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Coal Combustion Residuals Unit Factor of Safety Assessment

Virginia Electric and Power Company
Chesterfield Power Station
Upper (East) Pond
Chesterfield County, Virginia

GAI Project Number: C1500035.00

October 2016

Dominion

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Certification/Statement of Professional Opinion

The Factor of Safety Assessment (Assessment) for the Chesterfield Power Station Upper (East) Pond was prepared by GAI Consultants, Inc. (GAI). The Assessment was 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 Commonwealth of Virginia 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).

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.

Kevin M. Bortz, P.E.
Assistant Engineering Manager

Date 10/13/2016

COMMONWEALTH OF VIRGINIA
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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
Dominion	Virginia Electric and Power Company d/b/a Dominion
EPA	United States Environmental Protection Agency
GAI	GAI Consultants, Inc.
Station	Dominion Chesterfield Power Station
UEP	Upper (East) Pond
USGS	United States Geological Survey
VPDES Permit	Virginia Pollutant Discharge Elimination System Permit No. VA0004146

1.0 Introduction

The Chesterfield Power Station (Station) is owned by Virginia Electric and Power Company d/b/a Dominion Virginia Power (Dominion) and is located in Chesterfield, VA. The station includes the Upper (East) Pond (UEP) impoundment, which is used for the long term storage of coal combustion residuals (CCR).

The UEP is located on Dominion property at the Chesterfield Power Station in Chesterfield County, Virginia (coordinates 37° 22′ 15.2″ North and 77° 22′ 8.3″ West) and is bounded by the Old Channel of the James River on the south, Henricus Historical Park on the east, and Aiken Swamp on the north.

The UEP is regulated as an existing CCR surface impoundment under the United States Environmental Protection Agency'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).

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 UEP as required by § 257.73(e)(1).

4.0 Factor of Safety Assessment

The UEP is regulated by Virginia Pollutant Discharge Elimination System Permit No. VA0004146, issued by the Virginia Department of Environmental Quality. A stormwater sediment pond located at the eastern end of the UEP is used to control stormwater runoff during rain events. Impounded water within the UEP is limited to stormwater runoff collected within this stormwater sediment pond.

The UEP embankment at the stormwater sediment pond, near the pond outfall (VPDES Permit Outfall 005), was determined to be the critical section for purposes of this Assessment. The material strength parameters used in the analyses were obtained from *Geotechnical Engineering and Groundwater Hydrology Services, Ash Disposal Pond, Chesterfield Power Station* (Schnabel, 1982) and/or developed by GAI (VDEQ, 2016) based on previous subsurface exploration and laboratory testing. The phreatic surface used in the analyses was dependent on the condition being assessed and is discussed for each analysis.

The factors of safety calculated for each condition are summarized in Table 1.

Table 1 -
Calculated Factors of Safety -

Factor of Safety Condition	Minimum Factor of Safety	Calculated Factor of Safety
Long-term, maximum storage pool loading	1.50	1.79
Maximum surcharge pool loading	1.40	1.62
Seismic factor of safety	1.00	1.36
Liquefaction factor of safety	1.20	1.20

Calculations are included in Appendix A.

4.1 Long-Term Maximum Storage Pool Loading Condition

According to the preamble of the CCR Rule, Section E.3.b.ii.b, 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." The Rule goes on to state that "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."

Storage pools are only developed in the stormwater sediment pond, which receives stormwater runoff from the UEP. Normal pool in the stormwater sediment pond, as determined by an orifice in the outlet structure, is at elevation 28.33 feet (Virginia Power, 1992); therefore, the long term maximum storage pool loading condition will have a phreatic surface elevation of 28.33 feet. The phreatic surface through the embankment is based on a straight line estimation connecting elevation 28.33 feet and the elevation at the toe of the embankment at the critical cross section, which has an elevation of 2 feet.

The calculated static factor of safety is 1.79 for the embankment and meets the requirement for the long term maximum storage pool condition (1.50).

4.2 Maximum Surcharge Pool Loading Conditions

The water elevation for the maximum surcharge pool loading condition is based on the inflow design flood, which is the 1,000-year flood for a significant hazard dam (GAI, 2016). Based on the design flood, the phreatic surface will be at elevation 39.58 feet. The calculated static factor of safety is 1.62 for the embankment and meets the requirement for the maximum surcharge pool condition (1.40).

4.3 Seismic Factor of Safety

The seismic factor of safety was analyzed with a seismic loading event with a 2% probability of exceedance in 50 years, based on United States Geological Survey (USGS) seismic hazard maps. A peak ground acceleration of 0.128g was used in the analyses (Geosyntec, 2016).

The long term maximum storage pool loading condition was evaluated under seismic conditions. The calculated factor of safety of 1.36 for the embankment meets the requirement for a seismic event (1.00).

4.4 Liquefaction Factor of Safety

Liquefaction analyses used boring logs from previous subsurface investigations and a design earthquake with a magnitude of 5.7. The calculated factor of safety of 1.20 for the soils in the embankment (Youd, 2001) meets the requirement (1.20).

5.0 Conclusion

In GAI's opinion, the analyses show that the Chesterfield Upper (East) Pond meets or exceeds the factors of safety required by § 273.73(e)(1).

6.0 References

Dominion. 2014. *Report of 2014 Safety Inspection, Chesterfield Power Station Upper Ash Pond Dam.*

GAI Consultants Inc. 2015. *Dominion Chesterfield Power Station, Upper (East) Pond-Max Drawdown-Stability.*

GAI Consultants Inc. 2016. *Coal Combustion Residuals Inflow Design Flood Control System Plan, Upper (East) Pond, Chesterfield Power Station, Chesterfield County, Virginia*.

Geosyntec Consultants. 2016. *Memorandum – LAP and LVWWTS Seismic Design Data Analysis.*

Schnabel Engineering Associates. 1982. *Geotechnical Engineering and Groundwater Hydrology Services, Ash Disposal Pond, Chesterfield Power Station*.

Tuck Mapping. 2016. As-Built Contour Data. March 3, 2016

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.

Virginia Department of Environmental Quality. *Application for Solid Waste Permit Number 619*. 2016.

Virginia Power. 1992. *New Ash Pond Stop Log Conversion, DCR-91-20*. January 1992.

Virginia VPDES Permit No. VA0004146. *Revised Closure Plan, Upper (East) Pond, September 2003.*

Youd, T.L. *et. al.* "Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils." *Journal of Geotechnical and Geoenvironmental Engineering*. October 2001: 817-833.

APPENDIX A
Supporting Calculations

SUBJECT: CHESTERFIELD POWER STATION – SAEFTY FACTOR ASSESSMENT

BY TIM DATE 06/17/16 PROJ. NO. C150035.00

CHKD. BY KRH DATE 06/21/16 SHEET NO. 1 OF 9

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OBJECTIVE:

To evaluate the stability of the downstream portion of the embankment surrounding Dominion's Chesterfield Upper (East) Pond (UEP) Coal Combustion Residual storage facility at Chesterfield Power Station, Chesterfield County, Virginia. The analysis will address the requirements 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).

METHODOLOGY:

Evaluate stability using two-dimensional limit equilibrium analysis with the software program SLOPE/W and the Morgenstern-Price Method. The analysis will be run based on conditions outlined in the CCR Rule (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. Schnabel Engineering Associates, *Geotechnical Engineering and Groundwater Hydrology Services, Ash Disposal Pond, Chesterfield Power Station*; December 20, 1982.
3. Schnabel Engineering Associates, Inc. *Geotechnical Engineering Report: Upper Pond Stability Evaluation,* August 2014.
4. GAI Consultants Inc., 2003. *"Revised Closure Plan Upper (East) Pond, Chesterfield Power Station, Chesterfield County, Virginia."* September 2003.
5. GAI Consultants Inc., 2016. *DRAFT Coal Combustion Residuals Inflow Design Flood Control System Plan, Upper (East) Pond, Chesterfield Power Station, Chesterfield County, Virginia*. June 2016.
6. Virginia Power, 1992. New Ash Pond Stop Log Conversion, DCR-91-20. January 1992.
7. GAI Consultants Inc. 2016 Liquefaction Evaluation and Analysis, June 2016.
8. Geosyntec Consultants, 2016. *Memorandum – LAP and LVWWTS Seismic Design Data Analysis.* May 3, 2016.

BACKGROUND:

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.

ANALYSIS:

At the eastern end of the UEP, a stormwater sediment pond is used to control stormwater runoff during rain events. The UEP embankment at the stormwater sediment pond, near VPDES Outfall 005, was determined to be the critical section for purposes of this Assessment. The location and section is included in Attachment 2. The material strength parameters used in the analyses were obtained from *Geotechnical Engineering and Groundwater Hydrology Services, Ash Disposal Pond, Chesterfield Power Station* (Reference 2) and/or developed by GAI (Reference 4) based on previous subsurface exploration and laboratory testing.

Soil Type	γ_T (pcf)	c=c' (psf)	φ=φ' (Degrees)
Saturated CCR	90	0	24
Fill	125	0	30
Alluvium	120	0	30
SM-SC	135	0	35

The phreatic surface used in the analyses was dependent on the condition being assessed and is discussed for each analysis.

All calculations are included in Appendix A.

Long-Term Maximum Storage Pool Loading Condition

According to the CCR Rule preamble, 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." The Rule goes on to state that "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."

Stormwater runoff from the UEP is directed to the stormwater sediment pond and then directed into an outlet structure to VPDES Outfall 005. Normal pool in the stormwater sediment pond as determined by an orifice in the outlet structure is at elevation 28.33 feet (Reference 6); therefore, the long term maximum storage pool loading condition will have a phreatic surface elevation of 28.33 feet. The phreatic surface through the embankment is based on a straight line estimation connecting elevation 28.33 feet and the elevation at the toe of the embankment at the critical cross section, which has an elevation of 2 feet.

The calculated factor of safety is 1.79 for the embankment and meets the requirement for the long term maximum storage pool condition (1.50).

Maximum Surcharge Pool Loading Condition

The water elevation for the maximum surcharge pool loading condition is based on the inflow design flood, which is the 1000-year flood for a significant hazard dam (Reference 5). Based on the design flood, the phreatic surface will be at elevation 39.58 feet. The calculated factor of safety is 1.62 for the embankment and meets the requirement for the maximum surcharge pool condition (1.40).

Seismic Factor of Safety

The seismic factor of safety is run with a seismic loading event with a 2% probability of exceedance in 50 years, based on United States Geological Survey (USGS) seismic hazard maps. A peak ground acceleration of 0.128g was used in the analyses (Reference 8).

The long term maximum storage pool loading condition was evaluated under seismic conditions. The calculated factor of safety of 1.36 for the embankment meets the requirement for a seismic event (1.00).

Liquefaction Factor of Safety

Liquefaction analyses used boring logs from previous subsurface investigations and a design earthquake with a magnitude of 5.7. The liquefaction analysis can be found under a separate calculation (Reference 7). The calculated factor of safety of the soils in the embankment meets the requirement (1.20).

SUMMARY:

Based on the conditions in the CCR Rule, the UEP meets or exceeds the required factors of safety required by § 273.73(e)(1). A summary of the results are listed below

Loading Condition	Target FS	FS
Long Term Max Storage	1.50	1.79
Maximum Surcharge	1.40	1.62
Seismic	1.00	1.36
Liquefaction	1.20	1.20

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ATTACHMENT 1

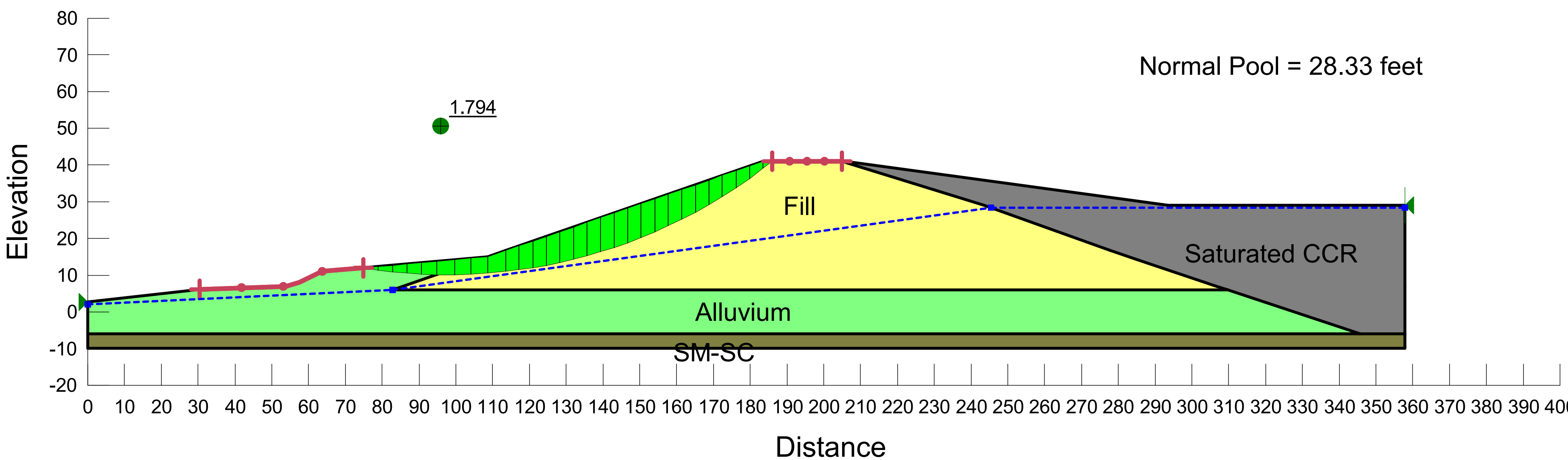
STABILITY ANALYSIS RESULTS

Horizontal Scale: 500
Vertical Scale: 500

By: TIM 6/6/2016
5
Ckd: KRH 6/21/2016
5/9

Chesterfield Upper (East) Pond
Safety Factor Assessment - Normal Pool
South Dike
C150035.00

Name: Saturated CCR Unit Weight: 90 pcf Cohesion: 0 psf Phi: 24 °
Name: Fill Unit Weight: 125 pcf Cohesion: 0 psf Phi: 27 °
Name: Alluvium Unit Weight: 120 pcf Cohesion: 0 psf Phi: 30 °
Name: SM-SC Unit Weight: 135 pcf Cohesion: 0 psf Phi: 35 °



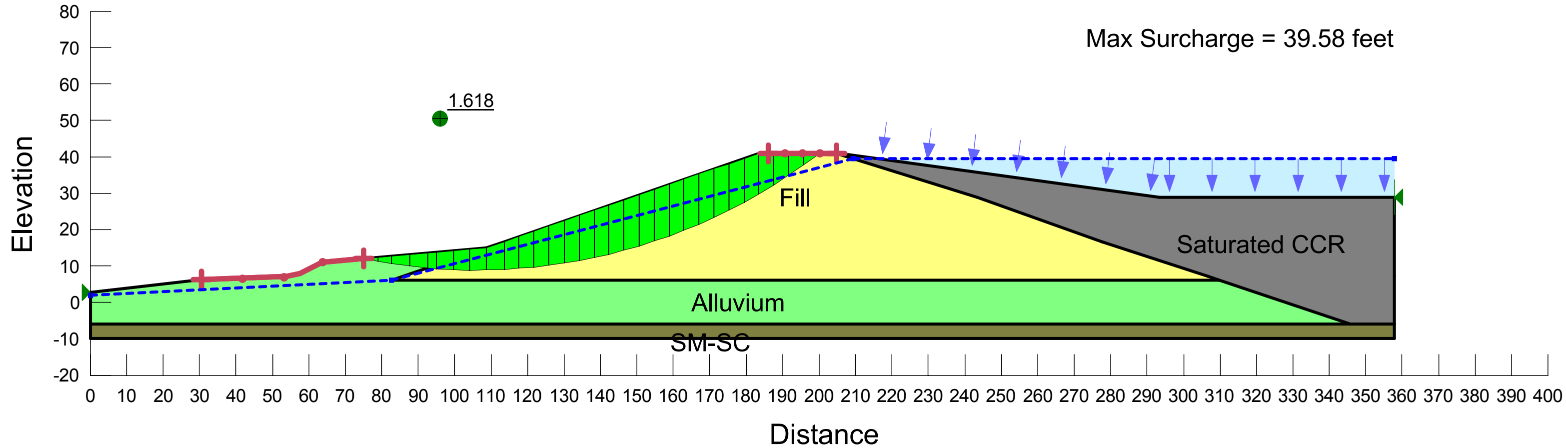
Horizontal Scale: 500
Vertical Scale: 500

By TIM 6/15/2016
Ckd: KRH 6/21/2016

6/9

Chesterfield Upper (East) Pond
Safety Factor Assessment - Max Surcharge
South Dike
C150035.00

Name: Saturated CCR Unit Weight: 90 pcf Cohesion: 0 psf Phi: 24 °
Name: Fill Unit Weight: 125 pcf Cohesion: 0 psf Phi: 30 °
Name: Alluvium Unit Weight: 120 pcf Cohesion: 0 psf Phi: 30 °
Name: SM-SC Unit Weight: 135 pcf Cohesion: 0 psf Phi 35 °



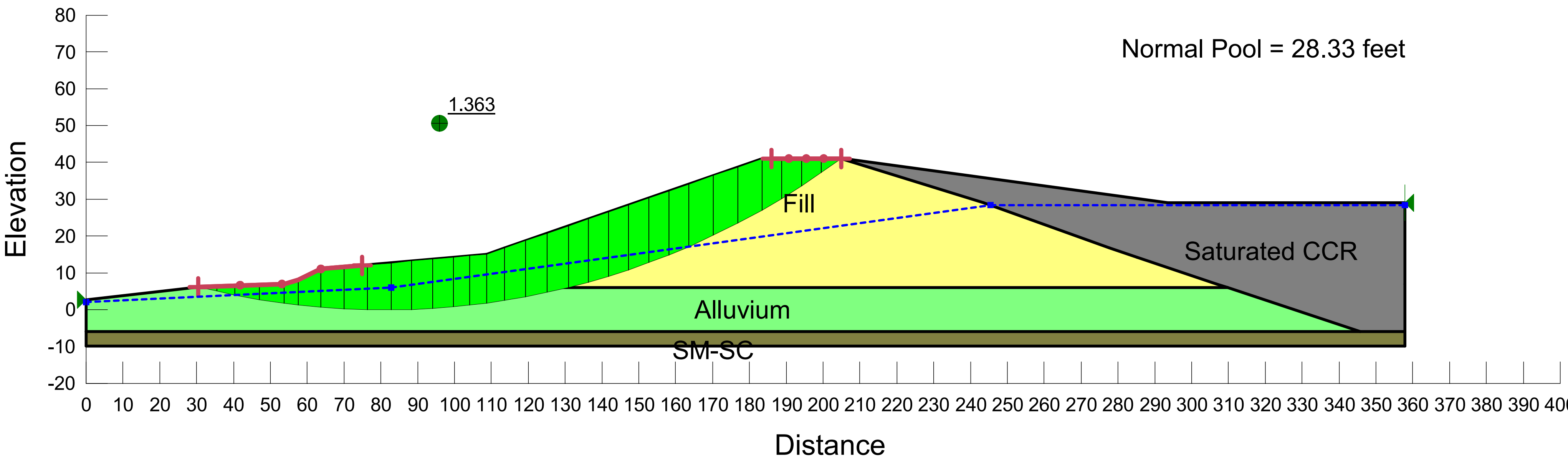
Horizontal Scale: 500
Vertical Scale: 500

By TIM 6/6/2016 7

Ckd: KRH 6/21/2016
7/9

Chesterfield Upper (East) Pond
Safety Factor Assessment - Normal Pool Seismic
South Dike
C150035.00

Name: Saturated CCR Unit Weight: 90 pcf Cohesion: 0 psf Phi: 24 °
Name: Fill Unit Weight: 125 pcf Cohesion: 0 psf Phi: 30 °
Name: Alluvium Unit Weight: 120 pcf Cohesion: 0 psf Phi: 30 °
Name: SM-SC Unit Weight: 135 pcf Cohesion: 0 psf Phi: 35 °
Seismic Value: 0.128g



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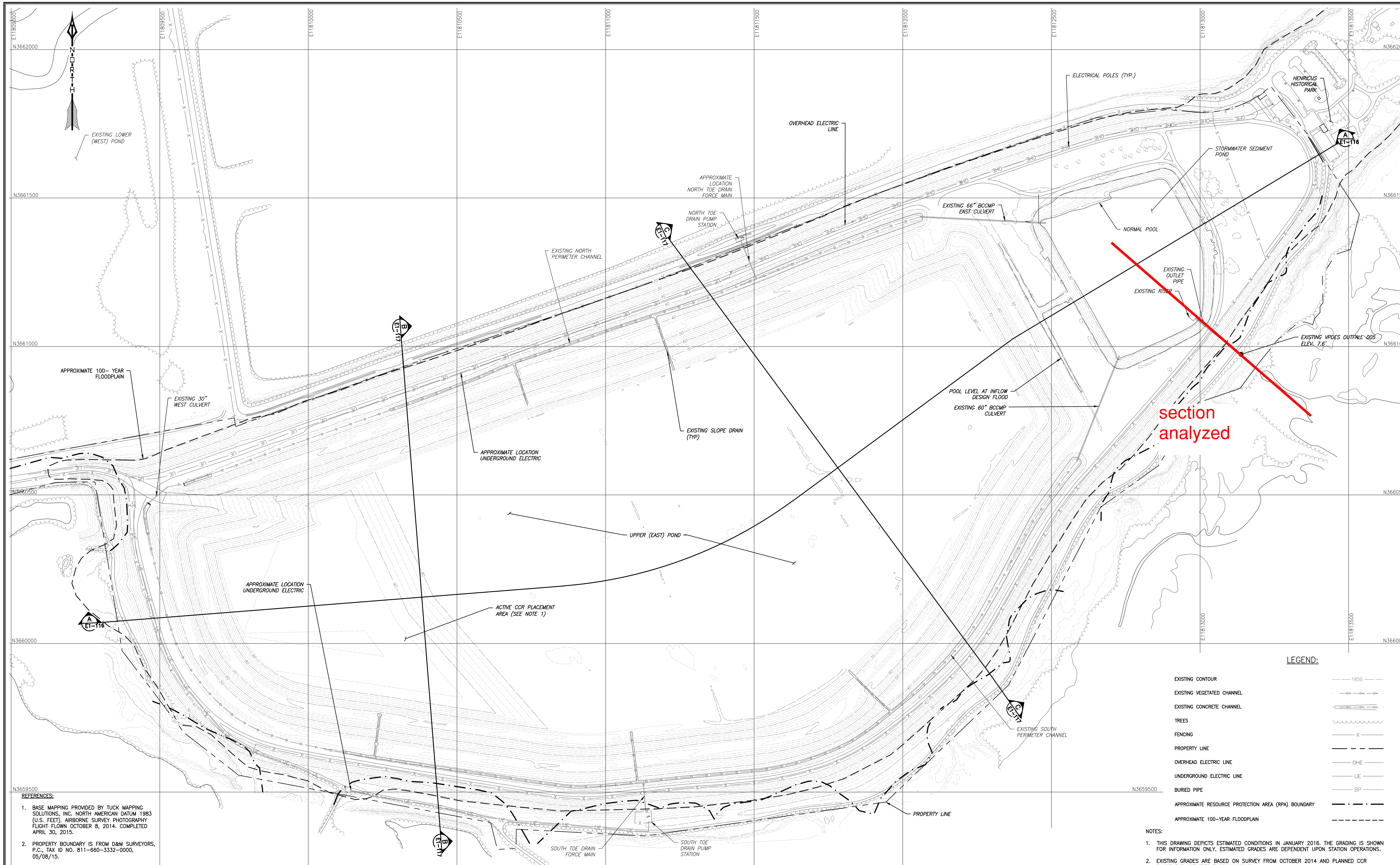
ATTACHMENT 2

DRAWINGS



REFERENCES:

1. BASE MAPPING PROVIDED BY TUCK MAPPING SOLUTIONS, INC. NORTH AMERICAN DATUM 1983 (U.S. FEET). AIRBORNE SURVEY PHOTOGRAPHY FLIGHT FLOWN OCTOBER 8, 2014. COMPLETED APRIL 30, 2015.
2. PROPERTY BOUNDARY IS FROM D&M SURVEYORS, P.C., TAX ID NO. 811-660-3332-0000, 05/08/15.
3. APPROXIMATE RPA BOUNDARY IS FROM GOLDER ASSOCIATES, "WETLAND DELINEATION MAP", DRAWING 1520610F01, 04/03/15.
4. APPROXIMATE 100-YEAR FLOODPLAIN LIMITS OBTAINED FROM FEMA PANELS 51041C0335D AND 51041C0351D.

LEGEND:

EXISTING CONTOUR	1850
EXISTING VEGETATED CHANNEL	
EXISTING CONCRETE CHANNEL	
TREES	
FENCING	X
PROPERTY LINE	
OVERHEAD ELECTRIC LINE	OHE
UNDERGROUND ELECTRIC LINE	UE
BURIED PIPE	BP
APPROXIMATE RESOURCE PROTECTION AREA (RPA) BOUNDARY	
APPROXIMATE 100-YEAR FLOODPLAIN	

NOTES:

1. THIS DRAWING DEPICTS ESTIMATED CONDITIONS IN JANUARY 2016. THE GRADING IS SHOWN FOR INFORMATION ONLY. ESTIMATED GRADES ARE DEPENDENT UPON STATION OPERATIONS.
2. EXISTING GRADES ARE BASED ON SURVEY FROM OCTOBER 2014 AND PLANNED CCR PLACEMENT ACTIVITIES THROUGH 2015.

SCALE: 1" = 120'

120 0 120 240

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

REVISION RECORD

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.

DRAWING TITLE

PLAN VIEW - EXISTING CONDITIONS

PROJECT	CLIENT
UPPER (EAST) POND HISTORY OF CONSTRUCTION CHESTERFIELD POWER STATION CHESTERFIELD COUNTY, VIRGINIA	DOMINION GLEN ALLEN, VIRGINIA

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

DRAWN BY:	CHECKED BY:	APPROVED BY:	GAI FILE NUMBER:
NEIMAJC			C150035-00-000-00-C-E1-115
DWG TYPE:	SCALE:	ISSUE DATE:	ALT./CLIENT DRAWING NUMBER:
	AS SHOWN	6/15/2016	
REVISION	SHEET NO.:		GAI DRAWING NUMBER:
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SUBJECT: CHESTERFIELD POWER STATION – UPPER (EAST) POND - LIQUEFACTION EVALUATION & ANALYSIS

BY TIM DATE 06/06/16 PROJ. NO. C150035.00

CHKD. BY FC DATE 06/09/2016 SHEET NO. 1 OF 5

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OBJECTIVE:

Determine the factor of safety against liquefaction for Dominion's existing Chesterfield Upper (East) Pond (UEP) Coal Combustion Residual (CCR) storage facility located at Chesterfield Power Station, Chesterfield County, Virginia.

METHODOLOGY:

Subsurface conditions will be analyzed in conjunction with the highest observed temporal phreatic surfaces. Field observations, soil borings, field test data, and other information from the References will be used to quantify the factor of safety against liquefaction (FS_L). The Simplified Procedure for Evaluating Liquefaction Potential (Simplified Procedure) with a design earthquake magnitude of 5.7 will be used for the analysis.

REFERENCES:

1. Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils, 2001.

2. MSHA Manual on Coal Waste Embankments, Chapter 7 Seismic Design: Stability and Deformation Analyses, May 2009.

3. Schnabel Engineering Consultants, Inc. *Geotechnical Engineering Report: Upper Pond Stability Evaluation*, August 2014.

4. VA DEQ Solid Waste Permit No 619 "Coal Combustion Residuals (CCR) Closure Plan, Virginia Electric and Power Company, Chesterfield Power Station, Upper (East) Pond, Chesterfield County, Virginia." Revised May 2016

5. Geosyntec Consultants, Memorandum, "LAP and LVWWTS Seismic Design Data Analysis" 03 May 2016.

6. GAI. "Review of Geosyntec Consultants (Geosyntec Memorandum, "LAP and LVWWTS Seismic Design Data Analysis".

7. 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.

8. Virginia Pollutant Discharge Elimination System Permit No. VA004146

SITE BACKGROUND:

CCR material at final grade within the UEP is currently covered with a 12-inch vegetated soil cover. In accordance with the CCR Closure Plan (part of DEQ Solid Waste Permit #619), CCR material within the UEP will be capped and covered by an engineered cover system meeting the requirements of Section 257.102(d)(3) of the CCR Rule. The engineered cover system will be placed over all CCR material within the UEP.

The engineered cover system will consist of the following (listed from bottom to top):

- -A prepared CCR or soil subgrade, or a nonwoven geotextile cushion geotextile placed over natural soils stripped of vegetation;
- -A 40-mil LLDPE geomembrane, meeting the requirements of CCR Rule Section 257.102(d)(3), which will serve as the infiltration layer;
- -A Geocomposite Drainage Net (GDN) with non-woven, needle punched geotextile heat bonded to both sides;
- -18 inches of a soil protective cover layer; and
- -Six inches of soil as a vegetative layer.

ASSUMPTIONS:

At the date of this analysis, the engineered cover system is not installed on the UEP. For purposes of analyzing liquefaction, the engineered cover system is assumed to be in place and the UEP is assumed to be at final grade. By analyzing liquefaction based on these assumptions, the analysis is conservative when compared to existing conditions (more CCR loading at final grades than current conditions and two feet of cover soil versus the current one foot).

Liquefaction was only analyzed at locations where boring data was available. CCR material placed in the UEP above the top of the embankment is assumed to have been dewatered and compacted in accordance with DEQ VPDES Permit No. VA004146 and thus is not susceptible to liquefaction.

ANALYSIS BACKGROUND:

The CCR Rule (Section 257.73(e)(1)(iv)) states that for impoundment embankments "constructed of soils that have susceptibility to liquefaction, the calculated liquefaction factor of safety must equal or exceed 1.20".

To calculate the liquefaction factor of safety for the UEP impoundment embankments, the site stratigraphy was analyzed with respect to soil classification, groundwater conditions, overburden, and age of the soil deposits. Published information (Reference 1) in conjunction with site visits and information from previous subsurface investigations performed by Schnabel from 1982-2005 (Reference 3) were employed to determine the site conditions for the liquefaction evaluation.

Borings within the limits of the UEP (see Attachment 2), including groundwater table observations, were used for the liquefaction analysis. Site stratigraphy was reconstructed based on field records compiled from the boring data, including N-values from Standard Penetration Tests (SPT), soil classification, layer thicknesses, and groundwater observations.

In-situ soils prior to the construction of the UEP consisted of alluvial and terrace deposited soils with minimal cohesion (Reference 3). The alluvial materials contained a mixture of sand, silt, and clay.

Initial CCR placement into the UEP consisted of sluiced material placed above the alluvial material. In-situ CCR and cover soil overburden thickness in the areas where boring data was available varies from 0 feet at the embankment interface to approximately 108 feet at proposed final closure grade.

Soil strata considered in the liquefaction analyses consisted of:

- In-situ alluvial soils prior to construction of the UEP
- Sluiced CCR material below ground water levels observed in the borings
- Dried CCR material above observed ground water levels
- UEP impoundment embankment soils where appropriate

Because of the heterogeneous nature of alluvial deposits, continuous "critical layers" could not be discerned throughout the site. However, to be conservative, each individual soil interval observed in the borings was evaluated for liquefaction potential. Sluiced material was also evaluated because of the high saturation.

Since the potentially liquefiable material does not exist in one continuous layer below ground water levels observed in the borings, the borings analyzed are intended to represent typical areas where pockets of the potentially liquefiable material may exist (note that the borings represent site conditions in the year the subsurface investigation was performed). Dewatered CCR material was placed and compacted to a unit weight of 93 pounds per cubic foot (pcf) (Reference 3).

Based on the criteria listed in References 1 and 2, the alluvial deposits and saturated CCR material exhibited characteristics typical of soils susceptible to liquefaction. These deposits were within 50 feet of the existing ground surface; and exhibited moderately low strength based on SPT data. From this information, liquefaction analysis using the "Simplified Procedure" (References 1 and 2) was deemed appropriate for the site.

To determine the potential for liquefaction using the "Simplified Procedure", SPT blow counts were used in conjunction with a design earthquake event having a magnitude 5.7. This earthquake magnitude was obtained from Reference 6. The maximum acceleration for the analysis was determined from Reference 5 to be 0.128g.

ANALYSIS PROCEDURE:

The following steps, and associated equations, were used to determine factors of safety against liquefaction (FS_L) in accordance with the "Simplified Procedure". Each individual soil interval was analyzed for each analyzed boring. Spreadsheets showing the calculations are included in Attachment 1 of the UEP Liquefaction Evaluation & Analysis.

Step 1: Develop cross-sections including soil properties, layer geometry, groundwater elevation, and average N-values for the analysis (Refer to stability analyses for typical cross-sections).

Step 2: Determine SPT blow count correction factors for the energy ratio (C_E), borehole diameter (C_B), rod length (C_R), and sampling method (C_S) as shown in Table 2 of Reference 1. For the drilling program, safety hammers or automatic trip hammers were used on all of the rigs (C_E = 0.7 -- conservative value); hollow stem augers with a diameter of approximately 3.25 inches were used for all of the holes (C_B=1.0); standard split-spoon samplers without liners were advanced in all the holes (C_S=1.0); and rod lengths up to approximately 60-feet were used.

Step 3: Calculate standard blow counts, N_{60}, by multiplying the field measured N-values by the correction factors determined in Step 2.

Step 4: Determine the effective vertical stress (σ_{vo}') for existing in-situ soil conditions at each test depth as follows:

$\sigma_{vo}' = \gamma_T \times z$ if the test depth, z, is above the water table depth, h

$\sigma_{vo}' = (\gamma_{sat} - \gamma_w) \times (z - h) + \gamma_T \times h$ if z>h

Step 5: Determine overburden pressure correction factor (C_N) for each test depth from Table 2 in Reference 1, with P_a = 1.04 tsf:

$$C_N = \sqrt{P_a / \sigma_{vo}'}$$

C_N shall be limited to 1.7

Step 6: Determine the design total vertical stress and the design effective vertical stresses at each test depth using the fly ash impoundment and/or fly ash embankment overburden. Unit weight for embankment fill and CCR material are based off values from Reference 4.

Step 7: Determine SPT blow counts normalized to overburden pressure, $(N_1)_{60} = N_{60} * C_N$

Step 8: Correct for fines content, by applying fines correction coefficients to (α and β) to $(N_1)_{60}$. Fines contents of the alluvial soils were not quantified by laboratory testing. To be conservative, a fines contents were based off of minimal values from lab data provided in Reference 3. If multiple soil layers were encountered in a boring, the minimum value for fines was used. Using Eq. 5 from Ref. 1:

$$(N_1)_{60cs} = \alpha + \beta (N_1)_{60}$$

Step 9: Determine the stress reduction factor, r_d. (Reference 1)

$$(r_d) = 1.0 - 0.00765z \text{ for } z \leq 9.15 \text{ m}$$

or

$$(r_d) = 1.174 - 0.0267z \text{ for } z < 9.15 \text{ m} \leq 23 \text{ m}$$

z is in meters

Step 10: Calculate the Cyclic Stress Ratio (CSR) using a_{max} = 0.128g, historic value for the site:

$$CSR = \left(\frac{0.65 \times a_{\max}}{g}\right) \times r_d \times \left(\frac{\sigma_{vo}}{\sigma_{vo}'}\right)$$

Step 11: Determine the Cyclic Resistance Ratio (CRR) for an earthquake of magnitude 7.5 based on the $(N_1)_{60cs}$ values (For $(N_1)_{60cs}$ < 30).

$$CRR_{7.5} = \frac{1}{34-(N_1)_{60}} + \frac{(N_1)_{60}}{135} + \frac{50}{(10\times(N_1)_{60}+45)^2} - \frac{1}{200}$$

Step 12: Calculate the earthquake Magnitude Scaling Factor (MSF) based on recommendations by Idriss for engineering practice, (Reference 1):

$$MSF = 10^{2.24}/M^{2.56}$$

Step 13: Calculate K_σ based on Reference 1,

$$K_\sigma = (\sigma'_{vo} / P_a)^{(f-1)}$$

where f = 0.6 for relative densities greater than or equal to 80%, f = 0.7 for relative densities greater than 40% but less than 80% and f = 0.8 for relative densities less than 40%.

Step 14: Calculate the corrected Cyclic Resistance Ratio using the previously determined correction factors and $CRR_{7.5}$.

$$CRR = K_\sigma \times K_\alpha \times CRR_{7.5}$$

Where K_α = 1 based on recommendations from Reference 1

Step 15: Calculate the factor of safety against liquefaction, FS_L.

$$FS_L = \frac{CRR}{CSR} \times MSF$$

RESULTS:

Factor of Safety calculations are contained in Attachment 1. Results of the analyses for UEP sections taken at boring locations meet minimum 1.20 factor of safety required in the CCR Rule (Section 257.73(e)(1)(iv)).

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ATTACHMENT 1

FS_L SPREADSHEETS

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Dominion
Chesterfield Power Station
Upper (East) Pond
Liquefaction Analysis

C150035.00
By: TIM 06/03/16
Checked by: FC 06/09/2016

BORING B-2 (1982)

G.S. Elev. =	26.6		W.T. Elev. =	2.2 (feet)	Bottom Elev. =	-3.4	Fines Content =	15	Atmospheric Pressure	100 kPa
$\gamma_{overburden}$ =	120.0 (pcf)				Top Elev. =	26.6	Relative Density=	30%		1.04 tsf
γ_{sat} =	125.0 (pcf)		Est. EQ Mag	5.7			f=	0.8		
γ_{soil} =	120.0									

Test Depth (m)	Test Depth (ft)	N	C_E	C_B	C_S	C_R	N_{60}	Existing σ'_{vo} (tsf)	C_N	Design σ_{vo} (tsf)	Design σ_{vo}' (tsf)	$(N_1)_{60}$	α	β	$(N_1)_{60cs}$	r_d	a_{max}	CSR	$CRR_{7.5}$	MSF	K_σ	K_α	CRR	FS_L
			Table 2[1]						Eq. (9)[1]			Eq. (8)[1]	Eq. (6)[1]	Eq. (7)[1]	Eq. (5)[1]	Eq. (2)[1]		Eq. (1)[1]	Eq. (4)[1]	Eq. (24)[1]	Eq. (31)[1]			Eq. (30)[1]
0.5	1.5	22	0.7	1.0	1.0	0.75	12	0.09	1.70	0.1	0.1	20	2	1.1	24	1.00	0.128	0.083	0.27	2.0	1.60	1.00	0.43	-
1.7	5.5	10	0.7	1.0	1.0	0.75	5	0.33	1.70	0.3	0.3	9	2	1.1	12	0.99	0.128	0.082	0.13	2.0	1.28	1.00	0.17	-
3.2	10.5	8	0.7	1.0	1.0	0.80	4	0.63	1.28	0.6	0.6	5	2	1.1	8	0.98	0.128	0.082	0.10	2.0	1.12	1.00	0.11	-
4.7	15.5	8	0.7	1.0	1.0	0.85	5	0.93	1.06	0.9	0.9	5	2	1.1	8	0.96	0.128	0.080	0.10	2.0	1.03	1.00	0.10	-
6.2	20.5	8	0.7	1.0	1.0	0.95	5	1.23	0.92	1.2	1.2	5	2	1.1	8	0.95	0.128	0.079	0.10	2.0	0.97	1.00	0.10	-
7.8	25.5	4	0.7	1.0	1.0	0.95	3	1.50	0.83	1.5	1.5	2	2	1.1	4	0.94	0.128	0.078	0.06	2.0	0.93	1.00	0.06	1.54
9.1	30.0	11	0.7	1.0	1.0	0.95	7	1.64	0.80	1.8	1.6	6	2	1.1	9	0.93	0.128	0.087	0.10	2.0	0.92	1.00	0.09	2.07

FS_{min} 1.54

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)

References:
(1) Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils, 2001
(2) MSHA Manual on Coal Waste Embankments, Chapter 7 Seismic Design: Stability and Deformation Analyses, May 2009

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Dominion
Chesterfield Power Station
Upper (East) Pond
Liquefaction Analysis

C150035.00
By: TIM 06/03/16
Checked by: FC 06/09/2016

BORING B-3 (1982)

G.S. Elev. = 31.8 W.T. Elev. = 3.2 (feet) Bottom Elev. = -28.2 Fines Content = 15 Atmospheric Pressure 100 kPa

$\gamma_{overburden}$ = 120.0 (pcf) Top Elev. = 31.8 Relative Density= 30% 1.04 tsf

γ_{sat} = 125.0 (pcf) Est. EQ Mag 5.7 f= 0.8

γ_{soil} = 120.0

			Table 2[1]						Eq. (9)[1]			Eq. (8)[1]	Eq. (6)[1]	Eq. (7)[1]	Eq. (5)[1]	Eq. (2)[1]		Eq. (1)[1]	Eq. (4)[1]	Eq. (24)[1]	Eq. (31)[1]			Eq. (30)[1]
Test Depth (m)	Test Depth (ft)	N	C_E	C_B	C_S	C_R	N_{60}	Existing σ'_{vo} (tsf)	C_N	Design σ_{vo} (tsf)	Design σ_{vo}' (tsf)	$(N_1)_{60}$	α	β	$(N_1)_{60cs}$	r_d	a_{max}	CSR	$CRR_{7.5}$	MSF	K_σ	K_α	CRR	FS_L
0.5	1.5	37	0.7	1.0	1.0	0.75	19	0.09	1.70	0.1	0.1	32	2	1.1	30	1.00	0.128	0.083	0.47	2.0	1.60	1.00	0.75	-
1.7	5.5	11	0.7	1.0	1.0	0.75	6	0.33	1.70	0.3	0.3	10	2	1.1	13	0.99	0.128	0.082	0.14	2.0	1.28	1.00	0.18	-
3.2	10.5	13	0.7	1.0	1.0	0.80	7	0.63	1.28	0.6	0.6	9	2	1.1	12	0.98	0.128	0.082	0.13	2.0	1.12	1.00	0.15	-
4.7	15.5	12	0.7	1.0	1.0	0.85	7	0.93	1.06	0.9	0.9	7	2	1.1	10	0.96	0.128	0.080	0.11	2.0	1.03	1.00	0.11	-
6.2	20.5	7	0.7	1.0	1.0	0.95	5	1.23	0.92	1.2	1.2	5	2	1.1	8	0.95	0.128	0.079	0.10	2.0	0.97	1.00	0.10	-
7.8	25.5	6	0.7	1.0	1.0	0.95	4	1.53	0.82	1.5	1.5	3	2	1.1	5	0.94	0.128	0.078	0.07	2.0	0.93	1.00	0.07	-
9.3	30.5	10	0.7	1.0	1.0	0.95	7	1.78	0.76	1.8	1.8	5	2	1.1	8	0.93	0.128	0.077	0.10	2.0	0.90	1.00	0.09	2.34
10.8	35.5	20	0.7	1.0	1.0	1.00	14	1.93	0.73	2.1	1.9	10	2	1.1	13	0.89	0.128	0.082	0.14	2.0	0.89	1.00	0.12	2.93
12.3	40.5	13	0.7	1.0	1.0	1.00	9	2.09	0.71	2.5	2.1	6	2	1.1	9	0.85	0.128	0.084	0.10	2.0	0.87	1.00	0.09	2.14
13.9	45.5	24	0.7	1.0	1.0	1.00	17	2.24	0.68	2.8	2.2	12	2	1.1	15	0.80	0.128	0.085	0.16	2.0	0.86	1.00	0.14	3.29
15.4	50.5	100	0.7	1.0	1.0	1.00	70	2.40	0.66	3.1	2.4	46	2	1.1	30	0.76	0.128	0.082	0.47	2.0	0.85	1.00	0.40	9.76
16.9	55.5	49	0.7	1.0	1.0	1.00	34	2.56	0.64	3.4	2.6	22	2	1.1	26	0.72	0.128	0.078	0.31	2.0	0.83	1.00	0.26	6.67
18.3	60.0	47	0.7	1.0	1.0	1.00	33	2.70	0.62	3.7	2.7	20	2	1.1	24	0.69	0.128	0.079	0.27	2.0	0.83	1.00	0.22	5.57

FS_{min} 2.14

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)

References:
(1) Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils, 2001
(2) MSHA Manual on Coal Waste Embankments, Chapter 7 Seismic Design: Stability and Deformation Analyses, May 2009

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Dominion
Chesterfield Power Station
Upper (East) Pond
Liquefaction Analysis

C150035.00
By: TIM 06/03/16
Checked by: FC 06/09/2016

BORING B-4 (1982)

G.S. Elev. = 25.2 | W.T. Elev. = 2.1 (feet) | Bottom Elev. = -6.5 | Fines Content = 15 | Atmospheric Pressure 100 kPa

$\gamma_{overburden}$ = 120.0 (pcf) | Top Elev. = 25.2 | Relative Density= 30% | 1.04 tsf

γ_{sat} = 125.0 (pcf) | Est. EQ Mag 5.7 | f= 0.8

γ_{soil} = 120.0

Test Depth (m)	Test Depth (ft)	N	C_E	C_B	C_S	C_R	N_{60}	Existing σ'_{vo} (tsf)	C_N	Design σ_{vo} (tsf)	Design σ_{vo}' (tsf)	$(N_1)_{60}$	α	β	$(N_1)_{60cs}$	r_d	a_{max}	CSR	$CRR_{7.5}$	MSF	K_σ	K_α	CRR	FS_L
			Table 2[1]						Eq. (9)[1]			Eq. (8)[1]	Eq. (6)[1]	Eq. (7)[1]	Eq. (5)[1]	Eq. (2)[1]		Eq. (1)[1]	Eq. (4)[1]	Eq. (24)[1]	Eq. (31)[1]			Eq. (30)[1]
0.5	1.5	35	0.7	1.0	1.0	0.75	18	0.09	1.70	0.1	0.1	31	2	1.1	30	1.00	0.128	0.083	0.47	2.0	1.60	1.00	0.75	-
1.7	5.5	11	0.7	1.0	1.0	0.75	6	0.33	1.70	0.3	0.3	10	2	1.1	13	0.99	0.128	0.082	0.14	2.0	1.28	1.00	0.18	-
3.2	10.5	8	0.7	1.0	1.0	0.80	4	0.63	1.28	0.6	0.6	5	2	1.1	8	0.98	0.128	0.082	0.10	2.0	1.12	1.00	0.11	-
4.7	15.5	9	0.7	1.0	1.0	0.85	5	0.93	1.06	0.9	0.9	5	2	1.1	8	0.96	0.128	0.080	0.10	2.0	1.03	1.00	0.10	-
6.2	20.5	6	0.7	1.0	1.0	0.95	4	1.23	0.92	1.2	1.2	4	2	1.1	6	0.95	0.128	0.079	0.08	2.0	0.97	1.00	0.08	-
7.8	25.5	6	0.7	1.0	1.0	0.95	4	1.46	0.84	1.5	1.5	3	2	1.1	5	0.94	0.128	0.078	0.07	2.0	0.93	1.00	0.07	1.79
9.3	30.5	50	0.7	1.0	1.0	0.95	33	1.62	0.80	1.8	1.6	26	2	1.1	30	0.93	0.128	0.087	0.47	2.0	0.92	1.00	0.43	9.89
10.7	35.0	21	0.7	1.0	1.0	1.00	15	1.45	0.77	1.5	1.5	12	2	1.1	15	0.89	0.128	0.074	0.16	2.0	0.93	1.00	0.15	4.05

FS_{min} 1.79

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)

References:

(1) Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils, 2001
(2) MSHA Manual on Coal Waste Embankments, Chapter 7 Seismic Design: Stability and Deformation Analyses, May 2009

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Dominion
Chesterfield Power Station
Upper (East) Pond
Liquefaction Analysis

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By: TIM 06/03/16
Checked by: FC 06/09/2016

BORING B-6 (1982)

G.S. Elev. = 15.0 W.T. Elev. = 1.5 (feet) Bottom Elev. = -10.0 Fines Content = 5 Atmospheric Pressure 100 kPa

$\gamma_{overburden}$ = 120.0 (pcf) Top Elev. = 15.0 Relative Density= 30% 1.04 tsf

γ_{sat} = 125.0 (pcf) Est. EQ Mag 5.7 f= 0.8

γ_{soil} = 120.0

Test Depth (m)	Test Depth (ft)	N	C_E	C_B	C_S	C_R	N_{60}	Existing σ'_{vo} (tsf)	C_N	Design σ_{vo} (tsf)	Design σ_{vo}' (tsf)	$(N_1)_{60}$	α	β	$(N_1)_{60cs}$	r_d	a_{max}	CSR	$CRR_{7.5}$	MSF	K_σ	K_α	CRR	FS_L
			Table 2[1]						Eq. (9)[1]			Eq. (8)[1]	Eq. (6)[1]	Eq. (7)[1]	Eq. (5)[1]	Eq. (2)[1]		Eq. (1)[1]	Eq. (4)[1]	Eq. (24)[1]	Eq. (31)[1]			Eq. (30)[1]
0.5	1.5	31	0.7	1.0	1.0	0.75	16	0.09	1.70	0.1	0.1	27	0	1.0	27	1.00	0.128	0.083	0.34	2.0	1.60	1.00	0.54	-
1.7	5.5	9	0.7	1.0	1.0	0.75	5	0.33	1.70	0.3	0.3	9	0	1.0	9	0.99	0.128	0.082	0.10	2.0	1.28	1.00	0.13	-
3.2	10.5	5	0.7	1.0	1.0	0.80	3	0.63	1.28	0.6	0.6	4	0	1.0	4	0.98	0.128	0.082	0.06	2.0	1.12	1.00	0.07	-
4.7	15.5	80	0.7	1.0	1.0	0.85	48	0.87	1.09	0.9	0.9	52	0	1.0	52	0.96	0.128	0.080	0.32	2.0	1.03	1.00	0.33	8.25
6.2	20.5	20	0.7	1.0	1.0	0.95	13	1.03	1.00	1.2	1.0	13	0	1.0	13	0.95	0.128	0.095	0.14	2.0	1.01	1.00	0.14	2.95
7.6	25.0	24	0.7	1.0	1.0	0.95	16	1.17	0.94	1.5	1.2	15	0	1.0	15	0.94	0.128	0.098	0.16	2.0	0.97	1.00	0.16	3.27

FS_{min} 2.95

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)

References:
(1) Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils, 2001
(2) MSHA Manual on Coal Waste Embankments, Chapter 7 Seismic Design: Stability and Deformation Analyses, May 2009

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Dominion
Chesterfield Power Station
Upper (East) Pond
Liquefaction Analysis

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By: TIM 06/03/16
Checked by: FC 06/09/2016

BORING B-8 (1982)

G.S. Elev. = 8.2 W.T. Elev. = 1.5 (feet) Bottom Elev. = -16.8 Fines Content = 5 Atmospheric Pressure 100 kPa

$\gamma_{overburden}$ = 120.0 (pcf) Top Elev. = 8.2 Relative Density= 30% 1.04 tsf

γ_{sat} = 125.0 (pcf) Est. EQ Mag 5.7 f= 0.8

γ_{soil} = 120.0

			Table 2[1]						Eq. (9)[1]			Eq. (8)[1]	Eq. (6)[1]	Eq. (7)[1]	Eq. (5)[1]	Eq. (2)[1]		Eq. (1)[1]	Eq. (4)[1]	Eq. (24)[1]	Eq. (31)[1]			Eq. (30)[1]
Test Depth (m)	Test Depth (ft)	N	C_E	C_B	C_S	C_R	N_{60}	Existing σ'_{vo} (tsf)	C_N	Design σ_{vo} (tsf)	Design σ_{vo}' (tsf)	$(N_1)_{60}$	α	β	$(N_1)_{60cs}$	r_d	a_{max}	CSR	$CRR_{7.5}$	MSF	K_σ	K_α	CRR	FS_L
0.5	1.5	42	0.7	1.0	1.0	0.75	22	0.09	1.70	0.1	0.1	30	0	1.0	30	1.00	0.128	0.083	0.47	2.0	1.60	1.00	0.75	-
1.7	5.5	10	0.7	1.0	1.0	0.75	5	0.33	1.70	0.3	0.3	9	0	1.0	9	0.99	0.128	0.082	0.10	2.0	1.28	1.00	0.13	-
3.2	10.5	4	0.7	1.0	1.0	0.80	2	0.52	1.41	0.6	0.5	3	0	1.0	3	0.98	0.128	0.098	0.06	2.0	1.16	1.00	0.07	1.43
4.7	15.5	93	0.7	1.0	1.0	0.85	55	0.68	1.24	1.0	0.7	30	0	1.0	30	0.96	0.128	0.114	0.47	2.0	1.08	1.00	0.51	8.95
6.2	20.5	100	0.7	1.0	1.0	0.95	67	0.83	1.12	1.3	0.8	30	0	1.0	30	0.95	0.128	0.128	0.47	2.0	1.05	1.00	0.49	7.66
7.6	25.0	98	0.7	1.0	1.0	0.95	65	0.97	1.04	1.5	1.0	30	0	1.0	30	0.94	0.128	0.117	0.47	2.0	1.01	1.00	0.47	8.03

FS_{min} 1.43

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)

References: (1) Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils, 2001
(2) MSHA Manual on Coal Waste Embankments, Chapter 7 Seismic Design: Stability and Deformation Analyses, May 2009

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Dominion
Chesterfield Power Station
Upper (East) Pond
Liquefaction Analysis

C150035.00
By: TIM 06/03/16
Checked by: FC 06/09/2016

BORING B-9 (1982)

G.S. Elev. = 12.0 W.T. Elev. = 9.7 (feet) Bottom Elev. = -48.0 Fines Content = 13 Atmospheric Pressure 100 kPa

$\gamma_{overburden}$ = 120.0 (pcf) Top Elev. = 12.0 Relative Density= 30% 1.04 tsf

γ_{sat} = 125.0 (pcf) Est. EQ Mag 5.7 f= 0.8

γ_{soil} = 120.0

			Table 2[1]						Eq. (9)[1]			Eq. (8)[1]	Eq. (6)[1]	Eq. (7)[1]	Eq. (5)[1]	Eq. (2)[1]		Eq. (1)[1]	Eq. (4)[1]	Eq. (24)[1]	Eq. (31)[1]			Eq. (30)[1]
Test Depth (m)	Test Depth (ft)	N	C_E	C_B	C_S	C_R	N_{60}	Existing σ'_{vo} (tsf)	C_N	Design σ_{vo} (tsf)	Design σ_{vo}' (tsf)	$(N_1)_{60}$	α	β	$(N_1)_{60cs}$	r_d	a_{max}	CSR	$CRR_{7.5}$	MSF	K_σ	K_α	CRR	FS_L
0.5	1.5	37	0.7	1.0	1.0	0.75	19	0.09	1.70	0.1	0.1	32	2	1.1	30	1.00	0.128	0.083	0.47	2.0	1.60	1.00	0.75	-
1.7	5.5	6	0.7	1.0	1.0	0.75	3	0.24	1.70	0.3	0.2	5	2	1.1	8	0.99	0.128	0.124	0.10	2.0	1.39	1.00	0.14	2.26
3.2	10.5	5	0.7	1.0	1.0	0.80	3	0.39	1.63	0.7	0.4	5	2	1.1	8	0.98	0.128	0.143	0.10	2.0	1.21	1.00	0.12	1.68
4.7	15.5	18	0.7	1.0	1.0	0.85	11	0.55	1.38	1.0	0.6	15	2	1.1	19	0.96	0.128	0.133	0.20	2.0	1.12	1.00	0.22	3.31
6.2	20.5	68	0.7	1.0	1.0	0.95	45	0.71	1.21	1.3	0.7	54	2	1.1	30	0.95	0.128	0.147	0.47	2.0	1.08	1.00	0.51	6.94
7.8	25.5	58	0.7	1.0	1.0	0.95	39	0.86	1.10	1.6	0.9	43	2	1.1	30	0.94	0.128	0.139	0.47	2.0	1.03	1.00	0.48	6.91
9.3	30.5	100	0.7	1.0	1.0	0.95	67	1.02	1.01	1.9	1.0	68	2	1.1	30	0.93	0.128	0.147	0.47	2.0	1.01	1.00	0.47	6.39
10.8	35.5	100	0.7	1.0	1.0	1.00	70	1.18	0.94	2.2	1.2	66	2	1.1	30	0.89	0.128	0.136	0.47	2.0	0.97	1.00	0.46	6.76
12.3	40.5	100	0.7	1.0	1.0	1.00	70	1.33	0.88	2.5	1.3	62	2	1.1	30	0.85	0.128	0.136	0.47	2.0	0.96	1.00	0.45	6.62
13.9	45.5	36	0.7	1.0	1.0	1.00	25	1.49	0.84	2.8	1.5	21	2	1.1	25	0.80	0.128	0.124	0.29	2.0	0.93	1.00	0.27	4.35
15.4	50.5	60	0.7	1.0	1.0	1.00	42	1.65	0.79	3.2	1.6	33	2	1.1	30	0.76	0.128	0.126	0.47	2.0	0.92	1.00	0.43	6.83
16.9	55.5	40	0.7	1.0	1.0	1.00	28	1.80	0.76	3.5	1.8	21	2	1.1	25	0.72	0.128	0.116	0.29	2.0	0.90	1.00	0.26	4.48
18.3	60.0	38	0.7	1.0	1.0	1.00	27	1.94	0.73	3.7	1.9	20	2	1.1	24	0.69	0.128	0.112	0.27	2.0	0.89	1.00	0.24	4.29

FS_{min} 1.68

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)

References: (1) Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils, 2001
(2) MSHA Manual on Coal Waste Embankments, Chapter 7 Seismic Design: Stability and Deformation Analyses, May 2009

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Dominion
Chesterfield Power Station
Upper (East) Pond
Liquefaction Analysis

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By: TIM 06/03/16
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BORING B-12 (1982)

G.S. Elev. =	23.5	W.T. Elev. =	2.5 (feet)	Bottom Elev. =	-6.5	Fines Content =	25	Top Sat CCR Elev. =	35
$\gamma_{overburden}$ =	93.0 (pcf)	γ_{cover} =	120 (pcf)	Top CCR Elev. =	126.0	Relative Density=	30%	Bottom Sat CCR Elev. =	23.5
γ_{sat} =	98.0 (pcf)	Est. EQ Mag	5.7	Top Cover Elev. =	128.0	f=	0.8		
γ_{soil} =	120.0								

Atmospheric Pressure 100 kPa
1.04 tsf

Test Depth (m)	Test Depth (ft)	N	C_E	C_B	C_S	C_R	N_{60}	Existing σ'_{vo} (tsf)	C_N	Design σ_{vo} (tsf)	Design σ_{vo}' (tsf)	$(N_1)_{60}$	α	β	$(N_1)_{60cs}$	r_d	a_{max}	CSR	$CRR_{7.5}$	MSF	K_σ	K_α	CRR	FS_L
			Table 2[1]						Eq. (9)[1]			Eq. (8)[1]	Eq. (6)[1]	Eq. (7)[1]	Eq. (5)[1]	Eq. (2)[1]		Eq. (1)[1]	Eq. (4)[1]	Eq. (24)[1]	Eq. (31)[1]			Eq. (30)[1]
0.5	1.5	18	0.7	1.0	1.0	0.75	9	0.07	1.70	5.0	5.0	15	4	1.1	21	1.00	0.128	0.083	0.23	2.0	0.73	1.00	0.17	-
1.7	5.5	11	0.7	1.0	1.0	0.75	6	0.26	1.70	5.2	5.2	10	4	1.1	15	0.99	0.128	0.082	0.16	2.0	0.72	1.00	0.12	-
3.2	10.5	15	0.7	1.0	1.0	0.80	8	0.49	1.28	5.5	5.5	10	4	1.1	15	0.98	0.128	0.082	0.16	2.0	0.72	1.00	0.12	-
4.7	15.5	20	0.7	1.0	1.0	0.85	12	0.72	1.06	5.8	5.8	13	4	1.1	18	0.96	0.128	0.080	0.19	2.0	0.71	1.00	0.13	-
6.2	20.5	19	0.7	1.0	1.0	0.95	13	0.95	0.92	6.1	6.1	12	4	1.1	17	0.95	0.128	0.079	0.18	2.0	0.70	1.00	0.13	-
7.8	25.5	14	0.7	1.0	1.0	0.95	9	1.06	0.86	6.4	6.1	8	4	1.1	13	0.94	0.128	0.082	0.14	2.0	0.70	1.00	0.10	2.44
9.1	30.0	27	0.7	1.0	1.0	0.95	18	1.14	0.82	6.7	6.4	15	4	1.1	21	0.93	0.128	0.081	0.23	2.0	0.70	1.00	0.16	3.95

FS_{min} 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)

References: (1) Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils, 2001
(2) MSHA Manual on Coal Waste Embankments, Chapter 7 Seismic Design: Stability and Deformation Analyses, May 2009

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Dominion
Chesterfield Power Station
Upper (East) Pond
Liquefaction Analysis

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BORING B-13 (1982)

G.S. Elev. = 22.0 W.T. Elev. = 2.5 (feet) Bottom Elev. = -6.5 Fines Content = 15 Top Sat CCR Elev. = 35 Atmospheric Pressure 100 kPa

$\gamma_{overburden}$ = 93.0 (pcf) γ_{cover} = 120 (pcf) Top CCR Elev. = 128.0 Relative Density= 30% Bottom Sat CCR Elev. = 22 1.04 tsf

γ_{sat} = 98.0 (pcf) Est. EQ Mag 5.7 Top Cover Elev. = 130.0 f= 0.8

γ_{soil} = 120.0

Test Depth (m)	Test Depth (ft)	N	C_E	C_B	C_S	C_R	N_{60}	Existing σ'_{vo} (tsf)	C_N	Design σ_{vo} (tsf)	Design σ_{vo}' (tsf)	$(N_1)_{60}$	α	β	$(N_1)_{60cs}$	r_d	a_{max}	CSR	$CRR_{7.5}$	MSF	K_σ	K_α	CRR	FS_L
				Table 2[1]					Eq. (9)[1]			Eq. (8)[1]	Eq. (6)[1]	Eq. (7)[1]	Eq. (5)[1]	Eq. (2)[1]		Eq. (1)[1]	Eq. (4)[1]	Eq. (24)[1]	Eq. (31)[1]			Eq. (30)[1]
0.5	1.5	10	0.7	1.0	1.0	0.75	5	0.07	1.70	5.2	5.2	9	2	1.1	12	1.00	0.128	0.083	0.13	2.0	0.72	1.00	0.09	-
2.0	6.5	11	0.7	1.0	1.0	0.75	6	0.30	1.63	5.5	5.5	10	2	1.1	13	0.98	0.128	0.082	0.14	2.0	0.72	1.00	0.10	-
3.5	11.5	9	0.7	1.0	1.0	0.80	5	0.53	1.23	5.8	5.8	6	2	1.1	9	0.97	0.128	0.081	0.10	2.0	0.71	1.00	0.07	-
5.0	16.5	16	0.7	1.0	1.0	0.85	10	0.77	1.02	6.1	6.1	10	2	1.1	13	0.96	0.128	0.080	0.14	2.0	0.70	1.00	0.10	-
6.1	20.0	10	0.7	1.0	1.0	0.95	7	0.92	0.93	6.3	5.9	7	2	1.1	10	0.95	0.128	0.084	0.11	2.0	0.71	1.00	0.08	1.90

FS_{min} 1.90

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)

References:
(1) Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils, 2001
(2) MSHA Manual on Coal Waste Embankments, Chapter 7 Seismic Design: Stability and Deformation Analyses, May 2009

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Dominion
Chesterfield Power Station
Upper (East) Pond
Liquefaction Analysis

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By: TIM 06/03/16
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BORING B-1 (2000)

G.S. Elev. = 41.6 W.T. Elev. = 7.6 (feet) Bottom Elev. = -8.4 Fines Content = 3 Atmospheric Pressure 100 kPa

$\gamma_{overburden}$ = 120.0 (pcf) Top Elev. = 41.6 Relative Density= 50% 1.04 tsf

γ_{sat} = 125.0 (pcf) Est. EQ Mag 5.7 f= 0.7

γ_{soil} = 120.0

			Table 2[1]						Eq. (9)[1]			Eq. (8)[1]	Eq. (6)[1]	Eq. (7)[1]	Eq. (5)[1]	Eq. (2)[1]		Eq. (1)[1]	Eq. (4)[1]	Eq. (24)[1]	Eq. (31)[1]			Eq. (30)[1]
Test Depth (m)	Test Depth (ft)	N	C_E	C_B	C_S	C_R	N_{60}	Existing σ'_{vo} (tsf)	C_N	Design σ_{vo} (tsf)	Design σ_{vo}' (tsf)	$(N_1)_{60}$	α	β	$(N_1)_{60cs}$	r_d	a_{max}	CSR	$CRR_{7.5}$	MSF	K_σ	K_α	CRR	FS_L
0.6	2.0	12	0.7	1.0	1.0	0.75	6	0.12	1.70	0.1	0.1	10	0	1.0	10	1.00	0.128	0.083	0.11	2.0	2.02	1.00	0.22	-
1.2	4.0	31	0.7	1.0	1.0	0.75	16	0.24	1.70	0.2	0.2	27	0	1.0	27	0.99	0.128	0.082	0.34	2.0	1.64	1.00	0.56	-
1.8	6.0	15	0.7	1.0	1.0	0.75	8	0.36	1.70	0.4	0.4	14	0	1.0	14	0.99	0.128	0.082	0.15	2.0	1.33	1.00	0.20	-
2.4	8.0	19	0.7	1.0	1.0	0.75	10	0.48	1.47	0.5	0.5	15	0	1.0	15	0.98	0.128	0.082	0.16	2.0	1.25	1.00	0.20	-
3.0	10.0	21	0.7	1.0	1.0	0.80	12	0.60	1.32	0.6	0.6	16	0	1.0	16	0.98	0.128	0.082	0.17	2.0	1.18	1.00	0.20	-
4.9	16.0	14	0.7	1.0	1.0	0.85	8	0.96	1.04	1.0	1.0	8	0	1.0	8	0.96	0.128	0.080	0.10	2.0	1.01	1.00	0.10	-
6.4	21.0	23	0.7	1.0	1.0	0.95	15	1.26	0.91	1.3	1.3	14	0	1.0	14	0.95	0.128	0.079	0.15	2.0	0.94	1.00	0.14	-
7.9	26.0	23	0.7	1.0	1.0	0.95	15	1.56	0.82	1.6	1.6	12	0	1.0	12	0.94	0.128	0.078	0.13	2.0	0.88	1.00	0.11	-
9.4	31.0	29	0.7	1.0	1.0	0.95	19	1.86	0.75	1.9	1.9	14	0	1.0	14	0.92	0.128	0.077	0.15	2.0	0.83	1.00	0.12	-
11.0	36.0	43	0.7	1.0	1.0	1.00	30	2.10	0.70	2.2	2.1	21	0	1.0	21	0.88	0.128	0.077	0.23	2.0	0.81	1.00	0.19	4.94
12.5	41.0	17	0.7	1.0	1.0	1.00	12	2.26	0.68	2.5	2.3	8	0	1.0	8	0.84	0.128	0.076	0.10	2.0	0.79	1.00	0.08	2.11
14.0	46.0	29	0.7	1.0	1.0	1.00	20	2.42	0.66	2.8	2.4	13	0	1.0	13	0.80	0.128	0.078	0.14	2.0	0.78	1.00	0.11	2.82
15.2	50.0	16	0.7	1.0	1.0	1.00	11	2.54	0.64	3.0	2.5	7	0	1.0	7	0.77	0.128	0.077	0.09	2.0	0.77	1.00	0.07	1.82

FS_{min} 1.82

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)

References:

(1) Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils, 2001

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Dominion
Chesterfield Power Station
Upper (East) Pond
Liquefaction Analysis

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BORING B-2 (2000)

G.S. Elev. = 41.5 | W.T. Elev. = 7.3 (feet) | Bottom Elev. = -8.5 | Fines Content = 3 | Atmospheric Pressure 100 kPa

$\gamma_{overburden}$ = 120.0 (pcf) | Top Elev. = 41.5 | Relative Density= 30% | 1.04 tsf

γ_{sat} = 125.0 (pcf) | Est. EQ Mag 5.7 | f= 0.8

γ_{soil} = 120.0

									Eq. (9)[1]			Eq. (8)[1]	Eq. (6)[1]	Eq. (7)[1]	Eq. (5)[1]	Eq. (2)[1]		Eq. (1)[1]	Eq. (4)[1]	Eq. (24)[1]	Eq. (31)[1]			Eq. (30)[1]
			Table 2[1]																					
Test Depth (m)	Test Depth (ft)	N	C_E	C_B	C_S	C_R	N_{60}	Existing σ'_{vo} (tsf)	C_N	Design σ_{vo} (tsf)	Design σ_{vo}' (tsf)	$(N_1)_{60}$	α	β	$(N_1)_{60cs}$	r_d	a_{max}	CSR	$CRR_{7.5}$	MSF	K_σ	K_α	CRR	FS_L
0.6	2.0	8	0.7	1.0	1.0	0.75	4	0.12	1.70	0.1	0.1	7	0	1.0	7	1.00	0.128	0.083	0.09	2.0	1.60	1.00	0.14	-
1.2	4.0	24	0.7	1.0	1.0	0.75	13	0.24	1.70	0.2	0.2	22	0	1.0	22	0.99	0.128	0.082	0.24	2.0	1.39	1.00	0.33	-
1.8	6.0	24	0.7	1.0	1.0	0.75	13	0.36	1.70	0.4	0.4	22	0	1.0	22	0.99	0.128	0.082	0.24	2.0	1.21	1.00	0.29	-
2.4	8.0	19	0.7	1.0	1.0	0.75	10	0.48	1.47	0.5	0.5	15	0	1.0	15	0.98	0.128	0.082	0.16	2.0	1.16	1.00	0.19	-
3.0	10.0	19	0.7	1.0	1.0	0.80	11	0.60	1.32	0.6	0.6	15	0	1.0	15	0.98	0.128	0.082	0.16	2.0	1.12	1.00	0.18	-
4.9	16.0	16	0.7	1.0	1.0	0.85	10	0.96	1.04	1.0	1.0	10	0	1.0	10	0.96	0.128	0.080	0.11	2.0	1.01	1.00	0.11	-
6.4	21.0	35	0.7	1.0	1.0	0.95	23	1.26	0.91	1.3	1.3	21	0	1.0	21	0.95	0.128	0.079	0.23	2.0	0.96	1.00	0.22	-
7.9	26.0	16	0.7	1.0	1.0	0.95	11	1.56	0.82	1.6	1.6	9	0	1.0	9	0.94	0.128	0.078	0.10	2.0	0.92	1.00	0.09	-
9.4	31.0	10	0.7	1.0	1.0	0.95	7	1.86	0.75	1.9	1.9	5	0	1.0	5	0.92	0.128	0.077	0.07	2.0	0.89	1.00	0.06	-
11.0	36.0	29	0.7	1.0	1.0	1.00	20	2.11	0.70	2.2	2.1	14	0	1.0	14	0.88	0.128	0.077	0.15	2.0	0.87	1.00	0.13	3.38
12.5	41.0	19	0.7	1.0	1.0	1.00	13	2.26	0.68	2.5	2.3	9	0	1.0	9	0.84	0.128	0.076	0.10	2.0	0.85	1.00	0.09	2.37
14.0	46.0	9	0.7	1.0	1.0	1.00	6	2.42	0.66	2.8	2.4	4	0	1.0	4	0.80	0.128	0.078	0.06	2.0	0.85	1.00	0.05	1.28
15.2	50.0	9	0.7	1.0	1.0	1.00	6	2.55	0.64	3.0	2.5	4	0	1.0	4	0.77	0.128	0.077	0.06	2.0	0.84	1.00	0.05	1.30

FS_{min} 1.28

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)

References:

(1) Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils, 2001
(2) MSHA Manual on Coal Waste Embankments, Chapter 7 Seismic Design: Stability and Deformation Analyses, May 2009

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Dominion
Chesterfield Power Station
Upper (East) Pond
Liquefaction Analysis

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Checked by: FC 06/09/2016

BORING B-3 (2000)

G.S. Elev. = 41.4 | W.T. Elev. = 7.3 (feet) | Bottom of CCR Elev. = 31.9 | Fines Content = 13 | Atmospheric Pressure 100 kPa

$\gamma_{overburden}$ = 120.0 (pcf) | Top of CCR Elev. = 45.0 | Relative Density= 30% | 1.04 tsf

γ_{sat} = 125.0 (pcf) | Est. EQ Mag 5.7 | f= 0.8

γ_{soil} = 115.0

			Table 2[1]						Eq. (9)[1]			Eq. (8)[1]	Eq. (6)[1]	Eq. (7)[1]	Eq. (5)[1]	Eq. (2)[1]		Eq. (1)[1]	Eq. (4)[1]	Eq. (24)[1]	Eq. (31)[1]			Eq. (30)[1]
Test Depth (m)	Test Depth (ft)	N	C_E	C_B	C_S	C_R	N_{60}	Existing σ'_{vo} (tsf)	C_N	Design σ_{vo} (tsf)	Design σ_{vo}' (tsf)	$(N_1)_{60}$	α	β	$(N_1)_{60cs}$	r_d	a_{max}	CSR	$CRR_{7.5}$	MSF	K_σ	K_α	CRR	FS_L
0.6	2.0	13	0.7	1.0	1.0	0.75	7	0.12	1.70	0.3	0.3	12	2	1.1	15	1.00	0.128	0.083	0.16	2.0	1.28	1.00	0.20	-
1.2	4.0	17	0.7	1.0	1.0	0.75	9	0.24	1.70	0.4	0.4	15	2	1.1	19	0.99	0.128	0.082	0.20	2.0	1.21	1.00	0.24	-
1.8	6.0	19	0.7	1.0	1.0	0.75	10	0.36	1.70	0.5	0.5	17	2	1.1	21	0.99	0.128	0.082	0.23	2.0	1.16	1.00	0.27	-
2.4	8.0	4	0.7	1.0	1.0	0.75	2	0.48	1.47	0.7	0.7	3	2	1.1	5	0.98	0.128	0.082	0.07	2.0	1.08	1.00	0.08	-
3.0	10.0	2	0.7	1.0	1.0	0.8	1	0.60	1.32	0.8	0.8	1	2	1.1	3	0.98	0.128	0.082	0.06	2.0	1.05	1.00	0.06	-
4.9	16.0	16	0.7	1.0	1.0	0.85	10	0.96	1.04	1.1	1.1	10	2	1.1	13	0.96	0.128	0.080	0.14	2.0	0.99	1.00	0.14	-
6.4	21.0	11	0.7	1.0	1.0	0.95	7	1.26	0.91	1.4	1.4	6	2	1.1	9	0.95	0.128	0.079	0.10	2.0	0.94	1.00	0.09	-
7.9	26.0	5	0.7	1.0	1.0	0.95	3	1.56	0.82	1.7	1.7	2	2	1.1	4	0.94	0.128	0.078	0.06	2.0	0.91	1.00	0.05	-
9.4	31.0	5	0.7	1.0	1.0	0.95	3	1.86	0.75	2.0	2.0	2	2	1.1	4	0.92	0.128	0.077	0.06	2.0	0.88	1.00	0.05	-
11.0	36.0	7	0.7	1.0	1.0	1	5	2.11	0.70	2.3	2.3	4	2	1.1	6	0.88	0.128	0.073	0.08	2.0	0.85	1.00	0.07	1.92
12.5	41.0	6	0.7	1.0	1.0	1	4	2.26	0.68	2.7	2.4	3	2	1.1	5	0.84	0.128	0.079	0.07	2.0	0.85	1.00	0.06	1.52
14.0	46.0	11	0.7	1.0	1.0	1	8	2.42	0.66	3.0	2.6	5	2	1.1	8	0.80	0.128	0.077	0.10	2.0	0.83	1.00	0.08	2.08
15.2	50.0	14	0.7	1.0	1.0	1	10	2.54	0.64	3.2	2.7	6	2	1.1	9	0.77	0.128	0.076	0.10	2.0	0.83	1.00	0.08	2.11

FS_{min} 1.52

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)

References: (1) Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils, 2001

(2) MSHA Manual on Coal Waste Embankments, Chapter 7 Seismic Design: Stability and Deformation Analyses, May 2009

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Chesterfield Power Station
Upper (East) Pond
Liquefaction Analysis

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Checked by: FC 06/09/2016

BORING B-4 (2000)

G.S. Elev. = 40.8 W.T. Elev. = 8.1 (feet) Bottom of CCR Elev. = 12.2 Fines Content = 13 Atmospheric Pressure 100 kPa

$\gamma_{overburden}$ = 93.0 (pcf) γ_{cover} = 120 (pcf) Top of CCR Elev. = 48.0 Relative Density= 30% 1.04 tsf

γ_{sat} = 98.0 (pcf) Est. EQ Mag 5.7 Top of Cover Elev. = 50.0 f= 0.8

γ_{CCR} = 93.0

				Table 2[1]					Eq. (9)[1]			Eq. (8)[1]	Eq. (6)[1]	Eq. (7)[1]	Eq. (5)[1]	Eq. (2)[1]		Eq. (1)[1]	Eq. (4)[1]	Eq. (24)[1]	Eq. (31)[1]			Eq. (30)[1]
Test Depth (m)	Test Depth (ft)	N	C_E	C_B	C_S	C_R	N_{60}	Existing σ'_{vo} (tsf)	C_N	Design σ_{vo} (tsf)	Design σ_{vo}' (tsf)	$(N_1)_{60}$	α	β	$(N_1)_{60cs}$	r_d	a_{max}	CSR	$CRR_{7.5}$	MSF	K_σ	K_α	CRR	FS_L
0.6	2.0	6	0.7	1.0	1.0	0.75	3	0.09	1.70	0.5	0.5	5	2	1.1	8	1.00	0.128	0.083	0.10	2.0	1.16	1.00	0.12	-
1.2	4.0	11	0.7	1.0	1.0	0.75	6	0.19	1.70	0.6	0.6	10	2	1.1	13	0.99	0.128	0.082	0.14	2.0	1.12	1.00	0.16	-
1.8	6.0	17	0.7	1.0	1.0	0.75	9	0.28	1.70	0.7	0.7	15	2	1.1	19	0.99	0.128	0.082	0.20	2.0	1.08	1.00	0.22	-
2.4	8.0	2	0.7	1.0	1.0	0.75	1	0.37	1.47	0.8	0.8	1	2	1.1	3	0.98	0.128	0.082	0.06	2.0	1.05	1.00	0.06	1.46
3.0	10.0	2	0.7	1.0	1.0	0.80	1	0.47	1.32	0.9	0.9	1	2	1.1	3	0.98	0.128	0.082	0.06	2.0	1.03	1.00	0.06	1.46
4.9	16.0	5	0.7	1.0	1.0	0.85	3	0.74	1.04	1.2	1.2	3	2	1.1	5	0.96	0.128	0.080	0.07	2.0	0.97	1.00	0.07	1.75
6.4	21.0	2	0.7	1.0	1.0	0.95	1	0.98	0.91	1.4	1.4	1	2	1.1	3	0.95	0.128	0.079	0.06	2.0	0.94	1.00	0.06	1.52
7.9	26.0	1	0.7	1.0	1.0	0.95	1	1.21	0.82	1.7	1.7	1	2	1.1	3	0.94	0.128	0.078	0.06	2.0	0.91	1.00	0.05	1.28
9.4	31.0	13	0.7	1.0	1.0	0.95	9	1.44	0.75	1.9	1.9	7	2	1.1	10	0.92	0.128	0.077	0.11	2.0	0.89	1.00	0.10	2.60
11.0	36.0	1	0.7	1.0	1.0	1.00	1	1.58	0.72	2.1	2.0	1	2	1.1	3	0.88	0.128	0.077	0.06	2.0	0.88	1.00	0.05	1.30
12.5	41.0	32	0.7	1.0	1.0	1.00	22	1.67	0.70	2.4	2.1	15	2	1.1	19	0.84	0.128	0.080	0.20	2.0	0.87	1.00	0.17	4.25
15.2	50.0	30	0.7	1.0	1.0	1.00	21	1.83	0.66	2.8	2.3	14	2	1.1	17	0.77	0.128	0.078	0.18	2.0	0.85	1.00	0.15	3.85

FS_{min} 1.28

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)

References:
(1) Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils, 2001
(2) MSHA Manual on Coal Waste Embankments, Chapter 7 Seismic Design: Stability and Deformation Analyses, May 2009

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BORING B-5 (2000)

G.S. Elev. = 41.7 | W.T. Elev. = 8.3 (feet) | Bottom of CCR Elev. = -3.3 | Fines Content = 51 | Atmospheric Pressure 100 kPa

$\gamma_{overburden}$ = 93.0 (pcf) γ_{cover} = 120 (pcf) | Top of CCR Elev. = 118.0 | Relative Density= 30% | 1.04 tsf

γ_{sat} = 98.0 (pcf) | Est. EQ Mag 5.7 | Top of Cover Elev.= 120.0 | f= 0.8

γ_{CCR} = 93.0

				Table 2[1]					Eq. (9)[1]			Eq. (8)[1]	Eq. (6)[1]	Eq. (7)[1]	Eq. (5)[1]	Eq. (2)[1]		Eq. (1)[1]	Eq. (4)[1]	Eq. (24)[1]	Eq. (31)[1]			Eq. (30)[1]
Test Depth (m)	Test Depth (ft)	N	C_E	C_B	C_S	C_R	N_{60}	Existing σ'_{vo} (tsf)	C_N	Design σ_{vo} (tsf)	Design σ_{vo}' (tsf)	$(N_1)_{60}$	α	β	$(N_1)_{60cs}$	r_d	a_{max}	CSR	$CRR_{7.5}$	MSF	K_σ	K_α	CRR	FS_L
0.6	2.0	7	0.7	1.0	1.0	0.75	4	0.09	1.70	3.8	3.8	7	5	1.2	13	1.00	0.128	0.083	0.14	2.0	0.77	1.00	0.11	-
1.2	4.0	19	0.7	1.0	1.0	0.75	10	0.19	1.70	3.9	3.9	17	5	1.2	25	0.99	0.128	0.082	0.29	2.0	0.77	1.00	0.22	-
1.8	6.0	13	0.7	1.0	1.0	0.75	7	0.28	1.70	3.9	3.9	12	5	1.2	19	0.99	0.128	0.082	0.20	2.0	0.77	1.00	0.15	-
2.4	8.0	7	0.7	1.0	1.0	0.75	4	0.37	1.68	4.0	4.0	7	5	1.2	13	0.98	0.128	0.082	0.14	2.0	0.76	1.00	0.11	2.68
3.0	10.0	3	0.7	1.0	1.0	0.80	2	0.47	1.49	4.1	4.1	3	5	1.2	9	0.98	0.128	0.082	0.10	2.0	0.76	1.00	0.08	1.95
4.9	16.0	1	0.7	1.0	1.0	0.85	1	0.74	1.19	4.4	4.4	1	5	1.2	6	0.96	0.128	0.080	0.08	2.0	0.75	1.00	0.06	1.50
6.4	21.0	1	0.7	1.0	1.0	0.95	1	0.98	1.03	4.6	4.6	1	5	1.2	6	0.95	0.128	0.079	0.08	2.0	0.74	1.00	0.06	1.52
7.9	26.0	1	0.7	1.0	1.0	0.95	1	1.21	0.93	4.9	4.9	1	5	1.2	6	0.94	0.128	0.078	0.08	2.0	0.73	1.00	0.06	1.54
9.4	31.0	1	0.7	1.0	1.0	0.95	1	1.44	0.85	5.1	5.1	1	5	1.2	6	0.92	0.128	0.077	0.08	2.0	0.73	1.00	0.06	1.56
11.0	36.0	1	0.7	1.0	1.0	1.00	1	1.60	0.81	5.3	5.3	1	5	1.2	6	0.88	0.128	0.073	0.08	2.0	0.72	1.00	0.06	1.64
12.5	41.0	1	0.7	1.0	1.0	1.00	1	1.69	0.78	5.6	5.4	1	5	1.2	6	0.84	0.128	0.072	0.08	2.0	0.72	1.00	0.06	1.67
14.0	46.0	10	0.7	1.0	1.0	1.00	7	1.78	0.76	5.8	5.4	5	5	1.2	11	0.80	0.128	0.071	0.12	2.0	0.72	1.00	0.09	2.54

FS_{min} 1.50

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)

References:

(1) Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils, 2001
(2) MSHA Manual on Coal Waste Embankments, Chapter 7 Seismic Design: Stability and Deformation Analyses, May 2009

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Liquefaction Analysis

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BORING B-6 (2000)

G.S. Elev. = 35.9 W.T. Elev. = 13.5 (feet) Bottom of CCR Elev. = 3.9 Fines Content = 51 Atmospheric Pressure 100 kPa

$\gamma_{overburden}$ = 93.0 (pcf) γ_{cover} = 120 (pcf) Top of CCR Elev. = 73.0 Relative Density= 30% 1.04 tsf

γ_{sat} = 98.0 (pcf) Est. EQ Mag 5.7 Top of Cover Elev.= 75.0 f= 0.8

γ_{CCR} = 93.0

						Table 2[1]				Eq. (9)[1]			Eq. (8)[1]	Eq. (6)[1]	Eq. (7)[1]	Eq. (5)[1]	Eq. (2)[1]		Eq. (1)[1]	Eq. (4)[1]	Eq. (24)[1]	Eq. (31)[1]			Eq. (30)[1]
Test Depth (m)	Test Depth (ft)	N	C_E	C_B	C_S	C_R	N_{60}	Existing σ'_{vo} (tsf)	C_N	Design σ_{vo} (tsf)	Design σ_{vo}' (tsf)	$(N_1)_{60}$	α	β	$(N_1)_{60cs}$	r_d	a_{max}	CSR	$CRR_{7.5}$	MSF	K_σ	K_α	CRR	FS_L
0.6	2.0	16	0.7	1.0	1.0	0.75	8	0.09	1.70	1.9	1.9	14	5	1.2	22	1.00	0.128	0.083	0.24	2.0	0.89	1.00	0.21	-
1.2	4.0	13	0.7	1.0	1.0	0.75	7	0.19	1.70	2.0	2.0	12	5	1.2	19	0.99	0.128	0.082	0.20	2.0	0.88	1.00	0.18	-
1.8	6.0	3	0.7	1.0	1.0	0.75	2	0.28	1.70	2.1	2.1	3	5	1.2	9	0.99	0.128	0.082	0.10	2.0	0.87	1.00	0.09	2.20
2.4	8.0	6	0.7	1.0	1.0	0.75	3	0.37	1.68	2.2	2.2	5	5	1.2	11	0.98	0.128	0.082	0.12	2.0	0.86	1.00	0.10	2.44
3.0	10.0	6	0.7	1.0	1.0	0.80	3	0.47	1.49	2.3	2.3	4	5	1.2	10	0.98	0.128	0.082	0.11	2.0	0.85	1.00	0.09	2.20
4.9	16.0	2	0.7	1.0	1.0	0.85	1	0.74	1.19	2.6	2.6	1	5	1.2	6	0.96	0.128	0.080	0.08	2.0	0.83	1.00	0.07	1.75
6.4	21.0	2	0.7	1.0	1.0	0.95	1	0.98	1.03	2.8	2.8	1	5	1.2	6	0.95	0.128	0.079	0.08	2.0	0.82	1.00	0.07	1.77
7.9	26.0	1	0.7	1.0	1.0	0.95	1	1.11	0.97	3.1	3.1	1	5	1.2	6	0.94	0.128	0.078	0.08	2.0	0.80	1.00	0.06	1.54
9.4	31.0	6	0.7	1.0	1.0	0.95	4	1.19	0.93	3.3	3.3	4	5	1.2	10	0.92	0.128	0.077	0.11	2.0	0.79	1.00	0.09	2.34
11.0	36.0	42	0.7	1.0	1.0	1.00	29	1.28	0.90	3.6	3.6	26	5	1.2	30	0.88	0.128	0.073	0.47	2.0	0.78	1.00	0.37	10.14
12.5	41.0	36	0.7	1.0	1.0	1.00	25	1.37	0.87	3.8	3.8	22	5	1.2	31	0.84	0.128	0.070	0.56	2.0	0.77	1.00	0.43	12.29
14.0	46.0	25	0.7	1.0	1.0	1.00	18	1.46	0.84	4.0	4.0	15	5	1.2	23	0.80	0.128	0.067	0.26	2.0	0.76	1.00	0.20	5.97
15.2	50.0	19	0.7	1.0	1.0	1.00	13	1.53	0.82	4.2	4.2	11	5	1.2	18	0.77	0.128	0.064	0.19	2.0	0.76	1.00	0.14	4.38

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} 1.54

References:

(1) Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils, 2001
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C150035.00
By: TIM 06/03/16
Checked by: FC 06/09/2016

BORING B-501 (2004)

G.S. Elev. = 42.0 W.T. Elev. = 16.9 (feet) Bottom Elev. = 7.0 Fines Content = 3 Atmospheric Pressure 100 kPa

$\gamma_{overburden}$ = 120.0 (pcf) Top Elev. = 42.0 Relative Density= 50% 1.04 tsf

γ_{sat} = 125.0 (pcf) Est. EQ Mag 5.7 f= 0.7

γ_{soil} = 120.0

Test Depth (m)	Test Depth (ft)	N	C_E	C_B	C_S	C_R	N_{60}	Existing σ'_{vo} (tsf)	C_N	Design σ_{vo} (tsf)	Design σ_{vo}' (tsf)	$(N_1)_{60}$	α	β	$(N_1)_{60cs}$	r_d	a_{max}	CSR	$CRR_{7.5}$	MSF	K_σ	K_α	CRR	FS_L
					Table 2[1]				Eq. (9)[1]			Eq. (8)[1]	Eq. (6)[1]	Eq. (7)[1]	Eq. (5)[1]	Eq. (2)[1]		Eq. (1)[1]	Eq. (4)[1]	Eq. (24)[1]	Eq. (31)[1]			Eq. (30)[1]
0.6	2.0	21	0.7	1.0	1.0	0.75	11	0.12	1.70	0.1	0.1	19	0	1.0	19	1.00	0.128	0.083	0.20	2.0	2.02	1.00	0.40	-
1.2	4.0	13	0.7	1.0	1.0	0.75	7	0.24	1.70	0.2	0.2	12	0	1.0	12	0.99	0.128	0.082	0.13	2.0	1.64	1.00	0.21	-
1.8	6.0	13	0.7	1.0	1.0	0.75	7	0.36	1.70	0.4	0.4	12	0	1.0	12	0.99	0.128	0.082	0.13	2.0	1.33	1.00	0.17	-
2.4	8.0	24	0.7	1.0	1.0	0.75	13	0.48	1.47	0.5	0.5	19	0	1.0	19	0.98	0.128	0.082	0.20	2.0	1.25	1.00	0.25	-
3.0	10.0	55	0.7	1.0	1.0	0.80	31	0.60	1.32	0.6	0.6	41	0	1.0	41	0.98	0.128	0.082	0.16	2.0	1.18	1.00	0.19	-
4.9	16.0	30	0.7	1.0	1.0	0.85	18	0.96	1.04	1.0	1.0	19	0	1.0	19	0.96	0.128	0.080	0.20	2.0	1.01	1.00	0.20	-
6.4	21.0	56	0.7	1.0	1.0	0.95	37	1.26	0.91	1.3	1.3	34	0	1.0	30	0.95	0.128	0.079	0.47	2.0	0.94	1.00	0.44	-
7.9	26.0	63	0.7	1.0	1.0	0.95	42	1.53	0.82	1.6	1.5	34	0	1.0	30	0.94	0.128	0.083	0.47	2.0	0.90	1.00	0.42	10.12
9.4	31.0	37	0.7	1.0	1.0	0.95	25	1.69	0.78	1.9	1.7	20	0	1.0	20	0.92	0.128	0.086	0.22	2.0	0.86	1.00	0.19	4.42
10.4	34.0	50	0.7	1.0	1.0	1.00	35	1.78	0.76	2.1	1.8	27	0	1.0	27	0.90	0.128	0.087	0.34	2.0	0.85	1.00	0.29	6.67

FS_{min} 4.42

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)

References:
(1) Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils, 2001
(2) MSHA Manual on Coal Waste Embankments, Chapter 7 Seismic Design: Stability and Deformation Analyses, May 2009

gai consultants

Dominion
Chesterfield Power Station
Upper (East) Pond
Liquefaction Analysis

C150035.00
By: TIM 06/03/16
Checked by: FC 06/09/2016

BORING B-502 (2004)

G.S. Elev. = 42.0 W.T. Elev. = 10.4 (feet) Bottom Elev. = -12.9 Fines Content = 3 γ_{CCR}= 93 pcf Atmospheric Pressure 100 kPa

$\gamma_{overburden}$ = 120.0 (pcf) pcf Top Elev. = 42.0 Relative Density= 30% γ_{CCRsat}= 98 pcf 1.04 tsf

γ_{sat} = 125.0 (pcf) Est. EQ Mag 5.7 Bottom CCR Elev= 29.0 f= 0.8

γ_{soil} = 120.0

				Table 2[1]					Eq. (9)[1]			Eq. (8)[1]	Eq. (6)[1]	Eq. (7)[1]	Eq. (5)[1]	Eq. (2)[1]		Eq. (1)[1]	Eq. (4)[1]	Eq. (24)[1]	Eq. (31)[1]			Eq. (30)[1]
Test Depth (m)	Test Depth (ft)	N	C_E	C_B	C_S	C_R	N_{60}	Existing σ'_{vo} (tsf)	C_N	Design σ_{vo} (tsf)	Design σ_{vo}' (tsf)	$(N_1)_{60}$	α	β	$(N_1)_{60cs}$	r_d	a_{max}	CSR	$CRR_{7.5}$	MSF	K_σ	K_α	CRR	FS_L
0.6	2.0	4	0.7	1.0	1.0	0.75	2	0.12	1.70	0.1	0.1	3	0	1.0	3	1.00	0.128	0.083	0.06	2.0	1.60	1.00	0.10	2.41
1.2	4.0	5	0.7	1.0	1.0	0.75	3	0.24	1.70	0.2	0.2	5	0	1.0	5	0.99	0.128	0.082	0.07	2.0	1.39	1.00	0.10	2.44
1.8	6.0	4	0.7	1.0	1.0	0.75	2	0.36	1.70	0.3	0.3	3	0	1.0	3	0.99	0.128	0.082	0.06	2.0	1.28	1.00	0.08	1.95
2.4	8.0	3	0.7	1.0	1.0	0.75	2	0.48	1.47	0.4	0.4	3	0	1.0	3	0.98	0.128	0.082	0.06	2.0	1.21	1.00	0.07	1.71
3.5	11.5	4	0.7	1.0	1.0	0.80	2	0.69	1.23	0.5	0.5	2	0	1.0	2	0.97	0.128	0.081	0.05	2.0	1.16	1.00	0.06	1.48
4.9	16.0	21	0.7	1.0	1.0	0.85	12	0.96	1.04	0.7	0.7	12	0	1.0	12	0.96	0.128	0.080	0.13	2.0	1.08	1.00	0.14	3.50
6.4	21.0	13	0.7	1.0	1.0	0.95	9	1.26	0.91	1.0	1.0	8	0	1.0	8	0.95	0.128	0.079	0.10	2.0	1.01	1.00	0.10	2.53
7.9	26.0	72	0.7	1.0	1.0	0.95	48	1.56	0.82	1.2	1.2	30	0	1.0	30	0.94	0.128	0.078	0.47	2.0	0.97	1.00	0.46	11.79
9.4	31.0	38	0.7	1.0	1.0	0.95	25	1.86	0.75	1.4	1.4	19	0	1.0	19	0.92	0.128	0.077	0.20	2.0	0.94	1.00	0.19	4.94
11.0	36.0	18	0.7	1.0	1.0	1.00	13	2.03	0.72	2.3	2.1	9	0	1.0	9	0.88	0.128	0.080	0.10	2.0	0.87	1.00	0.09	2.25
12.5	41.0	5	0.7	1.0	1.0	1.00	4	2.19	0.69	2.6	2.6	3	0	1.0	3	0.84	0.128	0.070	0.06	2.0	0.83	1.00	0.05	1.43
14.0	46.0	30	0.7	1.0	1.0	1.00	21	2.35	0.67	2.9	3.0	14	0	1.0	14	0.80	0.128	0.064	0.15	2.0	0.81	1.00	0.12	3.75
15.2	50.0	50	0.7	1.0	1.0	1.00	35	2.47	0.65	3.1	3.4	23	0	1.0	23	0.77	0.128	0.058	0.26	2.0	0.79	1.00	0.21	7.24

FS_{min} 1.43

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)

References:

(1) Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils, 2001

(2) MSHA Manual on Coal Waste Embankments, Chapter 7 Seismic Design: Stability and Deformation Analyses, May 2009

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Dominion
Chesterfield Power Station
Upper (East) Pond
Liquefaction Analysis

C150035.00
By: TIM 06/03/16
Checked by: FC 06/09/2016

BORING B-503 (2004)

G.S. Elev. = 42.0 W.T. Elev. = 8.9 (feet) Bottom Elev. = -13.0 Fines Content = 3 Atmospheric Pressure 100 kPa

$\gamma_{overburden}$ = 120.0 (pcf) Top Elev. = 42.0 Relative Density= 50% 1.04 tsf

γ_{sat} = 125.0 (pcf) Est. EQ Mag 5.7 f= 0.7

γ_{soil} = 120.0

			Table 2[1]						Eq. (9)[1]			Eq. (8)[1]	Eq. (6)[1]	Eq. (7)[1]	Eq. (5)[1]	Eq. (2)[1]		Eq. (1)[1]	Eq. (4)[1]	Eq. (24)[1]	Eq. (31)[1]			Eq. (30)[1]
Test Depth (m)	Test Depth (ft)	N	C_E	C_B	C_S	C_R	N_{60}	Existing σ'_{vo} (tsf)	C_N	Design σ_{vo} (tsf)	Design σ_{vo}' (tsf)	$(N_1)_{60}$	α	β	$(N_1)_{60cs}$	r_d	a_{max}	CSR	$CRR_{7.5}$	MSF	K_σ	K_α	CRR	FS_L
0.6	2.0	17	0.7	1.0	1.0	0.75	9	0.12	1.70	0.1	0.1	15	0	1.0	15	1.00	0.128	0.083	0.16	2.0	2.02	1.00	0.32	-
1.2	4.0	35	0.7	1.0	1.0	0.75	18	0.24	1.70	0.2	0.2	31	0	1.0	30	0.99	0.128	0.082	0.47	2.0	1.64	1.00	0.77	-
1.8	6.0	15	0.7	1.0	1.0	0.75	8	0.36	1.70	0.4	0.4	14	0	1.0	14	0.99	0.128	0.082	0.15	2.0	1.33	1.00	0.20	-
2.4	8.0	43	0.7	1.0	1.0	0.75	23	0.48	1.47	0.5	0.5	30	0	1.0	30	0.98	0.128	0.082	0.47	2.0	1.25	1.00	0.59	-
3.0	10.0	54	0.7	1.0	1.0	0.80	30	0.60	1.32	0.6	0.6	30	0	1.0	30	0.98	0.128	0.082	0.47	2.0	1.18	1.00	0.55	-
4.7	15.5	44	0.7	1.0	1.0	0.85	26	0.93	1.06	0.9	0.9	28	0	1.0	28	0.96	0.128	0.080	0.37	2.0	1.04	1.00	0.38	-
6.2	20.5	28	0.7	1.0	1.0	0.95	19	1.23	0.92	1.2	1.2	17	0	1.0	17	0.95	0.128	0.079	0.18	2.0	0.96	1.00	0.17	-
7.8	25.5	36	0.7	1.0	1.0	0.95	24	1.53	0.82	1.5	1.5	20	0	1.0	20	0.94	0.128	0.078	0.22	2.0	0.90	1.00	0.20	-
9.3	30.5	24	0.7	1.0	1.0	0.95	16	1.83	0.75	1.8	1.8	12	0	1.0	12	0.93	0.128	0.077	0.13	2.0	0.85	1.00	0.11	-
10.8	35.5	22	0.7	1.0	1.0	1.00	15	2.06	0.71	2.1	2.1	11	0	1.0	11	0.89	0.128	0.074	0.12	2.0	0.81	1.00	0.10	2.70
12.3	40.5	6	0.7	1.0	1.0	1.00	4	2.22	0.68	2.4	2.2	3	0	1.0	3	0.85	0.128	0.077	0.06	2.0	0.80	1.00	0.05	1.30
13.9	45.5	16	0.7	1.0	1.0	1.00	11	2.37	0.66	2.8	2.4	7	0	1.0	7	0.80	0.128	0.078	0.09	2.0	0.78	1.00	0.07	1.79
15.4	50.5	56	0.7	1.0	1.0	1.00	39	2.53	0.64	3.1	2.5	25	0	1.0	25	0.76	0.128	0.078	0.29	2.0	0.77	1.00	0.22	5.64

FS_{min} 1.30

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)

References: (1) Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils, 2001
(2) MSHA Manual on Coal Waste Embankments, Chapter 7 Seismic Design: Stability and Deformation Analyses, May 2009

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Dominion
Chesterfield Power Station
Upper (East) Pond
Liquefaction Analysis

C150035.00
By: TIM 06/03/16
Checked by: FC 06/09/2016

BORING B-504 (2004)

G.S. Elev. = 10.0 | W.T. Elev. = 1.0 (feet) | Bottom Elev. = -10.0 | Fines Content = 3 | Atmospheric Pressure 100 kPa

$\gamma_{overburden}$ = 120.0 (pcf) | Top Elev. = 10.0 | Relative Density= 30% | 1.04 tsf

γ_{sat} = 125.0 (pcf) | Est. EQ Mag 5.7 | f= 0.8

γ_{soil} = 120.0

			Table 2[1]						Eq. (9)[1]			Eq. (8)[1]	Eq. (6)[1]	Eq. (7)[1]	Eq. (5)[1]	Eq. (2)[1]		Eq. (1)[1]	Eq. (4)[1]	Eq. (24)[1]	Eq. (31)[1]			Eq. (30)[1]
Test Depth (m)	Test Depth (ft)	N	C_E	C_B	C_S	C_R	N_{60}	Existing σ'_{vo} (tsf)	C_N	Design σ_{vo} (tsf)	Design σ_{vo}' (tsf)	$(N_1)_{60}$	α	β	$(N_1)_{60cs}$	r_d	a_{max}	CSR	$CRR_{7.5}$	MSF	K_σ	K_α	CRR	FS_L
0.6	2.0	23	0.7	1.0	1.0	0.75	12	0.12	1.70	0.1	0.1	20	0	1.0	20	1.00	0.128	0.083	0.22	2.0	1.60	1.00	0.35	-
1.2	4.0	5	0.7	1.0	1.0	0.75	3	0.24	1.70	0.2	0.2	5	0	1.0	5	0.99	0.128	0.082	0.07	2.0	1.39	1.00	0.10	-
1.8	6.0	8	0.7	1.0	1.0	0.75	4	0.36	1.70	0.4	0.4	7	0	1.0	7	0.99	0.128	0.082	0.09	2.0	1.21	1.00	0.11	-
2.4	8.0	4	0.7	1.0	1.0	0.75	2	0.48	1.47	0.5	0.5	3	0	1.0	3	0.98	0.128	0.082	0.06	2.0	1.16	1.00	0.07	-
3.0	10.0	2	0.7	1.0	1.0	0.80	1	0.57	1.35	0.6	0.6	1	0	1.0	1	0.98	0.128	0.082	0.05	2.0	1.12	1.00	0.06	1.46
4.9	16.0	13	0.7	1.0	1.0	0.85	8	0.76	1.17	1.0	0.8	9	0	1.0	9	0.96	0.128	0.100	0.10	2.0	1.05	1.00	0.11	2.20
6.1	20.0	29	0.7	1.0	1.0	0.95	19	0.88	1.09	1.2	0.9	21	0	1.0	21	0.95	0.128	0.105	0.23	2.0	1.03	1.00	0.24	4.57

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} 1.46

References:
(1) Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils, 2001
(2) MSHA Manual on Coal Waste Embankments, Chapter 7 Seismic Design: Stability and Deformation Analyses, May 2009

gai consultants

Dominion
Chesterfield Power Station
Upper (East) Pond
Liquefaction Analysis

C150035.00
By: TIM 06/03/16
Checked by: FC 06/09/2016

BORING B-505 (2004)

G.S. Elev. = 11.0   W.T. Elev. = 4.0 (feet)   Bottom Elev. = -9.0   Fines Content = 3   Atmospheric Pressure 100 kPa

$\gamma_{overburden}$ = 120.0 (pcf)   Top Elev. = 11.0   Relative Density= 30%   1.04 tsf

γ_{sat} = 125.0 (pcf)   Est. EQ Mag 5.7   f= 0.8

γ_{soil} = 120.0

			Table 2[1]						Eq. (9)[1]			Eq. (8)[1]	Eq. (6)[1]	Eq. (7)[1]	Eq. (5)[1]	Eq. (2)[1]		Eq. (1)[1]	Eq. (4)[1]	Eq. (24)[1]	Eq. (31)[1]			Eq. (30)[1]
Test Depth (m)	Test Depth (ft)	N	C_E	C_B	C_S	C_R	N_{60}	Existing σ'_{vo} (tsf)	C_N	Design σ_{vo} (tsf)	Design σ_{vo}' (tsf)	$(N_1)_{60}$	α	β	$(N_1)_{60cs}$	r_d	a_{max}	CSR	$CRR_{7.5}$	MSF	K_σ	K_α	CRR	FS_L
0.6	2.0	27	0.7	1.0	1.0	0.75	14	0.12	1.70	0.1	0.1	24	0	1.0	24	1.00	0.128	0.083	0.27	2.0	1.60	1.00	0.43	-
1.2	4.0	15	0.7	1.0	1.0	0.75	8	0.24	1.70	0.2	0.2	14	0	1.0	14	0.99	0.128	0.082	0.15	2.0	1.39	1.00	0.21	-
1.8	6.0	13	0.7	1.0	1.0	0.75	7	0.36	1.70	0.4	0.4	12	0	1.0	12	0.99	0.128	0.082	0.13	2.0	1.21	1.00	0.16	-
2.4	8.0	2	0.7	1.0	1.0	0.75	1	0.45	1.52	0.5	0.5	2	0	1.0	2	0.98	0.128	0.082	0.05	2.0	1.16	1.00	0.06	1.46
3.0	10.0	4	0.7	1.0	1.0	0.80	2	0.51	1.43	0.6	0.5	3	0	1.0	3	0.98	0.128	0.098	0.06	2.0	1.16	1.00	0.07	1.43
4.9	16.0	9	0.7	1.0	1.0	0.85	5	0.70	1.22	1.0	0.7	6	0	1.0	6	0.96	0.128	0.114	0.08	2.0	1.08	1.00	0.09	1.58
6.1	20.0	29	0.7	1.0	1.0	0.95	19	0.83	1.12	1.2	0.8	21	0	1.0	21	0.95	0.128	0.119	0.23	2.0	1.05	1.00	0.24	4.03

FS_{min} 1.43

Notes:

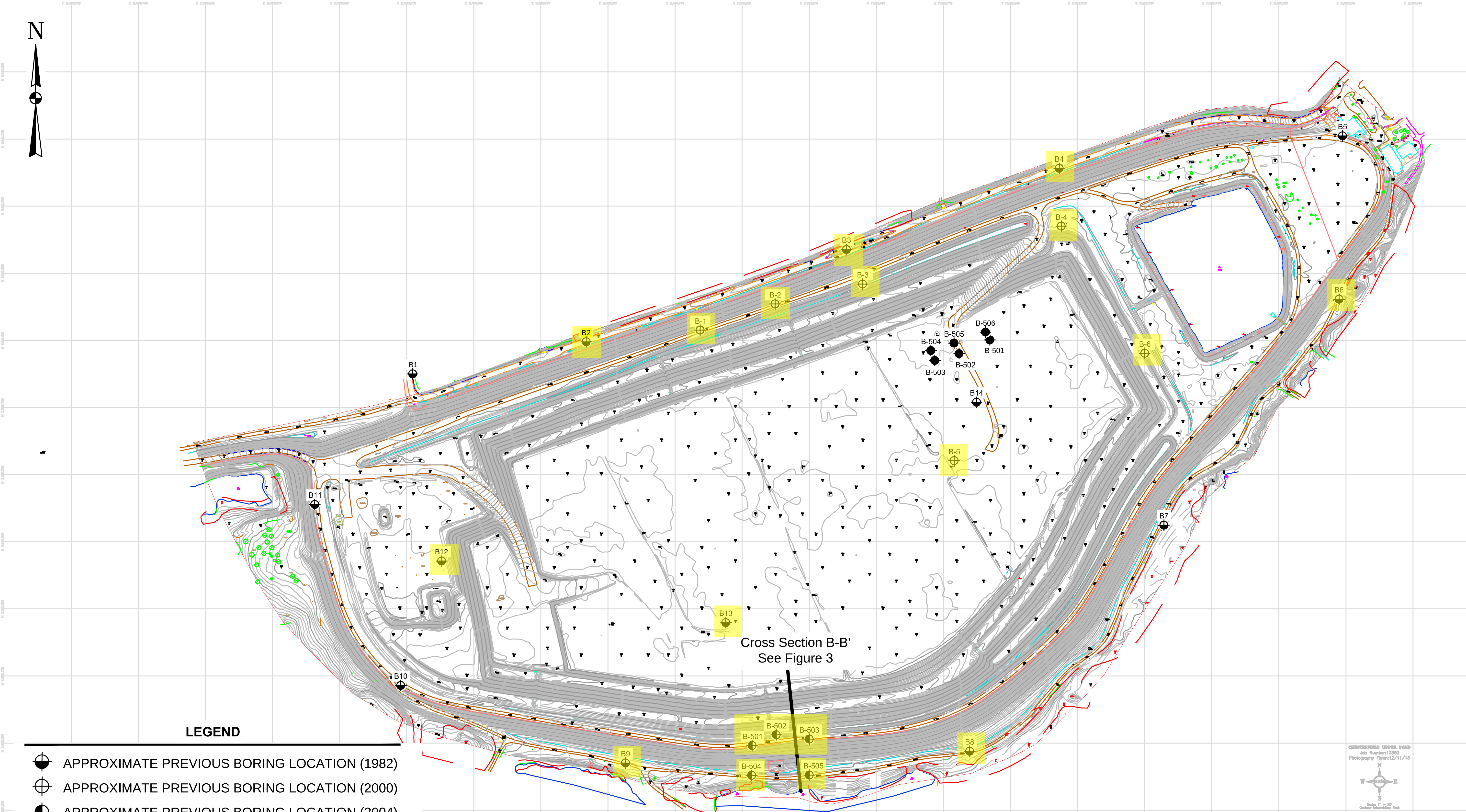
- σ'_{vo} Vertical Effective Stress (tons/ft^2)
- $(N_1)_{60}$ Standardized and Normalized SPT blow counts (blows/foot)
- r_d Stress Reduction Factor (dimensionless)
- a_{max} Peak horizontal ground surface acceleration (in g)
- CSR Cyclic stress ratio based on design earthquake (dimensionless)
- $CRR_{7.5}$ 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)

References: (1) Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils, 2001
(2) MSHA Manual on Coal Waste Embankments, Chapter 7 Seismic Design: Stability and Deformation Analyses, May 2009

gai consultants

ATTACHMENT

BORING LOCATION PLAN



LEGEND

- APPROXIMATE PREVIOUS BORING LOCATION (1982)
- APPROXIMATE PREVIOUS BORING LOCATION (2000)
- APPROXIMATE PREVIOUS BORING LOCATION (2004)
- APPROXIMATE PREVIOUS BORING LOCATION (2003 / 2005)
- APPROXIMATE CROSS SECTION LOCATION (SEE FIG. 3)

Base Plan by Ash AxisGeoSpatial LLC, Dated 12/11/13.

SCALE: 1"=350'

0 350' 700'

Schnabel ENGINEERING

CHESTERFIELD POWER STATION UPPER (EAST) ASH POND CHESTERFIELD COUNTY, VIRGINIA	Figure Name: BORING LOCATION PLAN	Done: P. JOHNSTON	Figure Number: 2
	Project Number: 14213000	Reviewed: E. MORRIS	Date: AUGUST 2014

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