Coal Combustion Residuals Unit Factor of Safety Assessment

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

GAI Project Number: C151119.07

April 2018

Prepared by: GAI Consultants, Inc.
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Certification/Statement of Professional Opinion

The 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.

CHARLES F. STRALEY
REGISTERED
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STATE OF
INDIANA
PROFESSIONAL ENGINEER

GAI Consultants, Inc.

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

Date April 17, 2018

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Acronyms

Assessment	Coal Combustion Residuals 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

This Factor of Safety Assessment is prepared pursuant to § 257.73(e)(1) of the CCR Rule [40 CFR § 257.73(e)(1)].

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 section 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 critical section with the lowest factors of safety against sliding was located at the SW Corner of the Impoundment. The minimum factors of safety against sliding calculated for each condition are summarized in Table 1.

Table 1
Calculated Factors of Safety

Factor of Safety Condition	Minimum Target Factor of Safety	Calculated Factor of Safety
Long-term, maximum storage pool loading	1.50	1.57
Maximum surcharge pool loading	1.40	1.57
Seismic factor of safety	1.00	1.31
Liquefaction factor of safety	1.20	>1.20

Calculations are 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 1.57 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 analysis. The calculated factor of safety is 1.31 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. The calculated liquefaction safety factors exceeded the minimum of 1.20 stated in the CCR Rule. The 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

GAI Consultants. *Geotechnical Summary Report*. August 2016.

GAI Consultants. *Groundwater Characterization Report.* September 2016.

GAI Consultants. 2018a. *History of Construction*. April 2018.

GAI Consultants. 2018b. *Inflow Design Flood Control System Plan*. April 2018.

APPENDIX A
Calculations

OBJECTIVE:

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 analyses will be performed using simplified Bishop's method.

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 2016, version 8.16.1.13452. 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. Additionally, detailed information regarding the cross section geometry of each section is included in the slope stability software output presented as Attachment 3.

The soil parameters used in the slope stability analyses are summarized in Attachment 2. 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. The piezometric surface used in the analysis is based on the groundwater elevation shown on the potentiometric surface readings conducted in September, 2016.

Based on the data subsurface investigation, 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.

The CCR material exhibited the weakest strength of the materials present in the dike. The dike was modeled with a conservative amount of CCR. While the model shows the CCR material being near the surface at parts of the dike, GAI does not expect CCR material to be present within the first few feet of the slope of the dike.

Seismic Conditions – The existing facility is located in Wayne County, which is an area of low to moderate seismic activity and risk. The peak horizontal ground acceleration at the proposed site (using a 2 percent probability of exceedance in 50 years) is approximately 0.075g. This acceleration was estimated using the 2014 USGS "Two-percent probability of exceedance in 50 years map of ground acceleration" data, which is included here as Attachment 4 (Reference 2).

SUMMARY:

Stability analyses performed for the existing dike are summarized in Attachment 3. Static and seismic conditions were evaluated using simplified Bishop method which is an equilibrium method that considers both shear and normal interslice forces and satisfies both moment and force equilibrium. 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 a seismic coefficient equal to 0.075g.

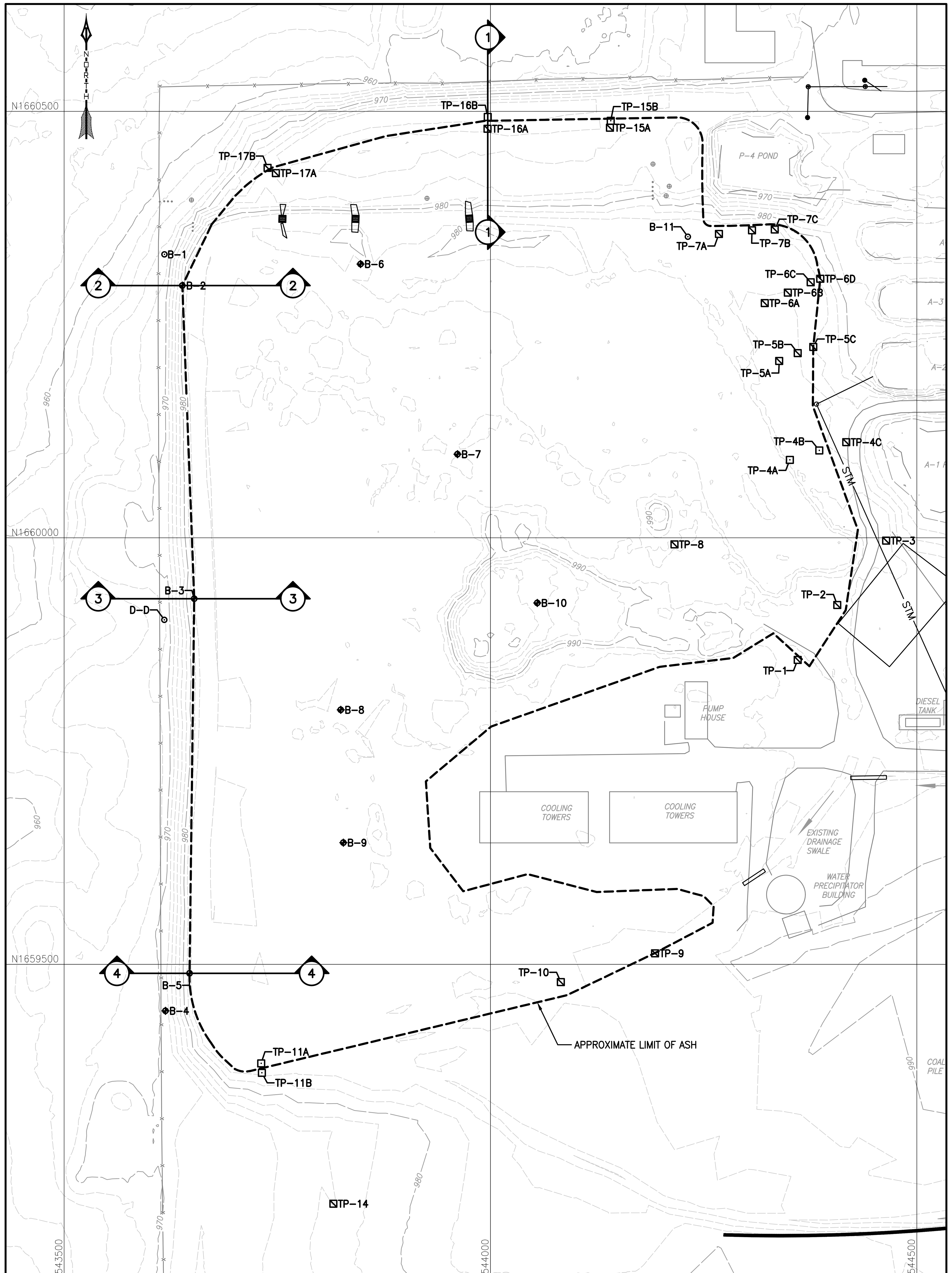
The following table summarizes the results of static and seismic slope stability analyses considering drained conditions for CCR material and dike soils.

Section	Condition Analyzed	Minimum Target Factor of Safety	Calculated Factor of Safety Drained Conditions
Section 2-2 NW Corner	Static	1.50	2.18
	Seismic	1.00	1.81
Section 3-3 Mid Alignment	Static	1.50	1.62
	Seismic	1.00	1.38
Section 4-4 SW Corner	Static	1.50	1.57
	Seismic	1.00	1.31

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'

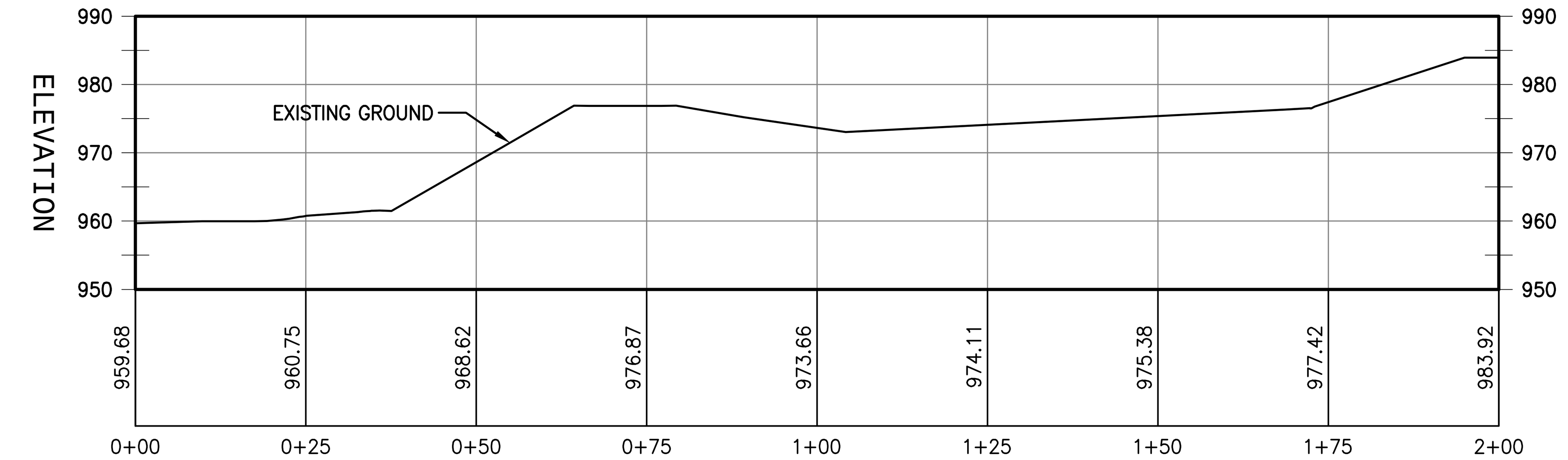
80 0 80 160

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:

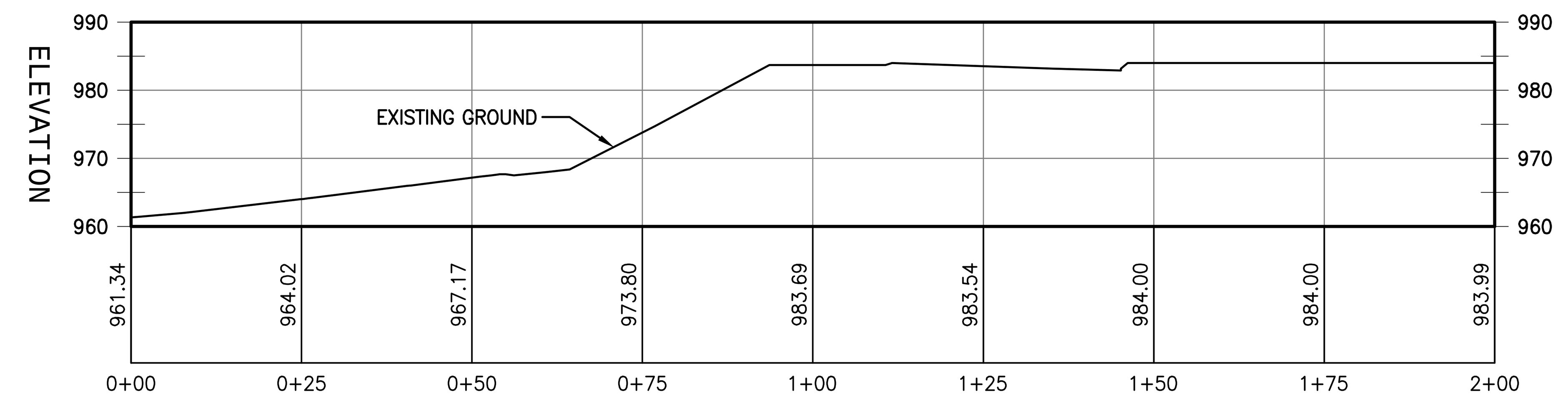
1. TP-12 AND TP-13 ARE LOCATED IN THE SOLAR FIELD SOUTH OF THE COAL PILE.
2. SECTION # CORRESPONDS TO BORING # AND THERE IS NO SECTION 1, 2, OR 4.



SECTION 1

SCALE: 1" = 20'

20 0 20 40



SECTION 2

SCALE: 1" = 20'

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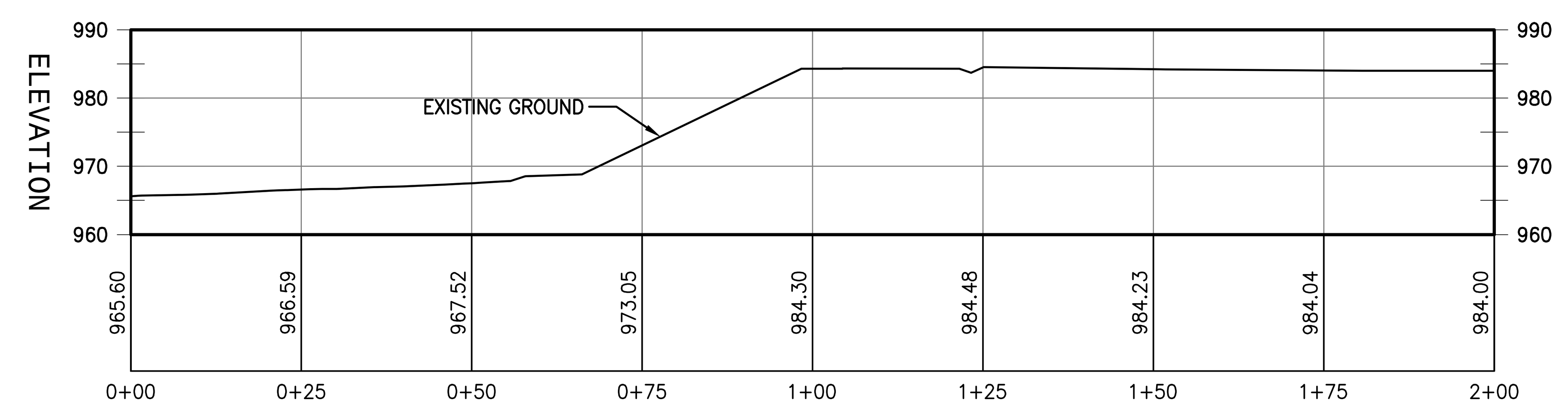
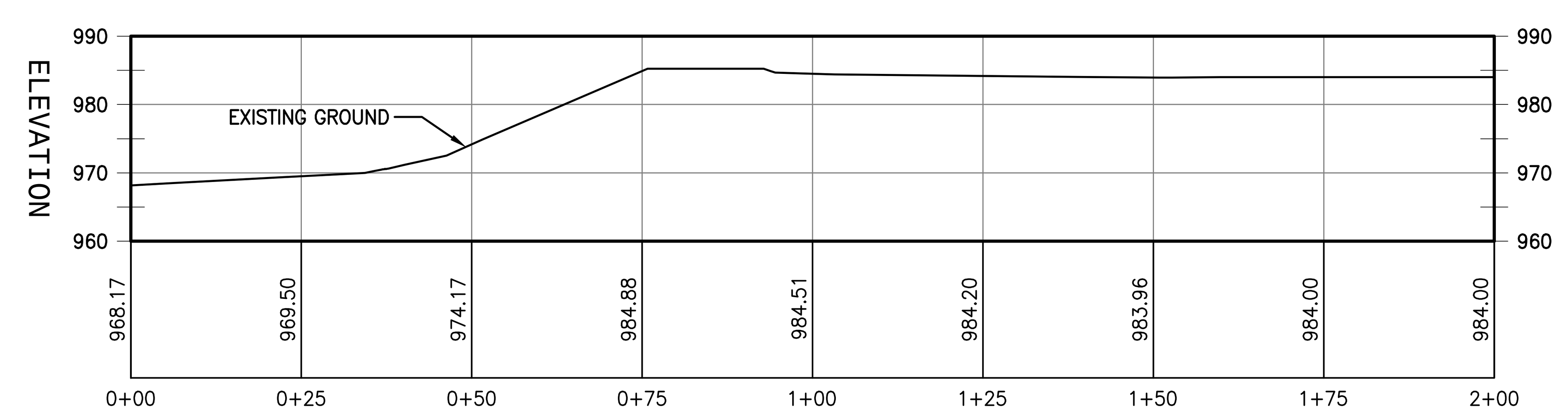


SECTION 3

SCALE: 1" = 20'

20 0 20 40



SECTION 4

SCALE: 1" = 20'

20 0 20 40

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

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

REVISION RECORD

REVISION

ALT./CLIENT DRAWING NUMBER:

SHEET NO.: 1 OF 1

GAI FILE NUMBER: C151119-07-004-C-D1-001

DRAWING TITLE

FIGURE 1 - SLOPE CROSS SECTIONS AND PLAN VIEW

CLIENT

RICHMOND POWER AND LIGHT
RICHMOND, INDIANA

PROJECT

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

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.

GAI CAD FILE PATH: Z:\Energy\2015\C151119.07 - RPL Impound Closure Spt\CAD\Production Drawings\C151119-07-004-C-D1-001.dwg PLOTTED ON: 4/2/2018 12:48:43 PM PLOTTED BY: Jeremy Slodowick PLOT FILE: GAI.stb

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

GAI DRAWING NUMBER:

D1-001

ATTACHMENT 2

SOIL PARAMETERS

By: CAG 4/05/2018
Checked: CFS 4/10/2018

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	50.0	28.0
Silty Sand	125.0	0.0	28.0
CCR Material	90.0	0.0	19.0

ATTACHMENT 3

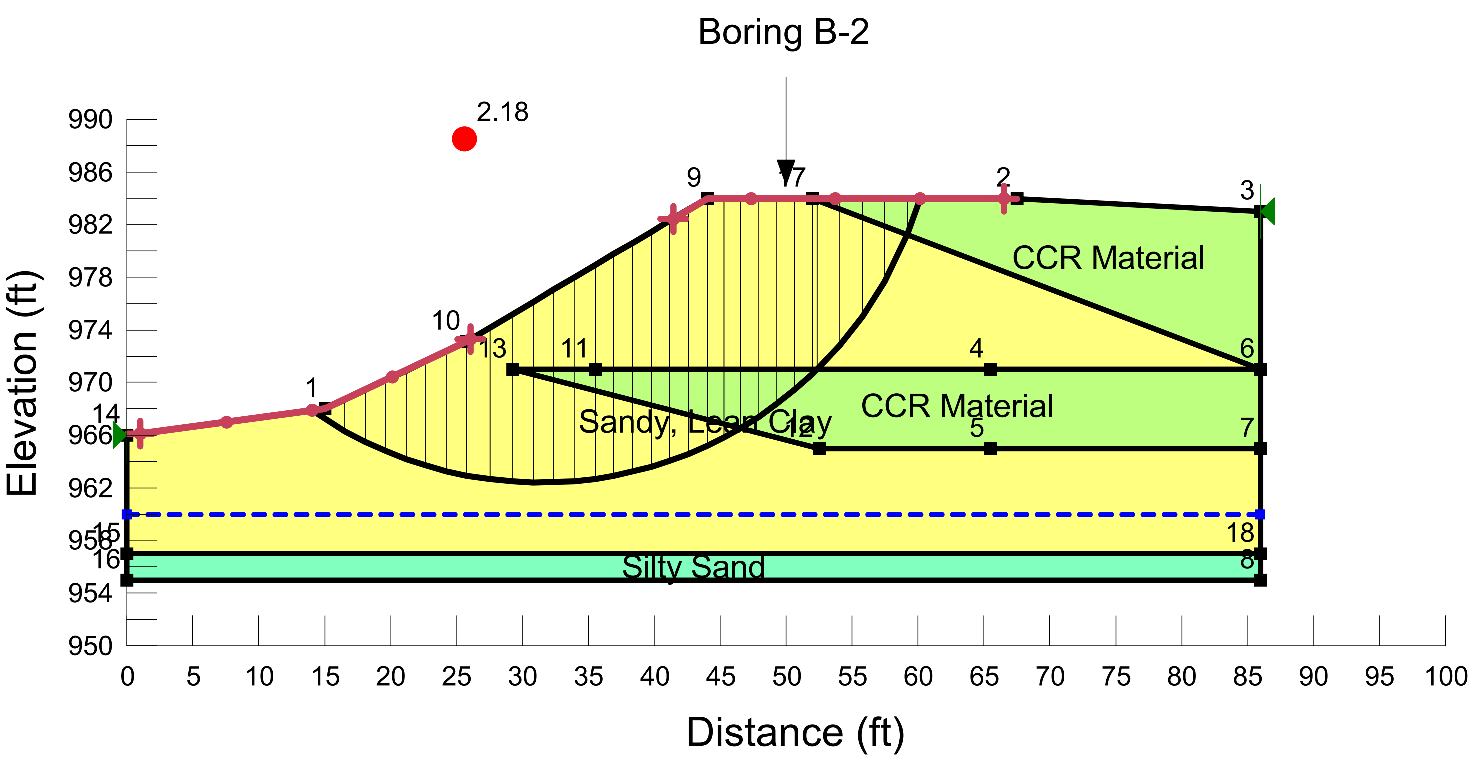
SLOPE STABILITY ANALYSIS RESULTS

By: CAG 4/5/2018
Checked: CFS 4/10/2018

Proj No.: C151119.07.004

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

Color	Name	Model	Unit Weight (pcf)	Cohesion' (psf)	Phi' (°)	Piezometric Line
	Sandy, Lean Clay	Mohr-Coulomb	130	50	28	1
	CCR Material	Mohr-Coulomb	90	0	19	1
	Silty Sand	Mohr-Coulomb	125	0	28	1

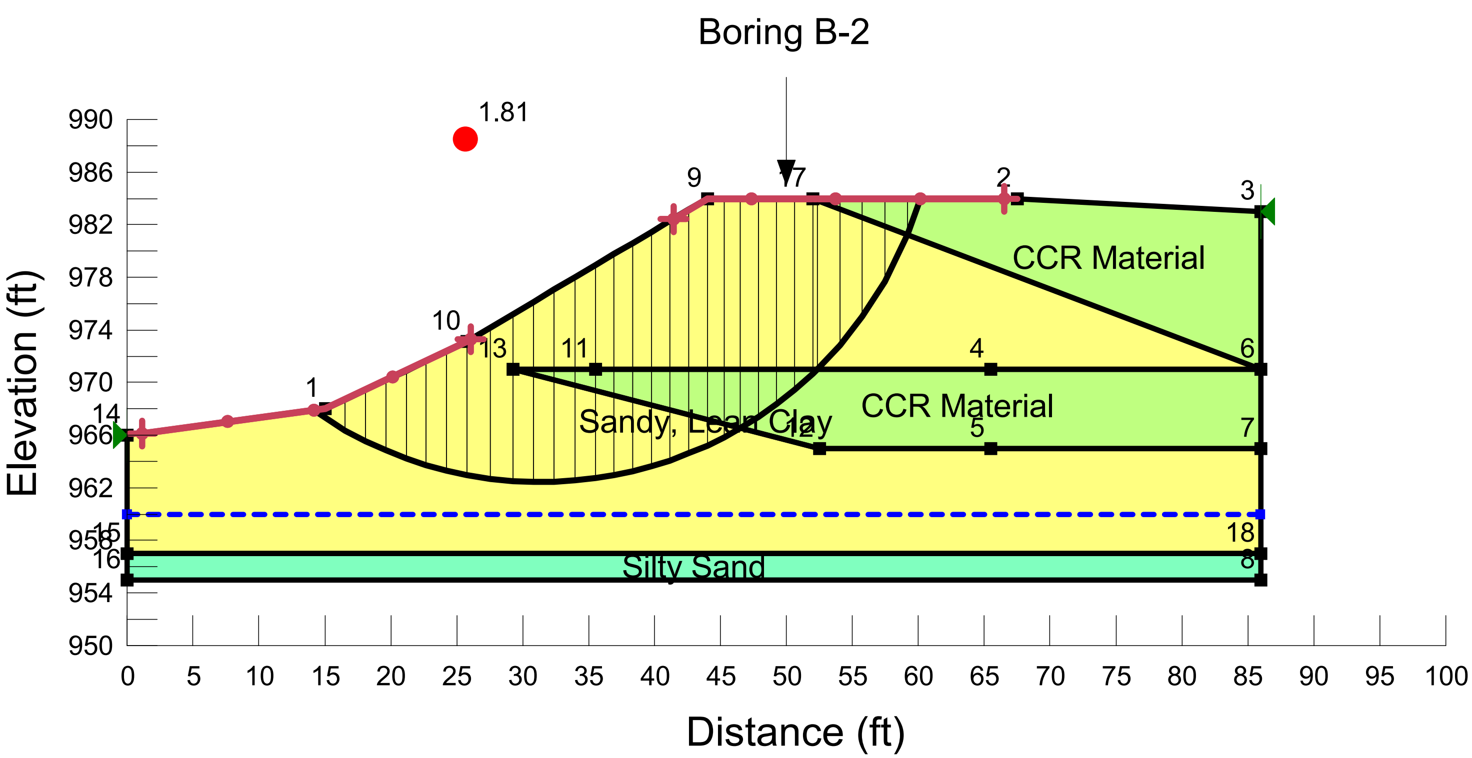


By: CAG 4/5/2018
Checked: CFS 4/10/2018

Proj No.: C151119.07.004

RP-L Surface Impoundment Existing Conditions - CCR Rule Factor of Safety
Section 2-2 - Northwest Dike
Drained - Horz Seismic Coef.: 0.075

Color	Name	Model	Unit Weight (pcf)	Cohesion' (psf)	Phi' (°)	Piezometric Line
	Sandy, Lean Clay	Mohr-Coulomb	130	50	28	1
	CCR Material	Mohr-Coulomb	90	0	19	1
	Silty Sand	Mohr-Coulomb	125	0	28	1

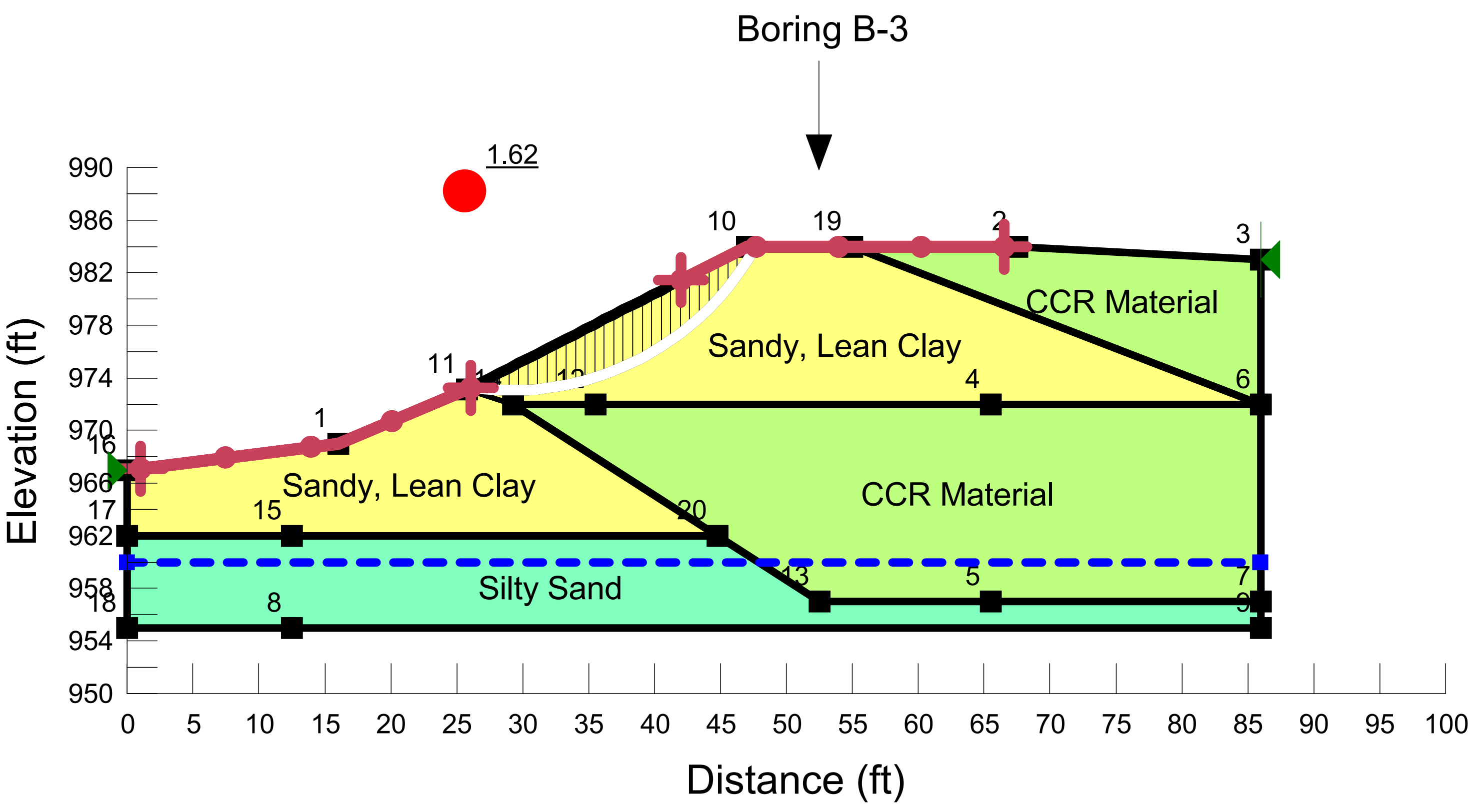


By: CAG 4/5/2018
Checked: CFS 4/10/2018

Proj No.: C151119.07.004

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

Color	Name	Model	Unit Weight (pcf)	Cohesion' (psf)	Phi' (°)	Piezometric Line
	Sandy, Lean Clay	Mohr-Coulomb	130	50	28	1
	CCR Material	Mohr-Coulomb	90	0	19	1
	Silty Sand	Mohr-Coulomb	125	0	28	1

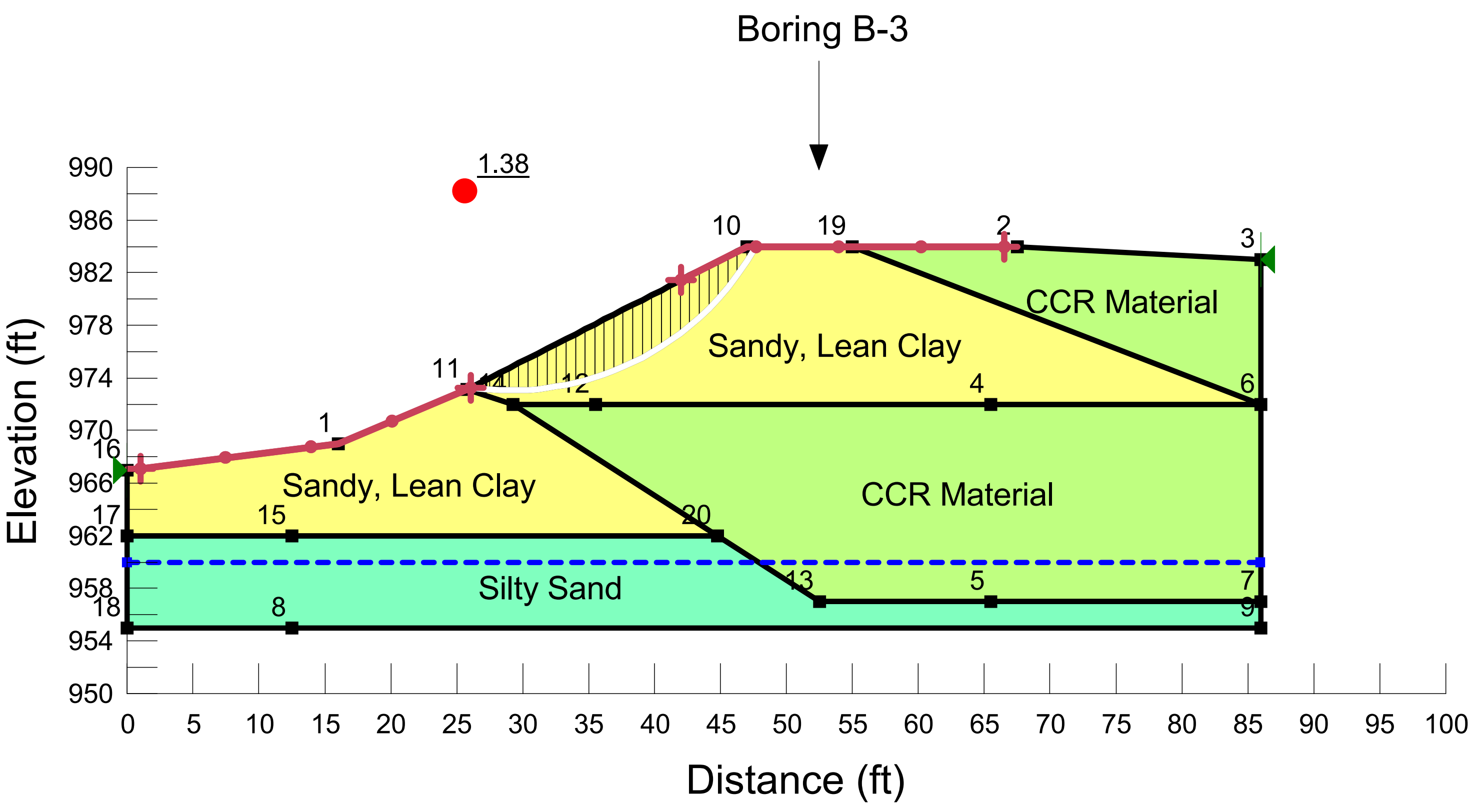


By: CAG 4/5/2018
Checked: CFS 4/10/2018

Proj No.: C151119.07.004

RP-L Surface Impoundment Existing Conditions - CCR Rule Factor of Safety
Section 3-3 - Center West Dike
Drained - Horz Seismic Coef.: 0.075

Color	Name	Model	Unit Weight (pcf)	Cohesion' (psf)	Phi' (°)	Piezometric Line
	Sandy, Lean Clay	Mohr-Coulomb	130	50	28	1
	CCR Material	Mohr-Coulomb	90	0	19	1
	Silty Sand	Mohr-Coulomb	125	0	28	1

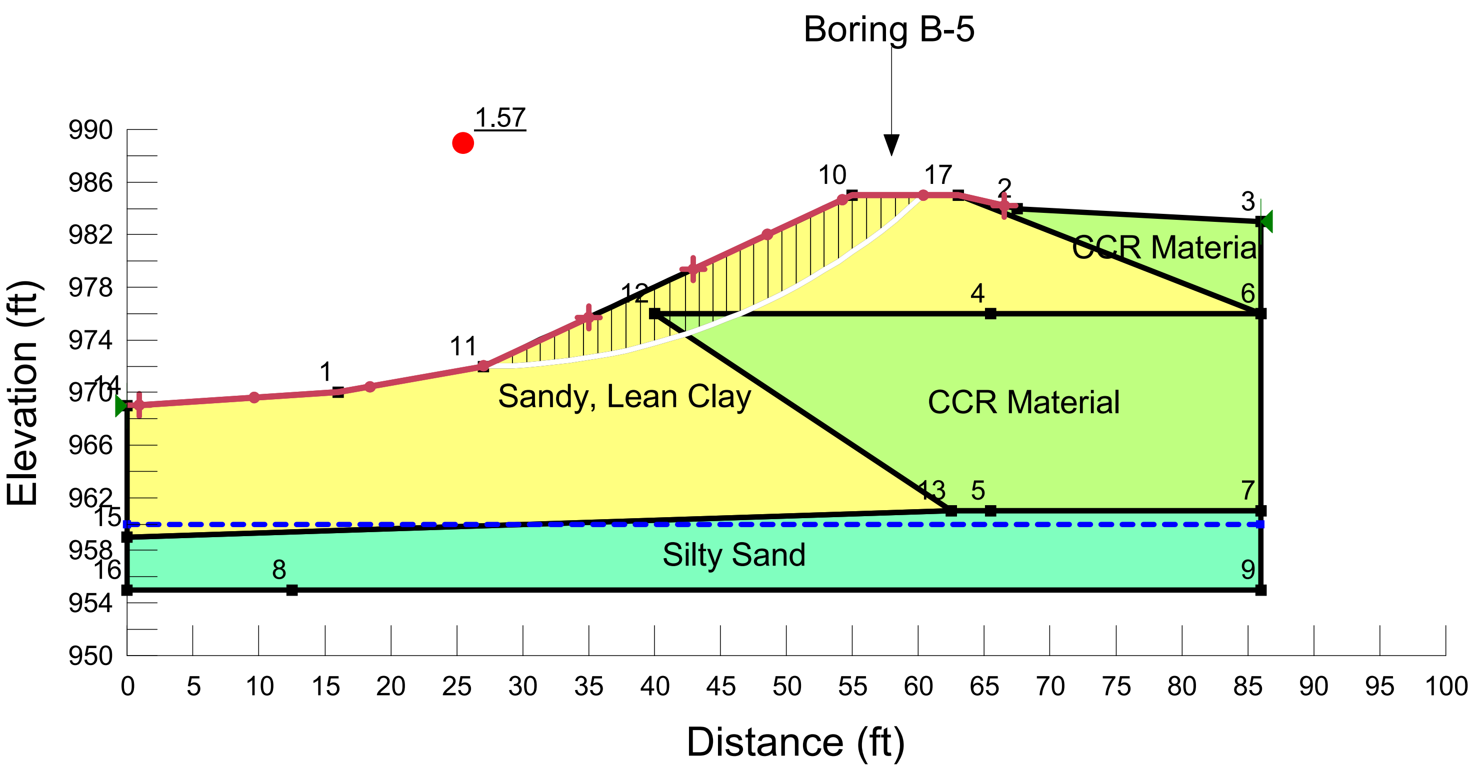


By: CAG 4/5/2018
Checked: CFS 4/10/2018

Proj No.: C151119.07.004

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

Color	Name	Model	Unit Weight (pcf)	Cohesion' (psf)	Phi' (°)	Piezometric Line
	Sandy, Lean Clay	Mohr-Coulomb	130	50	28	1
	CCR Material	Mohr-Coulomb	90	0	19	1
	Silty Sand	Mohr-Coulomb	125	0	28	1

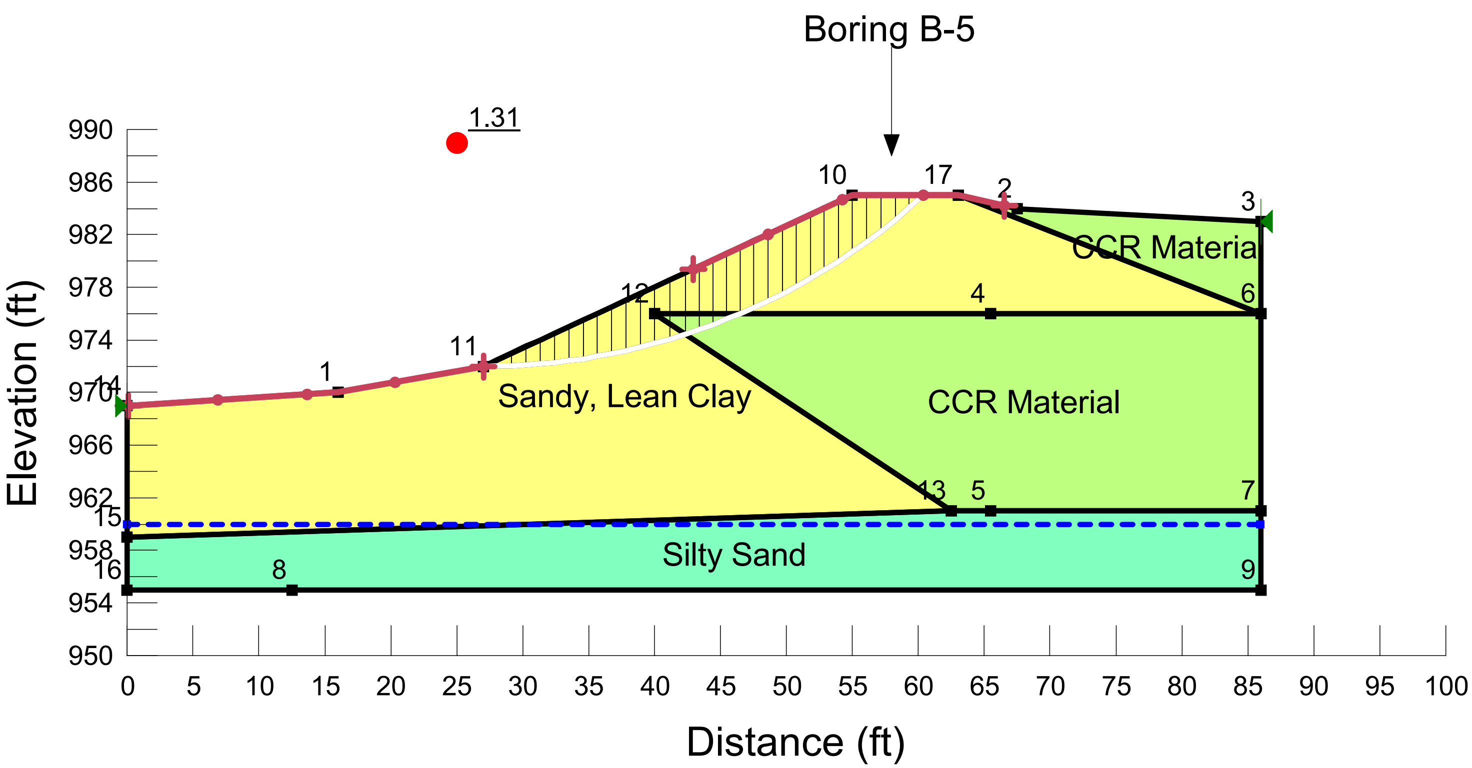


By: CAG 4/5/2018
Checked: CFS 4/10/2018

Proj No.: C151119.07.004

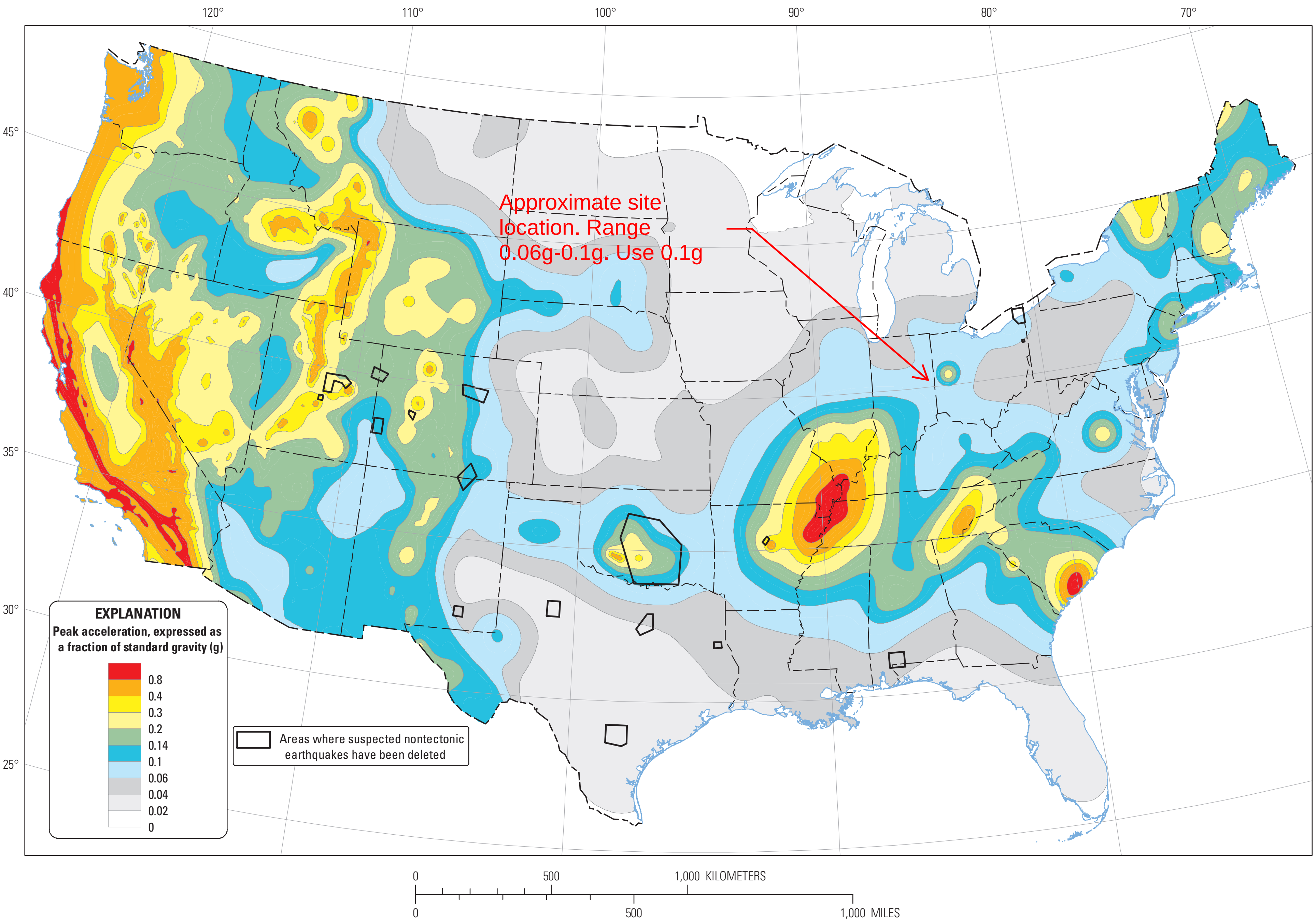
RP-L Surface Impoundment Existing Conditions - CCR Rule Factor of Safety
Section 4-4 - Southwest Dike
Drained - Horz Seismic Coef.: 0.075

Color	Name	Model	Unit Weight (pcf)	Cohesion' (psf)	Phi' (°)	Piezometric Line
	Sandy, Lean Clay	Mohr-Coulomb	130	50	28	1
	CCR Material	Mohr-Coulomb	90	0	19	1
	Silty Sand	Mohr-Coulomb	125	0	28	1



ATTACHMENT 4

USGS EARTHQUAKE GROUND ACCELERATION



Two-percent probability of exceedance in 50 years map of peak ground acceleration

-85.550	39.800	8.27883E-02
-85.500	39.800	8.18046E-02
-85.450	39.800	8.08038E-02
-85.400	39.800	7.98088E-02
-85.350	39.800	7.89001E-02
-85.300	39.800	7.79980E-02
-85.250	39.800	7.72036E-02
-85.200	39.800	7.64153E-02
-85.150	39.800	7.57786E-02
-85.100	39.800	7.51463E-02
-85.050	39.800	7.46980E-02
-85.000	39.800	7.42521E-02
-84.950	39.800	7.40163E-02
-84.900	39.800	7.37816E-02
-84.850	39.800	7.37577E-02
-84.800	39.800	7.37337E-02
-84.750	39.800	7.39373E-02
-84.700	39.800	7.41425E-02
-84.650	39.800	7.45271E-02
-84.600	39.800	7.49135E-02
-84.550	39.800	7.53995E-02
-84.500	39.800	7.58887E-02
-84.450	39.800	7.63389E-02
-84.400	39.800	7.67926E-02
-84.350	39.800	7.71080E-02
-84.300	39.800	7.74258E-02
-84.250	39.800	7.74466E-02
-84.200	39.800	7.74676E-02
-84.150	39.800	7.71305E-02
-84.100	39.800	7.67923E-02
-84.050	39.800	7.61055E-02

First two columns represent approximate coordinates of the Surface impoundment. Last column presents the peak ground acceleration (2% chance of exceedance in 50 years. Use 0.075g in seismic analysis.

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

																		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	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.

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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)	$(N_1)_{60}$	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:

FS_{min} 2.10

- 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

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

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	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:

FS_{min} 1.55

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. = 972.0
$\gamma_{overburden}$ = 100.0 (pcf)

W.T. Elev. = 962.0
a_{max} 0.11
Est. EQ Mag 6.1

Bottom Elev. = 972.0
Top Elev. = 972.0

																		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	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:

FS_{min} 4.74

- 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

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	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:

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} 1.58

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. = 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:

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} 1.39

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. = 975.6
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:

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} 1.40

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. = 975.1
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	-
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.

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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

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	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:

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} 1.61

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 W.T. Elev. = 969.4 Bottom Elev. = 986.0

$\gamma_{overburden}$ = 100.0 (pcf) a_{max} 0.11 Top Elev. = 986.0

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)	$(N_1)_{60}$	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

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. = 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.