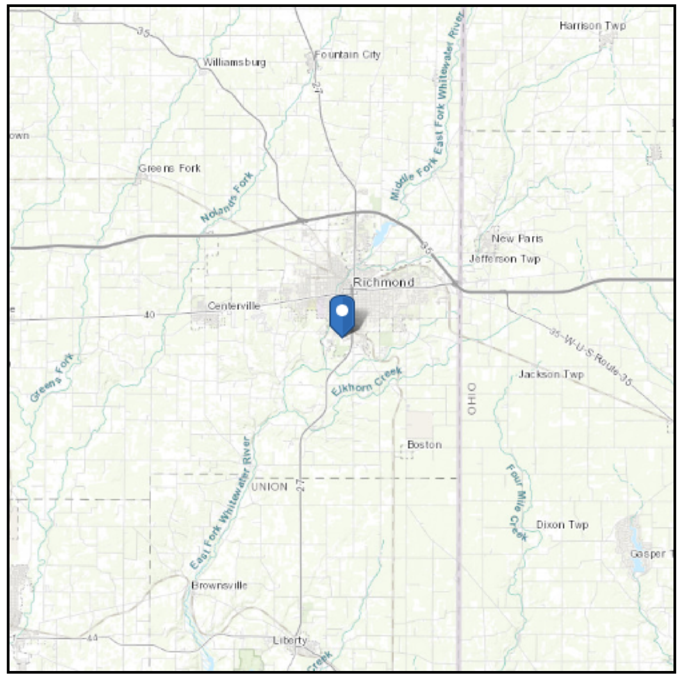


GMT 2016 Jul 28 20:03:26 Distance (R), magnitude (M), epsilon (E0,E) deaggregation for a site on rock with average vs= 760. m/s top 30 m. USGS CGHT PSHA2008 UPDATE Bins with lt 0.05% contrib. omitted

ASCE 7 Hazards Report

Address:
No Address at This Location

Standard:	ASCE/SEI 7-22	**Latitude:**	39.803111
Risk Category:	IV	**Longitude:**	-84.898261
Soil Class:	D - Stiff Soil	**Elevation:**	999.5276102624416 ft (NAVD 88)



Seismic

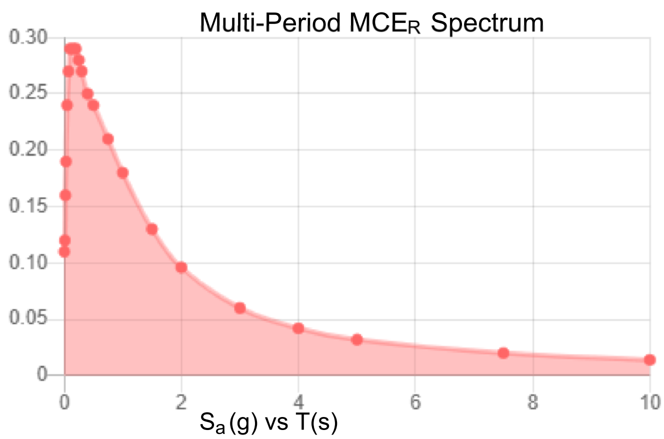
D - Stiff Soil

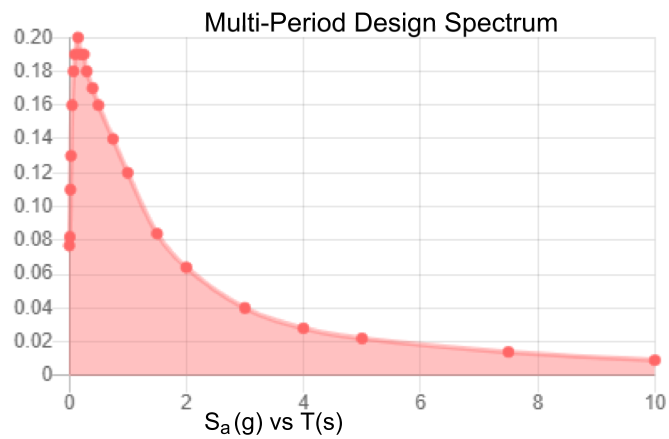
Site Soil Class:

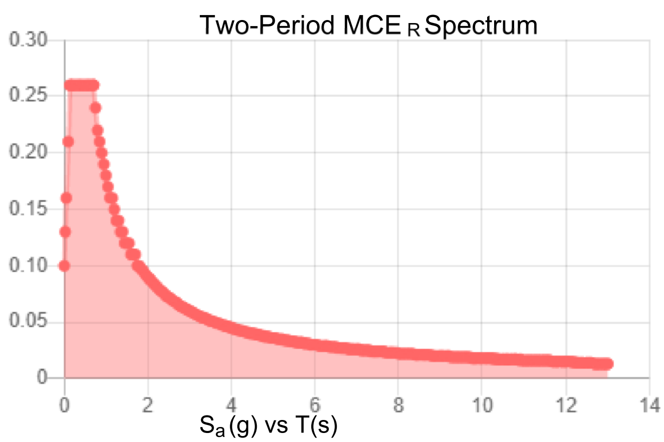
Results:

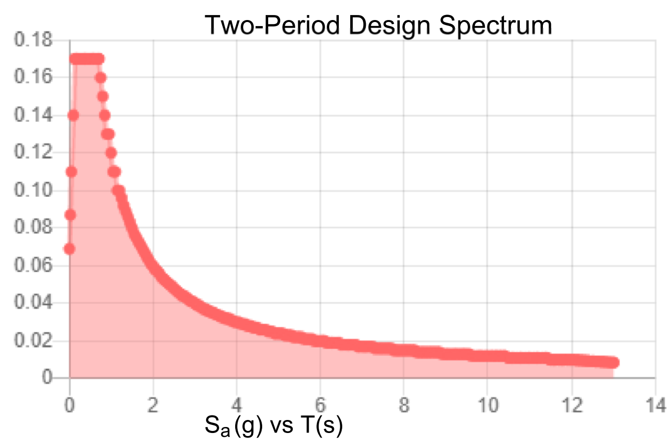
PGA_M :	0.1	T_L :	12
S_{MS} :	0.26	S_S :	0.2
S_{M1} :	0.18	S_1 :	0.085
S_{DS} :	0.17	V_{S30} :	260
S_{D1} :	0.12		

Seismic Design Category: C









MCE$_R$ Vertical Response Spectrum

Vertical ground motion data has not yet been made available by USGS.

Design Vertical Response Spectrum

Vertical ground motion data has not yet been made available by USGS.

Data Accessed: **Thu Apr 06 2023**

Date Source:

USGS Seismic Design Maps based on ASCE/SEI 7-22 and ASCE/SEI 7-22 Table 1.5-2. Additional data for site-specific ground motion procedures in accordance with ASCE/SEI 7-22 Ch. 21 are available from USGS.

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gai consultants

Richmond Power and Light
Whitewater Valley Station
Surface Impoundment
Liquefaction Analysis

C151119.02
By: AB 07/29/16
Ckd by: MURAOTI 11/11/2016

G.S. Elev. = 986.0
$\gamma_{overburden}$ = 100.0 (pcf)

W.T. Elev. = 976.9
a_{max} 0.11
Est. EQ Mag 6.1

Bottom Elev. = 986.0
Top Elev. = 986.0

Test Depth (m)	Test Depth (ft)	Test Elevation (ft)	Saturated Unit Weight (pcf)	Moist Unit Weight (pcf)	Fines Content (%)	N	C_E	C_B	C_S	C_R	N_{60}	Existing σ_{vo} (tsf)	Existing σ'_{vo} (tsf)	C_N	Design σ_{vo} (tsf)	Design σ_{vo}' (tsf)	$(N_1)_{60}$	Idriss and Boulanger (2008) ΔN for fines content	$(N_1)_{60cs}$	r_d	CSR	MSF	K_σ	CRR for M=7.5 and σ_{vc}'=1atm	CRR	Factor of Safety
0.3	1.0	985.0	100.0	90.0	30.0	4	0.8	1.0	1.0	0.75	2	0.0450	0.0450	1.70	0.05	0.05	4	5	9	1.0041	0.0718	1.4	1.10	0.114221	0.181	-
1.2	4.0	982.0	100.0	90.0	30.0	8	0.8	1.0	1.0	0.75	5	0.1800	0.1800	1.70	0.18	0.18	8	5	14	0.9910	0.0709	1.4	1.10	0.144107	0.229	-
2.1	7.0	979.0	100.0	90.0	30.0	10	0.8	1.0	1.0	0.75	6	0.3150	0.3150	1.70	0.32	0.32	10	5	16	0.9763	0.0698	1.4	1.10	0.160925	0.256	-
3.0	10.0	976.0	100.0	90.0	30.0	12	0.8	1.0	1.0	0.8	8	0.4545	0.4264	1.56	0.45	0.43	12	5	17	0.9600	0.0732	1.4	1.10	0.177558	0.282	3.85
4.0	13.0	973.0	100.0	90.0	30.0	21	0.8	1.0	1.0	0.85	14	0.6045	0.4828	1.47	0.60	0.48	21	5	26	0.9425	0.0844	1.4	1.10	0.326326	0.518	6.14
4.9	16.0	970.0	100.0	90.0	30.0	30	0.8	1.0	1.0	0.85	20	0.7545	0.5392	1.39	0.75	0.54	28	5	34	0.9237	0.0924	1.4	1.10	0.867819	1.378	14.91
5.8	19.0	967.0	100.0	90.0	30.0	18	0.8	1.0	1.0	0.85	12	0.9045	0.5956	1.32	0.90	0.60	16	5	22	0.9040	0.0982	1.4	1.08	0.226653	0.353	3.60
6.7	22.0	964.0	100.0	90.0	30.0	16	0.8	1.0	1.0	0.95	12	1.0545	0.6520	1.27	1.05	0.65	15	5	21	0.8834	0.1022	1.4	1.06	0.215361	0.331	3.24
7.6	25.0	961.0	100.0	90.0	30.0	16	0.8	1.0	1.0	0.95	12	1.2045	0.7084	1.21	1.20	0.71	15	5	20	0.8623	0.1048	1.4	1.05	0.207403	0.315	3.00
8.5	28.0	958.0	100.0	90.0	30.0	16	0.8	1.0	1.0	0.95	12	1.3545	0.7648	1.17	1.35	0.76	14	5	20	0.8406	0.1064	1.4	1.04	0.200761	0.302	2.83
9.4	31.0	955.0	100.0	90.0	30.0	19	0.8	1.0	1.0	0.95	14	1.5045	0.8212	1.13	1.50	0.82	16	5	22	0.8187	0.1072	1.4	1.03	0.227763	0.340	3.17

Notes:

σ'_{vo} Vertical Effective Stress (tons/ft^2)
$(N_1)_{60}$ Standardized and Normalized SPT blow counts (blows/foot)
r_d Stress Reduction Factor (dimensionless)
a_{max} Peak horizontal ground surface acceleration (in g)
CSR Cyclic stress ratio based on design earthquake (dimensionless)
$CRR_{7.5}$ Cyclic resistance ratio based on an earthquake of magnitude 7.5 (dimensionless)
MSF Magnitude scaling factor (dimensionless)
K_σ High overburden stress correction factor (dimensionless)
K_α Ground slope correction factor (dimensionless) [advised not to be used by reference]
CRR Corrected cyclic resistance ratio based on overburden pressure and ground surface slope (dimensionless) = CRR7.5 * Kσ * Kα
FS_L Factor of safety against liquefaction (dimensionless)

FS_{min} 2.83

References:

(1) 1. Idriss, I. M., and Boulanger, R. W. (2008).Soil liquefaction during earthquakes. Monograph MNO-12, Earthquake Engineering Research Institute, Oakland, CA, 261 pp.

Richmond Power and Light
Whitewater Valley Station
Surface impoundment
Liquefaction Analysis

C151119.02
By: AB 07/29/16
Ckd by:MURAOTI 11/11/2016

gai consultants

G.S. Elev. = 986.0
$\gamma_{overburden}$ = 100.0 (pcf)

W.T. Elev. = 976.0
a_{max} 0.11
Est. EQ Mag 6.1

Bottom Elev. = 986.0
Top Elev. = 986.0

Test Depth (m)	Test Depth (ft)	Test Elevation (ft)	Saturated Unit Weight (pcf)	Moist Unit Weight (pcf)	Fines Content (%)	N	C_E	C_B	C_S	C_R	N_{60}	Existing σ_{vo} (tsf)	Existing σ'_{vo} (tsf)	C_N	Design σ_{vo} (tsf)	Design σ_{vo}' (tsf)	$(N_1)_{60}$	Idriss and Boulanger (2008) ΔN for fines content	$(N_1)_{60cs}$	r_d	CSR	MSF	K_σ	CRR for M=7.5 and σ_{vc}'=1atm	CRR	Factor of Safety
0.3	1.0	985.0	100.0	90.0	30.0	16	0.8	1.0	1.0	0.75	10	0.0450	0.0450	1.70	0.05	0.05	16	5	22	1.0041	0.0718	1.4	1.10	0.228300	0.363	-
1.2	4.0	982.0	100.0	90.0	30.0	15	0.8	1.0	1.0	0.75	9	0.1800	0.1800	1.70	0.18	0.18	15	5	21	0.9910	0.0709	1.4	1.10	0.214195	0.340	-
2.1	7.0	979.0	100.0	90.0	30.0	15	0.8	1.0	1.0	0.75	9	0.3150	0.3150	1.70	0.32	0.32	15	5	21	0.9763	0.0698	1.4	1.10	0.214195	0.340	-
3.0	10.0	976.0	100.0	90.0	30.0	13	0.8	1.0	1.0	0.8	8	0.4500	0.4500	1.52	0.45	0.45	13	5	18	0.9600	0.0686	1.4	1.10	0.184074	0.292	4.26
4.0	13.0	973.0	100.0	90.0	30.0	15	0.8	1.0	1.0	0.85	10	0.6000	0.5064	1.44	0.60	0.51	15	5	20	0.9425	0.0798	1.4	1.10	0.205979	0.326	4.08
5.8	19.0	967.0	100.0	90.0	30.0	15	0.8	1.0	1.0	0.85	10	0.9000	0.6192	1.30	0.90	0.62	13	5	19	0.9040	0.0939	1.4	1.07	0.190035	0.292	3.11
6.7	22.0	964.0	100.0	90.0	30.0	11	0.8	1.0	1.0	0.95	8	1.0500	0.6756	1.24	1.05	0.68	10	5	16	0.8834	0.0982	1.4	1.05	0.162611	0.246	2.51
7.6	25.0	961.0	100.0	90.0	30.0	11	0.8	1.0	1.0	0.95	8	1.2000	0.7320	1.19	1.20	0.73	10	5	15	0.8623	0.1011	1.4	1.04	0.159075	0.239	2.36
8.5	28.0	958.0	100.0	90.0	30.0	19	0.8	1.0	1.0	0.95	14	1.3500	0.7884	1.15	1.35	0.79	17	5	22	0.8406	0.1029	1.4	1.04	0.232770	0.349	3.40
9.4	31.0	955.0	100.0	90.0	30.0	21	0.8	1.0	1.0	0.95	16	1.5000	0.8448	1.11	1.50	0.84	18	5	23	0.8187	0.1039	1.4	1.03	0.251264	0.374	3.60
10.4	34.0	952.0	100.0	90.0	30.0	29	0.8	1.0	1.0	1	23	1.6500	0.9012	1.08	1.65	0.90	25	5	30	0.7966	0.1043	1.4	1.03	0.506784	0.753	7.22
11.3	37.0	949.0	100.0	90.0	30.0	12	0.8	1.0	1.0	1	10	1.8000	0.9576	1.04	1.80	0.96	10	5	15	0.7745	0.1041	1.4	1.01	0.159416	0.232	2.23
12.2	40.0	946.0	100.0	90.0	30.0	11	0.8	1.0	1.0	1	9	1.9500	1.0140	1.01	1.95	1.01	9	5	14	0.7525	0.1035	1.4	1.00	0.150274	0.218	2.10

Notes:

σ'_{vo} Vertical Effective Stress (tons/ft^2)
$(N_1)_{60}$ Standardized and Normalized SPT blow counts (blows/foot)
r_d Stress Reduction Factor (dimensionless)
a_{max} Peak horizontal ground surface acceleration (in g)
CSR Cyclic stress ratio based on design earthquake (dimensionless)
$CRR_{7.5}$ Cyclic resistance ratio based on an earthquake of magnitude 7.5 (dimensionless)
MSF Magnitude scaling factor (dimensionless)
K_σ High overburden stress correction factor (dimensionless)
K_α Ground slope correction factor (dimensionless) [advised not to be used by reference]
CRR Corrected cyclic resistance ratio based on overburden pressure and ground surface slope (dimensionless) = CRR7.5 * Kσ * Kα
FS_L Factor of safety against liquefaction (dimensionless)

FS_{min} 2.10

References:

(1) 1. Idriss, I. M., and Boulanger, R. W. (2008).Soil liquefaction during earthquakes. Monograph MNO-12, Earthquake Engineering Research Institute, Oakland, CA, 261 pp.

gai consultants

Richmond Power and Light
Whitewater Valley Station
Surface Impoundment
Liquefaction Analysis

C151119.02
By: AB 07/29/16
Ckd by: MURAOTI 11/11/2016

G.S. Elev. = 986.0
$\gamma_{overburden}$ = 100.0 (pcf)

W.T. Elev. = 973.1
a_{max} 0.11
Est. EQ Mag 6.1

Bottom Elev. = 986.0
Top Elev. = 986.0

															Idriss and Boulanger (2008)										
Test Depth (m)	Test Depth (ft)	Test Elevation (ft)	Saturated Unit Weight (pcf)	Moist Unit Weight (pcf)	Fines Content (%)	N	C_E	C_B	C_S	C_R	N_{60}	Existing σ_{vo} (tsf)	Existing σ'_{vo} (tsf)	C_N	Design σ_{vo} (tsf)	Design σ_{vo}' (tsf)	$(N_1)_{60}$	ΔN for fines content	$(N_1)_{60cs}$	r_d	CSR	MSF	K_σ	CRR for M=7.5 and σ_{vc}'=1atm	CRR	Factor of Safety
0.3	1.0	985.0	100.0	90.0	30.0	14	0.8	1.0	1.0	0.75	8	0.0450	0.0450	1.70	0.05	0.05	14	5	20	1.0041	0.0718	1.4	1.10	0.201592	0.320	-
1.2	4.0	982.0	100.0	90.0	30.0	13	0.8	1.0	1.0	0.75	8	0.1800	0.1800	1.70	0.18	0.18	13	5	19	0.9910	0.0709	1.4	1.10	0.190183	0.302	-
2.1	7.0	979.0	100.0	90.0	30.0	15	0.8	1.0	1.0	0.75	9	0.3150	0.3150	1.70	0.32	0.32	15	5	21	0.9763	0.0698	1.4	1.10	0.214195	0.340	-
3.0	10.0	976.0	100.0	90.0	30.0	15	0.8	1.0	1.0	0.8	10	0.4500	0.4500	1.52	0.45	0.45	15	5	20	0.9600	0.0686	1.4	1.10	0.205698	0.327	-
4.0	13.0	973.0	100.0	90.0	30.0	9	0.8	1.0	1.0	0.85	6	0.5855	0.5824	1.34	0.59	0.58	8	5	14	0.9425	0.0677	1.4	1.06	0.144384	0.221	3.26
4.9	16.0	970.0	100.0	90.0	30.0	2	0.8	1.0	1.0	0.85	1	0.7355	0.6388	1.28	0.74	0.64	2	5	7	0.9237	0.0760	1.4	1.04	0.098837	0.148	1.95
5.8	19.0	967.0	100.0	90.0	30.0	1	0.8	1.0	1.0	0.85	1	0.8855	0.6952	1.23	0.89	0.70	1	5	6	0.9040	0.0823	1.4	1.03	0.093231	0.139	1.69
6.7	22.0	964.0	100.0	90.0	30.0	11	0.8	1.0	1.0	0.95	8	1.0355	0.7516	1.18	1.04	0.75	10	5	15	0.8834	0.0870	1.4	1.04	0.157957	0.236	2.72
7.6	25.0	961.0	100.0	90.0	30.0	9	0.8	1.0	1.0	0.95	7	1.1855	0.8080	1.14	1.19	0.81	8	5	13	0.8623	0.0905	1.4	1.03	0.141107	0.209	2.31
8.5	28.0	958.0	100.0	90.0	30.0	2	0.8	1.0	1.0	0.95	2	1.3355	0.8644	1.10	1.34	0.86	2	5	7	0.8406	0.0929	1.4	1.02	0.098408	0.144	1.55
9.4	31.0	955.0	100.0	90.0	30.0	26	0.8	1.0	1.0	0.95	20	1.4855	0.9208	1.06	1.49	0.92	21	5	26	0.8187	0.0944	1.4	1.02	0.327597	0.483	5.11
10.4	34.0	952.0	100.0	90.0	30.0	14	0.8	1.0	1.0	1	11	1.6355	0.9772	1.03	1.64	0.98	12	5	17	0.7966	0.0953	1.4	1.01	0.173352	0.252	2.64
11.3	37.0	949.0	100.0	90.0	30.0	39	0.8	1.0	1.0	1	31	1.7855	1.0336	1.01	1.79	1.03	31	5	37	0.7745	0.0957	1.4	1.00	1.634432	2.364	24.71
12.2	40.0	946.0	100.0	90.0	30.0	40	0.8	1.0	1.0	1	32	1.9355	1.0900	0.98	1.94	1.09	31	5	37	0.7525	0.0955	1.4	0.99	1.618958	2.305	24.13

Notes:

σ'_{vo} Vertical Effective Stress (tons/ft^2)
$(N_1)_{60}$ Standardized and Normalized SPT blow counts (blows/foot)
r_d Stress Reduction Factor (dimensionless)
a_{max} Peak horizontal ground surface acceleration (in g)
CSR Cyclic stress ratio based on design earthquake (dimensionless)
$CRR_{7.5}$ Cyclic resistance ratio based on an earthquake of magnitude 7.5 (dimensionless)
MSF Magnitude scaling factor (dimensionless)
K_σ High overburden stress correction factor (dimensionless)
K_α Ground slope correction factor (dimensionless) [advised not to be used by reference]
CRR Corrected cyclic resistance ratio based on overburden pressure and ground surface slope (dimensionless) = CRR7.5 * Kσ * Kα
FS_L Factor of safety against liquefaction (dimensionless)

FS_{min} 1.55

References:

(1) 1. Idriss, I. M., and Boulanger, R. W. (2008).Soil liquefaction during earthquakes. Monograph MNO-12, Earthquake Engineering Research Institute, Oakland, CA, 261 pp.

gai consultants

Richmond Power and Light
Whitewater Valley Station
Surface Impoundment
Liquefaction Analysis

C151119.02
By: AB 07/29/16
Ckd by:MURAOTI 11/11/2016

G.S. Elev. = 972.0 | W.T. Elev. = 962.0 | Bottom Elev. = 972.0

$\gamma_{overburden}$ = 100.0 (pcf) | a_{max} 0.11 | Top Elev. = 972.0

Est. EQ Mag 6.1

																		Idriss and Boulanger (2008)								
Test Depth (m)	Test Depth (ft)	Test Elevation (ft)	Saturated Unit Weight (pcf)	Moist Unit Weight (pcf)	Fines Content (%)	N	C_E	C_B	C_S	C_R	N_{60}	Existing σ_{vo} (tsf)	Existing σ'_{vo} (tsf)	C_N	Design σ_{vo} (tsf)	Design σ_{vo}' (tsf)	$(N_1)_{60}$	ΔN for fines content	$(N_1)_{60cs}$	r_d	CSR	MSF	K_σ	CRR for M=7.5 and σ_{vc}'=1atm	CRR	Factor of Safety
0.3	1.0	971.0	100.0	90.0	30.0	7	1.3	1.0	1.0	0.75	7	0.0450	0.0450	1.70	0.05	0.05	12	5	17	1.0041	0.0718	1.4	1.10	0.173581	0.276	-
1.1	3.5	968.5	100.0	90.0	30.0	13	1.3	1.0	1.0	0.75	13	0.1575	0.1575	1.70	0.16	0.16	22	5	27	0.9933	0.0710	1.4	1.10	0.343521	0.545	-
1.8	6.0	966.0	100.0	90.0	30.0	18	1.3	1.0	1.0	0.75	18	0.2700	0.2700	1.70	0.27	0.27	30	5	35	0.9814	0.0702	1.4	1.10	1.155283	1.835	-
2.6	8.5	963.5	100.0	90.0	30.0	11	1.3	1.0	1.0	0.75	11	0.3825	0.3825	1.65	0.38	0.38	18	5	23	0.9683	0.0692	1.4	1.10	0.250849	0.398	-
3.4	11.0	961.0	100.0	90.0	30.0	10	1.3	1.0	1.0	0.8	10	0.5000	0.4688	1.49	0.50	0.47	16	5	21	0.9543	0.0728	1.4	1.10	0.217125	0.345	4.74
4.1	13.5	958.5	100.0	90.0	30.0	33	1.3	1.0	1.0	0.85	36	0.6250	0.5158	1.42	0.63	0.52	52	5	57	0.9394	0.0814	1.4	1.10	2.000000	3.176	39.02

Notes:

σ'_{vo} Vertical Effective Stress (tons/ft^2)
$(N_1)_{60}$ Standardized and Normalized SPT blow counts (blows/foot)
r_d Stress Reduction Factor (dimensionless)
a_{max} Peak horizontal ground surface acceleration (in g)
CSR Cyclic stress ratio based on design earthquake (dimensionless)
$CRR_{7.5}$ Cyclic resistance ratio based on an earthquake of magnitude 7.5 (dimensionless)
MSF Magnitude scaling factor (dimensionless)
K_σ High overburden stress correction factor (dimensionless)
K_α Ground slope correction factor (dimensionless) [advised not to be used by reference]
CRR Corrected cyclic resistance ratio based on overburden pressure and ground surface slope (dimensionless) = CRR7.5 * Kσ * Kα
FS_L Factor of safety against liquefaction (dimensionless)

FS_{min} 4.74

References:

(1) 1. Idriss, I. M., and Boulanger, R. W. (2008).Soil liquefaction during earthquakes. Monograph MNO-12, Earthquake Engineering Research Institute, Oakland, CA, 261 pp.

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Richmond Power and Light
Whitewater Valley Station
Surface Impoundment
Liquefaction Analysis

C151119.02
By: AB 07/29/16
Ckd by:MURAOTI 11/11/2016

G.S. Elev. = 986.0
$\gamma_{overburden}$ = 100.0 (pcf)

W.T. Elev. = 976.0
a_{max} 0.11
Est. EQ Mag 6.1

Bottom Elev. = 986.0
Top Elev. = 986.0

Test Depth (m)	Test Depth (ft)	Test Elevation (ft)	Saturated Unit Weight (pcf)	Moist Unit Weight (pcf)	Fines Content (%)	N	C_E	C_B	C_S	C_R	N_{60}	Existing σ_{vo} (tsf)	Existing σ'_{vo} (tsf)	C_N	Design σ_{vo} (tsf)	Design σ_{vo}' (tsf)	$(N_1)_{60}$	α	β	$(N_1)_{60cs}$	Idriss and Boulanger (2008) ΔN for fines content	$(N_1)_{60cs}$	r_d	CSR	MSF	K_σ	CRR for M=7.5 and σ_{vc}'=1atm	CRR	Factor of Safety
0.3	1.0	985.0	100.0	90.0	30.0	17	0.8	1.0	1.0	0.75	10	0.0450	0.0450	1.70	0.05	0.05	17	5	1.1	24	5	23	1.0041	0.0718	1.4	1.10	0.244294	0.388	-
1.2	4.0	982.0	100.0	90.0	30.0	16	0.8	1.0	1.0	0.75	10	0.1800	0.1800	1.70	0.18	0.18	16	5	1.1	23	5	22	0.9910	0.0709	1.4	1.10	0.228300	0.363	-
2.1	7.0	979.0	100.0	90.0	30.0	7	0.8	1.0	1.0	0.75	4	0.3150	0.3150	1.70	0.32	0.32	7	5	1.1	13	5	13	0.9763	0.0698	1.4	1.10	0.136231	0.216	-
3.0	10.0	976.0	100.0	90.0	30.0	8	0.8	1.0	1.0	0.8	5	0.4500	0.4500	1.52	0.45	0.45	8	5	1.1	13	5	13	0.9600	0.0686	1.4	1.09	0.141289	0.222	3.23
4.0	13.0	973.0	100.0	90.0	30.0	12	0.8	1.0	1.0	0.85	8	0.6000	0.5064	1.44	0.60	0.51	12	5	1.1	18	5	17	0.9425	0.0798	1.4	1.09	0.174673	0.274	3.43
4.9	16.0	970.0	100.0	90.0	30.0	12	0.8	1.0	1.0	0.85	8	0.7500	0.5628	1.36	0.75	0.56	11	5	1.1	17	5	16	0.9237	0.0880	1.4	1.07	0.169062	0.262	2.97
5.8	19.0	967.0	100.0	90.0	30.0	15	0.8	1.0	1.0	0.85	10	0.9000	0.6192	1.30	0.90	0.62	13	5	1.1	19	5	19	0.9040	0.0939	1.4	1.07	0.190035	0.292	3.11
6.7	22.0	964.0	100.0	90.0	30.0	15	0.8	1.0	1.0	0.95	11	1.0500	0.6756	1.24	1.05	0.68	14	5	1.1	20	5	20	0.8834	0.0982	1.4	1.06	0.200346	0.306	3.11
7.6	25.0	961.0	100.0	90.0	30.0	17	0.8	1.0	1.0	0.95	13	1.2000	0.7320	1.19	1.20	0.73	15	5	1.1	22	5	21	0.8623	0.1011	1.4	1.05	0.215925	0.327	3.23
8.5	28.0	958.0	100.0	90.0	30.0	4	0.8	1.0	1.0	0.95	3	1.3500	0.7884	1.15	1.35	0.79	3	5	1.1	9	5	9	0.8406	0.1029	1.4	1.02	0.110285	0.163	1.58

Notes:

FS_{min} 1.58

- σ'_{vo} Vertical Effective Stress (tons/ft^2)
- $(N_1)_{60}$ Standardized and Normalized SPT blow counts (blows/foot)
- r_d Stress Reduction Factor (dimensionless)
- a_{max} Peak horizontal ground surface acceleration (in g)
- CSR Cyclic stress ratio based on design earthquake (dimensionless)
- $CRR_{7.5}$ Cyclic resistance ratio based on an earthquake of magnitude 7.5 (dimensionless)
- MSF Magnitude scaling factor (dimensionless)
- K_σ High overburden stress correction factor (dimensionless)
- K_α Ground slope correction factor (dimensionless) [advised not to be used by reference]
- CRR Corrected cyclic resistance ratio based on overburden pressure and ground surface slope (dimensionless) = CRR7.5 * Kσ * Kα
- FS_L Factor of safety against liquefaction (dimensionless)

References:

(1) 1. Idriss, I. M., and Boulanger, R. W. (2008).Soil liquefaction during earthquakes. Monograph MNO-12, Earthquake Engineering Research Institute, Oakland, CA, 261 pp.

Richmond Power and Light
Whitewater Valley Station
Surface Impoundment
Liquefaction Analysis

C151119.02
By: AB 07/29/16
Ckd by: MURAOTI 11/11/2016

G.S. Elev. = 982.0
$\gamma_{overburden}$ = 100.0 (pcf)

W.T. Elev. = 967.3
a_{max} 0.11
Est. EQ Mag 6.1

Bottom Elev. = 982.0
Top Elev. = 982.0

																					Idriss and Boulanger (2008)								
Test Depth (m)	Test Depth (ft)	Test Elevation (ft)	Saturated Unit Weight (pcf)	Moist Unit Weight (pcf)	Fines Content (%)	N	C_E	C_B	C_S	C_R	N_{60}	Existing σ_{vo} (tsf)	Existing σ'_{vo} (tsf)	C_N	Design σ_{vo} (tsf)	Design σ_{vo}' (tsf)	$(N_1)_{60}$	α	β	$(N_1)_{60cs}$	ΔN for fines content	$(N_1)_{60cs}$	r_d	CSR	MSF	K_σ	CRR for M=7.5 and σ_{vc}'=1atm	CRR	Factor of Safety
0.3	1.0	981.0	100.0	90.0	30.0	1	0.8	1.0	1.0	0.75	1	0.0450	0.0450	1.70	0.05	0.05	1	5	1.1	6	5	6	1.0041	0.0718	1.4	1.10	0.094370	0.150	-
1.2	4.0	978.0	100.0	90.0	30.0	4	0.8	1.0	1.0	0.75	2	0.1800	0.1800	1.70	0.18	0.18	4	5	1.1	9	5	9	0.9910	0.0709	1.4	1.10	0.114221	0.181	-
2.1	7.0	975.0	100.0	90.0	30.0	2	0.8	1.0	1.0	0.75	1	0.3150	0.3150	1.70	0.32	0.32	2	5	1.1	7	5	7	0.9763	0.0698	1.4	1.10	0.100745	0.160	-
3.0	10.0	972.0	100.0	90.0	30.0	1	0.8	1.0	1.0	0.80	1	0.4500	0.4500	1.52	0.45	0.45	1	5	1.1	6	5	6	0.9600	0.0686	1.4	1.07	0.094094	0.145	-
4.0	13.0	969.0	100.0	90.0	30.0	1	0.8	1.0	1.0	0.85	1	0.5850	0.5850	1.34	0.59	0.59	1	5	1.1	6	5	6	0.9425	0.0674	1.4	1.05	0.093688	0.141	-
4.9	16.0	966.0	100.0	90.0	30.0	1	0.8	1.0	1.0	0.85	1	0.7265	0.6859	1.23	0.73	0.69	1	5	1.1	6	5	6	0.9237	0.0700	1.4	1.03	0.093265	0.139	1.99
5.8	19.0	963.0	100.0	90.0	30.0	1	0.8	1.0	1.0	0.85	1	0.8765	0.7423	1.19	0.88	0.74	1	5	1.1	6	5	6	0.9040	0.0763	1.4	1.03	0.093067	0.138	1.81
6.7	22.0	960.0	100.0	90.0	30.0	3	0.8	1.0	1.0	0.95	2	1.0265	0.7987	1.14	1.03	0.80	3	5	1.1	8	5	8	0.8834	0.0812	1.4	1.02	0.104395	0.154	1.90
8.5	28.0	954.0	100.0	90.0	30.0	14	0.8	1.0	1.0	0.95	11	1.3265	0.9115	1.07	1.33	0.91	11	5	1.1	17	5	17	0.8406	0.0875	1.4	1.02	0.171577	0.252	2.88
9.4	31.0	951.0	100.0	90.0	30.0	20	0.8	1.0	1.0	0.95	15	1.4765	0.9679	1.04	1.48	0.97	16	5	1.1	22.1	5	21	0.8187	0.0893	1.4	1.01	0.220734	0.322	3.60
10.4	34.0	948.0	100.0	90.0	30.0	20	0.8	1.0	1.0	1.00	16	1.6265	1.0243	1.01	1.63	1.02	16	5	1.1	22.5	5	22	0.7966	0.0904	1.4	1.00	0.225900	0.327	3.61
11.3	37.0	945.0	100.0	90.0	30.0	22	0.8	1.0	1.0	1.00	18	1.7765	1.0807	0.98	1.78	1.08	17	5	1.1	24	5	23	0.7745	0.0910	1.4	0.99	0.243634	0.350	3.84
12.2	40.0	942.0	100.0	90.0	30.0	25	0.8	1.0	1.0	1.00	20	1.9265	1.1371	0.96	1.93	1.14	19	5	1.1	26	5	25	0.7525	0.0912	1.4	0.99	0.279282	0.397	4.36

Notes:

σ'_{vo} Vertical Effective Stress (tons/ft^2)
$(N_1)_{60}$ Standardized and Normalized SPT blow counts (blows/foot)
r_d Stress Reduction Factor (dimensionless)
a_{max} Peak horizontal ground surface acceleration (in g)
CSR Cyclic stress ratio based on design earthquake (dimensionless)
$CRR_{7.5}$ Cyclic resistance ratio based on an earthquake of magnitude 7.5 (dimensionless)
MSF Magnitude scaling factor (dimensionless)
K_σ High overburden stress correction factor (dimensionless)
K_α Ground slope correction factor (dimensionless) [advised not to be used by reference]
CRR Corrected cyclic resistance ratio based on overburden pressure and ground surface slope (dimensionless) = CRR7.5 * Kσ * Kα
FS_L Factor of safety against liquefaction (dimensionless)

FS_{min} 1.81

References:

(1) 1. Idriss, I. M., and Boulanger, R. W. (2008).Soil liquefaction during earthquakes. Monograph MNO-12, Earthquake Engineering Research Institute, Oakland, CA, 261 pp.

Richmond Power and Light
Whitewater Valley Station
Surface Impoundment
Liquefaction Analysis

G.S. Elev. = 984.0
$\gamma_{overburden}$ = 100.0 (pcf)

W.T. Elev. = 978.3
a_{max} 0.11
Est. EQ Mag 6.1

Bottom Elev. = 984.0
Top Elev. = 984.0

Idriss and Boulanger (2008)

Test Depth (m)	Test Depth (ft)	Test Elevation (ft)	Saturated Unit Weight (pcf)	Moist Unit Weight (pcf)	Fines Content (%)	N	C_E	C_B	C_S	C_R	N_{60}	Existing σ_{vo} (tsf)	Existing σ'_{vo} (tsf)	C_N	Design σ_{vo} (tsf)	Design σ_{vo}' (tsf)	$(N_1)_{60}$	α	β	$(N_1)_{60cs}$	ΔN for fines content	$(N_1)_{60cs}$	r_d	CSR	MSF	K_σ	CRR for M=7.5 and σ_{vc}'=1atm	CRR	Factor of Safety
0.3	1.0	983.0	100.0	90.0	30.0	4	0.8	1.0	1.0	0.75	2	0.0450	0.0450	1.70	0.05	0.05	4	5	1.1	9	5	9	1.0041	0.0718	1.4	1.10	0.114221	0.181	-
1.2	4.0	980.0	100.0	90.0	30.0	2	0.8	1.0	1.0	0.75	1	0.1800	0.1800	1.70	0.18	0.18	2	5	1.1	7	5	7	0.9910	0.0709	1.4	1.10	0.100745	0.160	-
2.1	7.0	977.0	100.0	90.0	30.0	0	0.8	1.0	1.0	0.75	0	0.3215	0.2809	1.70	0.32	0.28	0	5	1.1	5	5	5	0.9763	0.0799	1.4	1.10	0.088250	0.140	1.75
3.0	10.0	974.0	100.0	90.0	30.0	0	0.8	1.0	1.0	0.8	0	0.4715	0.3373	1.70	0.47	0.34	0	5	1.1	5	5	5	0.9600	0.0959	1.4	1.09	0.088250	0.138	1.44
4.0	13.0	971.0	100.0	90.0	30.0	10	0.8	1.0	1.0	0.85	7	0.6215	0.3937	1.63	0.62	0.39	11	5	1.1	17	5	16	0.9425	0.1064	1.4	1.10	0.168687	0.268	2.52
5.8	19.0	965.0	100.0	90.0	30.0	3	0.8	1.0	1.0	0.85	2	0.9215	0.5065	1.44	0.92	0.51	3	5	1.1	8	5	8	0.9040	0.1176	1.4	1.06	0.106502	0.163	1.39
6.7	22.0	962.0	100.0	90.0	30.0	13	0.8	1.0	1.0	0.95	10	1.0715	0.5629	1.36	1.07	0.56	13	5	1.1	20	5	19	0.8834	0.1202	1.4	1.08	0.192300	0.299	2.49
7.6	25.0	959.0	100.0	90.0	30.0	12	0.8	1.0	1.0	0.95	9	1.2215	0.6193	1.30	1.22	0.62	12	5	1.1	18	5	17	0.8623	0.1216	1.4	1.06	0.175860	0.270	2.22
8.5	28.0	956.0	100.0	90.0	30.0	17	0.8	1.0	1.0	0.95	13	1.3715	0.6757	1.24	1.37	0.68	16	5	1.1	22.4	5	21	0.8406	0.1220	1.4	1.06	0.224560	0.344	2.82
9.4	31.0	953.0	100.0	90.0	30.0	22	0.8	1.0	1.0	0.95	17	1.5215	0.7321	1.19	1.52	0.73	20	5	1.1	27	5	25	0.8187	0.1216	1.4	1.06	0.298075	0.455	3.74
10.4	34.0	950.0	100.0	90.0	30.0	25	0.8	1.0	1.0	1	20	1.6715	0.7885	1.15	1.67	0.79	23	5	1.1	30	5	28	0.7966	0.1207	1.4	1.05	0.399670	0.607	5.03
11.3	37.0	947.0	100.0	90.0	30.0	15	0.8	1.0	1.0	1	12	1.8215	0.8449	1.11	1.82	0.84	13	5	1.1	19	5	19	0.7745	0.1194	1.4	1.03	0.191047	0.283	2.37
12.2	40.0	944.0	100.0	90.0	30.0	37	0.8	1.0	1.0	1	30	1.9715	0.9013	1.08	1.97	0.90	32	5	1.1	40	5	37	0.7525	0.1177	1.4	1.04	1.851274	2.785	23.67

Notes:

FS_{min} 1.39

- σ'_{vo} Vertical Effective Stress (tons/ft^2)
- $(N_1)_{60}$ Standardized and Normalized SPT blow counts (blows/foot)
- r_d Stress Reduction Factor (dimensionless)
- a_{max} Peak horizontal ground surface acceleration (in g)
- CSR Cyclic stress ratio based on design earthquake (dimensionless)
- $CRR_{7.5}$ Cyclic resistance ratio based on an earthquake of magnitude 7.5 (dimensionless)
- MSF Magnitude scaling factor (dimensionless)
- K_σ High overburden stress correction factor (dimensionless)
- K_α Ground slope correction factor (dimensionless) [advised not to be used by reference]
- CRR Corrected cyclic resistance ratio based on overburden pressure and ground surface slope (dimensionless) = CRR7.5 * Kσ * Kα
- FS_L Factor of safety against liquefaction (dimensionless)

References:

(1) 1. Idriss, I. M., and Boulanger, R. W. (2008).Soil liquefaction during earthquakes. Monograph MNO-12, Earthquake Engineering Research Institute, Oakland, CA, 261 pp.

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Richmond Power and Light
Whitewater Valley Station
Surface Impoundment
Liquefaction Analysis

G.S. Elev. = 984.0
$\gamma_{overburden}$ = 100.0 (pcf)

W.T. Elev. = 975.6
a_{max} 0.11
Est. EQ Mag 6.1

Bottom Elev. = 984.0
Top Elev. = 984.0

																		Idriss and Boulanger (2008)								
Test Depth (m)	Test Depth (ft)	Test Elevation (ft)	Saturated Unit Weight (pcf)	Moist Unit Weight (pcf)	Fines Content (%)	N	C_E	C_B	C_S	C_R	N_{60}	Existing σ_{vo} (tsf)	Existing σ'_{vo} (tsf)	C_N	Design σ_{vo} (tsf)	Design σ_{vo}' (tsf)	$(N_1)_{60}$	ΔN for fines content	$(N_1)_{60cs}$	r_d	CSR	MSF	K_σ	CRR for M=7.5 and σ_{vc}'=1atm	CRR	Factor of Safety
0.3	1.0	983.0	100.0	90.0	30.0	2.00	0.80	1.0	1.0	0.75	1	0.0450	0.0450	1.70	0.05	0.05	2	5	7	1.0041	0.072	1.4	1.10	0.10	0.160	-
1.2	4.0	980.0	100.0	90.0	30.0	0.00	0.80	1.0	1.0	0.75	0	0.1800	0.1800	1.70	0.18	0.18	0	5	5	0.9910	0.071	1.4	1.10	0.09	0.140	-
2.1	7.0	977.0	100.0	90.0	30.0	0.00	0.80	1.0	1.0	0.75	0	0.3150	0.3150	1.70	0.32	0.32	0	5	5	0.9763	0.070	1.4	1.09	0.09	0.139	-
3.0	10.0	974.0	100.0	90.0	30.0	0.00	0.80	1.0	1.0	0.80	0	0.4580	0.4081	1.60	0.46	0.41	0	5	5	0.9600	0.077	1.4	1.07	0.09	0.137	1.77
4.9	16.0	968.0	100.0	90.0	30.0	0.00	0.80	1.0	1.0	0.85	0	0.7580	0.5209	1.42	0.76	0.52	0	5	5	0.9237	0.096	1.4	1.05	0.09	0.134	1.40
5.8	19.0	965.0	100.0	90.0	30.0	6.00	0.80	1.0	1.0	0.85	4	0.9080	0.5773	1.34	0.91	0.58	5	5	11	0.9040	0.102	1.4	1.06	0.12	0.189	1.86
6.7	22.0	962.0	100.0	90.0	30.0	7.00	0.80	1.0	1.0	0.95	5	1.0580	0.6337	1.28	1.06	0.63	7	5	12	0.8834	0.105	1.4	1.05	0.13	0.203	1.92
7.6	25.0	959.0	100.0	90.0	30.0	5.00	0.80	1.0	1.0	0.95	4	1.2080	0.6901	1.23	1.21	0.69	5	5	10	0.8623	0.108	1.4	1.04	0.12	0.177	1.64
8.5	28.0	956.0	100.0	90.0	30.0	7.00	0.80	1.0	1.0	0.95	5	1.3580	0.7465	1.18	1.36	0.75	6	5	12	0.8406	0.109	1.4	1.03	0.13	0.194	1.77
9.4	31.0	953.0	100.0	90.0	30.0	30.00	0.80	1.0	1.0	0.95	23	1.5080	0.8029	1.14	1.51	0.80	26	5	31	0.8187	0.110	1.4	1.06	0.59	0.892	8.11
10.4	34.0	950.0	100.0	90.0	30.0	30.00	0.80	1.0	1.0	1.00	24	1.6580	0.8593	1.10	1.66	0.86	26	5	32	0.7966	0.110	1.4	1.04	0.63	0.943	8.58
11.3	37.0	947.0	100.0	90.0	30.0	37.00	0.80	1.0	1.0	1.00	30	1.8080	0.9157	1.07	1.81	0.92	32	5	37	0.7745	0.109	1.4	1.04	1.74	2.603	23.81
12.2	40.0	944.0	100.0	90.0	30.0	38.00	0.80	1.0	1.0	1.00	30	1.9580	0.9721	1.04	1.96	0.97	32	5	37	0.7525	0.108	1.4	1.02	1.69	2.495	23.02

Notes:

FS_{min} 1.40

- σ'_{vo} Vertical Effective Stress (tons/ft^2)
- $(N_1)_{60}$ Standardized and Normalized SPT blow counts (blows/foot)
- r_d Stress Reduction Factor (dimensionless)
- a_{max} Peak horizontal ground surface acceleration (in g)
- CSR Cyclic stress ratio based on design earthquake (dimensionless)
- $CRR_{7.5}$ Cyclic resistance ratio based on an earthquake of magnitude 7.5 (dimensionless)
- MSF Magnitude scaling factor (dimensionless)
- K_σ High overburden stress correction factor (dimensionless)
- K_α Ground slope correction factor (dimensionless) [advised not to be used by reference]
- CRR Corrected cyclic resistance ratio based on overburden pressure and ground surface slope (dimensionless) = CRR7.5 * Kσ * Kα
- FS_L Factor of safety against liquefaction (dimensionless)

References:

(1) 1. Idriss, I. M., and Boulanger, R. W. (2008).Soil liquefaction during earthquakes. Monograph MNO-12, Earthquake Engineering Research Institute, Oakland, CA, 261 pp.

Richmond Power and Light
Whitewater Valley Station
Surface Impoundment
Liquefaction Analysis

C151119.02
By: AB 07/29/16
Ckd by: MURAOTI 11/11/2016

gai consultants

G.S. Elev. = 984.0
$\gamma_{overburden}$ = 100.0 (pcf)

W.T. Elev. = 975.1
a_{max} 0.11
Est. EQ Mag 6.1

Bottom Elev. = 984.0
Top Elev. = 984.0

Test Depth (m)	Test Depth (ft)	Test Elevation (ft)	Saturated Unit Weight (pcf)	Moist Unit Weight (pcf)	Fines Content (%)	N	C_E	C_B	C_S	C_R	N_{60}	Existing σ_{vo} (tsf)	Existing σ'_{vo} (tsf)	C_N	Design σ_{vo} (tsf)	Design σ_{vo}' (tsf)	$(N_1)_{60}$	ΔN for fines content (Idriss and Boulanger (2008))	$(N_1)_{60cs}$	r_d	CSR	MSF	K_σ	CRR for M=7.5 and σ_{vc}'=1atm	CRR	Factor of Safety
0.3	1.0	983.0	100.0	90.0	30.0	2.00	0.80	1.0	1.0	0.75	1	0.0450	0.0450	1.70	0.05	0.05	2	5	7	1.0041	0.072	1.4	1.10	0.10	0.160	-
1.2	4.0	980.0	100.0	90.0	30.0	0.00	0.80	1.0	1.0	0.75	0	0.1800	0.1800	1.70	0.18	0.18	0	5	5	0.9910	0.071	1.4	1.10	0.09	0.140	-
3.0	10.0	974.0	100.0	90.0	30.0	0.00	0.80	1.0	1.0	0.80	0	0.4555	0.4212	1.57	0.46	0.42	0	5	5	0.9600	0.074	1.4	1.07	0.09	0.136	1.84
4.0	13.0	971.0	100.0	90.0	30.0	0.00	0.80	1.0	1.0	0.85	0	0.6055	0.4776	1.48	0.61	0.48	0	5	5	0.9425	0.085	1.4	1.06	0.09	0.135	1.58
5.8	19.0	965.0	100.0	90.0	30.0	9.00	0.80	1.0	1.0	0.85	6	0.9055	0.5904	1.33	0.91	0.59	8	5	14	0.9040	0.099	1.4	1.06	0.14	0.220	2.22
6.7	22.0	962.0	100.0	90.0	30.0	11.00	0.80	1.0	1.0	0.95	8	1.0555	0.6468	1.27	1.06	0.65	11	5	16	0.8834	0.103	1.4	1.05	0.16	0.251	2.43
7.6	25.0	959.0	100.0	90.0	30.0	32.00	0.80	1.0	1.0	0.95	24	1.2055	0.7032	1.22	1.21	0.70	30	5	35	0.8623	0.106	1.4	1.10	1.11	1.760	16.7

Notes:

FS_{min} 1.58

- σ'_{vo} Vertical Effective Stress (tons/ft^2)
- $(N_1)_{60}$ Standardized and Normalized SPT blow counts (blows/foot)
- r_d Stress Reduction Factor (dimensionless)
- a_{max} Peak horizontal ground surface acceleration (in g)
- CSR Cyclic stress ratio based on design earthquake (dimensionless)
- $CRR_{7.5}$ Cyclic resistance ratio based on an earthquake of magnitude 7.5 (dimensionless)
- MSF Magnitude scaling factor (dimensionless)
- K_σ High overburden stress correction factor (dimensionless)
- K_α Ground slope correction factor (dimensionless) [advised not to be used by reference]
- CRR Corrected cyclic resistance ratio based on overburden pressure and ground surface slope (dimensionless) = CRR7.5 * Kσ * Kα
- FS_L Factor of safety against liquefaction (dimensionless)

References:

(1) 1. Idriss, I. M., and Boulanger, R. W. (2008).Soil liquefaction during earthquakes. Monograph MNO-12, Earthquake Engineering Research Institute, Oakland, CA, 261 pp.

gai consultants

Richmond Power and Light
Whitewater Valley Station
Surface Impoundment
Liquefaction Analysis

C151119.02
By: AB 07/29/16
Ckd by:MURAOTI 11/11/2016

G.S. Elev. = 996.0
$\gamma_{overburden}$ = 100.0 (pcf)

W.T. Elev. = 979.0
a_{max} 0.11
Est. EQ Mag 6.1

Bottom Elev. = 996.0
Top Elev. = 996.0

																					Idriss and Boulanger (2008)								
Test Depth (m)	Test Depth (ft)	Test Elevation (ft)	Saturated Unit Weight (pcf)	Moist Unit Weight (pcf)	Fines Content (%)	N	C_E	C_B	C_S	C_R	N_{60}	Existing σ_{vo} (tsf)	Existing σ'_{vo} (tsf)	C_N	Design σ_{vo} (tsf)	Design σ_{vo}' (tsf)	$(N_1)_{60}$	α	β	$(N_1)_{60cs}$	ΔN for fines content	$(N_1)_{60cs}$	r_d	CSR	MSF	K_σ	CRR for M=7.5 and σ_{vc}'=1atm	CRR	Factor of Safety
0.3	1.0	995.0	100.0	90.0	30.0	5.00	0.80	1.0	1.0	0.75	3	0.0450	0.0450	1.70	0.05	0.05	5	5	1.1	10	5	10	1.0041	0.072	1.4	1.10	0.12	0.193	-
1.2	4.0	992.0	100.0	90.0	30.0	23.00	0.80	1.0	1.0	0.75	14	0.1800	0.1800	1.70	0.18	0.18	23	5	1.1	31	5	29	0.9910	0.071	1.4	1.10	0.42	0.667	-
2.1	7.0	989.0	100.0	90.0	30.0	6.00	0.80	1.0	1.0	0.75	4	0.3150	0.3150	1.70	0.32	0.32	6	5	1.1	11	5	11	0.9763	0.070	1.4	1.10	0.13	0.204	-
3.0	10.0	986.0	100.0	90.0	30.0	4.00	0.80	1.0	1.0	0.80	3	0.4500	0.4500	1.52	0.45	0.45	4	5	1.1	9	5	9	0.9600	0.069	1.4	1.08	0.11	0.175	-
4.0	13.0	983.0	100.0	90.0	30.0	3.00	0.80	1.0	1.0	0.85	2	0.5850	0.5850	1.34	0.59	0.59	3	5	1.1	8	5	8	0.9425	0.067	1.4	1.05	0.11	0.159	-
4.9	16.0	980.0	100.0	90.0	30.0	1.00	0.80	1.0	1.0	0.85	1	0.7200	0.7200	1.20	0.72	0.72	1	5	1.1	6	5	6	0.9237	0.066	1.4	1.03	0.09	0.138	-
5.8	19.0	977.0	100.0	90.0	30.0	1.00	0.80	1.0	1.0	0.85	1	0.8650	0.8026	1.14	0.87	0.80	1	5	1.1	6	5	6	0.9040	0.070	1.4	1.02	0.09	0.137	1.96
7.6	25.0	971.0	100.0	90.0	30.0	1.00	0.80	1.0	1.0	0.95	1	1.1650	0.9154	1.07	1.17	0.92	1	5	1.1	6	5	6	0.8623	0.078	1.4	1.01	0.09	0.136	1.73
8.5	28.0	968.0	100.0	90.0	30.0	1.00	0.80	1.0	1.0	0.95	1	1.3150	0.9718	1.04	1.32	0.97	1	5	1.1	5.6	5	6	0.8406	0.081	1.4	1.01	0.09	0.135	1.66
9.4	31.0	965.0	100.0	90.0	30.0	1.00	0.80	1.0	1.0	0.95	1	1.4650	1.0282	1.01	1.47	1.03	1	5	1.1	6	5	6	0.8187	0.083	1.4	1.00	0.09	0.134	1.61
10.4	34.0	962.0	100.0	90.0	30.0	4.00	0.80	1.0	1.0	1.00	3	1.6150	1.0846	0.98	1.62	1.08	3	5	1.1	8	5	9	0.7966	0.085	1.4	1.00	0.11	0.155	1.83
11.3	37.0	959.0	100.0	90.0	30.0	16.00	0.80	1.0	1.0	1.00	13	1.7650	1.1410	0.96	1.77	1.14	12	5	1.1	18	5	18	0.7745	0.086	1.4	0.99	0.18	0.257	3.00
12.2	40.0	956.0	100.0	90.0	30.0	20.00	0.80	1.0	1.0	1.00	16	1.9150	1.1974	0.93	1.92	1.20	15	5	1.1	21	5	20	0.7525	0.086	1.4	0.98	0.21	0.297	3.45

Notes:

FS_{min} 1.61

σ'_{vo} Vertical Effective Stress (tons/ft^2)
$(N_1)_{60}$ Standardized and Normalized SPT blow counts (blows/foot)
r_d Stress Reduction Factor (dimensionless)
a_{max} Peak horizontal ground surface acceleration (in g)
CSR Cyclic stress ratio based on design earthquake (dimensionless)
$CRR_{7.5}$ Cyclic resistance ratio based on an earthquake of magnitude 7.5 (dimensionless)
MSF Magnitude scaling factor (dimensionless)
K_σ High overburden stress correction factor (dimensionless)
K_α Ground slope correction factor (dimensionless) [advised not to be used by reference]
CRR Corrected cyclic resistance ratio based on overburden pressure and ground surface slope (dimensionless) = CRR7.5 * Kσ * Kα
FS_L Factor of safety against liquefaction (dimensionless)

References:

(1) 1. Idriss, I. M., and Boulanger, R. W. (2008).Soil liquefaction during earthquakes. Monograph MNO-12, Earthquake Engineering Research Institute, Oakland, CA, 261 pp.

gai consultants

Richmond Power and Light
Whitewater Valley Station
Surface Impoundment
Liquefaction Analysis

G.S. Elev. = 986.0
$\gamma_{overburden}$ = 100.0 (pcf)

W.T. Elev. = 969.4
a_{max} 0.11
Est. EQ Mag 6.1

Bottom Elev. = 986.0
Top Elev. = 986.0

																					Idriss and Boulanger (2008)								
Test Depth (m)	Test Depth (ft)	Test Elevation (ft)	Saturated Unit Weight (pcf)	Moist Unit Weight (pcf)	Fines Content (%)	N	C_E	C_B	C_S	C_R	N_{60}	Existing σ_{vo} (tsf)	Existing σ'_{vo} (tsf)	C_N	Design σ_{vo} (tsf)	Design σ_{vo}' (tsf)	$(N_1)_{60}$	α	β	$(N_1)_{60cs}$	ΔN for fines content	$(N_1)_{60cs}$	r_d	CSR	MSF	K_σ	CRR for M=7.5 and σ_{vc}'=1atm	CRR	Factor of Safety
0.3	1.0	985.0	100.0	90.0	30.0	5.00	0.80	1.00	1.00	0.75	3	0.0450	0.0450	1.70	0.05	0.05	5	5	1.1	10	5	10	1.0041	0.072	1.4	1.10	0.12	0.193	-
1.2	4.0	982.0	100.0	90.0	30.0	10.00	0.80	1.00	1.00	0.75	6	0.1800	0.1800	1.70	0.18	0.18	10	5	1.1	16	5	16	0.9910	0.071	1.4	1.10	0.16	0.256	-
2.1	7.0	979.0	100.0	90.0	30.0	2.00	0.80	1.00	1.00	0.75	1	0.3150	0.3150	1.70	0.32	0.32	2	5	1.1	7	5	7	0.9763	0.070	1.4	1.10	0.10	0.160	-
3.0	10.0	976.0	100.0	90.0	30.0	0.00	0.80	1.00	1.00	0.80	0	0.4500	0.4500	1.52	0.45	0.45	0	5	1.1	5	5	5	0.9600	0.069	1.4	1.06	0.09	0.136	-
4.0	13.0	973.0	100.0	90.0	30.0	0.00	0.80	1.00	1.00	0.85	0	0.5850	0.5850	1.34	0.59	0.59	0	5	1.1	5	5	5	0.9425	0.067	1.4	1.04	0.09	0.133	-
4.9	16.0	970.0	100.0	90.0	30.0	0.00	0.80	1.00	1.00	0.85	0	0.7200	0.7200	1.20	0.72	0.72	0	5	1.1	5	5	5	0.9237	0.066	1.4	1.03	0.09	0.131	-
5.8	19.0	967.0	100.0	90.0	30.0	0.00	0.80	1.00	1.00	0.85	0	0.8670	0.7921	1.15	0.87	0.79	0	5	1.1	5	5	5	0.9040	0.071	1.4	1.02	0.09	0.130	1.84
6.7	22.0	964.0	100.0	90.0	30.0	8.00	0.80	1.00	1.00	0.95	6	1.0170	0.8485	1.11	1.02	0.85	7	5	1.1	12	5	12	0.8834	0.076	1.4	1.02	0.13	0.196	2.59
7.6	25.0	961.0	100.0	90.0	30.0	21.00	0.80	1.00	1.00	0.95	16	1.1670	0.9049	1.07	1.17	0.90	17	5	1.1	23.6	5	23	0.8623	0.080	1.4	1.02	0.24	0.355	4.47
8.5	28.0	958.0	100.0	90.0	30.0	21.00	0.80	1.00	1.00	0.95	16	1.3170	0.9613	1.04	1.32	0.96	17	5	1.1	23	5	22	0.8406	0.082	1.4	1.01	0.23	0.340	4.13
9.4	31.0	955.0	100.0	90.0	30.0	24.00	0.80	1.00	1.00	0.95	18	1.4670	1.0177	1.01	1.47	1.02	18	5	1.1	25	5	24	0.8187	0.084	1.4	1.00	0.26	0.384	4.55
10.4	34.0	952.0	100.0	90.0	30.0	17.00	0.80	1.00	1.00	1.00	14	1.6170	1.0741	0.99	1.62	1.07	13	5	1.1	19	5	19	0.7966	0.086	1.4	1.00	0.19	0.276	3.22
11.3	37.0	949.0	100.0	90.0	30.0	15.00	0.80	1.00	1.00	1.00	12	1.7670	1.1305	0.96	1.77	1.13	12	5	1.1	17	5	17	0.7745	0.087	1.4	0.99	0.17	0.247	2.86
12.2	40.0	946.0	100.0	90.0	30.0	18.00	0.80	1.00	1.00	1.00	14	1.9170	1.1869	0.94	1.92	1.19	14	5	1.1	20	5	19	0.7525	0.087	1.4	0.98	0.19	0.274	3.15

Notes:

σ'_{vo} Vertical Effective Stress (tons/ft^2)
$(N_1)_{60}$ Standardized and Normalized SPT blow counts (blows/foot)
r_d Stress Reduction Factor (dimensionless)
a_{max} Peak horizontal ground surface acceleration (in g)
CSR Cyclic stress ratio based on design earthquake (dimensionless)
$CRR_{7.5}$ Cyclic resistance ratio based on an earthquake of magnitude 7.5 (dimensionless)
MSF Magnitude scaling factor (dimensionless)
K_σ High overburden stress correction factor (dimensionless)
K_α Ground slope correction factor (dimensionless) [advised not to be used by reference]
CRR Corrected cyclic resistance ratio based on overburden pressure and ground surface slope (dimensionless) = CRR7.5 * Kσ * Kα
FS_L Factor of safety against liquefaction (dimensionless)

FS_{min} 1.84

References:

(1) 1. Idriss, I. M., and Boulanger, R. W. (2008).Soil liquefaction during earthquakes. Monograph MNO-12, Earthquake Engineering Research Institute, Oakland, CA, 261 pp.

Richmond Power and Light
Whitewater Valley Station
Surface Impoundment
Liquefaction Analysis

G.S. Elev. = 986.0
$\gamma_{overburden}$ = 100.0 (pcf)

W.T. Elev. = 979.8
a_{max} 0.11
Est. EQ Mag 6.1

Bottom Elev. = 986.0
Top Elev. = 986.0

																				Idriss and Boulanger (2008)								
Test Depth (m)	Test Depth (ft)	Test Elevation (ft)	Saturated Unit Weight (pcf)	Moist Unit Weight (pcf)	Fines Content (%)	N	C_E	C_B	C_S	C_R	N_{60}	Existing σ_{vo} (tsf)	Existing σ'_{vo} (tsf)	C_N	Design σ_{vo} (tsf)	Design σ_{vo}' (tsf)	$(N_1)_{60}$	α	β	$(N_1)_{60cs}$	ΔN for fines content	$(N_1)_{60cs}$	r_d	CSR	MSF	K_σ	CRR for M=7.5 and σ_{vc}'=1atm	CRR	Factor of Safety
0.3	1.0	985.0	100.0	90.0	30.0	22.00	0.80	1.0	1.0	0.75	13	0.0450	0.0450	1.70	0.05	0.05	22	5	1.1	29	5	28	1.0041	0.072	1.4	1.10	0.38	0.597	-
1.2	4.0	982.0	100.0	90.0	30.0	9.00	0.80	1.0	1.0	0.75	5	0.1800	0.1800	1.70	0.18	0.18	9	5	1.1	15	5	15	0.9910	0.071	1.4	1.10	0.15	0.242	-
2.1	7.0	979.0	100.0	90.0	30.0	8.00	0.80	1.0	1.0	0.75	5	0.3190	0.2940	1.70	0.32	0.29	8	5	1.1	14	5	14	0.9763	0.076	1.4	1.10	0.14	0.229	3.02
3.0	10.0	976.0	100.0	90.0	30.0	4.00	0.80	1.0	1.0	0.80	3	0.4690	0.3504	1.70	0.47	0.35	4	5	1.1	9	5	10	0.9600	0.092	1.4	1.10	0.12	0.184	2.01
4.0	13.0	973.0	100.0	90.0	30.0	5.00	0.80	1.0	1.0	0.85	3	0.6190	0.4068	1.60	0.62	0.41	5	5	1.1	11	5	11	0.9425	0.103	1.4	1.09	0.12	0.195	1.90
4.9	16.0	970.0	100.0	90.0	30.0	5.00	0.80	1.0	1.0	0.85	3	0.7690	0.4632	1.50	0.77	0.46	5	5	1.1	10	5	10	0.9237	0.110	1.4	1.08	0.12	0.188	1.72
5.8	19.0	967.0	100.0	90.0	30.0	10.00	0.80	1.0	1.0	0.85	7	0.9190	0.5196	1.42	0.92	0.52	10	5	1.1	15	5	15	0.9040	0.114	1.4	1.08	0.16	0.243	2.12
6.7	22.0	964.0	100.0	90.0	30.0	7.00	0.80	1.0	1.0	0.95	5	1.0690	0.5760	1.35	1.07	0.58	7	5	1.1	13	5	13	0.8834	0.117	1.4	1.06	0.14	0.209	1.78
7.6	25.0	961.0	100.0	90.0	30.0	15.00	0.80	1.0	1.0	0.95	11	1.2190	0.6324	1.28	1.22	0.63	15	5	1.1	20.8	5	20	0.8623	0.119	1.4	1.07	0.21	0.317	2.67
8.5	28.0	958.0	100.0	90.0	30.0	27.00	0.80	1.0	1.0	0.95	21	1.3690	0.6888	1.23	1.37	0.69	25	5	1.1	32	5	31	0.8406	0.119	1.4	1.09	0.53	0.826	6.92
9.4	31.0	955.0	100.0	90.0	30.0	45.00	0.80	1.0	1.0	0.95	34	1.5190	0.7452	1.18	1.52	0.75	40	5	1.1	49	5	46	0.8187	0.119	1.4	1.10	2.00	3.171	26.58
10.4	34.0	952.0	100.0	90.0	30.0	15.00	0.80	1.0	1.0	1.00	12	1.6690	0.8016	1.14	1.67	0.80	14	5	1.1	20	5	19	0.7966	0.119	1.4	1.03	0.19	0.291	2.45
11.3	37.0	949.0	100.0	90.0	30.0	18.00	0.80	1.0	1.0	1.00	14	1.8190	0.8580	1.10	1.82	0.86	16	5	1.1	22	5	21	0.7745	0.117	1.4	1.03	0.22	0.329	2.80
12.2	40.0	946.0	100.0	90.0	30.0	18.00	0.80	1.0	1.0	1.00	14	1.9690	0.9144	1.07	1.97	0.91	15	5	1.1	22	5	21	0.7525	0.116	1.4	1.02	0.22	0.316	2.73

Notes:

σ'_{vo} Vertical Effective Stress (tons/ft^2)
$(N_1)_{60}$ Standardized and Normalized SPT blow counts (blows/foot)
r_d Stress Reduction Factor (dimensionless)
a_{max} Peak horizontal ground surface acceleration (in g)
CSR Cyclic stress ratio based on design earthquake (dimensionless)
$CRR_{7.5}$ Cyclic resistance ratio based on an earthquake of magnitude 7.5 (dimensionless)
MSF Magnitude scaling factor (dimensionless)
K_σ High overburden stress correction factor (dimensionless)
K_α Ground slope correction factor (dimensionless) [advised not to be used by reference]
CRR Corrected cyclic resistance ratio based on overburden pressure and ground surface slope (dimensionless) = CRR7.5 * Kσ * Kα
FS_L Factor of safety against liquefaction (dimensionless)

FS_{min} 1.72

References:

(1) 1. Idriss, I. M., and Boulanger, R. W. (2008).Soil liquefaction during earthquakes. Monograph MNO-12, Earthquake Engineering Research Institute, Oakland, CA, 261 pp.

Richmond Power and Light
Whitewater Valley Station
Surface Impoundment
Liquefaction Analysis

G.S. Elev. = 983.0
$\gamma_{overburden}$ = 100.0 (pcf)

W.T. Elev. = 973.0
a_{max} 0.11
Est. EQ Mag 6.1

Bottom Elev. = 983.0
Top Elev. = 983.0

																				Idriss and Boulanger (2008)								
Test Depth (m)	Test Depth (ft)	Test Elevation (ft)	Saturated Unit Weight (pcf)	Moist Unit Weight (pcf)	Fines Content (%)	N	C_E	C_B	C_S	C_R	N_{60}	Existing σ_{vo} (tsf)	Existing σ'_{vo} (tsf)	C_N	Design σ_{vo} (tsf)	Design σ_{vo}' (tsf)	$(N_1)_{60}$	α	β	$(N_1)_{60cs}$	ΔN for fines content	$(N_1)_{60cs}$	r_d	CSR	MSF	K_σ	CRR for M=7.5 and σ_{vc}'=1atm	CRR	Factor of Safety
0.3	1.0	982.0	100.0	90.0	30.0	3.00	0.80	1.0	1.0	0.75	2	0.0450	0.0450	1.70	0.05	0.05	3	5	1.1	8	5	8	1.0041	0.072	1.4	1.10	0.11	0.170	-
1.2	4.0	979.0	100.0	90.0	30.0	1.00	0.80	1.0	1.0	0.75	1	0.1800	0.1800	1.70	0.18	0.18	1	5	1.1	6	5	6	0.9910	0.071	1.4	1.10	0.09	0.150	-
2.1	7.0	976.0	100.0	90.0	30.0	1.00	0.80	1.0	1.0	0.75	1	0.3150	0.3150	1.70	0.32	0.32	1	5	1.1	6	5	6	0.9763	0.070	1.4	1.10	0.09	0.149	-
3.0	10.0	973.0	100.0	90.0	30.0	0.00	0.80	1.0	1.0	0.80	0	0.4500	0.4500	1.52	0.45	0.45	0	5	1.1	5	5	5	0.9600	0.069	1.4	1.06	0.09	0.136	1.98
4.0	13.0	970.0	100.0	90.0	30.0	1.00	0.80	1.0	1.0	0.85	1	0.6000	0.5064	1.44	0.60	0.51	1	5	1.1	6	5	6	0.9425	0.080	1.4	1.06	0.09	0.144	1.80
4.9	16.0	967.0	100.0	90.0	30.0	0.00	0.80	1.0	1.0	0.85	0	0.7500	0.5628	1.36	0.75	0.56	0	5	1.1	5	5	5	0.9237	0.088	1.4	1.05	0.09	0.133	1.52
6.4	21.0	962.0	100.0	90.0	30.0	0.00	0.80	1.0	1.0	0.95	0	1.0000	0.6568	1.26	1.00	0.66	0	5	1.1	5	5	5	0.8904	0.097	1.4	1.04	0.09	0.132	1.36
7.9	26.0	957.0	100.0	90.0	30.0	2.00	0.80	1.0	1.0	0.95	2	1.2500	0.7508	1.18	1.25	0.75	2	5	1.1	7	5	7	0.8551	0.102	1.4	1.03	0.10	0.147	1.44
9.4	31.0	952.0	100.0	90.0	30.0	7.00	0.80	1.0	1.0	0.95	5	1.5000	0.8448	1.11	1.50	0.84	6	5	1.1	11.2	5	11	0.8187	0.104	1.4	1.02	0.13	0.187	1.80
10.4	34.0	949.0	100.0	90.0	30.0	11.00	0.80	1.0	1.0	1.00	9	1.6500	0.9012	1.08	1.65	0.90	9	5	1.1	15	5	15	0.7966	0.104	1.4	1.02	0.15	0.227	2.18
11.3	37.0	946.0	100.0	90.0	30.0	23.00	0.80	1.0	1.0	1.00	18	1.8000	0.9576	1.04	1.80	0.96	19	5	1.1	26	5	25	0.7745	0.104	1.4	1.01	0.28	0.410	3.94

Notes:

σ'_{vo} Vertical Effective Stress (tons/ft^2)
$(N_1)_{60}$ Standardized and Normalized SPT blow counts (blows/foot)
r_d Stress Reduction Factor (dimensionless)
a_{max} Peak horizontal ground surface acceleration (in g)
CSR Cyclic stress ratio based on design earthquake (dimensionless)
$CRR_{7.5}$ Cyclic resistance ratio based on an earthquake of magnitude 7.5 (dimensionless)
MSF Magnitude scaling factor (dimensionless)
K_σ High overburden stress correction factor (dimensionless)
K_α Ground slope correction factor (dimensionless) [advised not to be used by reference]
CRR Corrected cyclic resistance ratio based on overburden pressure and ground surface slope (dimensionless) = CRR7.5 * Kσ * Kα
FS_L Factor of safety against liquefaction (dimensionless)

FS_{min} 1.36

References:

(1) 1. Idriss, I. M., and Boulanger, R. W. (2008).Soil liquefaction during earthquakes. Monograph MNO-12, Earthquake Engineering Research Institute, Oakland, CA, 261 pp.

gai consultants

Richmond Power and Light
Whitewater Valley Station
Surface Impoundment
Liquefaction Analysis

C151119.25
By: RRJ 04/06/23
Checked by: AB 04/07/23

G.S. Elev. = 983.0
$\gamma_{overburden}$ = 100.0 (pcf)

W.T. Elev. = 973.0
a_{max} 0.11
Est. EQ Mag 6.1

Bottom Elev. = 983.0
Top Elev. = 983.0

																					Idriss and Boulanger (2008)								
Test Depth (m)	Test Depth (ft)	Test Elevation (ft)	Saturated Unit Weight (pcf)	Moist Unit Weight (pcf)	Fines Content (%)	N	C_E	C_B	C_S	C_R	N_{60}	Existing σ_{vo} (tsf)	Existing σ'_{vo} (tsf)	C_N	Design σ_{vo} (tsf)	Design σ_{vo}' (tsf)	$(N_1)_{60}$	α	β	$(N_1)_{60cs}$	ΔN for fines content	$(N_1)_{60cs}$	r_d	CSR	MSF	K_σ	CRR for M=7.5 and σ_{vc}'=1atm	CRR	Factor of Safety
0.3	1.0	982.0	100.0	90.0	30.0	2.00	0.80	1.0	1.0	0.75	1	0.0450	0.0450	1.70	0.05	0.05	2	5	1.1	7	5	7	1.0041	0.072	1.4	1.10	0.10	0.160	-
1.2	4.0	979.0	100.0	90.0	30.0	0.00	0.80	1.0	1.0	0.75	0	0.1800	0.1800	1.70	0.18	0.18	0	5	1.1	5	5	5	0.9910	0.071	1.4	1.10	0.09	0.140	-
2.1	7.0	976.0	100.0	90.0	30.0	1.00	0.80	1.0	1.0	0.75	1	0.3150	0.3150	1.70	0.32	0.32	1	5	1.1	6	5	6	0.9763	0.070	1.4	1.10	0.09	0.149	-
3.0	10.0	973.0	100.0	90.0	30.0	2.00	0.80	1.0	1.0	0.80	1	0.4500	0.4500	1.52	0.45	0.45	2	5	1.1	7	5	7	0.9600	0.069	1.4	1.07	0.10	0.155	2.25
4.0	13.0	970.0	100.0	90.0	30.0	0.00	0.80	1.0	1.0	0.85	0	0.6000	0.5064	1.44	0.60	0.51	0	5	1.1	5	5	5	0.9425	0.080	1.4	1.06	0.09	0.134	1.68
4.9	16.0	967.0	100.0	90.0	30.0	5.00	0.80	1.0	1.0	0.85	3	0.7500	0.5628	1.36	0.75	0.56	5	5	1.1	10	5	10	0.9237	0.088	1.4	1.06	0.12	0.180	2.05
6.4	21.0	962.0	100.0	90.0	30.0	16.00	0.80	1.0	1.0	0.95	12	1.0000	0.6568	1.26	1.00	0.66	15	5	1.1	22	5	21	0.8904	0.097	1.4	1.06	0.21	0.329	3.40
7.9	26.0	957.0	100.0	90.0	30.0	17.00	0.80	1.0	1.0	0.95	13	1.2500	0.7508	1.18	1.25	0.75	15	5	1.1	21	5	21	0.8551	0.102	1.4	1.04	0.21	0.322	3.16

Notes:

FS_{min} 1.68

σ'_{vo} Vertical Effective Stress (tons/ft^2)
$(N_1)_{60}$ Standardized and Normalized SPT blow counts (blows/foot)
r_d Stress Reduction Factor (dimensionless)
a_{max} Peak horizontal ground surface acceleration (in g)
CSR Cyclic stress ratio based on design earthquake (dimensionless)
$CRR_{7.5}$ Cyclic resistance ratio based on an earthquake of magnitude 7.5 (dimensionless)
MSF Magnitude scaling factor (dimensionless)
K_σ High overburden stress correction factor (dimensionless)
K_α Ground slope correction factor (dimensionless) [advised not to be used by reference]
CRR Corrected cyclic resistance ratio based on overburden pressure and ground surface slope (dimensionless) = CRR7.5 * Kσ * Kα
FS_L Factor of safety against liquefaction (dimensionless)

References:

(1) 1. Idriss, I. M., and Boulanger, R. W. (2008).Soil liquefaction during earthquakes. Monograph MNO-12, Earthquake Engineering Research Institute, Oakland, CA, 261 pp.

gai consultants

Richmond Power and Light
Whitewater Valley Station
Surface Impoundment
Liquefaction Analysis

G.S. Elev. = 986.0
$\gamma_{overburden}$ = 100.0 (pcf)

W.T. Elev. = 976.0
a_{max} 0.11
Est. EQ Mag 6.1

Bottom Elev. = 986.0
Top Elev. = 986.0

																					Idriss and Boulanger (2008)								
Test Depth (m)	Test Depth (ft)	Test Elevation (ft)	Saturated Unit Weight (pcf)	Moist Unit Weight (pcf)	Fines Content (%)	N	C_E	C_B	C_S	C_R	N_{60}	Existing σ_{vo} (tsf)	Existing σ'_{vo} (tsf)	C_N	Design σ_{vo} (tsf)	Design σ_{vo}' (tsf)	$(N_1)_{60}$	α	β	$(N_1)_{60cs}$	ΔN for fines content	$(N_1)_{60cs}$	r_d	CSR	MSF	K_σ	CRR for M=7.5 and σ_{vc}'=1atm	CRR	Factor of Safety
0.3	1.0	985.0	100.0	90.0	30.0	3.00	0.80	1.0	1.0	0.75	2	0.0450	0.0450	1.70	0.05	0.05	3	5	1.1	8	5	8	1.0041	0.072	1.4	1.10	0.11	0.170	-
0.9	3.0	983.0	100.0	90.0	30.0	7.00	0.80	1.0	1.0	0.75	4	0.1350	0.1350	1.70	0.14	0.14	7	5	1.1	13	5	13	0.9956	0.071	1.4	1.10	0.14	0.216	-
1.5	5.0	981.0	100.0	90.0	30.0	8.00	0.80	1.0	1.0	0.75	5	0.2250	0.2250	1.70	0.23	0.23	8	5	1.1	14	5	14	0.9863	0.071	1.4	1.10	0.14	0.229	-
2.1	7.0	979.0	100.0	90.0	30.0	4.00	0.80	1.0	1.0	0.75	2	0.3150	0.3150	1.70	0.32	0.32	4	5	1.1	9	5	9	0.9763	0.070	1.4	1.10	0.11	0.181	-
2.7	9.0	977.0	100.0	90.0	30.0	2.00	0.80	1.0	1.0	0.75	1	0.4050	0.4050	1.61	0.41	0.41	2	5	1.1	7	5	7	0.9656	0.069	1.4	1.08	0.10	0.156	-
3.4	11.0	975.0	100.0	90.0	30.0	0.00	0.80	1.0	1.0	0.80	0	0.5000	0.4688	1.49	0.50	0.47	0	5	1.1	5	5	5	0.9543	0.073	1.4	1.06	0.09	0.135	1.86
4.0	13.0	973.0	100.0	90.0	30.0	0.00	0.80	1.0	1.0	0.85	0	0.6000	0.5064	1.44	0.60	0.51	0	5	1.1	5	5	5	0.9425	0.080	1.4	1.06	0.09	0.134	1.68
4.6	15.0	971.0	100.0	90.0	30.0	4.00	0.80	1.0	1.0	0.85	3	0.7000	0.5440	1.39	0.70	0.54	4	5	1.1	9	5	9	0.9301	0.086	1.4	1.06	0.11	0.171	2.00
5.2	17.0	969.0	100.0	90.0	30.0	7.00	0.80	1.0	1.0	0.85	5	0.8000	0.5816	1.34	0.80	0.58	6	5	1.1	12	5	12	0.9172	0.090	1.4	1.06	0.13	0.199	2.21
5.8	19.0	967.0	100.0	90.0	30.0	7.00	0.80	1.0	1.0	0.85	5	0.9000	0.6192	1.30	0.90	0.62	6	5	1.1	12	5	12	0.9040	0.094	1.4	1.05	0.13	0.196	2.08
6.4	21.0	965.0	100.0	90.0	30.0	6.00	0.80	1.0	1.0	0.95	5	1.0000	0.6568	1.26	1.00	0.66	6	5	1.1	11	5	11	0.8904	0.097	1.4	1.04	0.13	0.190	1.96
7.0	23.0	963.0	100.0	90.0	30.0	22.00	0.80	1.0	1.0	0.95	17	1.1000	0.6944	1.23	1.10	0.69	21	5	1.1	27	5	26	0.8764	0.099	1.4	1.07	0.31	0.481	4.85
7.6	25.0	961.0	100.0	90.0	30.0	11.00	0.80	1.0	1.0	0.95	8	1.2000	0.7320	1.19	1.20	0.73	10	5	1.1	16	5	15	0.8623	0.101	1.4	1.04	0.16	0.239	2.36
8.2	27.0	959.0	100.0	90.0	30.0	10.00	0.80	1.0	1.0	0.95	8	1.3000	0.7696	1.16	1.30	0.77	9	5	1.1	14	5	14	0.8479	0.102	1.4	1.03	0.15	0.223	2.18
8.8	29.0	957.0	100.0	90.0	30.0	18.00	0.80	1.0	1.0	0.95	14	1.4000	0.8072	1.14	1.40	0.81	16	5	1.1	22	5	21	0.8333	0.103	1.4	1.04	0.22	0.325	3.15
9.4	31.0	955.0	100.0	90.0	30.0	14.00	0.80	1.0	1.0	0.95	11	1.5000	0.8448	1.11	1.50	0.84	12	5	1.1	18	5	17	0.8187	0.104	1.4	1.02	0.18	0.260	2.50
10.1	33.0	953.0	100.0	90.0	30.0	16.00	0.80	1.0	1.0	1.00	13	1.6000	0.8824	1.09	1.60	0.88	14	5	1.1	20	5	19	0.8039	0.104	1.4	1.02	0.20	0.291	2.79

Notes:

σ'_{vo} Vertical Effective Stress (tons/ft^2)
$(N_1)_{60}$ Standardized and Normalized SPT blow counts (blows/foot)
r_d Stress Reduction Factor (dimensionless)
a_{max} Peak horizontal ground surface acceleration (in g)
CSR Cyclic stress ratio based on design earthquake (dimensionless)
$CRR_{7.5}$ Cyclic resistance ratio based on an earthquake of magnitude 7.5 (dimensionless)
MSF Magnitude scaling factor (dimensionless)
K_σ High overburden stress correction factor (dimensionless)
K_α Ground slope correction factor (dimensionless) [advised not to be used by reference]
CRR Corrected cyclic resistance ratio based on overburden pressure and ground surface slope (dimensionless) = CRR7.5 * Kσ * Kα
FS_L Factor of safety against liquefaction (dimensionless)

FS_{min} 1.68

References:

(1) 1. Idriss, I. M., and Boulanger, R. W. (2008).Soil liquefaction during earthquakes. Monograph MNO-12, Earthquake Engineering Research Institute, Oakland, CA, 261 pp.

Richmond Power and Light
Whitewater Valley Station
Surface Impoundment
Liquefaction Analysis

G.S. Elev. = 984.0
$\gamma_{overburden}$ = 100.0 (pcf)

W.T. Elev. = 974.0
a_{max} 0.11
Est. EQ Mag 6.1

Bottom Elev. = 984.0
Top Elev. = 984.0

																					Idriss and Boulanger (2008)							
Test Depth (m)	Test Depth (ft)	Test Elevation (ft)	Saturated Unit Weight (pcf)	Moist Unit Weight (pcf)	Fines Content (%)	N	C_E	C_B	C_S	C_R	N_{60}	Existing σ_{vo} (tsf)	Existing σ'_{vo} (tsf)	C_N	Design σ_{vo} (tsf)	Design σ_{vo}' (tsf)	$(N_1)_{60}$	α	β	$(N_1)_{60cs}$	ΔN for fines content	$(N_1)_{60cs}$	r_d	CSR	MSF	K_σ	CRR for M=7.5 and σ_{vc}'=1atm	CRR	Factor of Safety
0.3	1.0	983.0	100.0	90.0	30.0	2.00	0.80	1.0	1.0	0.75	1	0.0450	0.0450	1.70	0.05	0.05	2	5	1.1	7	5	7	1.0041	0.072	1.4	1.10	0.10	0.160	-
0.9	3.0	981.0	100.0	90.0	30.0	3.00	0.80	1.0	1.0	0.75	2	0.1350	0.1350	1.70	0.14	0.14	3	5	1.1	8	5	8	0.9956	0.071	1.4	1.10	0.11	0.170	-
2.1	7.0	977.0	100.0	90.0	30.0	2.00	0.80	1.0	1.0	0.75	1	0.3150	0.3150	1.70	0.32	0.32	2	5	1.1	7	5	7	0.9763	0.070	1.4	1.10	0.10	0.160	-
2.7	9.0	975.0	100.0	90.0	30.0	3.00	0.80	1.0	1.0	0.75	2	0.4050	0.4050	1.61	0.41	0.41	3	5	1.1	8	5	8	0.9656	0.069	1.4	1.08	0.11	0.166	-
3.4	11.0	973.0	100.0	90.0	30.0	3.00	0.80	1.0	1.0	0.80	2	0.5000	0.4688	1.49	0.50	0.47	3	5	1.1	8	5	8	0.9543	0.073	1.4	1.07	0.11	0.164	2.25
4.0	13.0	971.0	100.0	90.0	30.0	2.00	0.80	1.0	1.0	0.85	1	0.6000	0.5064	1.44	0.60	0.51	2	5	1.1	7	5	7	0.9425	0.080	1.4	1.06	0.10	0.153	1.92
4.6	15.0	969.0	100.0	90.0	30.0	0.00	0.80	1.0	1.0	0.85	0	0.7000	0.5440	1.39	0.70	0.54	0	5	1.1	5	5	5	0.9301	0.086	1.4	1.05	0.09	0.134	1.56
5.2	17.0	967.0	100.0	90.0	30.0	8.00	0.80	1.0	1.0	0.85	5	0.8000	0.5816	1.34	0.80	0.58	7	5	1.1	13	5	13	0.9172	0.090	1.4	1.06	0.14	0.210	2.33
5.8	19.0	965.0	100.0	90.0	30.0	8.00	0.80	1.0	1.0	0.85	5	0.9000	0.6192	1.30	0.90	0.62	7	5	1.1	12	5	12	0.9040	0.094	1.4	1.05	0.14	0.206	2.19
6.4	21.0	963.0	100.0	90.0	30.0	6.00	0.80	1.0	1.0	0.95	5	1.0000	0.6568	1.26	1.00	0.66	6	5	1.1	11	5	11	0.8904	0.097	1.4	1.04	0.13	0.190	1.96
7.3	24.0	960.0	100.0	90.0	30.0	13.00	0.80	1.0	1.0	0.95	10	1.1500	0.7132	1.21	1.15	0.71	12	5	1.1	18	5	17	0.8694	0.100	1.4	1.05	0.18	0.267	2.66
8.2	27.0	957.0	100.0	90.0	30.0	22.00	0.80	1.0	1.0	0.95	17	1.3000	0.7696	1.16	1.30	0.77	19	5	1.1	26	5	25	0.8479	0.102	1.4	1.05	0.29	0.433	4.23
9.1	30.0	954.0	100.0	90.0	30.0	46.00	0.80	1.0	1.0	0.95	35	1.4500	0.8260	1.12	1.45	0.83	39	5	1.1	48	5	45	0.8260	0.104	1.4	1.07	2.00	3.083	29.74
10.1	33.0	951.0	100.0	90.0	30.0	22.00	0.80	1.0	1.0	1.00	18	1.6000	0.8824	1.09	1.60	0.88	19	5	1.1	26	5	25	0.8039	0.104	1.4	1.03	0.28	0.413	3.96
11.0	36.0	948.0	100.0	90.0	30.0	22.00	0.80	1.0	1.0	1.00	18	1.7500	0.9388	1.05	1.75	0.94	19	5	1.1	25	5	24	0.7818	0.104	1.4	1.02	0.27	0.391	3.75
11.9	39.0	945.0	100.0	90.0	30.0	25.00	0.80	1.0	1.0	1.00	20	1.9000	0.9952	1.02	1.90	1.00	20	5	1.1	27	5	26	0.7598	0.104	1.4	1.01	0.31	0.453	4.37
12.8	42.0	942.0	100.0	90.0	30.0	39.00	0.80	1.0	1.0	1.00	31	2.0500	1.0516	1.00	2.05	1.05	31	5	1.1	39	5	36	0.7381	0.103	1.4	1.00	1.53	2.204	21.42
13.4	44.0	940.0	100.0	90.0	30.0	17.00	0.80	1.0	1.0	1.00	14	2.1500	1.0892	0.98	2.15	1.09	13	5	1.1	19	5	19	0.7237	0.102	1.4	0.99	0.19	0.274	2.68

Notes:

σ'_{vo} Vertical Effective Stress (tons/ft^2)
$(N_1)_{60}$ Standardized and Normalized SPT blow counts (blows/foot)
r_d Stress Reduction Factor (dimensionless)
a_{max} Peak horizontal ground surface acceleration (in g)
CSR Cyclic stress ratio based on design earthquake (dimensionless)
$CRR_{7.5}$ Cyclic resistance ratio based on an earthquake of magnitude 7.5 (dimensionless)
MSF Magnitude scaling factor (dimensionless)
K_σ High overburden stress correction factor (dimensionless)
K_α Ground slope correction factor (dimensionless) [advised not to be used by reference]
CRR Corrected cyclic resistance ratio based on overburden pressure and ground surface slope (dimensionless) = CRR7.5 * Kσ * Kα
FS_L Factor of safety against liquefaction (dimensionless)

FS_{min} 1.56

References:

(1) 1. Idriss, I. M., and Boulanger, R. W. (2008).Soil liquefaction during earthquakes. Monograph MNO-12, Earthquake Engineering Research Institute, Oakland, CA, 261 pp.

Richmond Power and Light
Whitewater Valley Station
Surface Impoundment
Liquefaction Analysis

G.S. Elev. = 982.0
$\gamma_{overburden}$ = 100.0 (pcf)

W.T. Elev. = 972.0
a_{max} 0.11
Est. EQ Mag 6.1

Bottom Elev. = 982.0
Top Elev. = 982.0

																						Idriss and Boulanger (2008)								
Test Depth (m)	Test Depth (ft)	Test Elevation (ft)	Saturated Unit Weight (pcf)	Moist Unit Weight (pcf)	Fines Content (%)	N	C_E	C_B	C_S	C_R	N_{60}	Existing σ_{vo} (tsf)	Existing σ'_{vo} (tsf)	C_N	Design σ_{vo} (tsf)	Design σ_{vo}' (tsf)	$(N_1)_{60}$	α	β	$(N_1)_{60cs}$	ΔN for fines content	$(N_1)_{60cs}$	r_d	CSR	MSF	K_σ	CRR for M=7.5 and σ_{vc}'=1atm	CRR	Factor of Safety
0.3	1.0	981.0	100.0	90.0	30.0	3.00	0.80	1.0	1.0	0.75	2	0.0450	0.0450	1.70	0.05	0.05	3	5	1.1	8	5	8	1.0041	0.072	1.4	1.10	0.11	0.170	-
0.9	3.0	979.0	100.0	90.0	30.0	4.00	0.80	1.0	1.0	0.75	2	0.1350	0.1350	1.70	0.14	0.14	4	5	1.1	9	5	9	0.9956	0.071	1.4	1.10	0.11	0.181	-
2.1	7.0	975.0	100.0	90.0	30.0	1.00	0.80	1.0	1.0	0.75	1	0.3150	0.3150	1.70	0.32	0.32	1	5	1.1	6	5	6	0.9763	0.070	1.4	1.10	0.09	0.149	-
2.7	9.0	973.0	100.0	90.0	30.0	0.00	0.80	1.0	1.0	0.75	0	0.4050	0.4050	1.61	0.41	0.41	0	5	1.1	5	5	5	0.9656	0.069	1.4	1.07	0.09	0.137	-
3.4	11.0	971.0	100.0	90.0	30.0	0.00	0.80	1.0	1.0	0.80	0	0.5000	0.4688	1.49	0.50	0.47	0	5	1.1	5	5	5	0.9543	0.073	1.4	1.06	0.09	0.135	1.86
4.0	13.0	969.0	100.0	90.0	30.0	0.00	0.80	1.0	1.0	0.85	0	0.6000	0.5064	1.44	0.60	0.51	0	5	1.1	5	5	5	0.9425	0.080	1.4	1.06	0.09	0.134	1.68
4.6	15.0	967.0	100.0	90.0	30.0	0.00	0.80	1.0	1.0	0.85	0	0.7000	0.5440	1.39	0.70	0.54	0	5	1.1	5	5	5	0.9301	0.086	1.4	1.05	0.09	0.134	1.56
5.2	17.0	965.0	100.0	90.0	30.0	14.00	0.80	1.0	1.0	0.85	10	0.8000	0.5816	1.34	0.80	0.58	13	5	1.1	19	5	18	0.9172	0.090	1.4	1.07	0.18	0.286	3.17
6.4	21.0	961.0	100.0	90.0	30.0	5.00	0.80	1.0	1.0	0.95	4	1.0000	0.6568	1.26	1.00	0.66	5	5	1.1	10	5	10	0.8904	0.097	1.4	1.04	0.12	0.179	1.85
7.3	24.0	958.0	100.0	90.0	30.0	15.00	0.80	1.0	1.0	0.95	11	1.1500	0.7132	1.21	1.15	0.71	14	5	1.1	20	5	19	0.8694	0.100	1.4	1.05	0.20	0.297	2.96
8.2	27.0	955.0	100.0	90.0	30.0	17.00	0.80	1.0	1.0	0.95	13	1.3000	0.7696	1.16	1.30	0.77	15	5	1.1	21	5	20	0.8479	0.102	1.4	1.04	0.21	0.317	3.10
9.1	30.0	952.0	100.0	90.0	30.0	17.00	0.80	1.0	1.0	0.95	13	1.4500	0.8260	1.12	1.45	0.83	15	5	1.1	21	5	20	0.8260	0.104	1.4	1.03	0.20	0.304	2.93
10.1	33.0	949.0	100.0	90.0	30.0	20.00	0.80	1.0	1.0	1.00	16	1.6000	0.8824	1.09	1.60	0.88	17	5	1.1	24	5	23	0.8039	0.104	1.4	1.02	0.25	0.363	3.48
11.0	36.0	946.0	100.0	90.0	30.0	20.00	0.80	1.0	1.0	1.00	16	1.7500	0.9388	1.05	1.75	0.94	17	5	1.1	23	5	22	0.7818	0.104	1.4	1.01	0.24	0.347	3.33
11.9	39.0	943.0	100.0	90.0	30.0	22.00	0.80	1.0	1.0	1.00	18	1.9000	0.9952	1.02	1.90	1.00	18	5	1.1	25	5	23	0.7598	0.104	1.4	1.01	0.26	0.373	3.59
12.8	42.0	940.0	100.0	90.0	30.0	19.00	0.80	1.0	1.0	1.00	15	2.0500	1.0516	1.00	2.05	1.05	15	5	1.1	21	5	21	0.7381	0.103	1.4	1.00	0.21	0.306	2.97
14.0	46.0	936.0	100.0	90.0	30.0	18.00	0.80	1.0	1.0	1.00	14	2.2500	1.1268	0.96	2.25	1.13	14	5	1.1	20	5	19	0.7096	0.101	1.4	0.99	0.20	0.281	2.77

Notes:

σ'_{vo} Vertical Effective Stress (tons/ft^2)
$(N_1)_{60}$ Standardized and Normalized SPT blow counts (blows/foot)
r_d Stress Reduction Factor (dimensionless)
a_{max} Peak horizontal ground surface acceleration (in g)
CSR Cyclic stress ratio based on design earthquake (dimensionless)
$CRR_{7.5}$ Cyclic resistance ratio based on an earthquake of magnitude 7.5 (dimensionless)
MSF Magnitude scaling factor (dimensionless)
K_σ High overburden stress correction factor (dimensionless)
K_α Ground slope correction factor (dimensionless) [advised not to be used by reference]
CRR Corrected cyclic resistance ratio based on overburden pressure and ground surface slope (dimensionless) = CRR7.5 * Kσ * Kα
FS_L Factor of safety against liquefaction (dimensionless)

FS_{min} 1.56

References:

(1) 1. Idriss, I. M., and Boulanger, R. W. (2008).Soil liquefaction during earthquakes. Monograph MNO-12, Earthquake Engineering Research Institute, Oakland, CA, 261 pp.

gai consultants

Richmond Power and Light
Whitewater Valley Station
Surface Impoundment
Liquefaction Analysis

C151119.25
By: RRJ 04/06/23
Checked by: AB 04/07/23

G.S. Elev. = 984.0
$\gamma_{overburden}$ = 100.0 (pcf)

W.T. Elev. = 974.0
a_{max} 0.11
Est. EQ Mag 6.1

Bottom Elev. = 984.0
Top Elev. = 984.0

																					Idriss and Boulanger (2008)								
Test Depth (m)	Test Depth (ft)	Test Elevation (ft)	Saturated Unit Weight (pcf)	Moist Unit Weight (pcf)	Fines Content (%)	N	C_E	C_B	C_S	C_R	N_{60}	Existing σ_{vo} (tsf)	Existing σ'_{vo} (tsf)	C_N	Design σ_{vo} (tsf)	Design σ_{vo}' (tsf)	$(N_1)_{60}$	α	β	$(N_1)_{60cs}$	ΔN for fines content	$(N_1)_{60cs}$	r_d	CSR	MSF	K_σ	CRR for M=7.5 and σ_{vc}'=1atm	CRR	Factor of Safety
0.3	1.0	983.0	100.0	90.0	22.97	10.00	0.80	1.0	1.0	0.75	6	0.0450	0.0450	1.70	0.05	0.05	10	4	1.1	15	5	15	1.0041	0.072	1.4	1.10	0.16	0.249	-
1.2	4.0	980.0	100.0	90.0	22.97	16.00	0.80	1.0	1.0	0.75	10	0.1800	0.1800	1.70	0.18	0.18	16	4	1.1	22	5	21	0.9910	0.071	1.4	1.10	0.22	0.352	-
2.1	7.0	977.0	100.0	90.0	22.97	15.00	0.80	1.0	1.0	0.75	9	0.3150	0.3150	1.70	0.32	0.32	15	4	1.1	21	5	20	0.9763	0.070	1.4	1.10	0.21	0.330	-
3.0	10.0	974.0	100.0	90.0	22.97	8.00	0.80	1.0	1.0	0.80	5	0.4500	0.4500	1.52	0.45	0.45	8	4	1.1	13	5	13	0.9600	0.069	1.4	1.09	0.14	0.216	3.14
4.0	13.0	971.0	100.0	90.0	22.97	6.00	0.80	1.0	1.0	0.85	4	0.6000	0.5064	1.44	0.60	0.51	6	4	1.1	10	5	11	0.9425	0.080	1.4	1.07	0.12	0.190	2.38
4.9	16.0	968.0	100.0	90.0	22.97	4.00	0.80	1.0	1.0	0.85	3	0.7500	0.5628	1.36	0.75	0.56	4	4	1.1	8	5	9	0.9237	0.088	1.4	1.05	0.11	0.165	1.87
5.8	19.0	965.0	100.0	90.0	22.97	7.00	0.80	1.0	1.0	0.85	5	0.9000	0.6192	1.30	0.90	0.62	6	4	1.1	11	5	11	0.9040	0.094	1.4	1.05	0.13	0.190	2.03
6.7	22.0	962.0	100.0	90.0	22.97	5.00	0.80	1.0	1.0	0.95	4	1.0500	0.6756	1.24	1.05	0.68	5	4	1.1	9	5	10	0.8834	0.098	1.4	1.04	0.12	0.173	1.76
7.6	25.0	959.0	100.0	90.0	22.97	8.00	0.80	1.0	1.0	0.95	6	1.2000	0.7320	1.19	1.20	0.73	7	4	1.1	12	5	12	0.8623	0.101	1.4	1.04	0.13	0.200	1.97
8.5	28.0	956.0	100.0	90.0	22.97	1.00	0.80	1.0	1.0	0.95	1	1.3500	0.7884	1.15	1.35	0.79	1	4	1.1	5	5	6	0.8406	0.103	1.4	1.02	0.09	0.134	1.30
9.4	31.0	953.0	100.0	90.0	22.97	6.00	0.80	1.0	1.0	0.95	5	1.5000	0.8448	1.11	1.50	0.84	5	4	1.1	10	5	10	0.8187	0.104	1.4	1.02	0.12	0.173	1.67
10.4	34.0	950.0	100.0	90.0	22.97	0.00	0.80	1.0	1.0	1.00	0	1.6500	0.9012	1.08	1.65	0.90	0	4	1.1	4	5	5	0.7966	0.104	1.4	1.01	0.09	0.125	1.20
11.3	37.0	947.0	100.0	90.0	22.97	7.00	0.80	1.0	1.0	1.00	6	1.8000	0.9576	1.04	1.80	0.96	6	4	1.1	10	5	11	0.7745	0.104	1.4	1.01	0.12	0.179	1.72
12.2	40.0	944.0	100.0	90.0	22.97	15.00	0.80	1.0	1.0	1.00	12	1.9500	1.0140	1.01	1.95	1.01	12	4	1.1	17	5	17	0.7525	0.103	1.4	1.00	0.17	0.253	2.44

Notes:

σ'_{vo} Vertical Effective Stress (tons/ft^2)
$(N_1)_{60}$ Standardized and Normalized SPT blow counts (blows/foot)
r_d Stress Reduction Factor (dimensionless)
a_{max} Peak horizontal ground surface acceleration (in g)
CSR Cyclic stress ratio based on design earthquake (dimensionless)
$CRR_{7.5}$ Cyclic resistance ratio based on an earthquake of magnitude 7.5 (dimensionless)
MSF Magnitude scaling factor (dimensionless)
K_σ High overburden stress correction factor (dimensionless)
K_α Ground slope correction factor (dimensionless) [advised not to be used by reference]
CRR Corrected cyclic resistance ratio based on overburden pressure and ground surface slope (dimensionless) = CRR7.5 * Kσ * Kα
FS_L Factor of safety against liquefaction (dimensionless)

FS_{min} 1.20

References:

(1) 1. Idriss, I. M., and Boulanger, R. W. (2008).Soil liquefaction during earthquakes. Monograph MNO-12, Earthquake Engineering Research Institute, Oakland, CA, 261 pp.