Professional Engineer Certification Report for:

South Fly Ash Pond and Boiler Slag Pond Embankments at the Ohio Valley Electric Corporation Kyger Creek Station

Gallipolis, Ohio

Prepared for:

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DLZ Job No. 1521-3007.00

December 8, 2015

Prepared by:

DLZ

PROFESSIONAL ENGINEER CERTIFICATION REPORT

FOR

SOUTH FLY ASH POND, BOILER SLAG POND, AND CLEARWATER EMBANKMENTS

AT THE

OHIO VALLEY ELECTRIC CORPORATION (OVEC)

KYGER CREEK STATION

GALLOPOLIS, OHIO

For:

American Electric Power
1 Riverside Plaza
Columbus, Ohio 43215

By:

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USACE Slope Stability, Engineering Manual 1110-2-1902. October, 2003, page 1-6,
Chapter 5 "Liquefaction Potential Evaluation and Analysis" of EPA/600/R-95/051

1.0 INTRODUCTION

DLZ Ohio, Inc. (DLZ) has completed the engineering services for Professional Engineer Certification of the South Fly Ash Pond, Boiler Slag Pond, and Clearwater Pond embankments at the Ohio Valley Electric Corporation's (OVEC's) Kyger Creek Station located near Gallipolis, Ohio. The engineering services were performed in accordance with DLZ's May 14, 2015 proposal for the project.

2.0 SCOPE OF WORK

The scope of the work was developed by American Electric Power (AEP) in consideration of the recently mandated coal combustion residuals (CCR) rule that require a licensed Professional Engineer (P.E.) to certify that CCR impoundments have met the rule's minimum factor of safety requirements for embankment stability specified in the Federal Register 40 CFR Parts 257 and 261, Vol. 80, No. 74, dated April 17, 2015. According to the CCR rules, the minimum factor of safety requirements for the static, seismic, and liquefaction conditions are summarized in the following table.

Minimum Safety Factors Required

Load Case	Required Minimum Factor of Safety
Long Term, Maximum Storage Pool Condition	1.5
Maximum Surcharge Pool (50% PMF) Condition	1.4
Seismic Conditions from Maximum Operating Pool Elevation	1.0
Liquefaction	1.2

3.0 GENERAL PROJECT INFORMATION

The Kyger Creek Station is located along the Ohio River in Gallia County, Ohio, south of the town of Cheshire, Ohio. The Ohio River is located directly east of the facility and Kyger Creek flows along the west and south side of the facility. **Exhibit 1** shows the general location of the plant and is included in **Appendix I**.

The plant currently has two process and disposal areas for the coal combustion waste products generated at the plant, known as the Boiler Slag Pond and the South Fly Ash Pond. Overflow from the Boiler Slag Pond is carried into a reinforced concrete intake structure at the south end of the Boiler Slag Complex. Water entering the intake structure is discharged into a Clearwater Pond located to the southwest end of the Boiler Slag Pond. The Boiler Slag Pond and the Clearwater Pond is separated by a splitter dike. **Exhibits 2 and 3** show a more detailed layout of the ponds and are included in **Appendix I**. The configurations and the hydrologic and hydraulic data for the South Fly Ash Pond, the Boiler Slag Pond, and the Clearwater Pond, based on the historical information available, are summarized in the following tables.

Configurations of the Ponds[1]

Pond	Year Constructed	Height (feet)	Crest Elevation (MSL)[2]	Inboard Slope	Outboard Slope[3]
South Fly Ash	1955	40	590	2H:1V	2.3H:1V to 2.9H:1V
Boiler Slag	1955	41	582	2.25H:1V	2.6H:1V to 3H:1V
Clearwater	1980	30-45[1]	582	2.5H:1V to 3H:1V	2.5H:1V to 3H:1V

Note: 1)The pond information is based on the US EPA Assessment of Dam Safety of Coal Combustion Surface Impoundments (Task 3) Final Report prepared by Clough Harbor and Associates (CHA), dated February 24, 2010 and the 2009 Dam and Dike Inspection Report for Kyger Creek Power Station, Gallipolis, Ohio prepared by Stantec, dated April 21, 2009.
2)Elevations are in reference to NGVD 29.
3)The outboard slopes are based on the survey performed by DLZ in 2010.

Summary of Hydrologic and Hydraulic Data for the Ponds[1]

Pond	Drainage Area (acres)	Peak Flow Rate In (cfs)	50% PMF Storage Volume (ac-ft)	50% PMF Storage Peak Elevation (ft)
South Fly Ash	67.3	627.1	72.9	584.0
Boiler Slag	32.3	300.6	34.6	559.3
Clearwater	939	92.3	10.8	558.6

Note: 1)The hydrologic and hydraulic data is based on the US EPA Assessment of Dam Safety of Coal Combustion Surface Impoundments (Task 3) Final Report prepared by Clough Harbor and Associates (CHA), dated February 24, 2010.

Summary of Elevation Data for the Ponds (in 2010)

Pond	Top of Pond Elevation (feet)[1]	50% PMF Storage Peak Elevation (ft)[2]	Free-board (feet)	Normal Pool Elevation (feet)[3]
South Fly Ash	588 to 589	584.0	4 to 5	585
Boiler Slag	580 to 581	559.3	20.7 to 21.7	558
Clearwater	580	558.6	21.4	552

Note: 1) Elevation data is based on the elevations of the borings on the dike crest surveyed by DLZ in 2010.
2) Elevations are from the CHA's report.
3) Elevation data is from Gary Zych of AEP in 2010.

4.0 PREVIOUS SUBSURFACE EXPLORATION AND ENGINEERING ANALYSES

DLZ performed a subsurface exploration and various engineering analyses of the ash pond embankments, including the Clearwater Pond embankments, in 2010 to assess the stability requirements as recommended in the US EPA Assessment of Dam Safety of Coal Combustion Surface Impoundments (Task 3) Final Report prepared by Clough Harbor and Associates (CHA), dated February 24, 2010. A total of twenty-two borings and twelve piezometers were installed during the 2010 subsurface exploration. **Exhibits 4 and 5** show the approximate boring locations at pond dikes and are included in **Appendix II**. Logs of the borings are also included in **Appendix II**. Ground surface elevations at the borings and the embankment cross-sections at the boring locations were surveyed by DLZ. The elevations in the 2010 subsurface exploration were reported in reference to the National Geodetic Vertical Datum of 1929 (NGVD 29) in consistent with the historical information for the project.

It should be noted that elevations presented in this document are referenced to the 1929 datum (NGVD 29) unless noted otherwise.

As part of the 2010 pond embankment evaluations, slope stability and liquefaction analyses were conducted to assess the stability of the South Fly Ash Pond and the Boiler Slag Pond using the loading conditions recommended by CHA. Results of the analyses indicated that the embankments exhibited factors of safety exceeding the required minimum values recommended by CHA. In addition, the fine-grained soils at the pond locations were found to be not susceptible to liquefaction. Details of the subsurface exploration and results of the engineering analyses were summarized in a report titled "*Final Report for Kyger Creek Power Plant – Subsurface Investigation and Analysis of Ash Pond Embankments*" dated January 12, 2011.

5.0 PROFESSIONAL ENGINEER CERTIFICATION

5.1 Site Visit and Information Gathering

Personnel from DLZ visited the ash pond embankments on July 22, 2015. During the site visit, OVEC and AEP representatives were interviewed to gather current design information for the stability assessment and liquefaction evaluation.

Reportedly, there had not been significant changes in the overall conditions of the ash pond embankments since the 2010 subsurface exploration. However, seepage was observed at isolated locations on the east and west outboard slopes of the South Fly Ash Pond during the routine walk-through of the embankments over the past few years. Inverted filters/drains have been installed at the seep locations with approvals from the Ohio Department of Natural Resources. The observed seepage quantities appeared to be minor and did not appear to have adversely affected the integrity of the embankments.

5.2 Hydrologic and Hydraulic Evaluations

Hydrologic and hydraulic (H&H) evaluations were performed to ascertain the compliance of the ash pond embankments with the mandated CCR rules with regard to the H&H capacity requirements for surface impoundments. Based on the available hydraulic data for the ponds, the pool elevations at the South Fly Ash Pond and the Boiler Slag Pond under the required loading conditions were calculated and are summarized in the following table. Details of the H&H evaluations are included in **Appendix III**.

Summary of Elevation Data for the Ponds (PE Certification)

Pond	Present (Normal) Pool Elevation (feet)	Maximum Storage Pool Elevation (Maximum Operating Pool Elevation) (feet)[3]	Maximum Surcharge Pool (Flood) Elevation (feet)[2]
South Fly Ash	582.0	585.0[1]	586.0
Boiler Slag	557.0	558.0[1]	559.3
Clearwater	552.0	553.0[1]	558.6

[1]Per e-mail communication with personnel from AEP.
[2]Maximum surcharge pool (flood) elevations are the 50% PMF.

5.3 Stability Evaluations

Reportedly, there had not been any changes to the overall conditions of the embankments since the 2010 subsurface explorations. Consequently, the stability evaluations for the PE certification were performed essentially based on the information gathered in 2010.

The embankment stability evaluations were performed using UTEXAS3 Version 1.204. UTEXAS3 is a computer program used extensively by the Corps of Engineers and was developed by Stephen Wright of the University of Texas for the evaluation of slope stability. This program uses limit equilibrium to solve slope stability problems using the method of slices. Stability analyses were performed using Spencer's method, assuming circular failure surfaces. The phreatic surface used in these analyses was based on the highest water levels measured in the piezometers between August 2010 and September 2014. The water level readings were provided by AEP and are included in **Appendix IV**. The shear strength parameters used in the stability analyses are presented in the following table. A summary of the laboratory testing and the results of strength tests on selected samples performed in the 2010 subsurface investigation are included in **Appendix IV**.

Shear Strength Parameters for Slope Stability Analyses

Soil Stratum	γ_{wet} (pcf)	Total		Effective	
		c, psf	Φ,degree	c', psf	Φ',degree
Embankment Clay Fill	125	350	20	100	32
Very Soft Clay	120	250	16	50	26
Soft to Medium Stiff Clay	125	300	16	100	28
Medium Stiff to Stiff Clay	125	350	16	100	30
Stiff to Very Stiff Clay	125	500	16	100	32
Medium Dense to Dense Granular Soils	125	0	28 to 35, mostly 35	0	28 to 35, mostly 35

Pseudo-static slope stability analyses were performed for the seismic evaluation. According to the CCR rules, the seismic stability during and following a seismic event with a 2% probability of exceedance in 50 years and a horizontal spectral response acceleration for 1.0-second period (5% of Critical Damping) should be evaluated. Using these criteria, the United States Geological Survey (USGS) 2014 Seismic Hazard Map for the United States indicates that the Peak Ground Acceleration (PGA) for the site area is approximately 0.04g. It should be noted that the PGA of 0.04g is the peak ground acceleration for a uniform firm rock site condition (760 meters per second shear wave velocity in the upper 30 meter). Using the ground acceleration correlation between rock sites and soil sites and the correlation between the pseudo-static coefficient and the peak ground acceleration, a seismic coefficient of 0.06g was determined and used for the stability analyses. The USGS 2014 Seismic Hazard Map for the United States and the detailed calculations of the seismic coefficient are presented in **Exhibit 6** in **Appendix V**.

For seismic conditions, UTEXAS uses a pseudo-static analysis where a horizontal destabilizing force due to the ground acceleration of an earthquake is added to the total sliding force. This horizontal force is equal to the weight of the sliding mass times the seismic coefficient for the design seismic event for the site. The program applies the multistage analysis technique developed by Duncan and Wright (1990) and Shinoak Software (1991) to search for the most critical surface of sliding that gives the least factor of safety against such a failure. A three-stage stability computation was used for this investigation. The first set of computations is to compute the effective stresses along the shear surface to which the soil is consolidated prior to the seismic event. These consolidation stresses are used to estimate undrained shear strengths for the second-stage computations, when the earthquake occurs. These undrained shear strengths were calculated based on the procedure developed by Duncan and Wright (1990). The third set of computations is performed to check the possibility that drainage may occur and the drained strength may be lower than the calculated undrained strength. A comparison is made between the calculated drained strength and the calculated undrained strength. A conservative factor of safety is computed using the lower of the calculated drained or undrained strength.

Based on the available hydraulic data for the ponds, the pool elevations at the South Fly Ash Pond, the Boiler Slag Pond, and the Clearwater Pond under the required loading conditions were calculated and are summarized Section 5.2 of this report. These pool elevations were used in the stability analyses for this PE certification.

According to AEP, the ponds have always been operating at the maximum storage pool levels. Consequently, the maximum operating pool elevations, instead of the normal pool elevations, were used in the stability analyses for the seismic condition. Results of the stability analyses for the maximum surcharge pool condition indicated that the embankments exhibit factors of safety of 1.5 or greater for all sections analyzed. Consequently, stability analyses for the normal pool (long term) condition were not analyzed. A summary of the stability analyses is presented in the following tables. The graphic results of the stability analyses are included in **Appendix VI**.

Summary of Results of Stability Analyses

Pond/Section	**Pool Elevation Used for Analysis (feet)[1]**	**Critical Factor of Safety Calculated for Maximum Surcharge Pool Condition**	**Required Minimum Factor of Safety**		**Pool Elevation for Seismic Case (feet)[2]**	**Computed Factor of Safety for Seismic Case (Required Minimum F.S.)**	**Criteria Meet?**
			Long Term, Normal Pool Condition	**Maximum Surcharge Pool Condition**			
South Fly Ash (Critical Section 2)	586	1.51	1.5	1.4	585	1.18 (1.0)	Yes
Boiler Slag (Critical Section 2)	559.3	1.71	1.5	1.4	558	1.30 (1.0)	Yes
Clearwater (Critical Section 3)	558.6	1.85	1.5	1.4	553	1.36 (1.0)	Yes

[1]Maximum surcharge pool elevations.
[2]The ponds have always been operating at the maximum operating pool levels.

5.4 Liquefaction Evaluations`

Liquefaction evaluations were performed in the 2010 subsurface exploration. According to the map, “Earthquakes in Ohio and Vicinity 1776 – 2007,” prepared by USGS, the earthquake moment magnitude M_w for the site area is between 3.0 and 3.9. For the liquefaction analysis, an M_w of 3.9 was assumed. Additionally, the phreatic surface was conservatively assumed to be at the ground surface at the boring locations during an earthquake event. **Using the PGA of 0.06g for the site, as previously noted, the**

factors of safety are greater than 3.0 against liquefaction of the granular soils at the various depths encountered in the borings. Consequently, the granular soils are not susceptible to liquefaction for the assumed M_w of 3.9. For liquefaction evaluation of fine-grained soils, the guidelines from the Illinois Department of Transportation (IDOT), the US Army Corps of Engineers and the Ohio EPA were used. Results of the liquefaction evaluations indicated that the majority of the fine-grained soils at the site were not potentially liquefiable. However, a total of thirteen samples was identified to be potentially liquefiable using the IDOT criteria. Additional analyses using the "Simplified Method" by Youd et al (2001) were performed to further evaluate the liquefaction potential of these soils for the assumed earthquake magnitude and peak ground acceleration. Results of the "Simplified Method" indicated that the fine-grained soils were not susceptible to liquefaction. Reportedly, there have not been changes to the overall conditions of the embankments since the 2010 subsurface exploration; therefore, the results of the liquefaction evaluations performed in 2010 were used for the PE certification. Details of the liquefaction evaluations are included in **Appendix VII**.

6.0 CONCLUSIONS

Slope stability analyses and liquefaction evaluations have been conducted to assess the stability of the South Fly Ash Pond, the Boiler Slag Pond, and the Clearwater Pond using the loading conditions required by the current CCR rules specified in the Federal Register 40 CFR Parts 257 and 261, Vol. 80, No. 74, dated April 17, 2015. Results of the analyses indicate that the embankments exhibit factors of safety exceeding the required minimum values required by the current CCR rules.

7.0 REFERENCES

U.S. Army Corps of Engineers. Slope Stability. Engineering Manual 1110-2-1902. October, 2003.

United States Geological Survey (USGS). Documentation for the 2008 Update of the United States National Seismic Hazard Maps, 2008.

Youd, et. al. (2001). "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.

Design Guide, AGMU Memo 10.01 – Liquefaction Analysis. January 14, 2010. Illinois Department of Transportation.

United States Geological Survey (USGS) Map. Earthquakes in Ohio and Vicinity 1776-2007.

RCRA Subtitle D (258) Seismic Design Guidance for Muncipal Solid Waste Landfill Facilities, EPA/600/R-95/051, April 1995, Chapter 5 "Liquefaction Potential Evaluation and Analysis."

UTEXASED4, A Computer Program for Slope Stability Calculations, by Stephen G. Wright, 2004.

8.0 PROFESSIONAL ENGINEER CERTIFICATION

DLZ has completed the engineering services for Professional Engineer Certification of the South Fly Ash Pond, the Boiler Slag Pond, and the Clearwater Pond Embankments at the OVEC Kyger Creek Station.

Results of the stability analyses and liquefaction evaluations indicate that the embankments has met the coal combustion residuals (CCR) rule's minimum factor of safety requirements for embankment stability under the static, seismic, and liquefaction conditions as specified in the Federal Register 40 CFR Parts 257 and 261, Vol. 80, No. 74, dated April 17, 2015.

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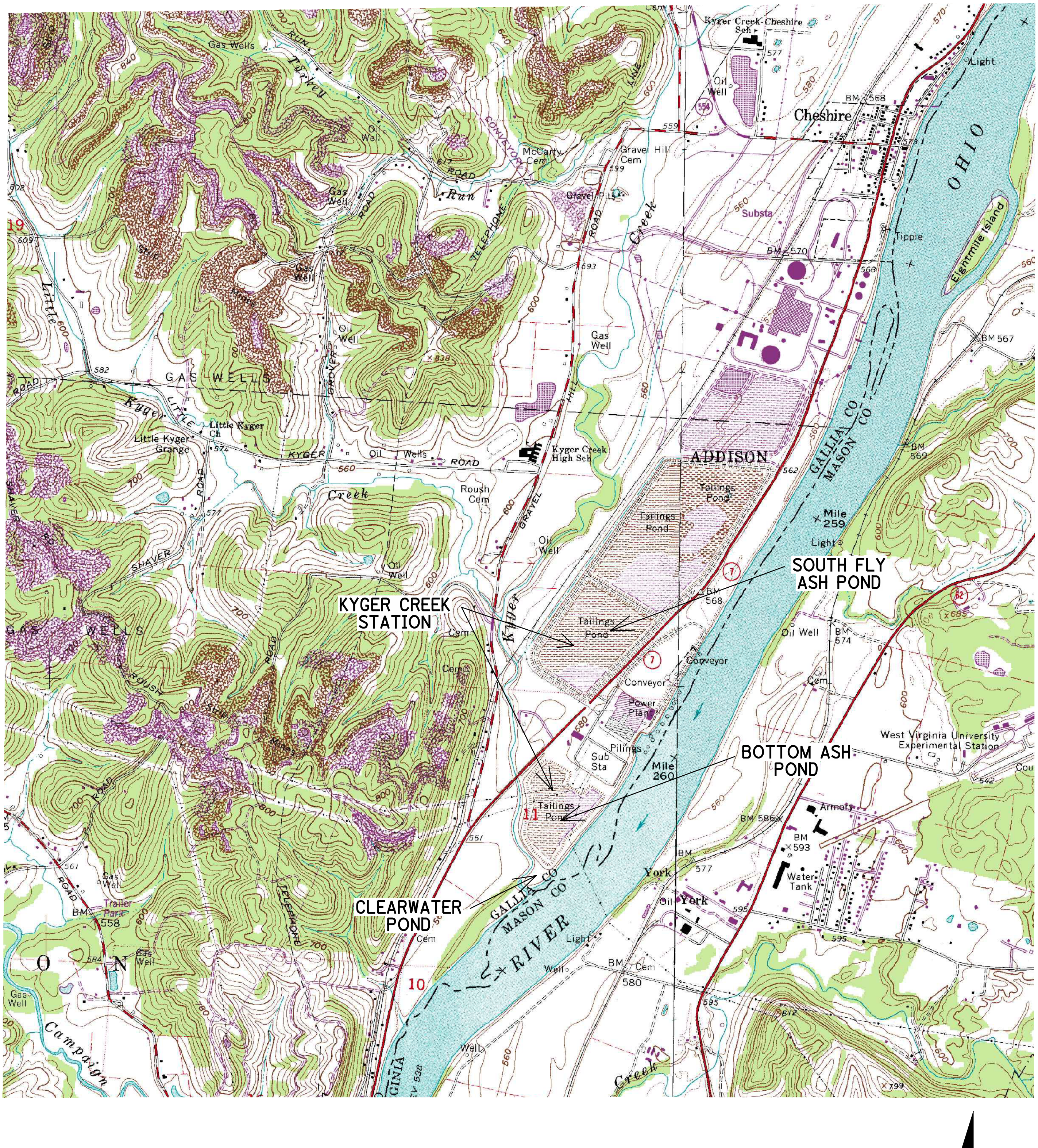
APPENDIX I

Exhibit 1 – General Site Location Map
Exhibit 2 – Layout of the South Fly Ash Pond
Exhibit 3 – Layout of the Boiler Slag Pond and the Clearwater Pond



SCALE: 1"=1/2MILE

DLZ

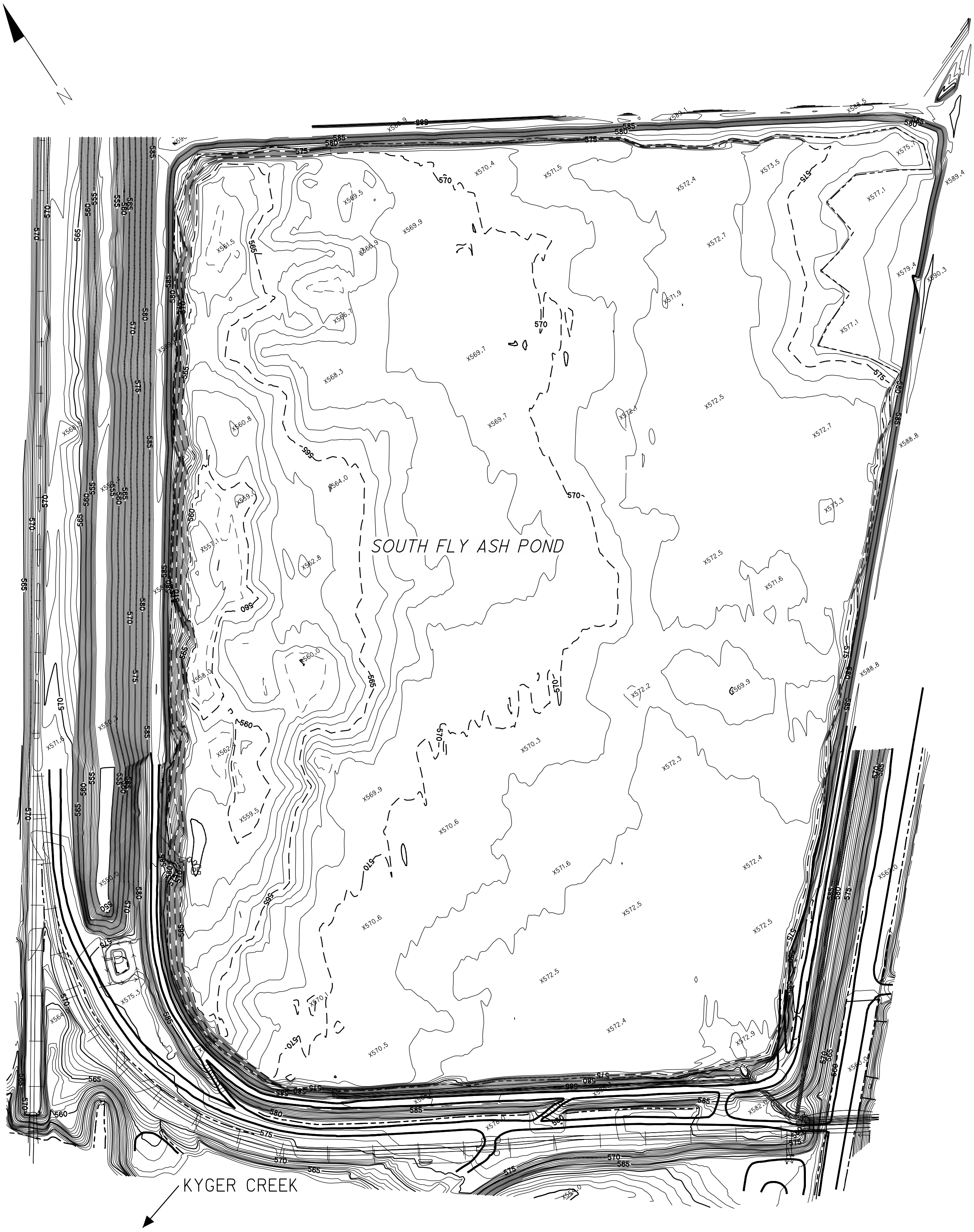
SITE LOCATION MAP

KYGER CREEK PLANT
OHIO VALLEY ELECTRIC CORP.
GALLIPOLIS, OHIO

PROJECT NO.
1021-3003.00

DATE: 11/12/2010

EXHIBIT 1



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DLZ

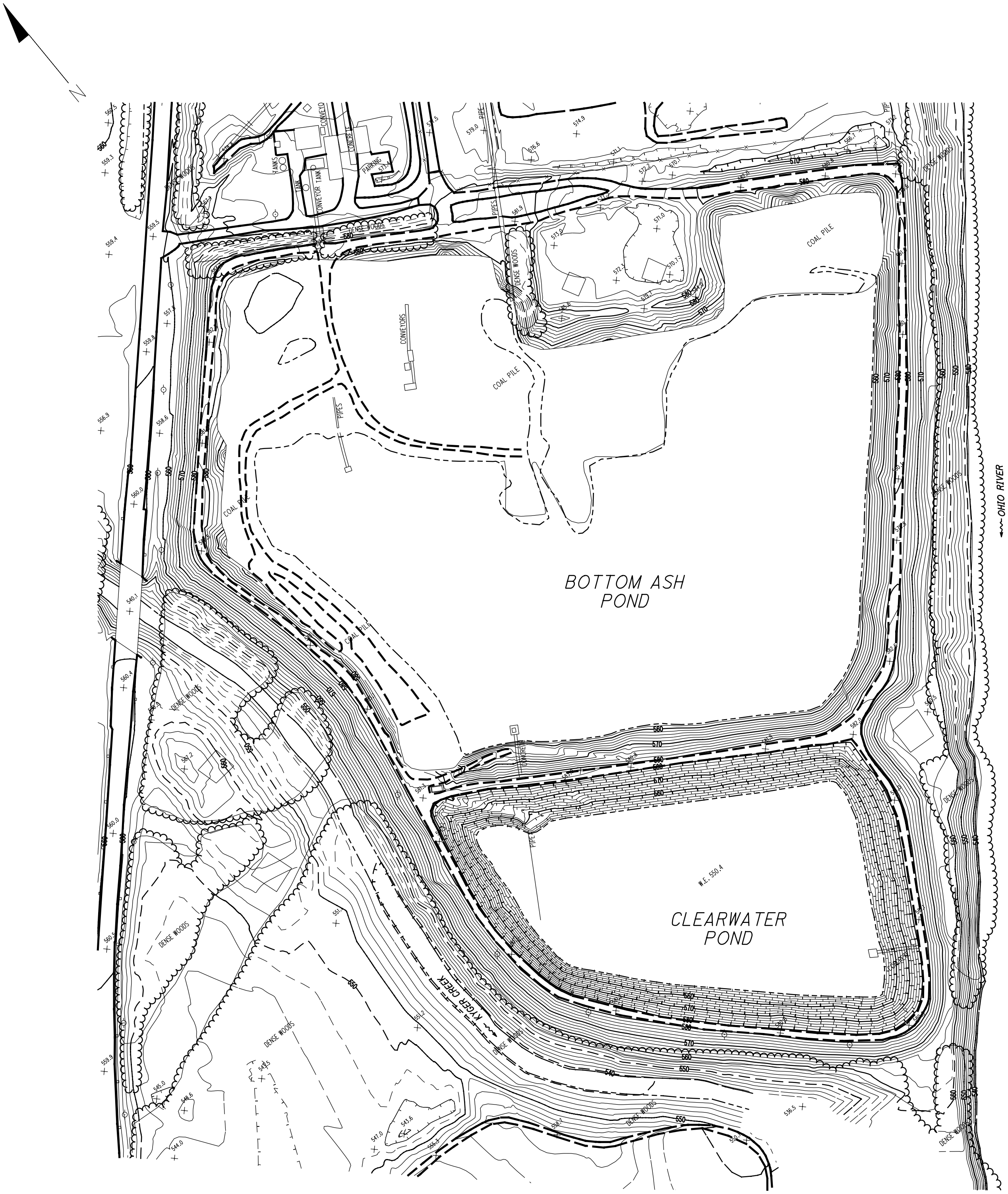
SOUTH FLY ASH POND

KYGER CREEK PLANT
OHIO VALLEY ELECTRIC CORP.
GALLIPOLIS, OHIO

PROJECT NO.
1021-3003.00

DATE: 11/12/2010

EXHIBIT 2



SCALE: 1"=300'

Bottom Ash Pond is also known as Boiler Slag Pond

DLZ

BOTTOM ASH POND

KYGER CREEK PLANT
OHIO VALLEY ELECTRIC CORP.
GALLIPOLIS, OHIO

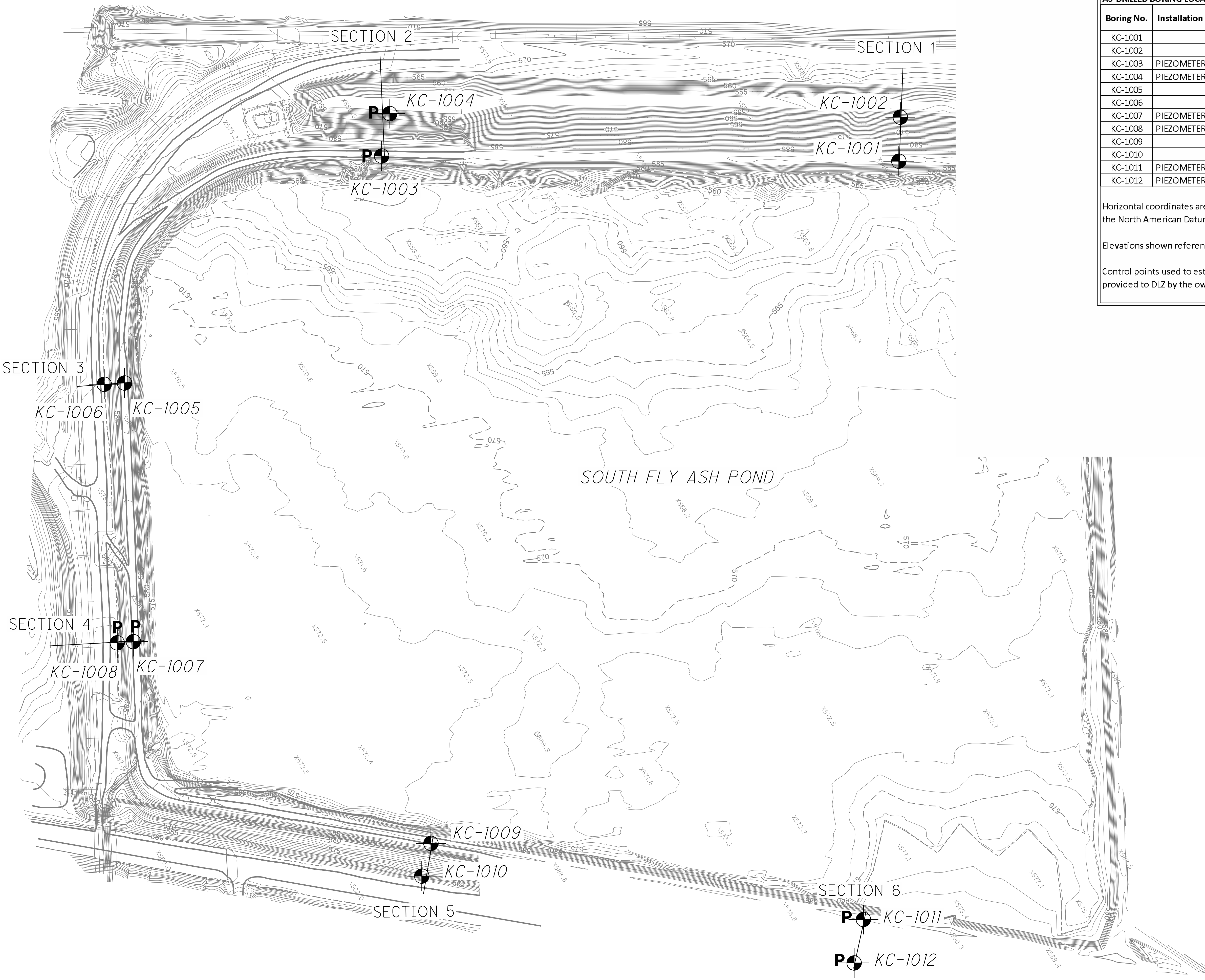
PROJECT NO. 1021-3003.00

DATE: 11/12/2010

EXHIBIT 3

APPENDIX II

Exhibit 4 – Boring Location Plan for the South Fly Ash Pond
Exhibit 5 – Boring Location Plan for the Boiler Slag Pond and the Clearwater Pond
Logs of Borings Performed in the 2010 Subsurface Investigation



AS-DRILLED BORING LOCATIONS

Boring No.	Installation	NORTHING	EASTING	ELEVATION (RISER)	ELEVATION (CASING)	ELEVATION (GROUND)
KC-1001		335792.74	2104707.66	-	-	589.27
KC-1002		335845.29	2104633.74	-	-	558.28
KC-1003	PIEZOMETER	334909.65	2104111.75	588.09	588.41	588.41
KC-1004	PIEZOMETER	334971.92	2104048.18	557.99	558.35	555.31
KC-1005		334210.21	2104210.16	-	-	588.24
KC-1006		334173.91	2104189.26	-	-	576.37
KC-1007	PIEZOMETER	333931.89	2104664.58	588.83	589.03	589.03
KC-1008	PIEZOMETER	333902.86	2104648.40	580.61	580.90	580.90
KC-1009		334214.40	2105349.14	-	-	589.16
KC-1010		334161.58	2105394.90	-	-	565.11
KC-1011	PIEZOMETER	334871.45	2105970.70	588.99	589.19	589.19
KC-1012	PIEZOMETER	334806.18	2106034.91	562.67	562.96	562.96

Horizontal coordinates are State Plane Grid, Ohio South Zone, and reference the North American Datum of 1927 (NAD 27)

Elevations shown reference the National Geodetic Vertical Datum of 1929 (NGVD 29)

Control points used to establish the coordinates on the respective datums were provided to DLZ by the owner (OVEC/AEP) at the time of the survey.

AS-DRILLED BORING

P PIEZOMETERS INSTALLED IN BORINGS AS INDICATED IN TABLE ABOVE

NOTE: TOPOGRAPHIC SURVEY INFORMATION SHOWN ON THIS PLAN IS FOR REFERENCE ONLY. TOPO INFORMATION WAS PROVIDED BY AEP/OVEC AND IS BASED ON AERIAL MAPPING (1994) AND FIELD SURVEY (1997). CURRENT ELEVATIONS MAY BE DIFFERENT THAN THOSE SHOWN ON PLAN.

EXHIBIT 4

0 50 100 200
HORIZONTAL SCALE IN FEET

DRAWN RKL
CHECKED SJR

SOUTH FLY ASH POND
GENERAL SITE PLAN

KYGER CREEK

1 / 6

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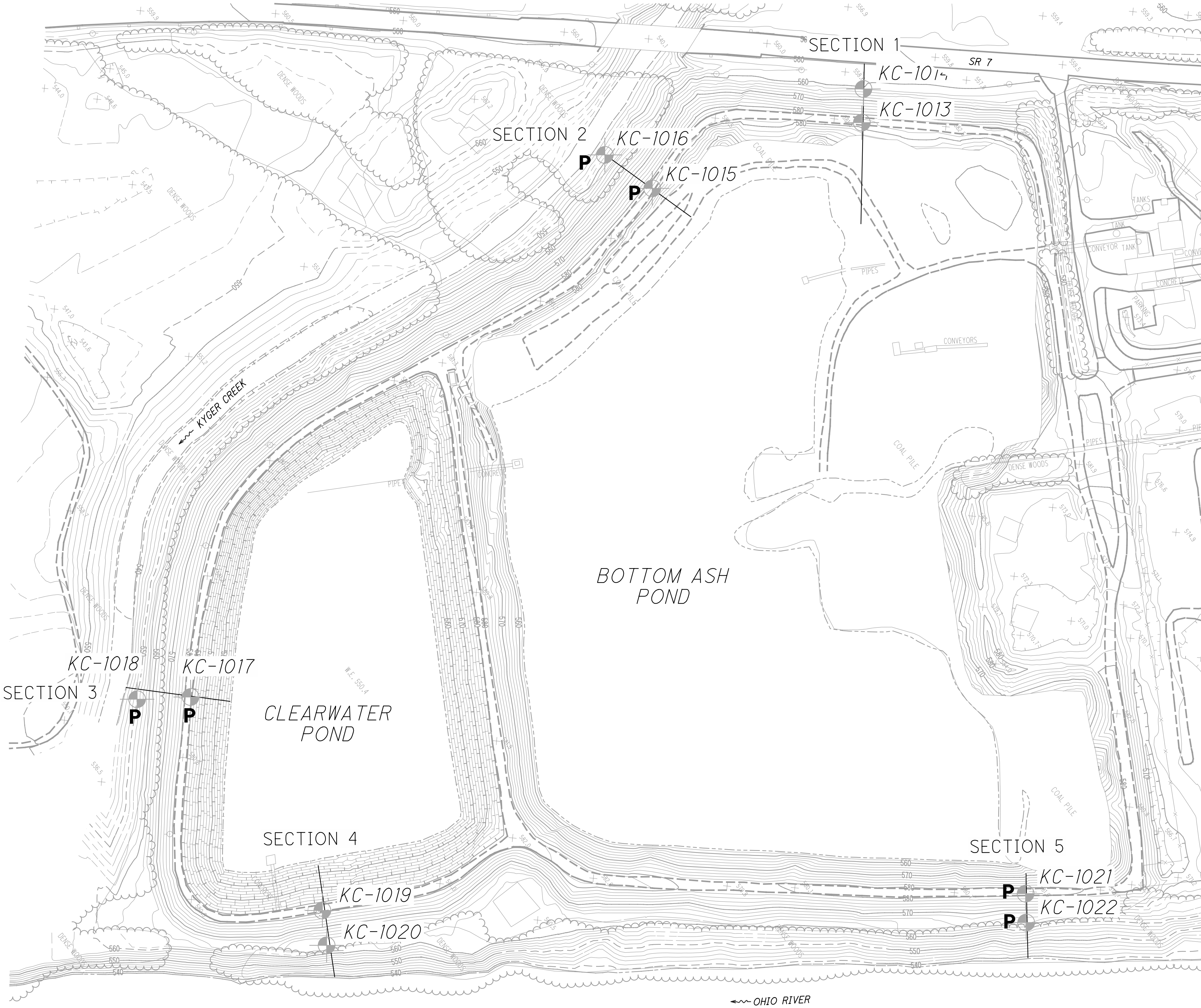
BOTTOM ASH POND GENERAL SITE PLAN

KYGER CREEK



AS-DRILLED BORING LOCATIONS							
Boring No.	**Installation**	**NORTHING**	**EASTING**	**ELEVATION (RISER)**	**ELEVATION (CASING)**	**ELEVATION (GROUND)**
KC-1013		332435.80	2104006.56	-	-	581.27
KC-1014		332476.01	2103962.06	-	-	558.59
KC-1015	PIEZOMETER	332073.06	2103860.39	580.07	580.41	580.41
KC-1016	PIEZOMETER	332045.57	2103760.75	546.70	546.87	543.80
KC-1017	PIEZOMETER	330862.99	2104039.31	579.69	580.07	580.07
KC-1018	PIEZOMETER	330786.90	2103981.94	550.10	550.35	547.34
KC-1019		330803.17	2104482.03	-	-	580.73
KC-1020		330769.60	2104534.81	-	-	559.51
KC-1021	PIEZOMETER	331789.94	2105253.04	579.92	580.18	580.18
KC-1022	PIEZOMETER	331758.02	2105293.51	565.54	565.75	562.69

Horizontal coordinates are State Plane Grid, Ohio South Zone, and reference the North American Datum of 1927 (NAD 27)

Elevations shown reference the National Geodetic Vertical Datum of 1929 (NGVD 29)

Control points used to establish the coordinates on the respective datums were provided to DLZ by the owner (OVEC/AEP) at the time of the survey.

AS-DRILLED BORING

P PIEZOMETERS INSTALLED IN BORINGS AS INDICATED IN TABLE ABOVE

NOTE: TOPOGRAPHIC SURVEY INFORMATION SHOWN ON THIS PLAN IS FOR REFERENCE ONLY. TOPO INFORMATION WAS PROVIDED BY AEP/OVEC AND IS BASED ON AERIAL MAPPING (1994) AND FIELD SURVEY (1997). CURRENT ELEVATIONS MAY BE DIFFERENT THAN SHOWN ON PLAN.

Bottom Ash Pond is also known as Boiler Slag Pond

HORIZONTAL SCALE IN FEET: 0 50 100 200

DRAWN RKL CHECKED SJR

2 / 6

EXHIBIT 5

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Client: OVEC-AEP | *Project:* Kyger Creek - Ash Impoundment Stability Analysis | *Job No.* 1021-3003.00

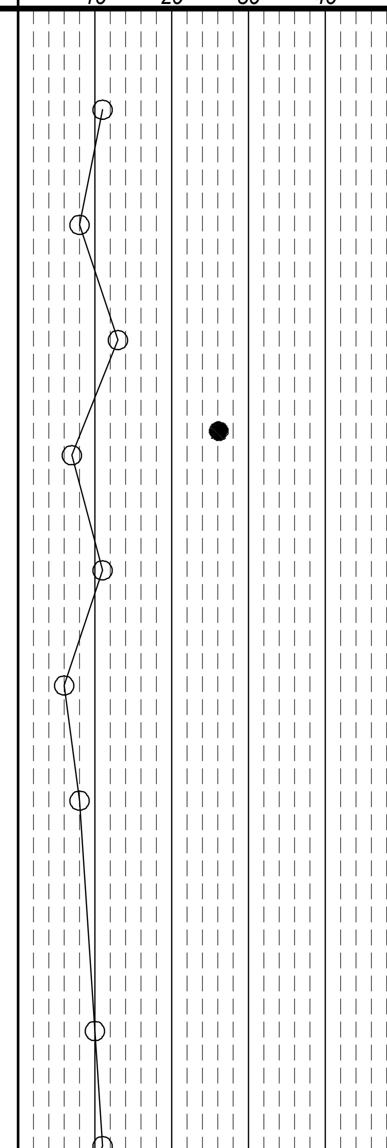
LOG OF: Boring KC-1001 | *Location:* As per plan | *Date Drilled:* 8/19/2010

WATER OBSERVATIONS:
Water seepage at: *46'-65'*
Water level at completion: *53.6' Prior to adding water.*
49.3 Final including drilling water.

FIELD NOTES:
Sealed borehole with bentonite grout.
Began adding drilling water at 50' to counteract heave.

Depth (ft)	Elev. (ft) 589.3	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	Graphic Log	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
0.3	589.0						3" Gravel							
		1 4 5	18	S-1		3.5	FILL: Stiff to very stiff brown and gray LEAN CLAY with sand (CL); moist.							
5		1 3 4	10	S-2		1.5								
6.0	583.3													
		3 6 5	18	S-3		4.0	FILL: Stiff to very stiff brown and gray LEAN CLAY with sand (CL); moist.							
10		2 2 4	15	S-4		1.0								
		1 4 5	18	S-5		3.0								
15		2 2 3	18	S-6		1.0								
		3 2 5	18	S-7		1.25								
20					ST-1									
		1 4 4	18	S-8		3.0								
25	564.3	2 4 5	18	S-9		2.25								

STANDARD PENETRATION (N60)
Natural Moisture Content, % - ●
PL ⊢—⊣ LL
Blows per foot - ○ / Non-Plastic - NP
10 20 30 40



Client: OVEC-AEP | **Project:** Kyger Creek - Ash Impoundment Stability Analysis | **Job No.** 1021-3003.00

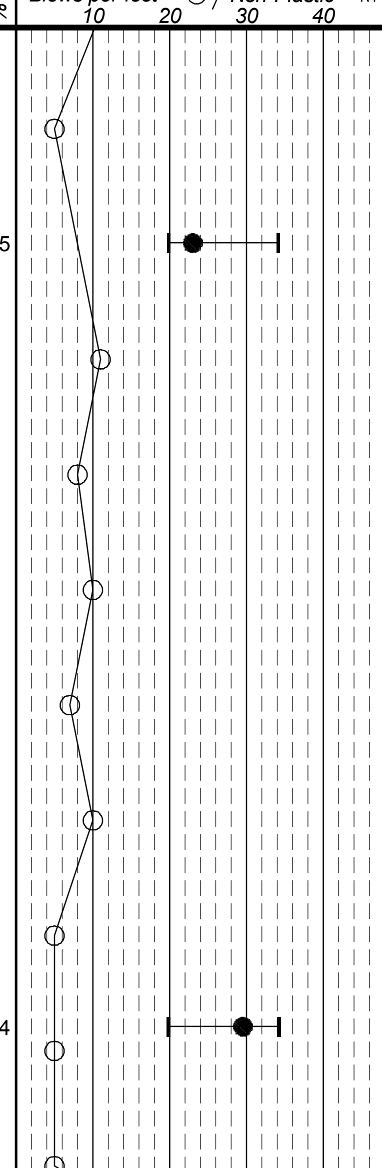
LOG OF: Boring KC-1001 | **Location:** As per plan | **Date Drilled:** 8/19/2010

WATER OBSERVATIONS:
Water seepage at: 46'-65'
Water level at completion: 53.6' Prior to adding water.
49.3 Final including drilling water.

FIELD NOTES:
Sealed borehole with bentonite grout.
Began adding drilling water at 50' to counteract heave.

Depth (ft)	Elev. (ft) 564.3	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
		1 1 3	18	S-10		1.5	FILL: Stifff brown and gray LEAN CLAY with sand (CL); moist.						
28.5	560.8				ST-2	2.5	FILL: Very stiff brown and gray LEAN CLAY (CL), trace fine to medium sand; moist.	0	0	1	7	47	45
31.0	558.3	2 4 5	18	S-11		2.5	FILL: Stiff to very stiff brown and gray sandy LEAN CLAY (CL); damp to moist.						
		2 3 4	18	S-12		1.0							
35.0	554.3	2 4 4	18	S-13		2.5	POSSIBLE FILL: Stiff to very stiff brown and gray sandy LEAN CLAY (CL); damp to moist.						
		1 3 3	18	S-14		1.25							
		WOH 2 6	18	S-15		1.5							
43.5	545.8	WOH WOH 4	18	S-16		0.75	Medium stiff brown LEAN CLAY with sand (CL); damp to moist.						
46.0	543.3	WOH WOH 4	18	S-17		1.5	Stiff brown LEAN CLAY (CL), trace fine sand; moist. @ 47.0' Clayey sand seam layer	0	0	0	8	58	34
48.5	540.8	WOH WOH		S-18A		0.75	Medium stiff gray sandy LEAN CLAY (CL); moist.						
49.4	539.9	4	18	S-18B			Loose gray silty SAND (SM); wet.						
50	539.3												

STANDARD PENETRATION (N60)
Natural Moisture Content, % - ●
PL ⊢—⊣ LL
Blows per foot - ○ / Non-Plastic - NP



Client: OVEC-AEP | *Project:* Kyger Creek - Ash Impoundment Stability Analysis | *Job No.* 1021-3003.00

LOG OF: Boring KC-1001 | *Location:* As per plan | *Date Drilled:* 8/19/2010

WATER OBSERVATIONS:
Water seepage at: 46'-65'
Water level at completion: 53.6' Prior to adding water.
49.3 Final including drilling water.

FIELD NOTES:
Sealed borehole with bentonite grout.
Began adding drilling water at 50' to counteract heave.

Depth (ft)	Elev. (ft) 539.3	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay	STANDARD PENETRATION (N60) / Natural Moisture Content, %
							Loose gray silty SAND (SM); wet.							
52.0	537.3						Dense light brown SAND with gravel (SW), trace silt; wet.							
55		10 16 33	18	S-19				42	17	18	21	--3--		NP; 59
57.0	532.3						Very dense light brown silty SAND with gravel (SM); wet.							
60		33 43 35	12	S-20										94
63.5	525.8	18 14 19	10	S-21			Dense light brown GRAVEL with silt with sand (GP-GM); wet.							
65.0	524.3						Bottom of Boring - 65.0'							

STANDARD PENETRATION (N60) Natural Moisture Content, % - ●
PL ⊢—⊣ LL
Blows per foot - ○ / Non-Plastic - NP
10 20 30 40

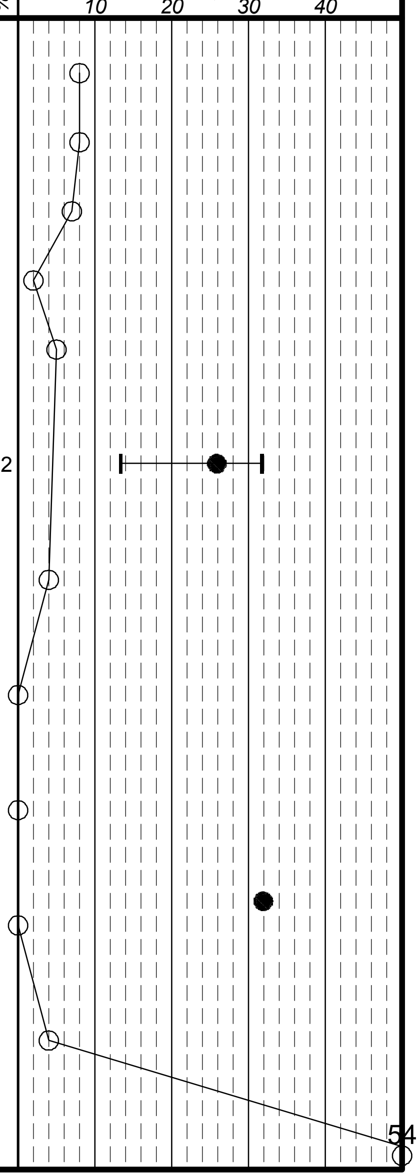
Client: OVEC-AEP | *Project:* Kyger Creek - Ash Impoundment Stability Analysis | *Job No.* 1021-3003.00

LOG OF: Boring KC-1002 | *Location:* As per plan | *Date Drilled:* 8/25/2010

WATER OBSERVATIONS:
Water seepage at: 6.0-7.5, 13.5-58.5
Water level at completion: 18.0' Prior to adding water
FIELD NOTES:

Depth (ft)	Elev. (ft) 558.3	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
0.2	558.1	1 4 3	18	S-1		3.5	Topsoil - 2" FILL: Very stiff brown sandy LEAN CLAY (CL); damp to moist.						
		2 3 4	3	S-2		3.5							
		2 3 3	6	S-3		2.5							
5.0	553.3	2 1 1	2	S-4			POSSIBLE FILL: Very loose to loose brown SAND with silt (SP-SM); moist to wet.						
		2 2 2	2	S-5									
8.5	549.8				ST-1		Very soft to soft brown sandy LEAN CLAY (CL); moist to wet.	0	0	0	16	52	32
		WOH 1 2	18	S-6		0.5							
		WOH WOH WOH	18	S-7		0.25							
		WOH WOH WOH	18	S-8		0.25							
		WOH WOH WOH	18	S-9		<0.25							
		1 1 2	18	S-10		0.5	@ 21.0', gray.						
23.5	534.8	WOH 12 33	6	S-11			Medium dense to dense gray GRAVEL with silt with sand (GW-GM); wet.						
25	533.3												

STANDARD PENETRATION (N60)
Natural Moisture Content, % - ●
PL ├──┤ LL
Blows per foot - ○ / Non-Plastic - NP



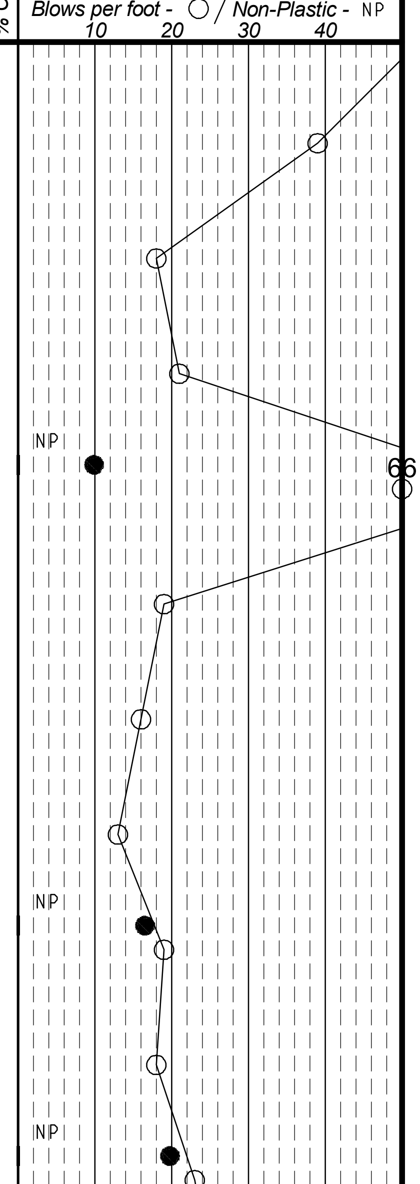
Client: OVEC-AEP | *Project:* Kyger Creek - Ash Impoundment Stability Analysis | *Job No.* 1021-3003.00

LOG OF: Boring KC-1002 | *Location:* As per plan | *Date Drilled:* 8/25/2010

WATER OBSERVATIONS:
Water seepage at: 6.0-7.5, 13.5-58.5
Water level at completion: 18.0' Prior to adding water
FIELD NOTES:

Depth (ft)	Elev. (ft) 533.3	Blows per 6"	Recovery	Sample No. Drive	Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
							Medium dense to dense gray GRAVEL with silt with sand (GW-GM); wet.						
		13 20 12	18	S-12									
30		3 6 9	10	S-13									
		2 7 10	10	S-14									
33.0	525.3						Very dense gray SAND with silt with gravel (SW-SM); wet.						
35		25 30 25	18	S-15				45	12	17	18	--8--	
36.0	522.3						Medium dense to dense gray GRAVEL with silt with sand (GW-GM); wet.						
		6 7 9	8	S-16									
40		7 8 5	5	S-17									
		3 4 7	1	S-18									
43.5	514.8						Medium dense gray SAND with silt with gravel (SP-SM); wet.						
45		11 5 11	8	S-19				18	11	23	41	--7--	
46.0	512.3						Medium dense gray SAND (SW), trace gravel; wet.						
		7 5 10	14	S-20									
50	508.3	5 7 12	12	S-21				4	20	67	9	--0--	

STANDARD PENETRATION (N60)
Natural Moisture Content, % - ●
PL ⊢——⊣ LL
Blows per foot - ○ / Non-Plastic - NP



Client: OVEC-AEP	Project: Kyger Creek - Ash Impoundment Stability Analysis	Job No. 1021-3003.00
LOG OF: Boring KC-1002	Location: As per plan	Date Drilled: 8/25/2010

WATER OBSERVATIONS:
Water seepage at: 6.0-7.5, 13.5-58.5
Water level at completion: 18.0' Prior to adding water
FIELD NOTES:

Depth (ft)	Elev. (ft) 508.3	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	Graphic Log	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay	STANDARD PENETRATION (N60) / Natural Moisture Content, % - ● / PL ⊢—⊣ LL / Blows per foot - ○ / Non-Plastic - NP (10 20 30 40)
50.5	507.8						Medium dense gray SAND (SW), trace gravel; wet.								
55		10 10 13	1	S-22											
58.5	499.8														
59.3	499.0	20 50/3"	2	S-23			Soft to medium hard gray SILTSTONE interbedded with SHALE; highly weathered to decomposed, argillaceous, micaceous.								50+
60							Bottom of Boring - 59.3'								
65															
70															
75															

Client: OVEC-AEP | **Project:** Kyger Creek - Ash Impoundment Stability Analysis | **Job No.** 1021-3003.00

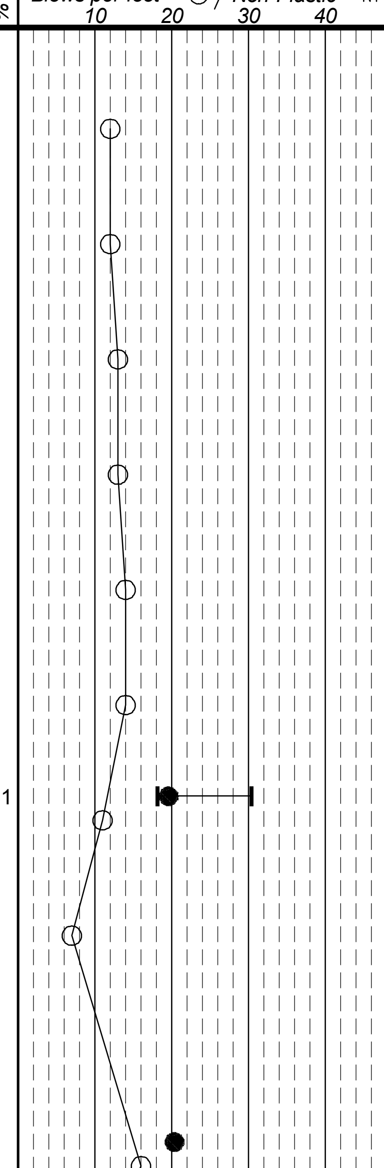
LOG OF: Boring KC-1003 | **Location:** As per plan | **Date Drilled:** 8/18/2010

WATER OBSERVATIONS:
Water seepage at: 43'-65'
Water level at completion: 48.1' Prior to adding water.
41.1' Final including drilling water.

FIELD NOTES:
Sealed borehole with bentonite grout.
Installed piezometer in offset boring.

Depth (ft)	Elev. (ft) 588.4	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
0.3	588.1						3" GRAVEL						
		3 4 6	18	S-1		3.5	FILL: Very stiff brown SILTY CLAY with sand (CL-ML); contains organic material; damp.						
		3 4 6	18	S-2		3.0							
		3 5 6	18	S-3		1.25	@ 6.0' brown and gray						
8.5	579.9												
		3 5 6	18	S-4		4.5+	FILL: Very stiff to hard brown and gray LEAN CLAY with sand (CL); moist.						
		3 5 7	18	S-5		2.0							
		3 4 8	18	S-6		4.25							
		3 4 5	18	S-7		2.25		0	0	1	23	45	31
18.5	569.9												
		2 3 3	18	S-8		2.5	FILL: Very stiff brown and gray LEAN CLAY (CL), trace sand; moist.						
					ST-1								
25	563.4	4 5 8	18	S-9		2.5							

STANDARD PENETRATION (N60)
Natural Moisture Content, % - ●
PL ⊢—⊣ LL
Blows per foot - ○ / Non-Plastic - NP



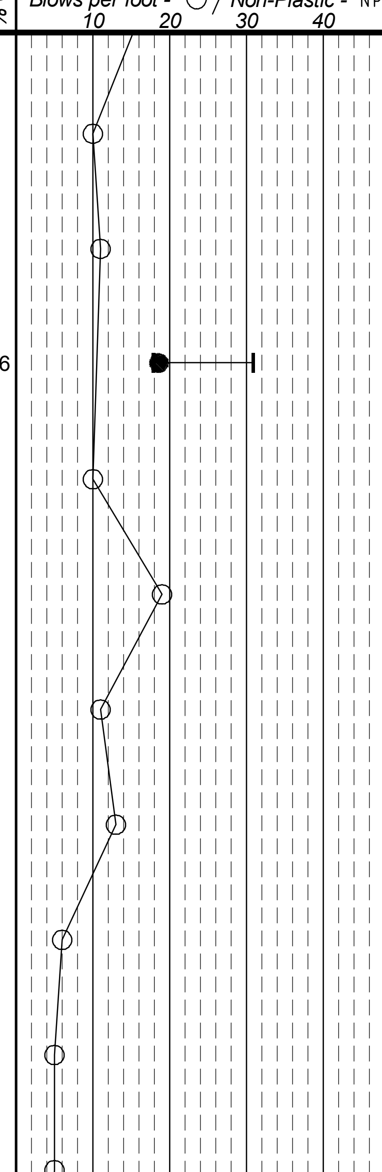
Client: OVEC-AEP	Project: Kyger Creek - Ash Impoundment Stability Analysis	Job No. 1021-3003.00
LOG OF: Boring KC-1003	Location: As per plan	Date Drilled: 8/18/2010

WATER OBSERVATIONS:
Water seepage at: 43'-65'
Water level at completion: 48.1' Prior to adding water. 41.1' Final including drilling water.

FIELD NOTES:
Sealed borehole with bentonite grout.
Installed piezometer in offset boring.

Depth (ft)	Elev. (ft) 563.4	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	Graphic Log	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
		2 3 5	18	S-10		3.0	FILL: Very stiff brown and gray LEAN CLAY (CL), trace sand; contains organic material; moist.							
28.5	559.9	2 3 6	18	S-11		1.5	FILL: Stiff to very stiff brown LEAN CLAY (CL), trace sand; moist.							
30					ST-2	4.0	@31.0'-33.0', with fine sand.		0	0	0	17	47	36
33.5	554.9	2 3 5	18	S-12		4.0	Stiff to very stiff brown LEAN CLAY (CL), trace sand; moist.							
35		4 7 9	18	S-13		3.5								
		2 3 6	18	S-14		2.5								
40		2 3 8	18	S-15		1.5								
43.0	545.4	1 2 3	18	S-16		1.5	Stiff brown and gray LEAN CLAY with sand (CL); moist.							
45.0 (45)	543.4	WOH 1 3	18	S-17		0.25	Very soft to soft dark gray LEAN CLAY with sand (CL), contains shell fragments; moist.							
48.5	539.9	WOH 1 3	18	S-18		1.25	Stiff dark gray LEAN CLAY with sand (CL), contains shell fragments; moist.							
50	538.4													

STANDARD PENETRATION (N60)
Natural Moisture Content, % - ●
PL ⊢—⊣ LL
Blows per foot - ○ / Non-Plastic - NP



DLZ Ohio, Inc. * 6121 Huntley Road, Columbus, Ohio 43229 * (614) 888-0040

Client: OVEC-AEP | *Project:* Kyger Creek - Ash Impoundment Stability Analysis | *Job No.* 1021-3003.00

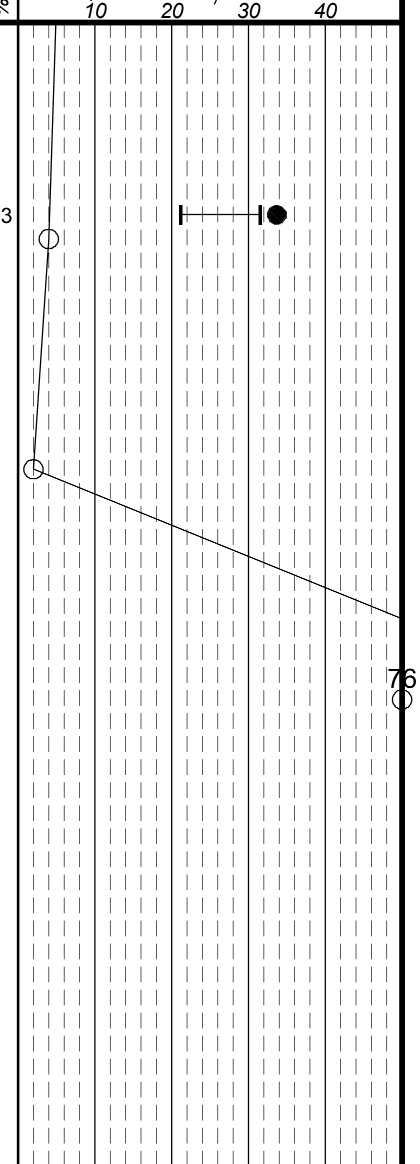
LOG OF: Boring KC-1003 | *Location:* As per plan | *Date Drilled:* 8/18/2010

WATER OBSERVATIONS:
Water seepage at: 43'-65'
Water level at completion: 48.1' Prior to adding water. 41.1' Final including drilling water.

FIELD NOTES:
Sealed borehole with bentonite grout.
Installed piezometer in offset boring.

Depth (ft)	Elev. (ft) 538.4	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
							Soft to medium stiff dark gray LEAN CLAY with sand (CL), contains shell fragments; moist.						
55		WOH WOH 3	18	S-19		0.5	@53.5'-55.0', wet.	0	0	0	17	50	33
59.5	528.9	WOH WOH 2	18	S-20		0.75							
60							Medium stiff dark gray sandy LEAN CLAY (CL); contains organic material and shell fragments; moist. Began adding drilling water at 60' to counteract heave.						
63.0	525.4						Very dense brown SAND with silt (SW-SM); wet.						
65.0	523.4	27 33 30	10	S-21									
							Bottom of Boring - 65.0'						
70													
75													

STANDARD PENETRATION (N60)
Natural Moisture Content, % - ●
PL ⊢—⊣ LL
Blows per foot - ○ / Non-Plastic - NP



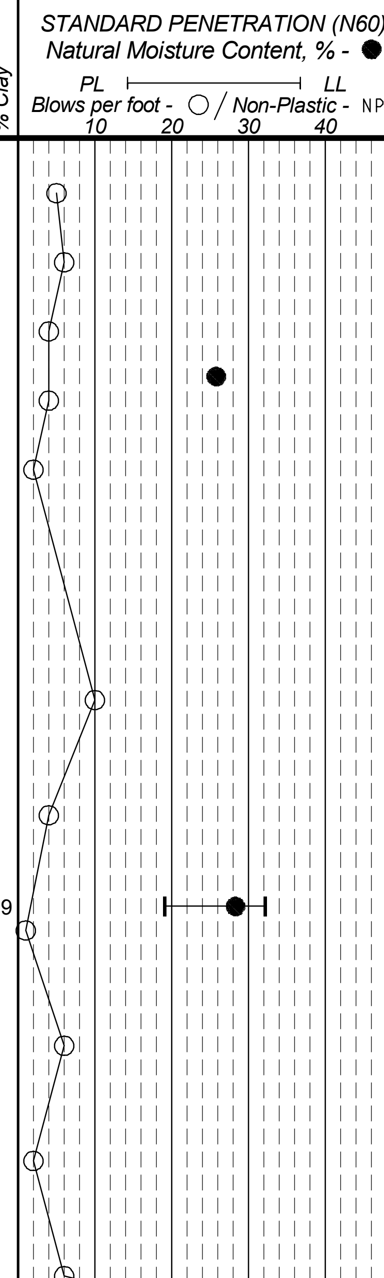
Client: OVEC-AEP | *Project:* Kyger Creek - Ash Impoundment Stability Analysis | *Job No.* 1021-3003.00

LOG OF: Boring KC-1004 | *Location:* As per plan | *Date Drilled:* 8/26/2010

WATER OBSERVATIONS:
Water seepage at: 11.0'-30.0'
Water level at completion: 15.9' Prior to adding water.

FIELD NOTES:

Depth (ft)	Elev. (ft) 555.3	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
0.3	555.0	2 2 2	9	S-1		1.0	Topsoil - 4" Medium stiff to stiff brown sandy LEAN CLAY (CL); moist.						
		2 3 2	18	S-2		1.5							
		2 1 2	18	S-3		0.5							
5		WOH 1 2	18	S-4		0.5							
		WOH 1 1	18	S-5		0.5							
10					ST-1								
11.0	544.3	1 3 5	18	S-6		0.75	Medium stiff brown sandy LEAN CLAY (CL); contains moist to wet sandy silt seams up to 2" in thickness; moist to wet.						
15		WOH 1 2	18	S-7		1.0							
15.5	539.8	WOH WOH 1	18	S-8		0.75	Medium stiff brown LEAN CLAY with sand (CL); moist.	0	0	0	20	51	29
17.5	537.8	WOH 2 3	18	S-9		0.75	Medium stiff brown sandy LEAN CLAY (CL); contains moist to wet sandy silt seams up to 2" in thickness; moist to wet.						
20		4 1 1	12	S-10		0.5	@ 21.0', gray.						
25	530.3	1 2 3	18	S-11		1.0							



DLZ Ohio, Inc. * 6121 Huntley Road, Columbus, Ohio 43229 * (614) 888-0040

Client: OVEC-AEP	Project: Kyger Creek - Ash Impoundment Stability Analysis	Job No. 1021-3003.00
LOG OF: Boring KC-1004	Location: As per plan	Date Drilled: 8/26/2010

WATER OBSERVATIONS:
Water seepage at: 11.0'-30.0'
Water level at completion: 15.9' Prior to adding water.
FIELD NOTES:

Depth (ft)	Elev. (ft) 530.3	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay	STANDARD PENETRATION (N60) / Natural Moisture Content
26.0	529.3	2, 17, 40	18	S-12			Very dense brown SAND with silt with gravel (SW-SM); wet.	40	15	22	17	--6--		NP; 69
		50/5"	5	S-13										50+
31.0	524.3	24, 18, 25	18	S-14			Medium dense brown GRAVEL with silt with sand (GW-GM); wet.							52
33.5	521.8	3, 6, 7	10	S-15			Medium dense grayish brown SAND with gravel (SW), trace silt; wet.	33	26	27	12	--2--		NP; 13
35.0	520.3						Bottom of Boring - 35.0'							

STANDARD PENETRATION (N60)
Natural Moisture Content, % - ●
PL ⊢—⊣ LL
Blows per foot - ○ / Non-Plastic - NP
10 20 30 40

Depth scale: 30, 35, 40, 45, 50

DLZ Ohio, Inc. * 6121 Huntley Road, Columbus, Ohio 43229 * (614) 888-0040

Client: OVEC-AEP | *Project:* Kyger Creek - Ash Impoundment Stability Analysis | *Job No.* 1021-3003.00

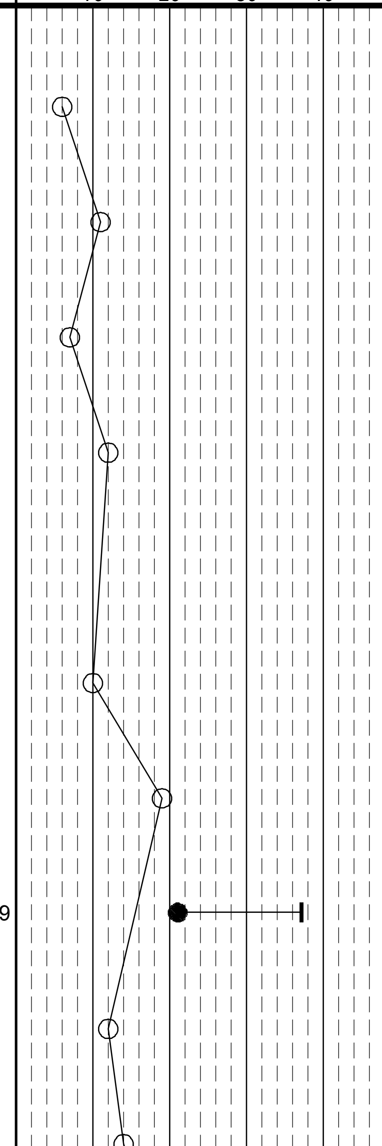
LOG OF: Boring KC-1005 | *Location:* As per plan | *Date Drilled:* 8/17/2010

WATER OBSERVATIONS:
Water seepage at: 48.5'-65.0'
Water level at completion: 57.4' Prior to adding water.
17.0' Final including drilling water.

FIELD NOTES:
Sealed borehole with bentonite grout.

Depth (ft)	Elev. (ft)	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	Graphic Log	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
	588.2													
0.3	587.9						3" GRAVEL							
		2 2 3	18	S-1		4.25	FILL: Stiff to very stiff to hard brown SILTY CLAY with sand (CL-ML); damp. @1.0'-2.5', hard.							
5		1 4 5	10	S-2		1.5								
		2 2 4	18	S-3		2.5	@ 6.0' brown and gray							
8.5	579.7	3 5 5	18	S-4		3.75	FILL: Very stiff brown and gray LEAN CLAY with sand (CL); moist.							
10					ST-1									
13.5	574.7	1 3 5	18	S-5		2.5	FILL: Very stiff to hard light brown and gray LEAN CLAY (CL), trace sand; moist.							
15		3 7 9	18	S-6		4.5+								
20					ST-2	4.0	@18.5'-20.5', little fine and medium sand.		0	0	2	11	48	39
		2 4 6	18	S-7		3.0								
25	563.2	2 4 8	18	S-8		3.75								

STANDARD PENETRATION (N60)
Natural Moisture Content, % - ●
PL ⊢——⊣ LL
Blows per foot - ○ / Non-Plastic - NP
10 20 30 40



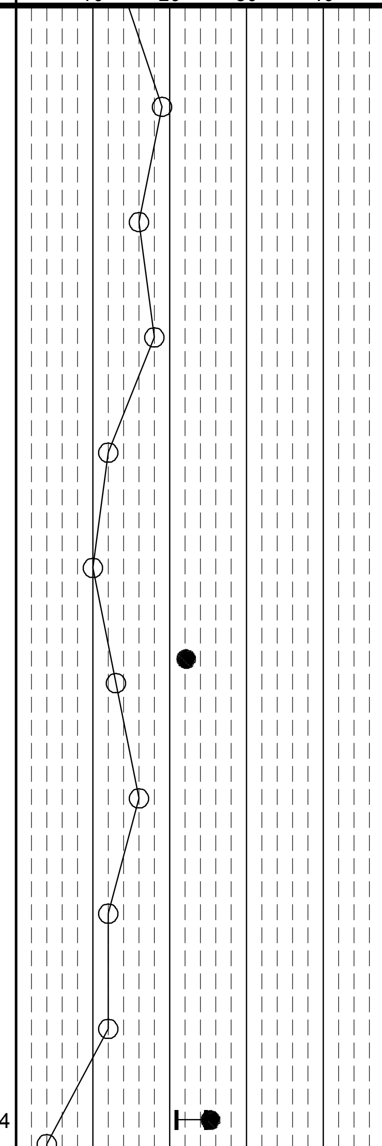
Client: OVEC-AEP	*Project:* Kyger Creek - Ash Impoundment Stability Analysis	*Job No.* 1021-3003.00
LOG OF: Boring KC-1005	*Location:* As per plan	*Date Drilled:* 8/17/2010

WATER OBSERVATIONS:
Water seepage at: *48.5'-65.0'*
Water level at completion: *57.4' Prior to adding water.*
17.0' Final including drilling water.

FIELD NOTES:
Sealed borehole with bentonite grout.

Depth (ft)	Elev. (ft) 563.2	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	Graphic Log	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
							FILL: Stiff to very stiff light brown and gray LEAN CLAY (CL), trace sand; moist.							
		4 6 10	18	S-9		4.0								
28.5	559.7													
		3 6 7	18	S-10		3.5	POSSIBLE FILL: Stiff to very stiff light brown and gray LEAN CLAY (CL), trace sand; moist.							
30														
		5 7 8	18	S-11		3.5								
		2 4 6	18	S-12		3.0	@ 33.5' trace roots							
35														
		2 3 5	18	S-13		2.0	@ 36.5' contains black particles							
		2 5 6	18	S-14		3.5								
40														
		3 5 8	18	S-15		3.25								
		1 5 5	18	S-16		1.5								
45														
		2 4 6	18	S-17		1.5								
48.0	540.2						Stiff to very stiff brown LEAN CLAY (CL), trace sand; moist.							
		WOH 1 2	18	S-18		0.25			0	0	0	30	46	24
50	538.2													

STANDARD PENETRATION (N60)
Natural Moisture Content, % - ●
PL ⊢⊣ LL
Blows per foot - ○ / Non-Plastic - NP
10 20 30 40



Client: OVEC-AEP | *Project:* Kyger Creek - Ash Impoundment Stability Analysis | *Job No.* 1021-3003.00

LOG OF: Boring KC-1005 | *Location:* As per plan | *Date Drilled:* 8/17/2010

WATER OBSERVATIONS:
Water seepage at: 48.5'-65.0'
Water level at completion: 57.4' Prior to adding water.
17.0' Final including drilling water.

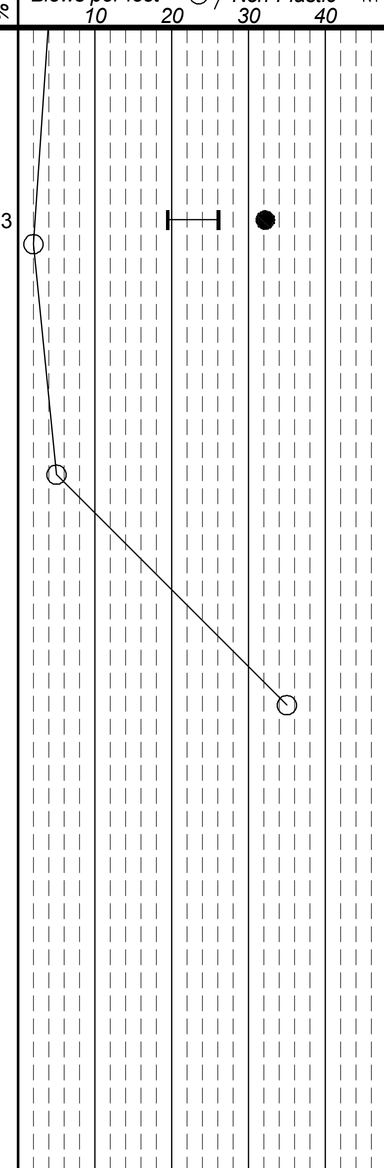
FIELD NOTES:
Sealed borehole with bentonite grout.

Elevation at ground surface: 538.2

Depth (ft)	Elev. (ft)	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
53.5	534.7						Stiff to very stiff brown LEAN CLAY (CL), trace sand; moist. @48.5'-64.5', wet interlaminating silty sand layers less than 1".						
57.0	531.2	WOH WOH 2	12	S-19		0.25	Soft gray SILTY CLAY with sand (CL-ML); contains shell particles; wet.	0	0	0	26	51	23
63.5	524.7	1 1 3	16	S-20			Very loose to loose gray clayey SAND (SC); moist.						
65.0	523.2	1 9 20	18	S-21A S-21B			Medium dense brown and gray SAND with silt with gravel (SW-SM); wet.						
							Bottom of Boring - 65.0'						

Depth scale: 55, 60, 65, 70, 75

STANDARD PENETRATION (N60)
Natural Moisture Content, % - ●
PL ├──┤ LL
Blows per foot - ○ / Non-Plastic - NP



DLZ Ohio, Inc. * 6121 Huntley Road, Columbus, Ohio 43229 * (614) 888-0040

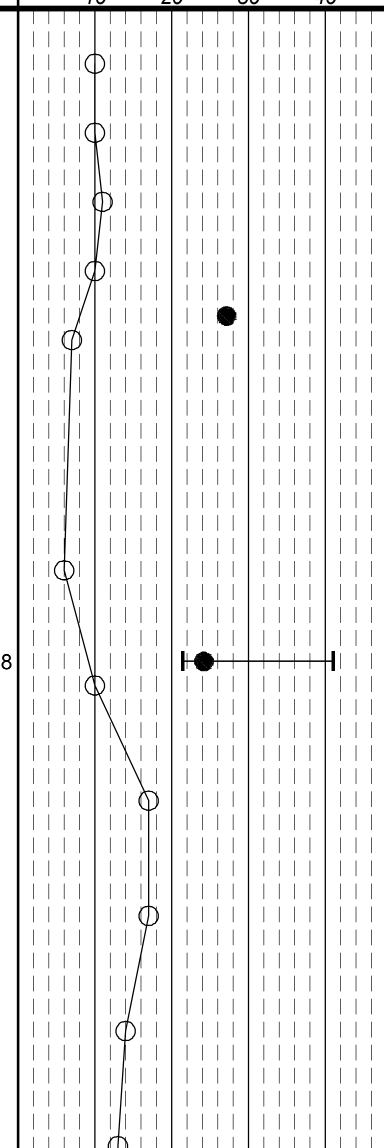
Client: OVEC-AEP	Project: Kyger Creek - Ash Impoundment Stability Analysis	Job No. 1021-3003.00
LOG OF: Boring KC-1006	Location: As per plan	Date Drilled: 8/24/2010

WATER OBSERVATIONS:
Water seepage at: 38.5'-50.0'
Water level at completion: 49.0' Prior to adding water.

FIELD NOTES:

Depth (ft)	Elev. (ft) 576.4	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
0.3	576.2						Aggregate - 3"						
1.5	574.9	6 4 4	18	S-1			FILL: Medium dense dark gray to black SAND with silt with gravel (SP-SM); contains cinders; moist.						
		3 4 4	13	S-2		1.5	FILL: Stiff to very stiff mottled brown and gray LEAN CLAY with sand (CL); damp to moist.						
		3 3 6	12	S-3		2.75							
5		2 2 6	18	S-4		2.5							
		2 2 4	6	S-5		1.0							
10					ST-1								
		WOH 2 3	18	S-6		2.5							
13.0	563.4												
15		2 3 5	18	S-7		2.5	FILL: Very stiff mottled brown and gray LEAN CLAY (CL), trace fine to medium sand; moist.	0	0	2	8	42	48
16.0	560.4	3 6 8	18	S-8		3.75	POSSIBLE FILL: Very stiff brown LEAN CLAY with sand (CL); damp to moist.						
18.5	557.9												
20		3 6 8	18	S-9		4.5+	POSSIBLE FILL: Hard brown LEAN CLAY (CL); contains cinders; damp.						
21.0	555.4	5 5 7	18	S-10		2.5	Stiff to very stiff mottled brown and gray LEAN CLAY with sand (CL); damp.						
25	551.4	3 5 6	18	S-11		1.5							

STANDARD PENETRATION (N60)
Natural Moisture Content, % - ●
PL ⊢—⊣ LL
Blows per foot - ○ / Non-Plastic - NP



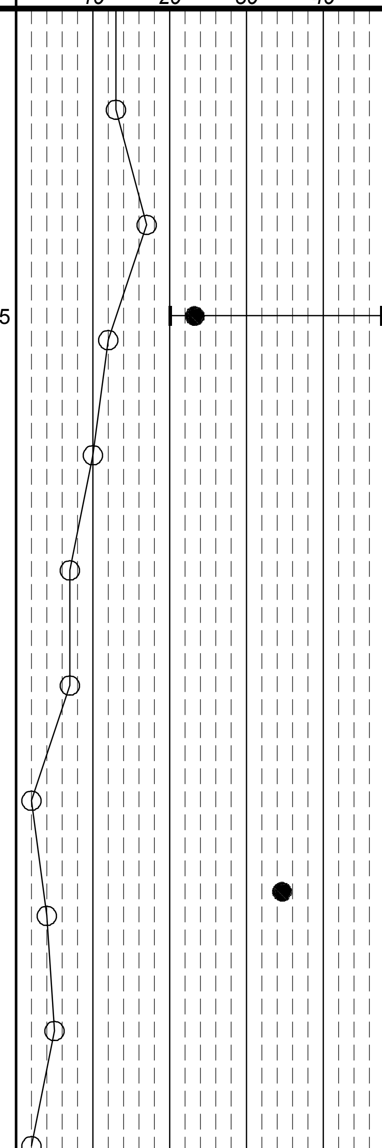
Client: OVEC-AEP | *Project:* Kyger Creek - Ash Impoundment Stability Analysis | *Job No.* 1021-3003.00

LOG OF: Boring KC-1006 | *Location:* As per plan | *Date Drilled:* 8/24/2010

WATER OBSERVATIONS:
Water seepage at: 38.5'-50.0'
Water level at completion: 49.0' Prior to adding water.
FIELD NOTES:

Depth (ft)	Elev. (ft) 551.4	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	Graphic Log	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
		2 4 7	18	S-12		3.5	Stiff to very stiff mottled brown and gray LEAN CLAY with sand (CL); damp.							
30		4 6 8	18	S-13		2.75	@ 28.0'-31.0', brown.							
		4 5 5	18	S-14		1.5			0	0	2	18	45	35
35		2 4 4	18	S-15		1.5								
		1 2 4	18	S-16		0.75	@ 36.0'-38.5', medium stiff, gray.							
38.5	537.9													
40		WOH 3 3	18	S-17		0.75	Medium stiff gray sandy LEAN CLAY (CL); contains moist to wet sandy silt seams up to 1" in thickness; moist to wet.							
		WOH 1 1	18	S-18		0.5								
45		WOH 1 2	18	S-19		0.75								
		WOH 1 3	18	S-20		0.75								
50.0 (50)	526.4	WOH WOH 2	3	S-21		0.5	Bottom of Boring - 50.0'							

STANDARD PENETRATION (N60)
Natural Moisture Content, % - ●
PL ├──┤ LL
Blows per foot - ○ / Non-Plastic - NP



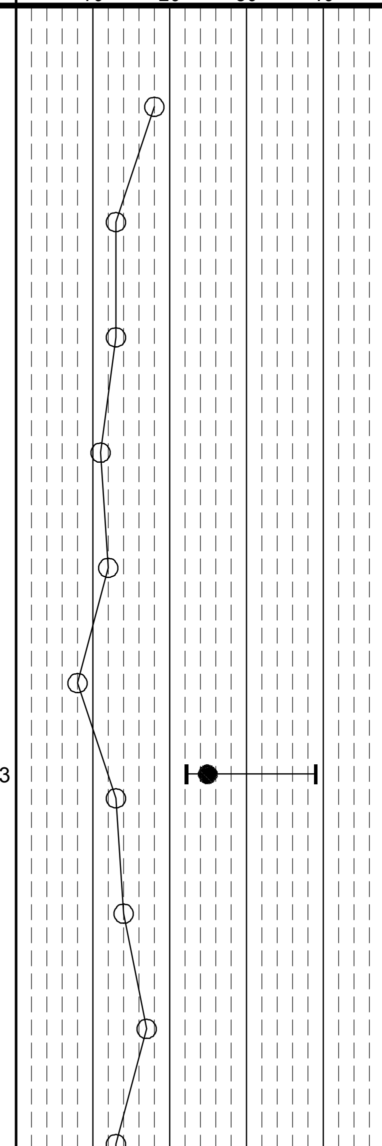
Client: OVEC-AEP | Project: Kyger Creek - Ash Impoundment Stability Analysis | Job No. 1021-3003.00

LOG OF: Boring KC-1007 | Location: As per plan | Date Drilled: 8/16/2010 to 8/17/2010

WATER OBSERVATIONS:
Water seepage at: 53.5'-65.0'
Water level at completion: 49.0' Prior to adding water.
27.4' Final including drilling water.

FIELD NOTES:
Sealed borehole with bentonite grout.
Installed piezometer in offset boring.

Depth (ft)	Elev. (ft) 589.0	Blows per 6"	Recovery	Sample No. (Drive)	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
0.2	588.8					2" GRAVEL						
		4 7 8	1	S-1		FILL: Very stiff brown and gray LEAN CLAY with sand (CL); damp to moist.						
		4 5 6	18	S-2	3.5							
		3 5 6	10	S-3	3.5							
8.5	580.5	3 3 6	18	S-4	3.25	FILL: Very stiff brown LEAN CLAY (CL), trace sand; damp to moist.						
		3 5 5	18	S-5	4.0							
13.5	575.5	3 3 4	18	S-6	3.0	FILL: Very stiff light brown and gray LEAN CLAY (CL), trace sand; damp to moist. @15.0'-17.5', little fine to medium sand.						
		3 5 6	18	S-7	3.0		0	0	3	10	44	43
		4 5 7	18	S-8	2.5							
		5 5 9	18	S-9	2.5							
25	564.0	5 5 6	18	S-10	3.0							



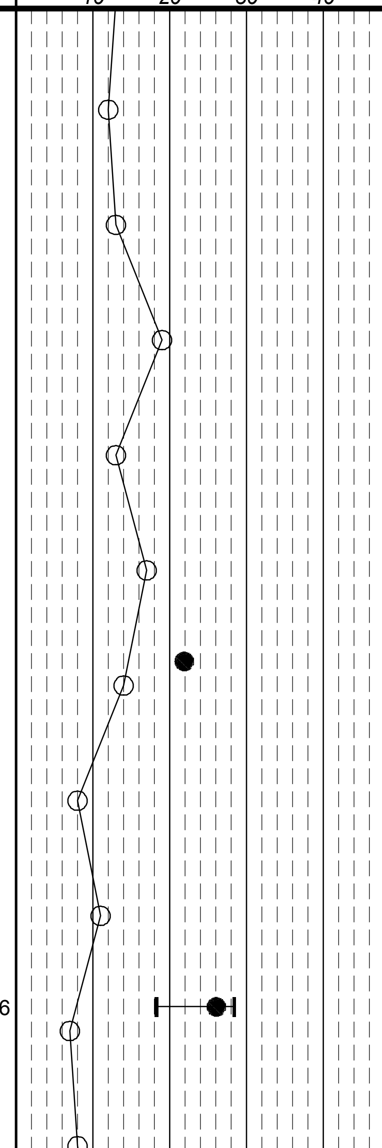
Client: OVEC-AEP	Project: Kyger Creek - Ash Impoundment Stability Analysis	Job No. 1021-3003.00
LOG OF: Boring KC-1007	Location: As per plan	Date Drilled: 8/16/2010 to 8/17/2010

WATER OBSERVATIONS:
Water seepage at: 53.5'-65.0'
Water level at completion: 49.0' Prior to adding water.
27.4' Final including drilling water.

FIELD NOTES:
Sealed borehole with bentonite grout.
Installed piezometer in offset boring.

Depth (ft)	Elev. (ft) 564.0	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	Graphic Log	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
		4 5 5	18	S-11		2.0	FILL: Very stiff light brown and gray LEAN CLAY (CL), trace sand; damp to moist. @ 26.0'-27.5' gray, trace organics							
28.5	560.5													
		3 4 7	18	S-12		1.5	Stiff brown and gray LEAN CLAY with sand (CL); moist.							
31.0	558.0													
		3 7 9	18	S-13		4.5+	Hard gray LEAN CLAY (CL), trace sand; trace organics; moist.							
33.5	555.5													
		3 5 6	18	S-14		3.75	Very stiff brown and gray LEAN CLAY (CL), trace sand; moist.							
		3 6 8	18	S-15		3.5								
38.5	550.5													
		4 6 6	18	S-16		2.5	Very stiff brown and gray LEAN CLAY with sand (CL); moist.							
		1 3 4	18	S-17		2.5								
43.5	545.5													
		2 4 5	18	S-18		2.0	Medium stiff brown and gray sandy LEAN CLAY (CL); moist.							
45.5	543.5													
		2 3 3	18	S-19		0.5	Soft to medium stiff brown and gray LEAN CLAY with sand (CL); moist.		0	0	0	22	52	26
48.0	541.0													
		2 3 4	18	S-20		1.5	Medium stiff brown and gray sandy LEAN CLAY (CL); moist.							
50	*539.0*													

STANDARD PENETRATION (N60)
Natural Moisture Content, % - ●
PL ⊢—⊣ LL
Blows per foot - ○ / Non-Plastic - NP



Client: OVEC-AEP | *Project:* Kyger Creek - Ash Impoundment Stability Analysis | *Job No.* 1021-3003.00

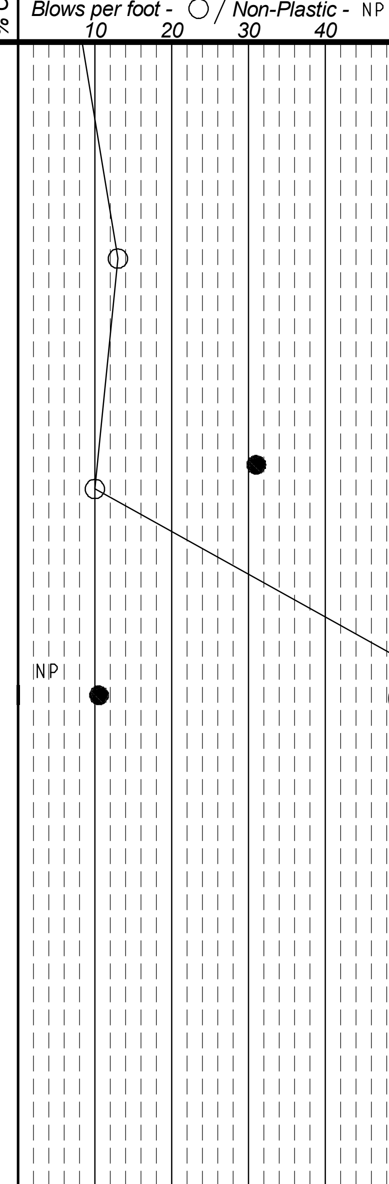
LOG OF: Boring KC-1007 | *Location:* As per plan | *Date Drilled:* 8/16/2010 to 8/17/2010

WATER OBSERVATIONS:
Water seepage at: *53.5'-65.0'*
Water level at completion: *49.0' Prior to adding water.*
27.4' Final including drilling water.

FIELD NOTES:
Sealed borehole with bentonite grout.
Installed piezometer in offset boring.

Depth (ft)	Elev. (ft) 539.0	Blows per 6"	Recovery	Sample No. Drive	Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
							Stiff brown and gray sandy LEAN CLAY (CL); moist.						
				S-21B			@ 53.0' gray, trace shells						
54.5	534.5	2 4 7	18	S-21A		1.5							
55							Medium dense gray silty SAND (SM); moist.						
57.0	532.0						Stiff gray sandy LEAN CLAY (CL); moist.						
60		3 4 4	18	S-22		1.5	@ 58.5'-60.0' wet silty sand lenses < 1"						
63.0	526.0						Very dense brown SAND with silt with gravel (SW-SM); moist to wet.						
65.0	524.0	17 31 22	10	S-23			@ 63.5', encountered 3 feet of sand heave after pulling drill rod.	33	19	20	19	--9--	
							Bottom of Boring - 65.0'						
70													
75													

STANDARD PENETRATION (N60)
Natural Moisture Content, % - ●
PL ⊢—⊣ LL
Blows per foot - ○ / Non-Plastic - NP



Client: OVEC-AEP | **Project:** Kyger Creek - Ash Impoundment Stability Analysis | **Job No.** 1021-3003.00

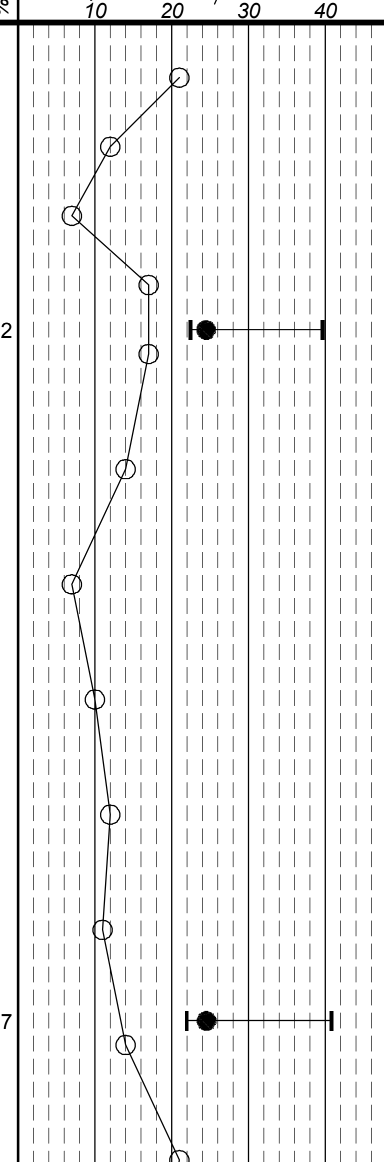
LOG OF: Boring KC-1008 | **Location:** As per plan | **Date Drilled:** 8/24/2010

WATER OBSERVATIONS:
Water seepage at: 35.5'-40.0'
Water level at completion: NFW

FIELD NOTES:

Depth (ft)	Elev. (ft) 580.9	Blows per 6"	Recovery	Sample No. Drive	Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
0.2	580.7	7 6 11	18	S-1			Aggregate - 2"						
1.5	579.4						FILL: Medium stiff dark gray to black silty, clayey GRAVEL with sand (GC-GM); contains cinders; damp.						
3.0	577.9	10 7 3	13	S-2			FILL: Medium dense dark gray to black SAND with silt with gravel (SP-SM); contains cinders; moist.						
		2 3 3	8	S-3		1.5	FILL: Stiff to very stiff brown sandy LEAN CLAY (CL); damp to moist.						
5		3 6 8	18	S-4		3.5							
		4 7 7	18	S-5		3.5	@6.0'-7.5', trace sand; moist.	0	0	0	5	53	42
		3 4 8	18	S-6		2.5							
10													
		1 3 3	18	S-7		1.25							
13.5	567.4												
		3 4 4	18	S-8		1.5	FILL: Stiff gray LEAN CLAY (CL); moist.						
15													
16.0	564.9												
		2 4 6	18	S-9		2.5	FILL: Very stiff brown LEAN CLAY (CL); damp to moist.						
		2 4 5	18	S-10		2.25							
20													
21.0	559.9												
		4 6 6	18	S-11		3.5	Very stiff brown LEAN CLAY (CL), trace fine to medium sand; damp to moist	0	0	1	5	47	47
		4 8 9	18	S-12		4.0	@ 23.5', brownish gray.						
25	555.9												

STANDARD PENETRATION (N60)
Natural Moisture Content, % - ●
PL ⊢—⊣ LL
Blows per foot - ○ / Non-Plastic - NP



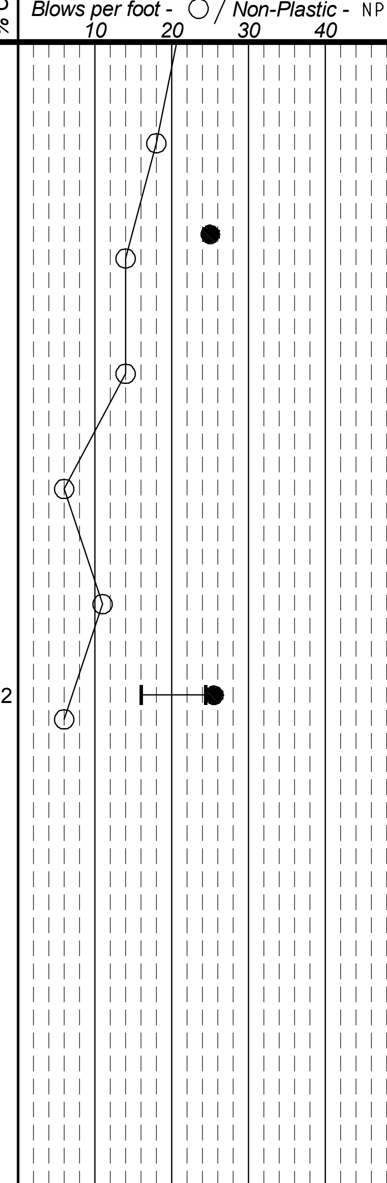
Client: OVEC-AEP | *Project:* Kyger Creek - Ash Impoundment Stability Analysis | *Job No.* 1021-3003.00

LOG OF: Boring KC-1008 | *Location:* As per plan | *Date Drilled:* 8/24/2010

WATER OBSERVATIONS:
Water seepage at: 35.5'-40.0'
Water level at completion: NFW
FIELD NOTES:

Depth (ft)	Elev. (ft) 555.9	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	Graphic Log	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
25.5	555.4						Very stiff brown LEAN CLAY (CL); damp to moist.							
		6 7 8	18	S-13		4.5+	@ 26.0'-28.5', hard.							
30		2 5 7	18	S-14		3.5								
		4 5 7	18	S-15		3.5								
33.5	547.4						Stiff brown sandy LEAN CLAY (CL); moist.							
35		2 2 3	18	S-16		1.25								
36.0	544.9						Medium stiff brown sandy LEAN CLAY (CL); contains moist to wet sandy silt seams; moist to wet.							
		3 4 5	18	S-17		0.5								
40.0	540.9	1 2 3	18	S-18		0.5			0	0	0	35	43	22
							Bottom of Boring - 40.0'							
45														
50														

STANDARD PENETRATION (N60)
Natural Moisture Content, % - ●
PL ├──┤ LL
Blows per foot - ○ / Non-Plastic - NP

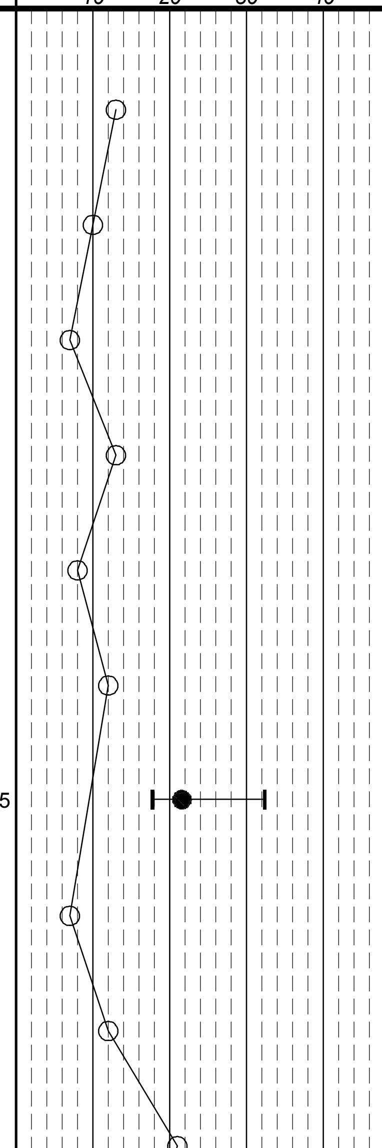


Client: OVEC-AEP	*Project:* Kyger Creek - Ash Impoundment Stability Analysis	*Job No.* 1021-3003.00
LOG OF: Boring KC-1009	*Location:* As per plan	*Date Drilled:* 8/19/2010 to 8/20/2010

WATER OBSERVATIONS:
Water seepage at: 43.5'-65.0'
Water level at completion: 47.0' Prior to adding water.
38.2' Final including drilling water.

FIELD NOTES:
Sealed borehole with bentonite grout.
Began adding drilling water at 50' to counteract heave.

Depth (ft)	Elev. (ft) 589.2	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
0.2	589.0						2" GRAVEL						
		3, 5, 6	18	S-1		4.5+	FILL: Hard dark brown LEAN CLAY (CL), trace sand, trace organics; damp to moist.						
5		4, 4, 4	18	S-2		4.5+							
		2, 2, 4	18	S-3		2.0	@6.0'-8.5', stiff to very stiff.						
8.5	580.7						FILL: Very stiff brown LEAN CLAY with sand (CL), trace gravel; moist.						
10		2, 4, 7	7	S-4		2.25							
11.0	578.2						FILL: Very stiff to hard brown and gray LEAN CLAY (CL), trace sand; moist.						
		4, 5, 2	18	S-5		4.5+							
15		1, 4, 6	10	S-6		3.5							
16.0	573.2						FILL: Very stiff brown LEAN CLAY with sand (CL); moist.						
					ST-1	2.25		0	0	1	28	36	35
20		1, 2, 4	18	S-7		2.5							
		2, 3, 7	18	S-8		2.5							
23.5	565.7						FILL: Hard brown and gray LEAN CLAY (CL), trace sand; damp to moist.						
25	564.2	4, 6, 11	18	S-9		4.5+							



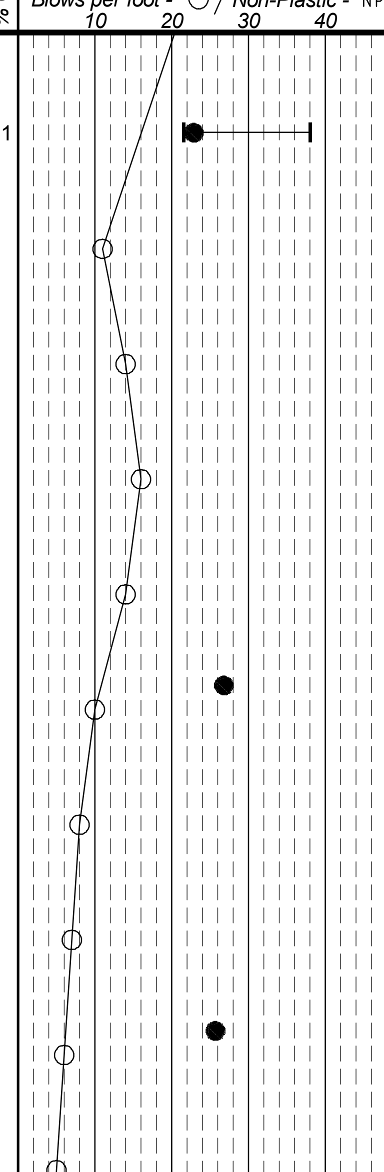
Client: OVEC-AEP	Project: Kyger Creek - Ash Impoundment Stability Analysis	Job No. 1021-3003.00
LOG OF: Boring KC-1009	Location: As per plan	Date Drilled: 8/19/2010 to 8/20/2010

WATER OBSERVATIONS:
Water seepage at: 43.5'-65.0'
Water level at completion: 47.0' Prior to adding water.
38.2' Final including drilling water.

FIELD NOTES:
Sealed borehole with bentonite grout.
Began adding drilling water at 50' to counteract heave.

Depth (ft)	Elev. (ft) 564.2	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
					ST-2	4.0	FILL: Very stiff brown and gray LEAN CLAY (CL), trace sand; damp to moist.	0	0	1	6	52	41
28.5	560.7												
30		3 4 5	18	S-10		2.0	Very stiff brown and gray LEAN CLAY (CL), trace sand; damp to moist.						
		3 5 7	14	S-11		2.25							
35		3 5 8	18	S-12		2.0	@ 34.0' trace organics						
36.0	553.2												
		2 5 7	18	S-13		2.0	Stiff brown LEAN CLAY (CL), trace sand; moist to wet.						
40		2 3 5	18	S-14		1.0							
		WOH 3 4	18	S-15		1.0							
43.0	546.2												
45		WOH 3 3	18	S-16		1.25	Medium stiff brown sandy LEAN CLAY (CL); contains small silty sand layers; moist to wet.						
		WOH 1 4	18	S-17		0.75							
48.5	540.7												
50	539.2	WOH 1 3	18	S-18		1.0	Stiff brown LEAN CLAY with sand (CL); wet.						

STANDARD PENETRATION (N60)
Natural Moisture Content, % - ●
PL ⊢—⊣ LL
Blows per foot - ○ / Non-Plastic - NP



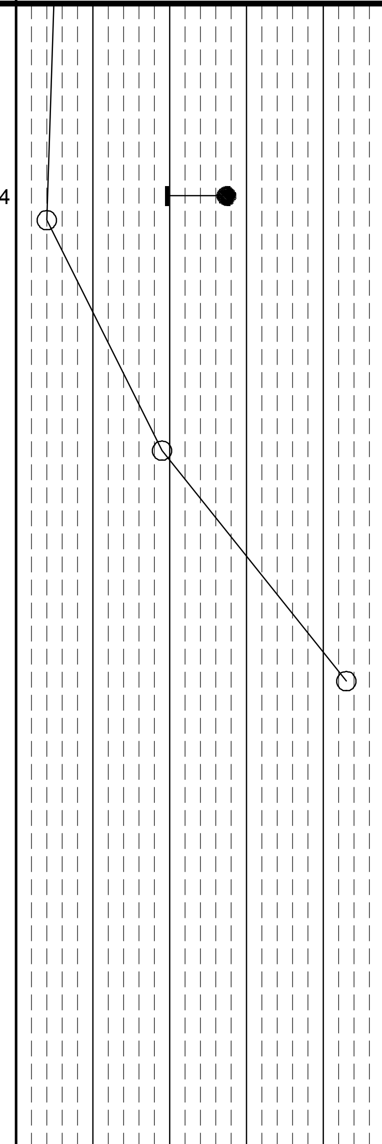
Client: OVEC-AEP | *Project:* Kyger Creek - Ash Impoundment Stability Analysis | *Job No.* 1021-3003.00

LOG OF: Boring KC-1009 | *Location:* As per plan | *Date Drilled:* 8/19/2010 to 8/20/2010

WATER OBSERVATIONS:
Water seepage at: 43.5'-65.0'
Water level at completion: 47.0' Prior to adding water.
38.2' Final including drilling water.

FIELD NOTES:
Sealed borehole with bentonite grout.
Began adding drilling water at 50' to counteract heave.

Depth (ft)	Elev. (ft) 539.2	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	Graphic Log	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
							Stiff brown LEAN CLAY with sand (CL); contains small silty sand layers; wet.							
53.5	535.7	WOH 1 2	18	S-19		0.5	Medium stiff brown and gray sandy LEAN CLAY (CL); contains small wet silty sand layers; wet.		0	0	0	31	45	24
		WOH 2 14	18	S-20		1.0								
61.0	528.2	20 19 17	12	S-21			Dense brown SAND with silt with gravel (SW-SM); wet.							
65.0	524.2						Bottom of Boring - 65.0'							



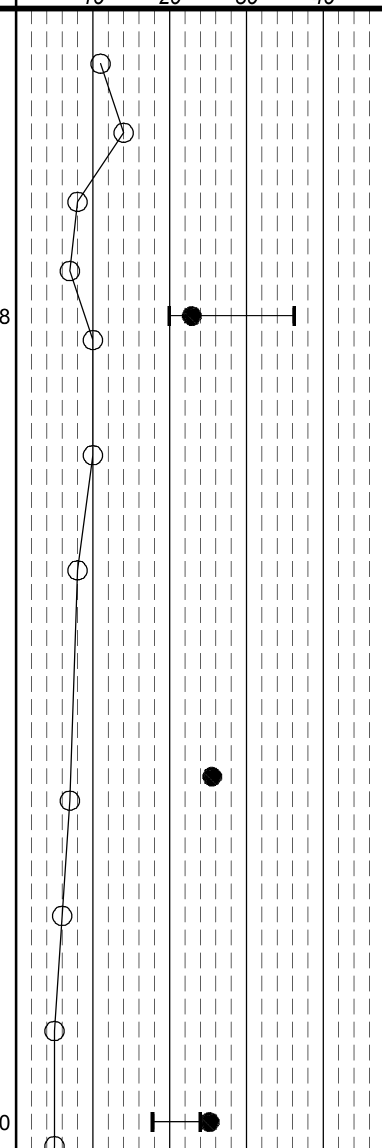
Client: OVEC-AEP	*Project:* Kyger Creek - Ash Impoundment Stability Analysis	*Job No.* 1021-3003.00
LOG OF: Boring KC-1010	*Location:* As per plan	*Date Drilled:* 9/10/2010

WATER OBSERVATIONS:
Water seepage at: *21.0'-45.0'*
Water level at completion: *32.8' Prior to adding water.*
21' Final including drilling water.

FIELD NOTES:
Sealed borehole with bentonite grout.
Began adding drilling water at 37.5' to counteract heave.

Depth (ft)	Elev. (ft) 565.1	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
0.3	564.9	2 / 4 / 5	7	S-1		3.5	Topsoil - 3"						
							FILL: Stiff to very stiff brown LEAN CLAY with sand (CL); damp to moist.						
		4 / 6 / 6	12	S-2		3.0							
3.0	562.1	3 / 3 / 4	18	S-3		1.5	FILL: Stiff to very stiff brown LEAN CLAY with sand (CL); damp to moist.						
5		1 / 3 / 3	4	S-4		1.5							
6.0	559.1	2 / 4 / 4	10	S-5		1.75	Stiff to very stiff brown LEAN CLAY with sand (CL); damp to moist. @6.0'-7.5', trace sand; moist.	0	0	0	4	58	38
10		2 / 3 / 5	11	S-6		1.75							
		2 / 3 / 4	18	S-7		1.25							
15					ST-1								
		1 / 3 / 3	18	S-8		1.5							
18.5	546.6	1 / 2 / 3	18	S-9		0.75	Soft to medium stiff brown sandy LEAN CLAY (CL); contains moist to wet sandy silt seams; moist to wet.						
20		1 / 2 / 2	18	S-10		0.5							
25	540.1	1 / 2 / 2	18	S-11		0.5		0	0	0	44	35	20

STANDARD PENETRATION (N60)
Natural Moisture Content, % - ●
PL ⊢—⊣ LL
Blows per foot - ○ / Non-Plastic - NP
10 20 30 40



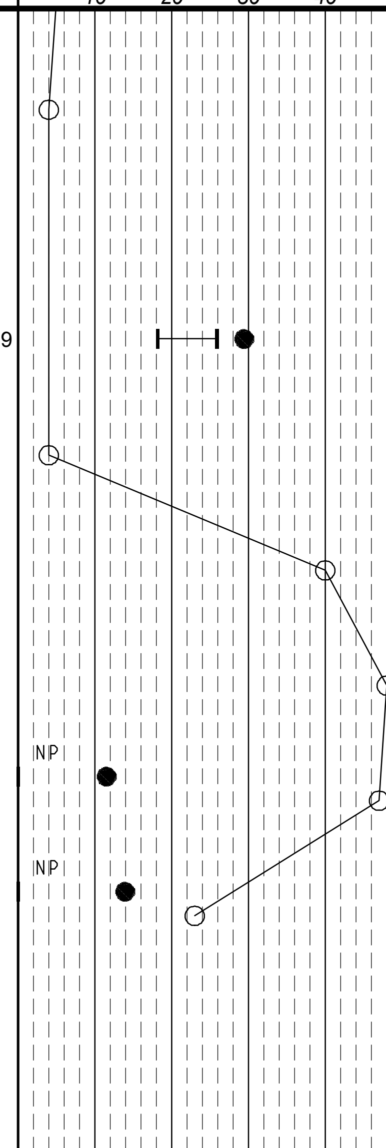
Client: OVEC-AEP	Project: Kyger Creek - Ash Impoundment Stability Analysis	Job No. 1021-3003.00
LOG OF: Boring KC-1010	Location: As per plan	Date Drilled: 9/10/2010

WATER OBSERVATIONS:
Water seepage at: 21.0'-45.0'
Water level at completion: 32.8' Prior to adding water.
21' Final including drilling water.

FIELD NOTES:
Sealed borehole with bentonite grout.
Began adding drilling water at 37.5' to counteract heave.

Depth (ft)	Elev. (ft) 540.1	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
							Soft to medium stiff brown sandy LEAN CLAY (CL); contains moist to wet sandy silt seams; moist to wet.						
		WOH 1 2	18	S-12		<0.25	@26.0'-28.0', very soft.						
							@ 28.5'-30.0', Shelby tube press attempted, insuffecent recovery.						
30						0.75							
					ST-2			0	0	0	31	50	19
		WOH 1 2	18	S-13		0.5	@ 33.5'-36.0', gray.						
35													
36.0	529.1												
		9 15 18	8	S-14			Dense gray GRAVEL with silt with sand (GW-GM); wet.						
		9 17 23	10	S-15									
40													
41.0	524.1	8 19 20	16	S-16			Dense gray GRAVEL (GW) with sand, trace silt; wet.	54	12	21	10	--3--	
43.5	521.6	7 9 10	5	S-17			Medium dense gray SAND with silt with gravel (SW-SM); wet.	23	15	41	14	--7--	
45.0 (45)	520.1						Bottom of Boring - 45.0'						
50													

STANDARD PENETRATION (N60)
Natural Moisture Content, % - ●
PL LL
Blows per foot - ○ / Non-Plastic - NP

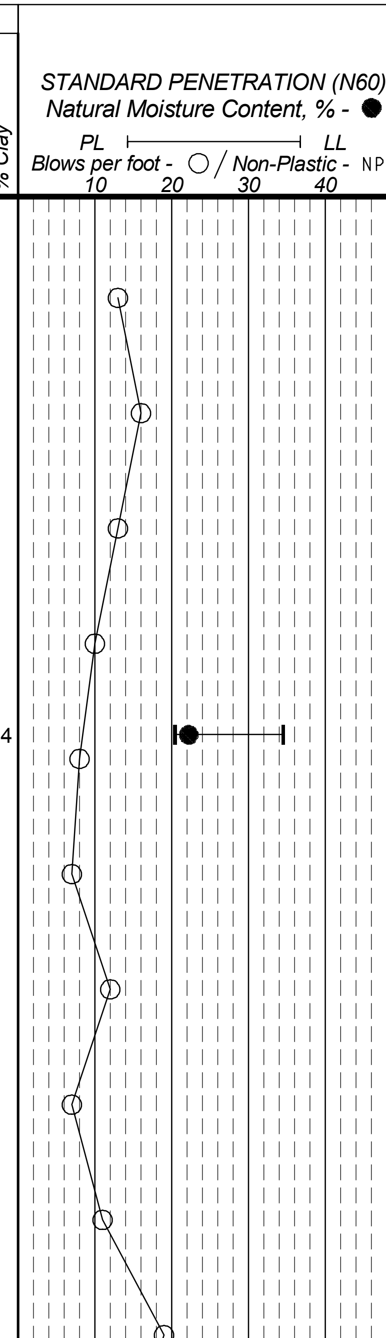


Client: OVEC-AEP | Project: Kyger Creek - Ash Impoundment Stability Analysis | Job No. 1021-3003.00

LOG OF: Boring KC-1011 | Location: As per plan | Date Drilled: 8/20/2010 to 8/23/2010

WATER OBSERVATIONS:
Water seepage at: 43.5'-70.0'
Water level at completion: 49.5' Prior to adding water.
FIELD NOTES:

Depth (ft)	Elev. (ft) 589.2	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
0.3	589.0						Aggregate - 3"						
		4 5 6	18	S-1		4.5+	FILL: Hard brown LEAN CLAY with sand (CL); damp.						
5		5 6 7	11	S-2		4.5+							
6.0	583.2	5 5 6	18	S-3		4.0	FILL: Very stiff brown LEAN CLAY (CL); damp.						
10		3 4 4	18	S-4		3.5							
		3 3 4	18	S-5		2.0	@ 11.0'-16.0', stiff, little fine sand; moist.	0	0	0	11	55	34
15		1 3 3	16	S-6		1.0							
		1 3 7	18	S-7		4.5+	@ 16.0', hard.						
18.5	570.7	1 3 3	18	S-8		2.75	FILL: Very stiff brown LEAN CLAY with sand (CL); damp to moist.						
20		2 4 5	18	S-9		3.0							
23.5	565.7	6 7 9	18	S-10		3.5	FILL: Very stiff brownish gray LEAN CLAY (CL); damp.						
25	564.2												

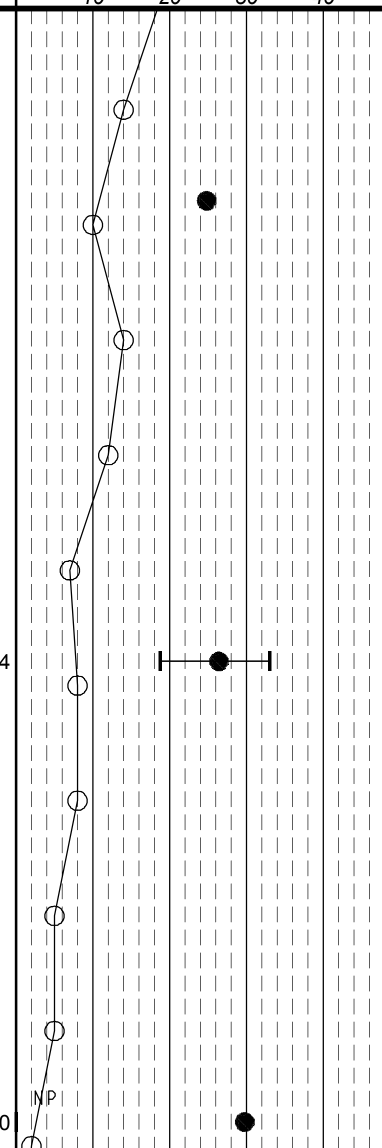


Client: OVEC-AEP	Project: Kyger Creek - Ash Impoundment Stability Analysis	Job No. 1021-3003.00
LOG OF: Boring KC-1011	Location: As per plan	Date Drilled: 8/20/2010 to 8/23/2010

WATER OBSERVATIONS:
Water seepage at: 43.5'-70.0'
Water level at completion: 49.5' Prior to adding water.
FIELD NOTES:

Depth (ft)	Elev. (ft) 564.2	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	Graphic Log	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
26.0	563.2	4 6 6	18	S-11		2.5	FILL: Very stiff gray LEAN CLAY with sand (CL); damp.							
28.5	560.7	2 2 6	18	S-12		2.5	Very stiff brown LEAN CLAY (CL); damp to moist.							
30		3 5 7	18	S-13		2.25								
33.5	555.7	2 4 6	18	S-14		1.75	Stiff brown LEAN CLAY with sand (CL); damp to moist.							
35		1 3 3	18	S-15		1.0								
		WOH 3 4	18	S-16		1.25			0	0	0	15	51	34
40		WOH 3 4	18	S-17		1.0								
43.5	545.7	WOH 2 2	18	S-18		0.5	Soft brownish gray sandy LEAN CLAY (CL); contains moist to wet sandy silt seams; moist to wet.							
45		WOH 1 3	18	S-19		0.25								
48.5	540.7	WOH WOH 2	18	S-20			Very loose gray sandy SILT (ML); moist to wet.		0	0	0	42	38	20
50	539.2													

STANDARD PENETRATION (N60)
Natural Moisture Content, % - ●
PL ├──┤ LL
Blows per foot - ○ / Non-Plastic - NP



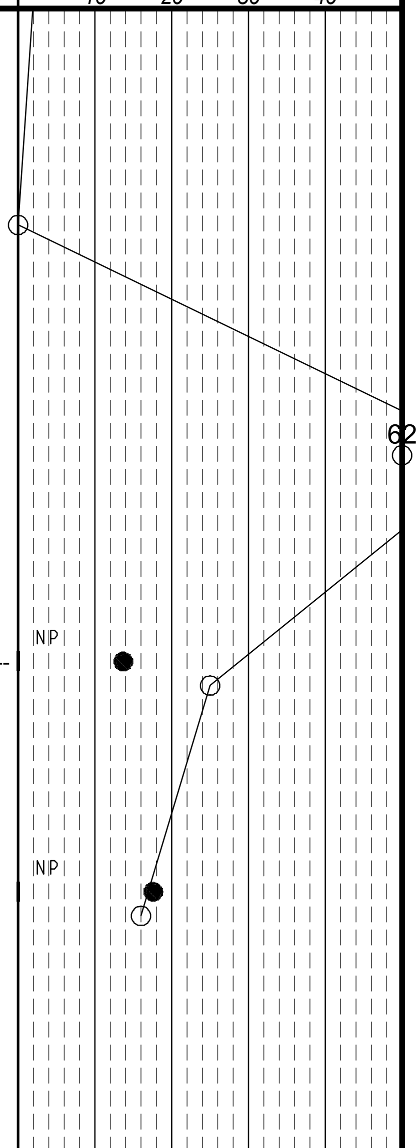
DLZ Ohio, Inc. * 6121 Huntley Road, Columbus, Ohio 43229 * (614) 888-0040

Client: OVEC-AEP	Project: Kyger Creek - Ash Impoundment Stability Analysis	Job No. 1021-3003.00
LOG OF: Boring KC-1011	Location: As per plan	Date Drilled: 8/20/2010 to 8/23/2010

WATER OBSERVATIONS:
Water seepage at: 43.5'-70.0'
Water level at completion: 49.5' Prior to adding water.
FIELD NOTES:

Depth (ft)	Elev. (ft) 539.2	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	Graphic Log	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
50.5	538.7						Soft brownish gray sandy LEAN CLAY (CL); contains moist to wet sandy silt seams; moist to wet.							
53.5	535.7	WOH WOH WOH	18	S-21		<0.25	Very soft brown LEAN CLAY (CL); damp to moist.							
58.5	530.7	23 28 23	7	S-22			Medium dense to very dense brown SAND with silt with gravel (SW-SM); wet. @58.5'-60.0', very dense.							
		9 10 11	10	S-23					20	10	36	22	--12--	
68.5	520.7	4 7 6	7	S-24			Medium dense brown SAND with silt with gravel (SP-SM); wet.		15	3	28	48	--6--	
70.0	519.2						Bottom of Boring - 70.0'							

STANDARD PENETRATION (N60)
Natural Moisture Content, % - ●
PL ⊢—⊣ LL
Blows per foot - ○ / Non-Plastic - NP



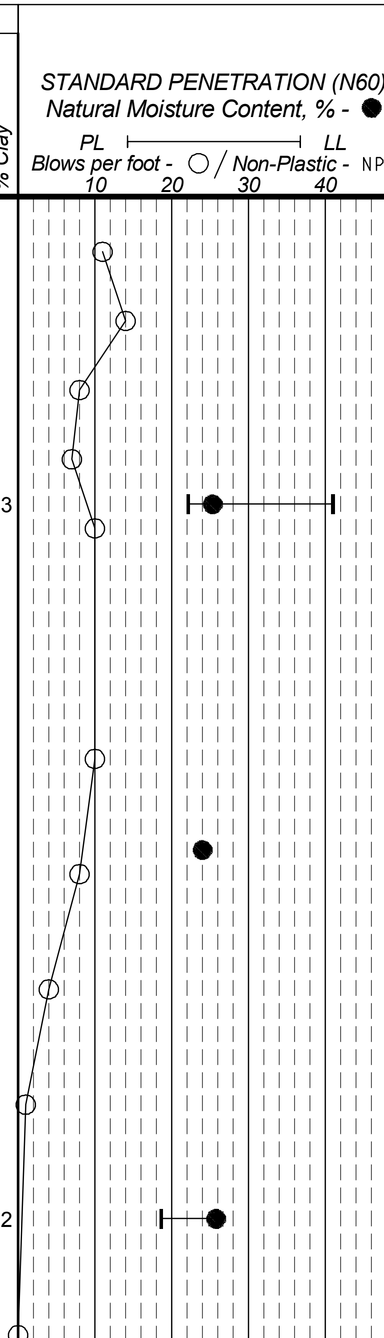
Client: OVEC-AEP | Project: Kyger Creek - Ash Impoundment Stability Analysis | Job No. 1021-3003.00

LOG OF: Boring KC-1012 | Location: As per plan | Date Drilled: 9/9/2010

WATER OBSERVATIONS:
Water seepage at: 16.0'-40.0'
Water level at completion: 21.9' Prior to adding water.
7.6' Final including drilling water.

FIELD NOTES:
Sealed borehole with bentonite grout.
Installed piezometer in offset boring.

Depth (ft)	Elev. (ft) 563.0	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
0.3	562.7	2 4 5	18	S-1		0.25	Topsoil - 4"						
1.5	561.5						FILL: Soft brown LEAN CLAY with sand (CL); wet.						
		4 6 6	18	S-2		1.5	Stiff to very stiff brown LEAN CLAY with sand (CL); moist.						
		3 3 4	12	S-3		2.5							
5		1 3 3	18	S-4		2.25	@ 4.5', damp.						
		2 4 4	18	S-5		2	@6.0'-7.5', trace sand; moist.	0	0	0	1	56	43
10					ST-1								
		2 3 5	18	S-6		1.75							
15		2 3 4	18	S-7		2							
16.0	547.0	1 1 2	18	S-8		0.25	Very soft to soft to brown sandy LEAN CLAY (CL); contains moist to wet sandy silt seams; moist to wet.						
20		WOH WOH 1	18	S-9		0.5							
					ST-2			0	0	0	35	43	22
25	538.0	WOH WOH WOH	18	S-10		0.25	@ 23.6'-26.0', gray.						



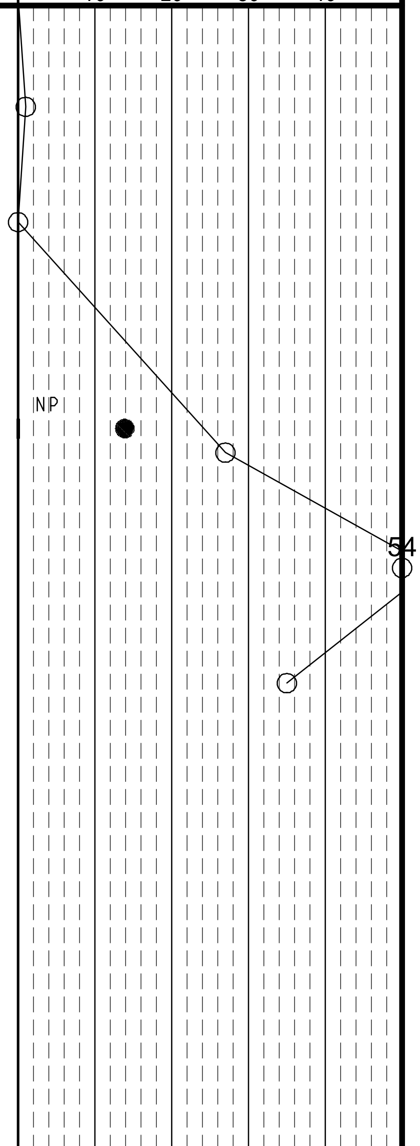
Client: OVEC-AEP	Project: Kyger Creek - Ash Impoundment Stability Analysis	Job No. 1021-3003.00
LOG OF: Boring KC-1012	Location: As per plan	Date Drilled: 9/9/2010

WATER OBSERVATIONS:
Water seepage at: 16.0'-40.0'
Water level at completion: 21.9' Prior to adding water.
7.6' Final including drilling water.

FIELD NOTES:
Sealed borehole with bentonite grout.
Installed piezometer in offset boring.

Depth (ft)	Elev. (ft) 538.0	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	Graphic Log	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
							Very soft to soft brown sandy LEAN CLAY (CL); contains moist to wet sandy silt seams; moist to wet.							
		WOH WOH 1	18	S-11		0.25								
30		WOH WOH WOH	18	S-12		<0.25								
					ST-3									
33.5	529.5						Medium dense to dense brown sandy GRAVEL (GP); wet. Began adding drilling water at 35' to counteract heave.							
35		3 8 14	10	S-13					59	16	14	7	--4--	
		8 22 23	3	S-14										
38.5	524.5						Medium dense brown SAND with gravel (SW); wet.							
40.0	523.0	8 14 15	6	S-15										
							Bottom of Boring - 40.0'							

STANDARD PENETRATION (N60)
Natural Moisture Content, % - ●
PL ├──┤ LL
Blows per foot - ○ / Non-Plastic - NP



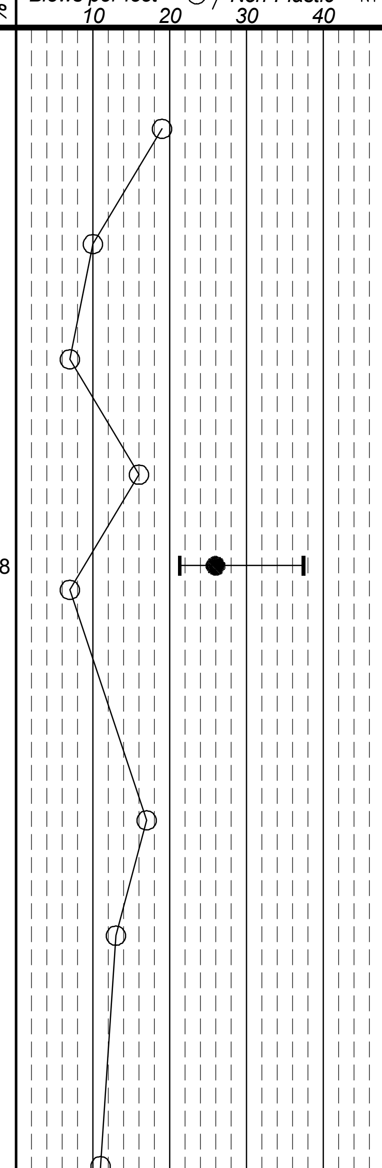
Client: OVEC-AEP | *Project:* Kyger Creek - Ash Impoundment Stability Analysis | *Job No.* 1021-3003.00

LOG OF: Boring KC-1013 | *Location:* As per plan | *Date Drilled:* 8/30/2010 to 9/1/2010

WATER OBSERVATIONS:
Water seepage at: 46.0'-60.0'
Water level at completion: 42.7' Prior to adding water.
FIELD NOTES:

Depth (ft)	Elev. (ft) 581.3	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
0.3	581.1						Aggregate - 3"						
		5 7 9	1	S-1			FILL: Very stiff brownish gray sandy LEAN CLAY (CL); damp to moist. @ 1.0'-2.5', low recovery, drove gravel.						
		4 4 4	18	S-2		3.00							
6.0	575.3	2 3 3	18	S-3		1.50	FILL: Stiff to very stiff brownish gray LEAN CLAY with sand (CL); slightly organic; damp to moist. @ 6.0'-7.5', sample contains tree root.						
		4 6 7	18	S-4		4.5+	@ 8.5'-11.0', hard.						
		3 3 3	18	S-5		3.00	@11.0'-12.5', trace gravel.	2	0	1	7	52	38
					ST-1	2.5							
16.0	565.3	5 6 8	18	S-6	ST-2	3.25	FILL: Very stiff brown sandy LEAN CLAY (CL); slightly organic; damp.						
18.5	562.8	3 5 6	18	S-7		2.50	FILL: Stiff to very stiff brownish gray to gray LEAN CLAY with sand (CL); slightly organic; damp to moist.						
25	556.3	2 4 5	18	S-8		1.00							

STANDARD PENETRATION (N60)
Natural Moisture Content, % - ●
PL —— LL
Blows per foot - ○ / Non-Plastic - NP



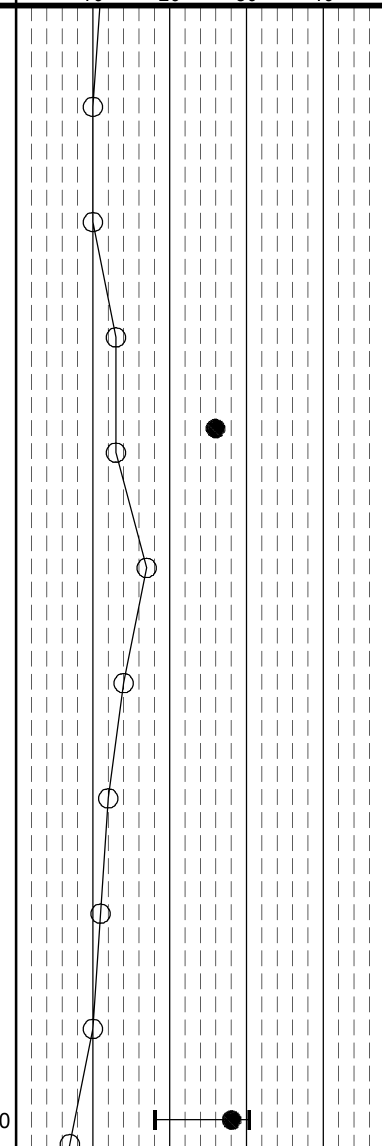
DLZ Ohio, Inc. * 6121 Huntley Road, Columbus, Ohio 43229 * (614) 888-0040

Client: OVEC-AEP | Project: Kyger Creek - Ash Impoundment Stability Analysis | Job No. 1021-3003.00

LOG OF: Boring KC-1013 | Location: As per plan | Date Drilled: 8/30/2010 to 9/1/2010

WATER OBSERVATIONS:
Water seepage at: 46.0'-60.0'
Water level at completion: 42.7' Prior to adding water.
FIELD NOTES:

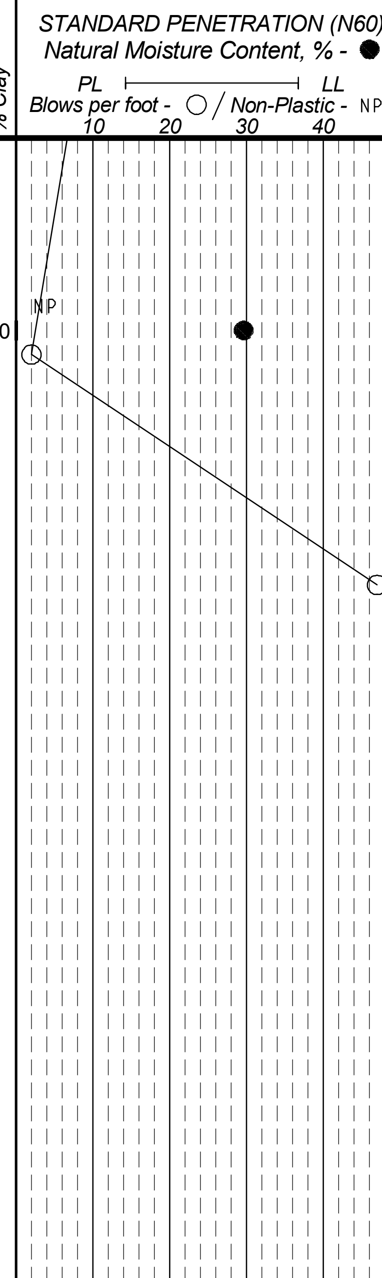
Depth (ft)	Elev. (ft) 556.3	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
							Stiff to very stiff brownish gray to gray LEAN CLAY with sand (CL); slightly organic; damp to moist.						
		3 4 4	18	S-9		1.50							
30		2 4 4	18	S-10		2.50	@ 28.5', brown, trace organic.						
		2 5 6	18	S-11		2.00							
35		4 5 6	18	S-12		1.50							
		4 6 8	18	S-13		2.00							
40		2 5 7	18	S-14		2.50							
		1 5 5	18	S-15		1.50							
45		1 4 5	18	S-16		1.50							
46.0	535.3												
		WOH 3 5	18	S-17		0.50	Soft to medium stiff brown sandy LEAN CLAY (CL); contains moist to wet sandy silt seams; moist to wet.						
50	531.3	1 3 3	18	S-18		0.75		0	0	0	23	47	30



Client: OVEC-AEP	Project: Kyger Creek - Ash Impoundment Stability Analysis	Job No. 1021-3003.00
LOG OF: Boring KC-1013	Location: As per plan	Date Drilled: 8/30/2010 to 9/1/2010

WATER OBSERVATIONS:
Water seepage at: 46.0'-60.0'
Water level at completion: 42.7' Prior to adding water.
FIELD NOTES:

Depth (ft)	Elev. (ft) 531.3	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
							Soft to medium stiff brown sandy LEAN CLAY (CL); contains moist to wet sandy silt seams; moist to wet.						
53.5	527.8	WOH 1 1	18	S-19			Very loose gray sandy SILT (ML); wet.	0	0	0	44	36	20
55					ST-3								
58.5	522.8	20 21 18	7	S-20			Dense brown GRAVEL with silt with sand (GP-GM); wet.						
60.0	521.3						Bottom of Boring - 60.0'						



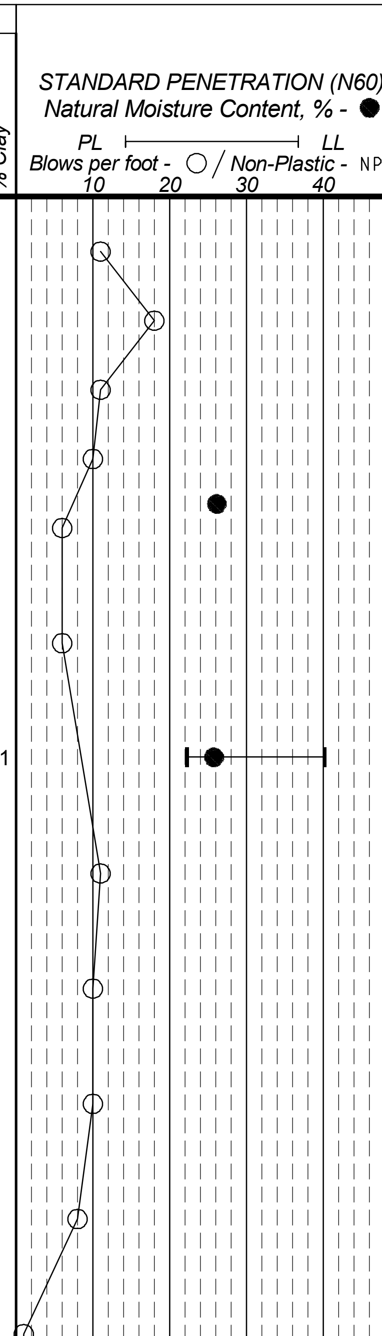
DLZ Ohio, Inc. * 6121 Huntley Road, Columbus, Ohio 43229 * (614) 888-0040

Client: OVEC-AEP | *Project:* Kyger Creek - Ash Impoundment Stability Analysis | *Job No.* 1021-3003.00

LOG OF: Boring KC-1014 | *Location:* As per plan | *Date Drilled:* 9/9/2010

WATER OBSERVATIONS:
Water seepage at: 7.5-8.5, 28.5'-40.0'
Water level at completion: 19.4' Final, no drilling water added.
FIELD NOTES: Sealed borehole with bentonite grout.

Depth (ft)	Elev. (ft) 558.6	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
0.3	558.4	2 3 6	9	S-1		3	Topsoil - 3"						
		6 6 9	18	S-2		4.5+	FILL: Very stiff to hard brown LEAN CLAY with sand (CL); damp to moist.						
3.0	555.6	3 4 5	18	S-3		2.5	Very stiff to hard brown LEAN CLAY with sand (CL); damp to moist.						
5		3 3 5	18	S-4		2.5							
		1 2 3	18	S-5		2.25							
							@7.5' - 8.5', possible seepage encountered.						
10		2 2 3	18	S-6		2	@ 8.5'-10.0', Shelby tube press attempted, drove SPT through interval.						
11.0	547.6				ST-1	2.25	Very stiff brown LEAN CLAY (CL), trace fine sand; moist.	0	0	0	2	57	41
13.0	545.6	2 4 5	18	S-7		1.75	Medium stiff to stiff brown LEAN CLAY with sand (CL); damp to moist.						
15		2 3 5	18	S-8		2							
20		2 4 4	18	S-9		2							
		1 3 4	18	S-10		2							
25	533.6	WOH WOH 1	18	S-11		0.75	@ 23.5', medium stiff, moist to wet.						



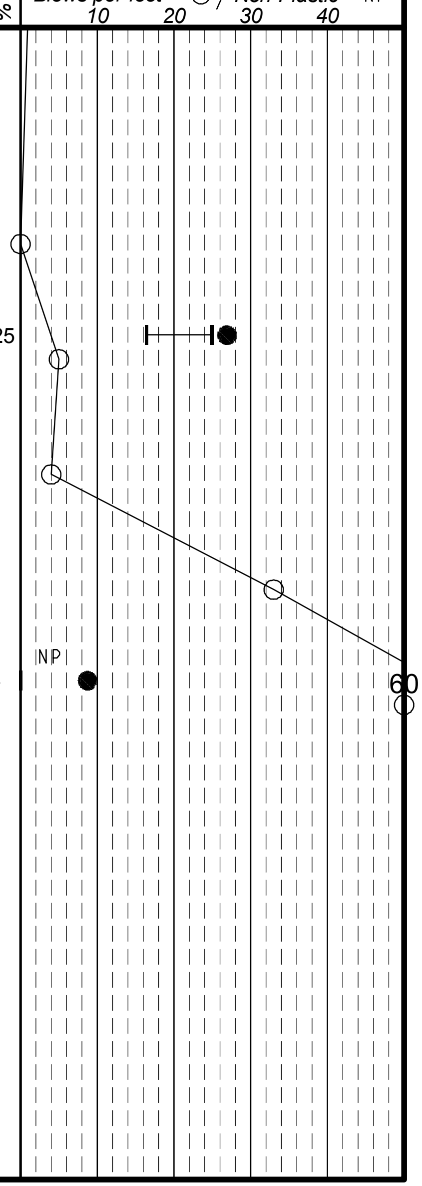
Client: OVEC-AEP | *Project:* Kyger Creek - Ash Impoundment Stability Analysis | *Job No.* 1021-3003.00

LOG OF: Boring KC-1014 | *Location:* As per plan | *Date Drilled:* 9/9/2010

WATER OBSERVATIONS:
Water seepage at: 7.5-8.5, 28.5'-40.0'
Water level at completion: 19.4' Final, no drilling water added.
FIELD NOTES: Sealed borehole with bentonite grout.

Depth (ft)	Elev. (ft) 533.6	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
26.0	532.6				ST-2		Very soft to soft brown sandy LEAN CLAY (CL); contains moist to wet sandy silt seams; moist to wet.						
		WOH WOH WOH	18	S-12		0.25							
30													
		2 2 2	18	S-13		0.25		0	0	0	32	43	25
		1 1 2	18	S-14		<0.25	@ 33.5', gray.						
35													
36.0	522.6	8 13 14	18	S-15			Medium dense to dense brownish gray GRAVEL with silt with sand (GW-GM); wet.						
40.0	518.6	14 24 26	18	S-16				52	11	19	12	--6--	
							Bottom of Boring - 40.0'						
45													
50													

STANDARD PENETRATION (N60)
Natural Moisture Content, % - ●
PL ├──┤ LL
Blows per foot - ○ / Non-Plastic - NP

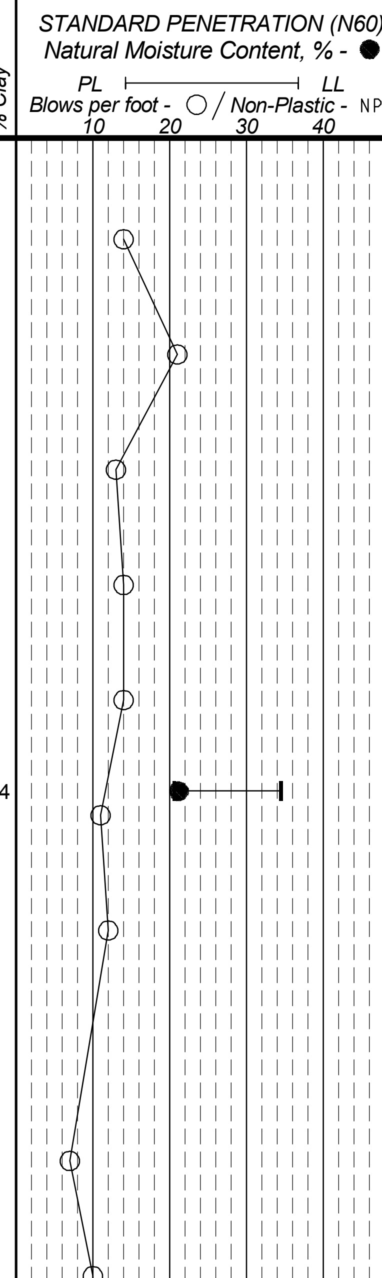


DLZ Ohio, Inc. * 6121 Huntley Road, Columbus, Ohio 43229 * (614) 888-0040

Client: OVEC-AEP	*Project:* Kyger Creek - Ash Impoundment Stability Analysis	*Job No.* 1021-3003.00
LOG OF: Boring KC-1015	*Location:* As per plan	*Date Drilled:* 8/31/2010

WATER OBSERVATIONS:
Water seepage at: 38.5'-60.0'
Water level at completion: 42.6' Prior to adding water.
FIELD NOTES:

Depth (ft)	Elev. (ft) 580.4	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
0.2	580.2						Aggregate - 2"						
		3 6 6	10	S-1		4.00	FILL: Very stiff to hard brown sandy LEAN CLAY (CL); damp.						
5		6 9 8	11	S-2		4.5+							
		4 5 6	14	S-3		2.50							
10		3 5 7	15	S-4		4.5+							
		2 5 7	18	S-5		3.00							
15		2 4 5	16	S-6		2.75	@13.5'-15.0', trace sand.	0	0	0	12	54	34
		1 4 6	18	S-7		2.00							
20					ST-1								
		2 2 4	15	S-8		3.50							
23.5	556.9												
25	555.4	2 3 5	18	S-9		3	FILL: Very stiff brownish gray LEAN CLAY with sand (CL); slightly organic; damp to moist.						



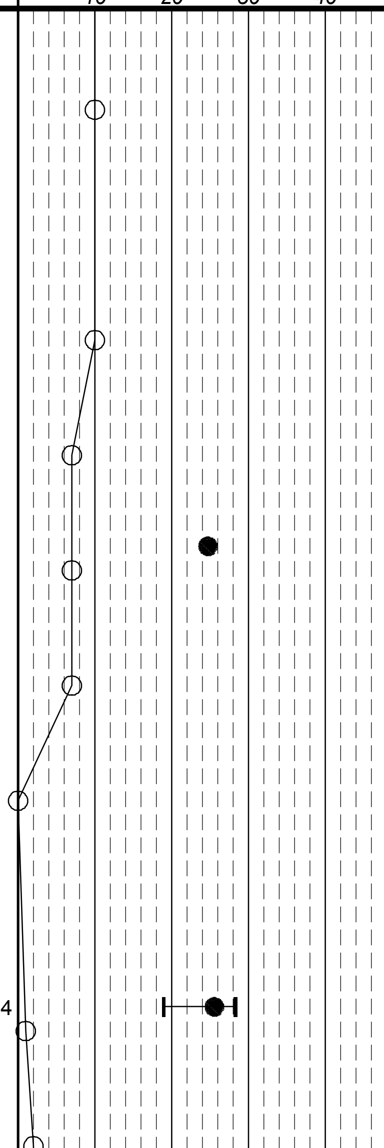
Client: OVEC-AEP | *Project:* Kyger Creek - Ash Impoundment Stability Analysis | *Job No.* 1021-3003.00

LOG OF: Boring KC-1015 | *Location:* As per plan | *Date Drilled:* 8/31/2010

WATER OBSERVATIONS:
Water seepage at: 38.5'-60.0'
Water level at completion: 42.6' Prior to adding water.
FIELD NOTES:

Depth (ft)	Elev. (ft) 555.4	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
26.0	554.4						POSSIBLE FILL: Stiff to very stiff brown LEAN CLAY with sand (CL); slightly organic; damp to moist.						
		1 4 4	18	S-10		2.50							
30					ST-2								
		2 4 4	18	S-11		2.00							
33.5	546.9						Stiff brown sandy LEAN CLAY (CL); contains moist to wet sandy silt seams; moist to wet.						
35		1 3 3	18	S-12		1.50							
		1 2 4	18	S-13		1.00							
38.5	541.9						Very soft to soft brown sandy LEAN CLAY (CL); contains moist to wet sandy silt seams; moist to wet.						
40		1 3 3	18	S-14		0.50							
		WOH WOH WOH	18	S-15		<0.25							
45					ST-3								
		WOH WOH 1	18	S-16		0.50		0	0	0	32	44	24
50	530.4	WOH 1 1	18	S-17		0.75							

STANDARD PENETRATION (N60)
Natural Moisture Content, % - ●
PL ├──┤ LL
Blows per foot - ○ / Non-Plastic - NP
10 20 30 40



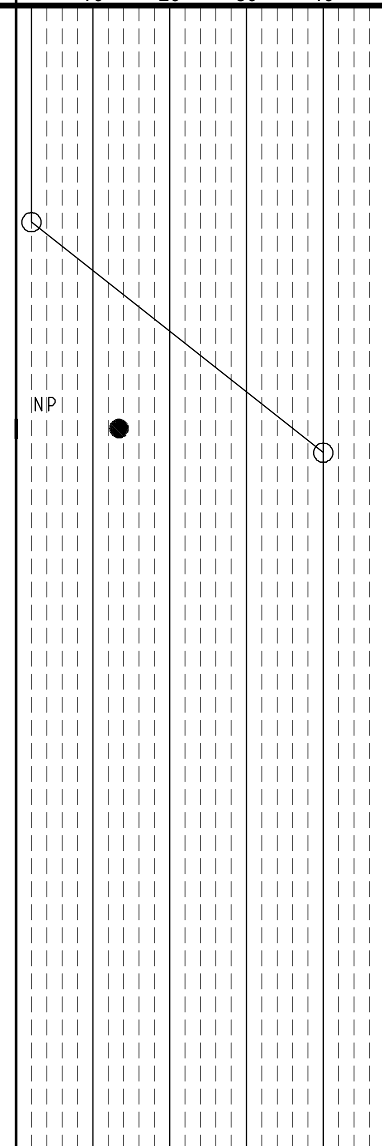
Client: OVEC-AEP | *Project:* Kyger Creek - Ash Impoundment Stability Analysis | *Job No.* 1021-3003.00

LOG OF: Boring KC-1015 | *Location:* As per plan | *Date Drilled:* 8/31/2010

WATER OBSERVATIONS:
Water seepage at: 38.5'-60.0'
Water level at completion: 42.6' Prior to adding water.
FIELD NOTES:

Depth (ft)	Elev. (ft) 530.4	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	Graphic Log	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
					ST-4		Medium stiff brown sandy LEAN CLAY (CL); contains moist to wet sandy silt seams; moist to wet.							
55		WOH WOH 2	18	S-18		0.75	@ 53.5', medium stiff.							
58.5	521.9													
60.0	520.4	1 17 16	7	S-19			Dense brown SAND with silt with gravel (SW-SM); wet.		43	8	21	22	--6--	
							Bottom of Boring - 60.0'							
65														
70														
75														

STANDARD PENETRATION (N60)
Natural Moisture Content, % - ●
PL ⊢—⊣ LL
Blows per foot - ○ / Non-Plastic - NP
10 20 30 40



Client: OVEC-AEP | Project: Kyger Creek - Ash Impoundment Stability Analysis | Job No. 1021-3003.00

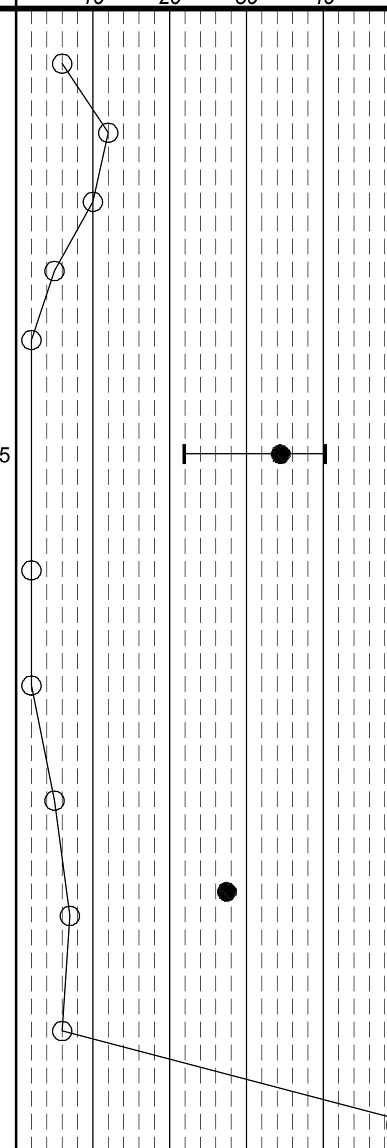
LOG OF: Boring KC-1016 | Location: As per plan | Date Drilled: 9/8/2010

WATER OBSERVATIONS:
Water seepage at: 23.0'-30.0'
Water level at completion: 5.5' Prior to adding water.
4.2' Final including drilling water.

FIELD NOTES:
Sealed borehole with bentonite grout.
Installed piezometer in offset boring.

Depth (ft)	Elev. (ft) 543.8	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
0.3	543.6	2 2 3	10	S-1		2.00	Topsoil - 3"						
		6 4 6	18	S-2		4.5+	FILL: Very stiff to hard brown LEAN CLAY with sand (CL); damp to moist.						
3.0	540.8	4 4 4	16	S-3		2.00	Very stiff to hard brown LEAN CLAY with sand (CL); damp to moist.						
5.4	538.4	3 2 2	18	S-4a S-4b		2.0 0.25							
		WOH 1 1	10	S-5		2.0	Soft to medium stiff gray LEAN CLAY with sand (CL); damp to moist.						
					ST-1		@8.5'-10.5', trace sand.	0	0	0	1	54	45
		WOH 1 1	18	S-6		1.25	@ 8.5'-13.5', stiff.						
		WOH WOH 2	18	S-7		0.75							
		WOH 1 3	18	S-8		0.75							
		1 1 5	18	S-9		1.50	@ 18.5'-21.0', stiff.						
		WOH 2 3	18	S-10		1.00							
23.5	520.3	15 22 30	18	S-11			Very dense SAND with silt with gravel (SW-SM); wet. Began adding drilling water at 25' to counteract heave.						
25	518.8												

STANDARD PENETRATION (N60)
Natural Moisture Content, % - ●
PL ├──┤ LL
Blows per foot - ○ / Non-Plastic - NP



DLZ Ohio, Inc. * 6121 Huntley Road, Columbus, Ohio 43229 * (614) 888-0040

Client: OVEC-AEP | Project: Kyger Creek - Ash Impoundment Stability Analysis | Job No. 1021-3003.00

LOG OF: Boring KC-1016 | Location: As per plan | Date Drilled: 9/8/2010

WATER OBSERVATIONS:
Water seepage at: 23.0'-30.0'
Water level at completion: 5.5' Prior to adding water.
4.2' Final including drilling water.

FIELD NOTES:
Sealed borehole with bentonite grout.
Installed piezometer in offset boring.

Depth (ft)	Elev. (ft) 518.8	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay	Natural Moisture Content / Blows per foot
		10 10 6	8	S-12			Medium dense to dense brown SAND with silt with gravel (SW-SM); wet.	34	16	31	13	--6--		NP
28.5	515.3	4 5 8	4	S-13			Medium dense brownish gray GRAVEL with sand (GW), trace silt; wet.	53	13	21	10	--3--		NP
30.0	513.8						Bottom of Boring - 30.0'							

STANDARD PENETRATION (N60)
Natural Moisture Content, % - ●
PL ⊢—⊣ LL
Blows per foot - ○ / Non-Plastic - NP
10 20 30 40

Depth scale: 30, 35, 40, 45, 50

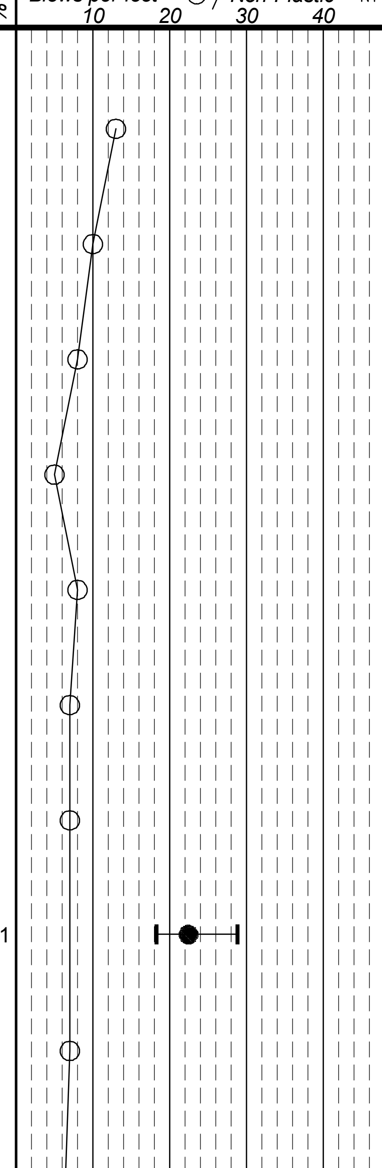
Client: OVEC-AEP | *Project:* Kyger Creek - Ash Impoundment Stability Analysis | *Job No.* 1021-3003.00

LOG OF: Boring KC-1017 | *Location:* As per plan | *Date Drilled:* 8/30/2010

WATER OBSERVATIONS:
Water seepage at: none
Water level at completion: NFW
FIELD NOTES:

Depth (ft)	Elev. (ft) 580.1	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
0.2	579.9						Aggregate - 2"						
		2 5 6	18	S-1		2.50	FILL: Stiff to very stiff brown sandy LEAN CLAY (CL); damp.						
5		2 4 4	18	S-2		1.25							
6.0	574.1	3 3 4	18	S-3		2.00	FILL: Very stiff brown LEAN CLAY with sand (CL); moist.						
8.5	571.6	1 2 2	18	S-4		1.00	FILL: Stiff to very stiff brown sandy LEAN CLAY (CL); moist.						
10		2 3 4	18	S-5		1.00							
15		1 3 3	18	S-6		2.25							
		1 2 4	10	S-7		1.00							
20					ST-1	1.5		0	0	0	23	46	31
21.0	559.1	1 1 5	18	S-8		1.25	FILL: Stiff brown LEAN CLAY with sand (CL); moist.						
25	555.1												

STANDARD PENETRATION (N60)
Natural Moisture Content, % - ●
PL ⊢ ⊣ LL
Blows per foot - ○ / Non-Plastic - NP



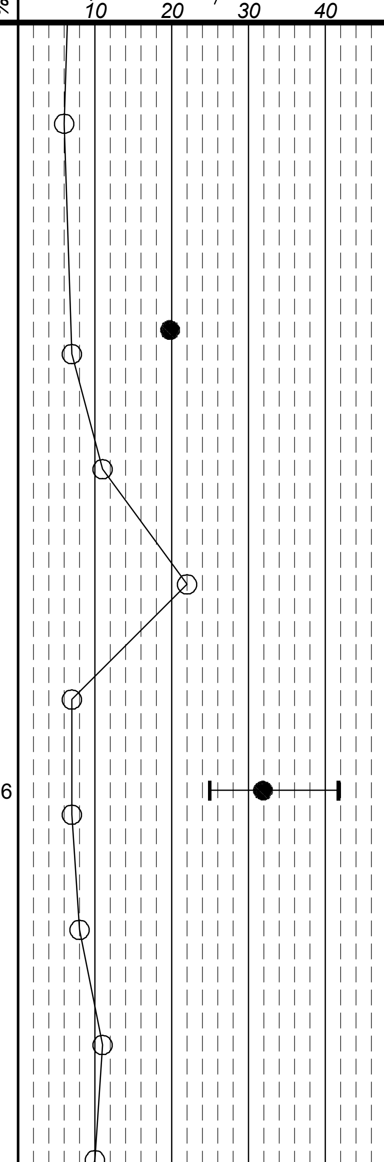
Client: OVEC-AEP | *Project:* Kyger Creek - Ash Impoundment Stability Analysis | *Job No.* 1021-3003.00

LOG OF: Boring KC-1017 | *Location:* As per plan | *Date Drilled:* 8/30/2010

WATER OBSERVATIONS:
Water seepage at: none
Water level at completion: NFW
FIELD NOTES:

Depth (ft)	Elev. (ft) 555.1	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
26.0	554.1						Stiff to very stiff brown sandy LEAN CLAY (CL); moist.						
		WOH 1 4	18	S-10		1.00							
30					ST-2								
		2 3 3	18	S-11		2.00							
35		1 3 6	3	S-12		2.50							
		4 8 10	18	S-13		3.00							
38.5	541.6						Stiff gray LEAN CLAY with sand (CL); slightly organic; moist.						
40		1 3 3	18	S-14		1.75							
		1 2 4	18	S-15		1.00	@41.0'-42.5', trace sand.	0	0	0	3	51	46
45		WOH 3 4	18	S-16		1.50	@ 43.5', brownish gray, trace organic.						
		2 4 5	18	S-17		1.75							
50	530.1	1 3 5	18	S-18		1.50							

STANDARD PENETRATION (N60)
Natural Moisture Content, % - ●
PL ⊢—⊣ LL
Blows per foot - ○ / Non-Plastic - NP



Client: OVEC-AEP | Project: Kyger Creek - Ash Impoundment Stability Analysis | Job No. 1021-3003.00

LOG OF: Boring KC-1017 | Location: As per plan | Date Drilled: 8/30/2010

WATER OBSERVATIONS:
Water seepage at: none
Water level at completion: NFW
FIELD NOTES:

Depth (ft)	Elev. (ft) 530.1	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
							Stiff brownish gray LEAN CLAY with sand (CL); moist.						
53.5	526.6	WOH WOH 1	18	S-19		0.75	Medium stiff brownish gray sandy LEAN CLAY (CL); moist.	0	0	0	18	54	28
					ST-3								
60.0	520.1	WOH 2 2	18	S-20		1.0							
							Bottom of Boring - 60.0'						

STANDARD PENETRATION (N60)
Natural Moisture Content, % - ●
PL |—| LL
Blows per foot - ○ / Non-Plastic - NP
10 20 30 40

55
65
70
75

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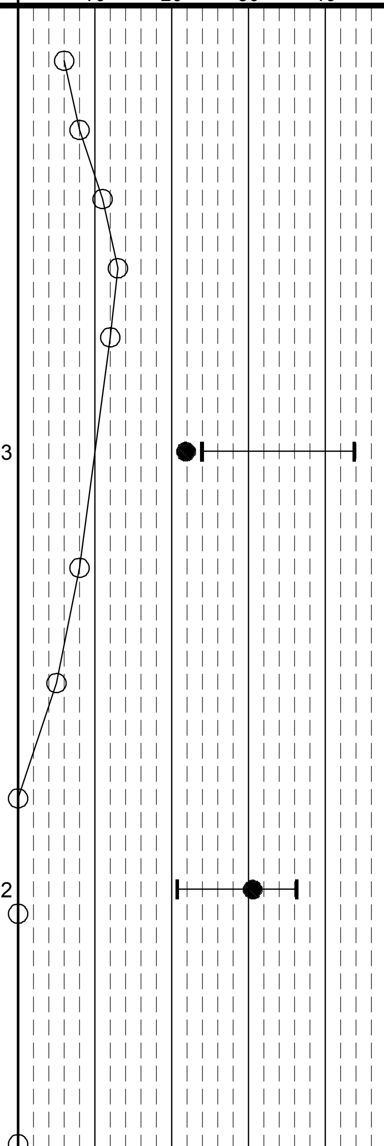
Client: OVEC-AEP	Project: Kyger Creek - Ash Impoundment Stability Analysis	Job No. 1021-3003.00
LOG OF: Boring KC-1018	Location: As per plan	Date Drilled: 9/7/2010

WATER OBSERVATIONS:
Water seepage at: 28.5'-48.0'
Water level at completion: 17.3' Prior to adding water.
8.7' Final including drilling water.

FIELD NOTES:
Sealed borehole with bentonite grout.
Installed piezometer in offset boring.

Depth (ft)	Elev. (ft) 547.3	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
0.3	547.0	1 3 2	10	S-1		3.00	Topsoil - 4"						
							Very stiff to hard brown LEAN CLAY with sand (CL); damp.						
		2 3 4	8	S-2		3.00							
		5 4 5	12	S-3		4.5+							
5		7 6 5	14	S-4		3.00							
		4 5 5	9	S-5		3.50							
8.5	538.8				ST-1	4.5	Hard brown LEAN CLAY (CL), trace fine sand; damp.	0	0	0	4	53	43
10													
11.0	536.3	1 2 5	5	S-6		1.00	Soft to medium stiff gray to brownish gray sandy LEAN CLAY (CL); moist.						
		1 2 2	18	S-7		1.0							
15													
		WOH WOH WOH	18	S-8		0.5							
18.0	529.3						Soft brownish gray LEAN CLAY (CL), trace fine sand; moist.						
		WOH WOH WOH	18	S-9		0.25		0	0	0	5	63	32
20													
21.0	526.3				ST-2		Soft to medium stiff gray to brownish gray sandy LEAN CLAY (CL); moist.						
25	522.3	WOH WOH WOH	18	S-10		0.50							

STANDARD PENETRATION (N60)
Natural Moisture Content, % - ●
PL ├──┤ LL
Blows per foot - ○ / Non-Plastic - NP
10 20 30 40



Client: OVEC-AEP | Project: Kyger Creek - Ash Impoundment Stability Analysis | Job No. 1021-3003.00

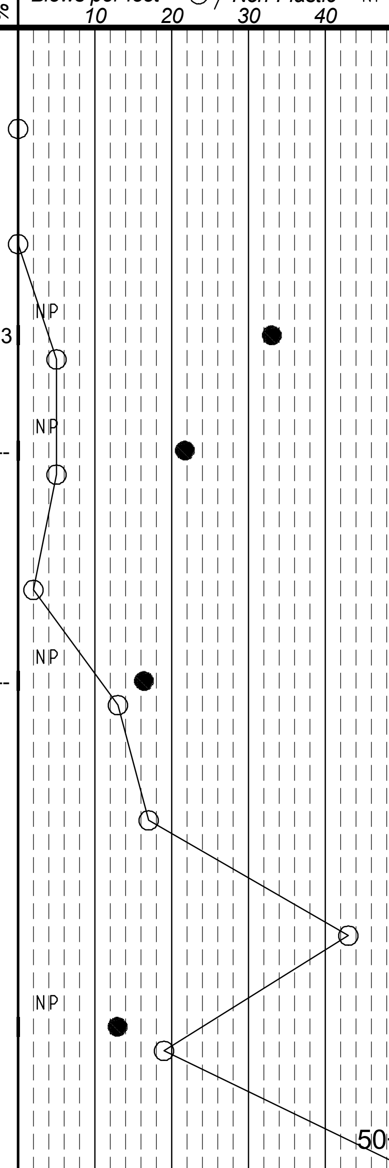
LOG OF: Boring KC-1018 | Location: As per plan | Date Drilled: 9/7/2010

WATER OBSERVATIONS:
Water seepage at: 28.5'-48.0'
Water level at completion: 17.3' Prior to adding water. 8.7' Final including drilling water.

FIELD NOTES:
Sealed borehole with bentonite grout.
Installed piezometer in offset boring.

Depth (ft)	Elev. (ft) 522.3	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
26.0	521.3	WOH WOH WOH	12	S-11		0.75	Medium stiff to stiff gray sandy LEAN CLAY (CL); contains wet sandy silt seams; moist to wet.						
		WOH WOH WOH	18	S-12		1.0	@ 28.5'-31.0', contains wet sandy silt seams. Began adding drilling water at 30' to counteract heave.						
31.0	516.3	WOH 1 3	18	S-13			Very loose to loose gray sandy SILT (ML); wet.	0	0	0	48	39	13
33.5	513.8	WOH 1 3	18	S-14			Loose gray SAND with silt (SW-SM), trace gravel; wet.	1	3	54	31	--11--	
36.0	511.3	WOH 1 1	18	S-15			Very loose gray silty, clayey SAND (SC-SM); wet.						
38.5	508.8	7 6 5	5	S-16			Medium dense gray GRAVEL with silt with sand (GP-GM); wet.	52	13	13	12	--10--	
41.0	506.3	3 6 8	3	S-17			Medium dense gray GRAVEL with sand (GW); wet.						
43.5	503.8	9 14 22	13	S-18			Dense to dense gray SAND with silt (SW-SM); wet.						
46.0	501.3	3 6 10	10	S-19			Medium dense gray SAND with gravel (SW), trace silt; wet.	38	20	31	8	--3--	
48.5	498.8												
48.7	498.6	50/2"	2	S-20			Soft gray SILTSTONE interbedded with SHALE; highly weathered to decomposed, argillaceous, micaceous.						

STANDARD PENETRATION (N60)
Natural Moisture Content, % - ●
PL ⊢—⊣ LL
Blows per foot - ○ / Non-Plastic - NP



Client: OVEC-AEP	Project: Kyger Creek - Ash Impoundment Stability Analysis	Job No. 1021-3003.00
LOG OF: Boring KC-1018	Location: As per plan	Date Drilled: 9/7/2010

WATER OBSERVATIONS:
Water seepage at: 28.5'-48.0'
Water level at completion: 17.3' Prior to adding water.
8.7' Final including drilling water.

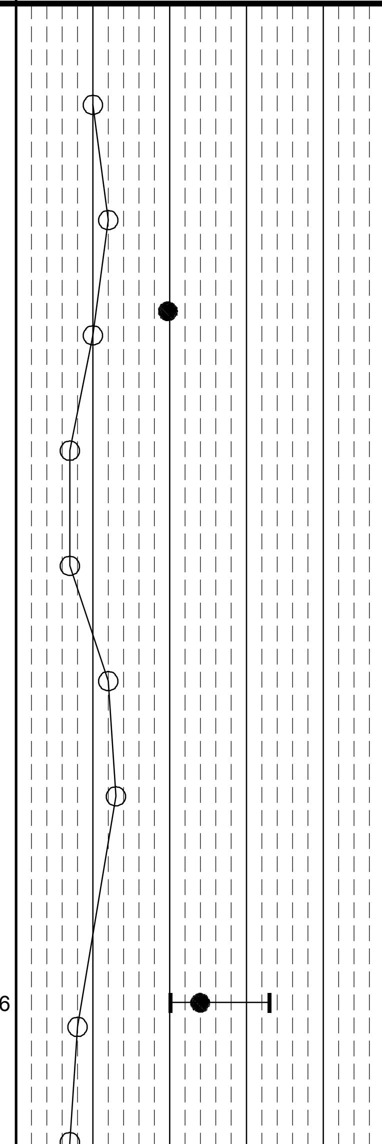
FIELD NOTES:
Sealed borehole with bentonite grout.
Installed piezometer in offset boring.

Depth (ft)	Elev. (ft) 497.3	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	Graphic Log	GRADATION % Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay	STANDARD PENETRATION (N60) Natural Moisture Content, % - ● PL ├─┤ LL Blows per foot - ○ / Non-Plastic - NP 10 20 30 40
							Bottom of Boring - 48.7'								
55															
60															
65															
70															
75															

Client: OVEC-AEP	Project: Kyger Creek - Ash Impoundment Stability Analysis	Job No. 1021-3003.00
LOG OF: Boring KC-1019	Location: As per plan	Date Drilled: 8/27/2010

WATER OBSERVATIONS:
Water seepage at: 45'-50.'
Water level at completion: 48.7' Prior to adding water.
FIELD NOTES:

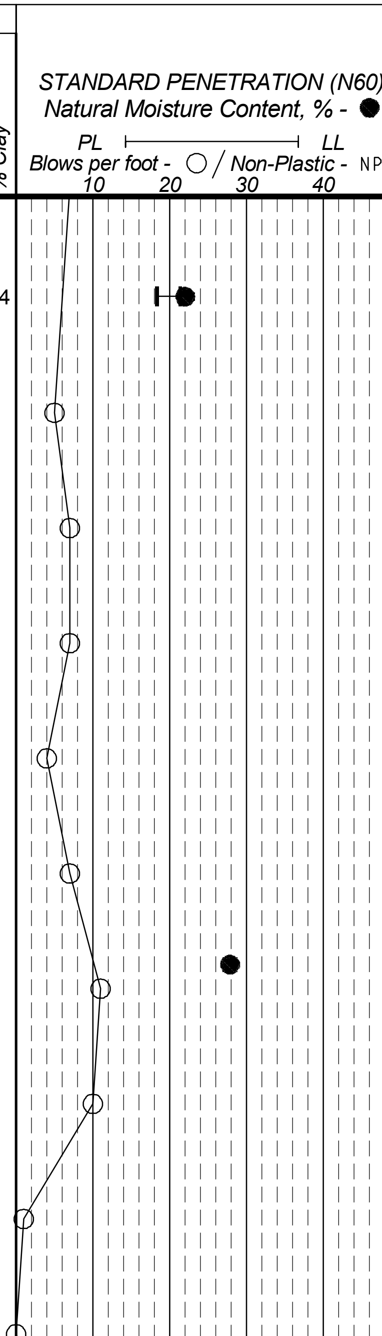
Depth (ft)	Elev. (ft) 580.7	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
0.2	580.5						Aggregate - 2"						
		2 4 4	10	S-1		3.0	FILL: Stiff to very stiff brown sandy LEAN CLAY (CL); damp.						
5		4 4 6	18	S-2		2.5							
6.0	574.7	2 3 5	18	S-3		3.0	FILL: Very stiff brown LEAN CLAY with sand (CL); damp.						
8.5	572.2	2 2 4	18	S-4		2.0	FILL: Stiff to very stiff brown sandy LEAN CLAY (CL); damp.						
10		2 2 4	18	S-5		2.0							
15		2 4 6	18	S-6		3.0	@ 13.5', gray.						
		3 4 7	18	S-7		3.5							
20					ST-1	--							
21.0	559.7	1 2 5	18	S-8		1.25	Stiff brown LEAN CLAY (CL), little fine sand; moist.	0	0	0	13	51	36
23.5	557.2	1 3 3	18	S-9		--	Medium stiff gray sandy SILTY CLAY (CL-ML); moist.						
25	555.7												



Client: OVEC-AEP	Project: Kyger Creek - Ash Impoundment Stability Analysis	Job No. 1021-3003.00
LOG OF: Boring KC-1019	Location: As per plan	Date Drilled: 8/27/2010

WATER OBSERVATIONS:
Water seepage at: 45'-50.'
Water level at completion: 48.7' Prior to adding water.
FIELD NOTES:

Depth (ft)	Elev. (ft) 555.7	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
					ST-2		Soft gray sandy SILT (ML); moist to wet.	0	0	0	38	38	24
28.5	552.2	WOH 1 3	18	S-10		--	Medium stiff gray sandy SILTY CLAY (CL-ML); moist.						
		WOH 2 4	18	S-11		--							
33.5	547.2	WOH 2 4	18	S-12		1.75	Stiff grayish brown LEAN CLAY with sand (CL); damp.						
36.0	544.7	WOH 1 2	18	S-13		0.75	Medium stiff grayish brown sandy LEAN CLAY (CL); moist.						
38.5	542.2	1 2 4	18	S-14		1.5	Stiff brown LEAN CLAY with sand (CL); damp to moist.						
		WOH 4 5	18	S-15		1.25							
		WOH 3 5	18	S-16		1.75							
46.0	534.7	WOH WOH 1	18	S-17		1.0	Soft to medium stiff brown sandy LEAN CLAY (CL); contains moist to wet sandy silt seams; moist.						
50	530.7	WOH WOH WOH	18	S-18		0.25	@ 48.5', wet.						



DLZ Ohio, Inc. * 6121 Huntley Road, Columbus, Ohio 43229 * (614) 888-0040

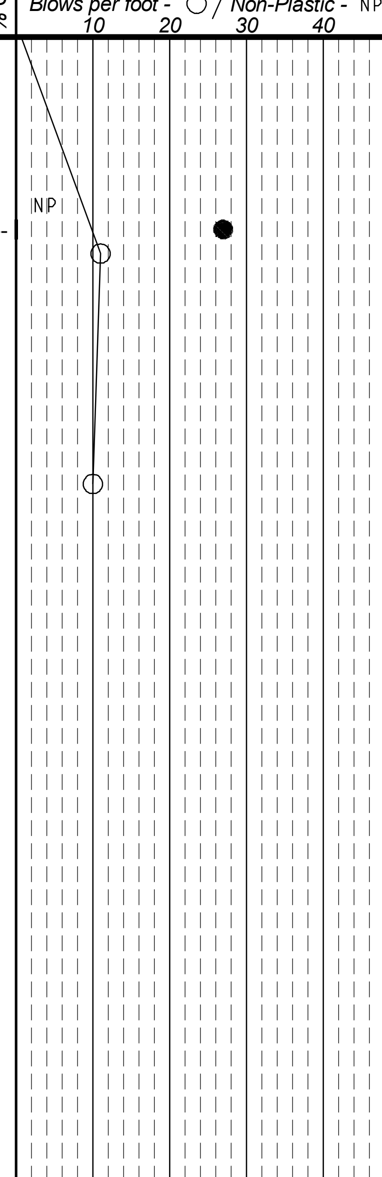
Client: OVEC-AEP | Project: Kyger Creek - Ash Impoundment Stability Analysis | Job No. 1021-3003.00

LOG OF: Boring KC-1019 | Location: As per plan | Date Drilled: 8/27/2010

WATER OBSERVATIONS:
Water seepage at: 45'-50.'
Water level at completion: 48.7' Prior to adding water.
FIELD NOTES:

Depth (ft)	Elev. (ft) 530.7	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetro-meter (tsf)	DESCRIPTION	Graphic Log	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
50.5	530.2						Soft to medium stiff brown sandy LEAN CLAY (CL); contains moist to wet sandy silt seams; moist.	▨						
53.5	527.2	1 4 5	18	S-19			Loose brown SAND with silt (SP-SM); wet.		0	0	1	89	--10--	
		WOH 3 5	18	S-20										
60.0	520.7						Bottom of Boring - 60.0'							

STANDARD PENETRATION (N60)
Natural Moisture Content, % - ●
PL ├──┤ LL
Blows per foot - ○ / Non-Plastic - NP



Client: OVEC-AEP | *Project:* Kyger Creek - Ash Impoundment Stability Analysis | *Job No.* 1021-3003.00

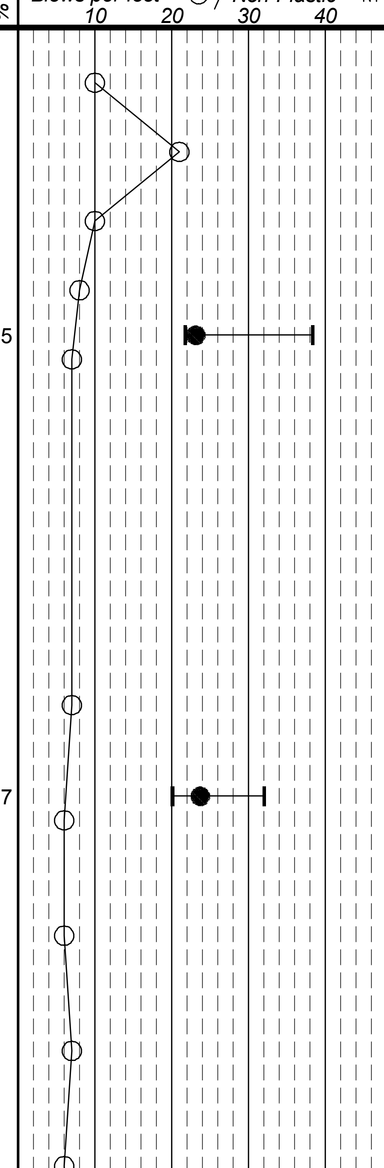
LOG OF: Boring KC-1020 | *Location:* As per plan | *Date Drilled:* 9/2/2010

WATER OBSERVATIONS:
Water seepage at: 23.0'-40.0'
Water level at completion: 26.8' Prior to adding water.

FIELD NOTES:

Depth (ft)	Elev. (ft) 559.5	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
0.3	559.3	3 3 5	10	S-1		4.5+	Topsoil - 3" Hard brown sandy LEAN CLAY (CL); damp.						
		8 8 9	7	S-2		1.50	@ 1.5', stiff.						
3.0	556.5	4 4 4	5	S-3			Loose brown silty SAND (SM); damp.						
5		3 3 4	15	S-4									
6.0	553.5	2 3 3	18	S-5		2.00	Stiff to very stiff brown sandy LEAN CLAY (CL); damp to moist. @6.0'-7.5', trace sand.	0	0	0	7	58	35
10					ST-1		@ 8.5'-10.5', unsuccessful attempt to collect press tube sample.						
15		1 3 3	18	S-6		2.5							
		1 2 3	18	S-7		1.00		0	0	0	19	54	27
18.5	541.0	1 1 4	18	S-8		1.5	Stiff brown LEAN CLAY with sand (CL); moist.						
20		1 2 4	18	S-9		1.50							
23.5	536.0	1 2 3	18	S-10		1.25	Stiff brown sandy LEAN CLAY (CL); contains moist to wet sandy silt seams; moist to wet.						
25	534.5												

STANDARD PENETRATION (N60)
Natural Moisture Content, % - ●
PL ├──┤ LL
Blows per foot - ○ / Non-Plastic - NP



Client: OVEC-AEP | Project: Kyger Creek - Ash Impoundment Stability Analysis | Job No. 1021-3003.00

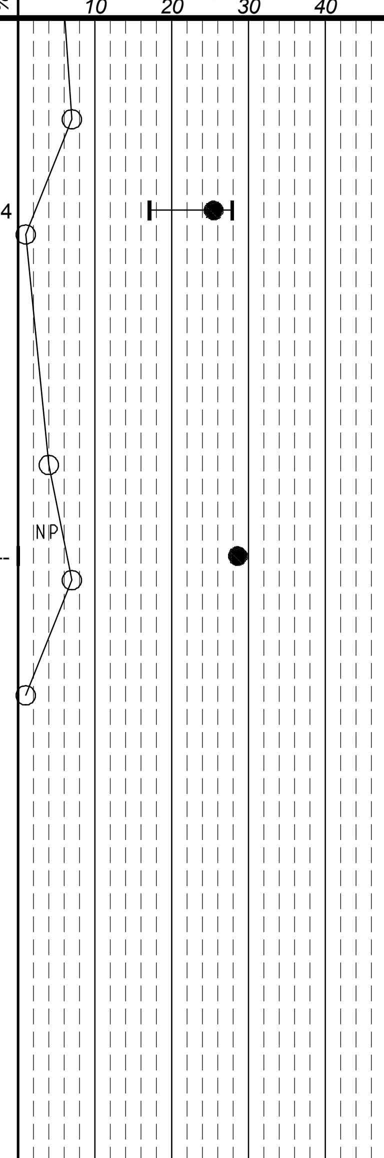
LOG OF: Boring KC-1020 | Location: As per plan | Date Drilled: 9/2/2010

WATER OBSERVATIONS:
Water seepage at: 23.0'-40.0'
Water level at completion: 26.8' Prior to adding water.

FIELD NOTES:

Depth (ft)	Elev. (ft) 534.5	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
		WOH 2 4	18	S-11		1.00	Stiff brown sandy LEAN CLAY (CL); contains moist to wet sandy silt seams; moist to wet.						
		WOH WOH 1	18	S-12		1.0		0	0	0	30	46	24
31.0	528.5				ST-2		Very loose to loose brown silty SAND (SM), trace gravel; wet.						
		1 1 2	18	S-13									
		1 2 4	18	S-14				0	0	2	84	--14--	
40.0	519.5	WOH WOH 1	18	S-15									
							Bottom of Boring - 40.0'						

STANDARD PENETRATION (N60)
Natural Moisture Content, % - ●
PL ├──┤ LL
Blows per foot - ○ / Non-Plastic - NP



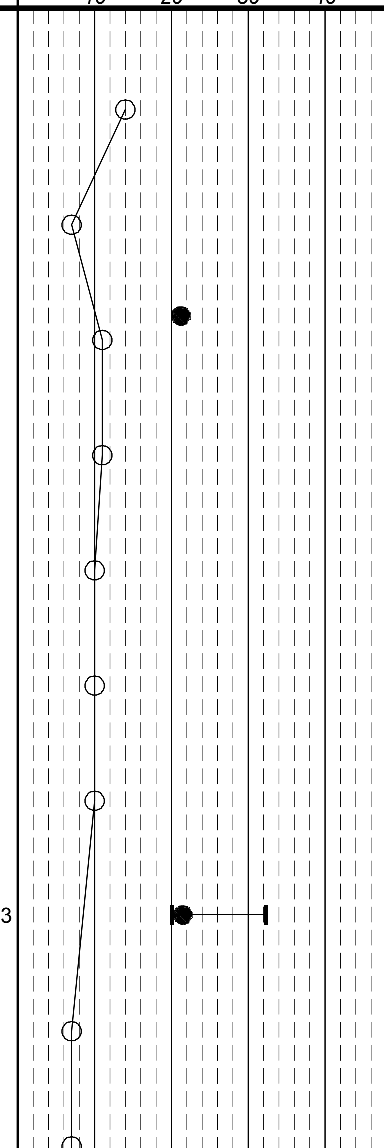
Client: OVEC-AEP | Project: Kyger Creek - Ash Impoundment Stability Analysis | Job No. 1021-3003.00

LOG OF: Boring KC-1021 | Location: As per plan | Date Drilled: 8/26/2010

WATER OBSERVATIONS:
Water seepage at: 33.5'-60.0'
Water level at completion: 47.0' Prior to adding water.
FIELD NOTES:

Depth (ft)	Elev. (ft) 580.2	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
0.3	580.0						Aggregate - 3"						
		6 6 6	10	S-1		4.5+	FILL: Hard brown sandy LEAN CLAY (CL); damp.						
3.5	576.7	3 3 3	18	S-2		2.5	FILL: Stiff to very stiff brown LEAN CLAY with sand (CL); damp.						
5													
		4 4 5	18	S-3		3.0							
		2 4 5	18	S-4		2.5							
10													
		2 3 5	18	S-5		1.5	@ 11.0', stiff, gray, contains black cinders.						
		1 4 4	6	S-6		1.0							
15													
		2 3 5	18	S-7		1.5							
18.5	561.7				ST-1	2.5	FILL: Very stiff gray sandy LEAN CLAY (CL); damp.	0	0	0	21	46	33
20													
21.0	559.2	3 3 3	18	S-8		2.0	FILL: Stiff to very stiff gray LEAN CLAY with sand (CL); moist.						
		2 2 4	18	S-9		2.5							
25	555.2												

STANDARD PENETRATION (N60)
Natural Moisture Content, % - ●
PL ├──┤ LL
Blows per foot - ○ / Non-Plastic - NP



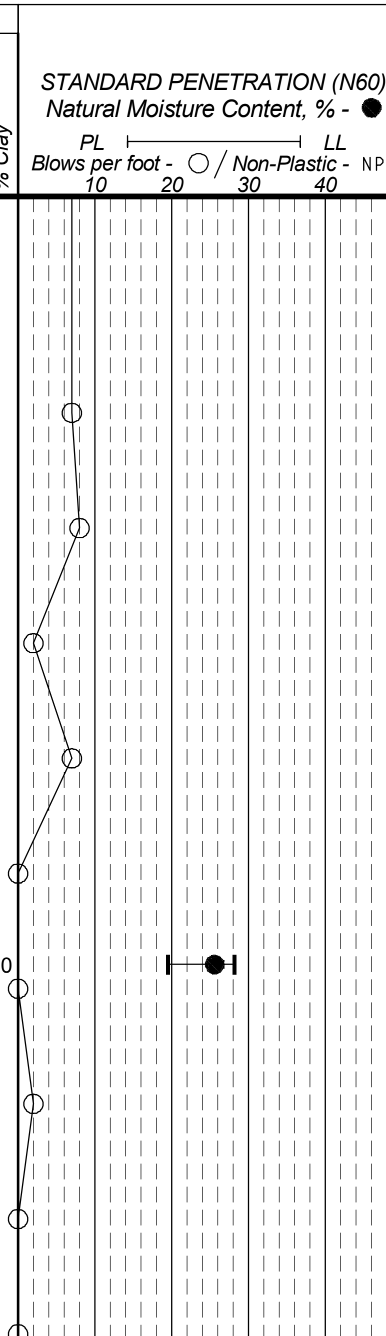
Client: OVEC-AEP | *Project:* Kyger Creek - Ash Impoundment Stability Analysis | *Job No.* 1021-3003.00

LOG OF: Boring KC-1021 | *Location:* As per plan | *Date Drilled:* 8/26/2010

WATER OBSERVATIONS:
Water seepage at: 33.5'-60.0'
Water level at completion: 47.0' Prior to adding water.
FIELD NOTES:

Depth (ft)	Elev. (ft) 555.2	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
					ST-2		Stiff to very stiff gray LEAN CLAY with sand (CL); moist.						
28.5	551.7	1 2 4	18	S-10		1.5	Stiff gray LEAN CLAY with sand (CL); moist.						
31.0	549.2	WOH 3 4	18	S-11		0.75	Medium stiff brown LEAN CLAY (CL); moist.						
33.5	546.7	WOH WOH 2	18	S-12		0.5	Medium stiff brownish gray sandy LEAN CLAY (CL); contains moist to wet sandy silt seams; moist to wet.						
36.0	544.2	WOH 2 4	18	S-13		1.25	Stiff brown LEAN CLAY with sand (CL); moist.						
38.5	541.7	WOH WOH WOH	18	S-14		0.5	Medium stiff brown sandy LEAN CLAY (CL); contains moist to wet sandy silt seams; moist to wet.						
		WOH WOH WOH	18	S-15		0.75		0	0	0	34	46	20
		WOH WOH 2	18	S-16		0.25							
		WOH WOH WOH	18	S-17		1.0							
50	530.2	WOH WOH WOH	18	S-18		0.5	@ 48.5', gray.						

Depth scale: 30, 35, 40, 45, 50



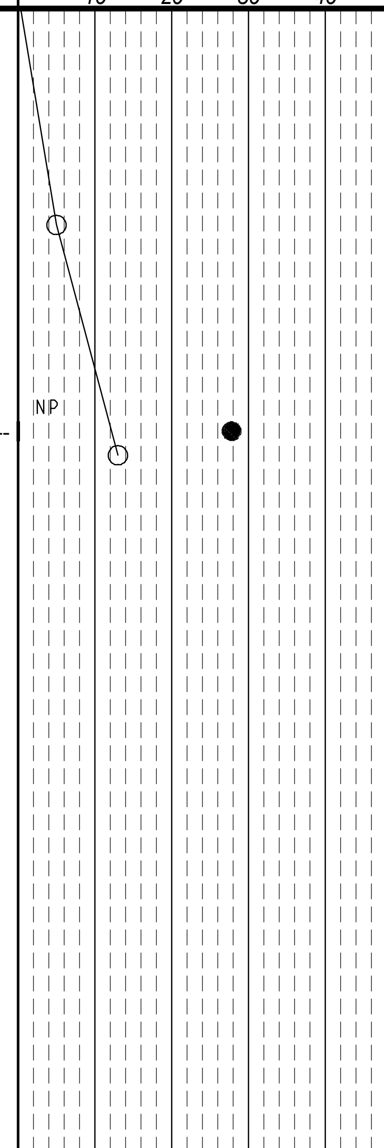
Client: OVEC-AEP | *Project:* Kyger Creek - Ash Impoundment Stability Analysis | *Job No.* 1021-3003.00

LOG OF: Boring KC-1021 | *Location:* As per plan | *Date Drilled:* 8/26/2010

WATER OBSERVATIONS:
Water seepage at: *33.5'-60.0'*
Water level at completion: *47.0' Prior to adding water.*
FIELD NOTES:

Depth (ft)	Elev. (ft) 530.2	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	Graphic Log	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
50.5	529.7						Soft gray sandy LEAN CLAY (CL); contains moist to wet sandy silt seams; moist to wet.							
55		1 1 3	18	S-19		0.25								
58.5	521.7													
60.0	520.2	1 4 7	18	S-20			Medium dense gray silty SAND (SM); wet.		0	1	12	74	--13--	
							Bottom of Boring - 60.0'							
65														
70														
75														

STANDARD PENETRATION (N60)
Natural Moisture Content, % - ●
PL ⊢—⊣ LL
Blows per foot - ○ / Non-Plastic - NP



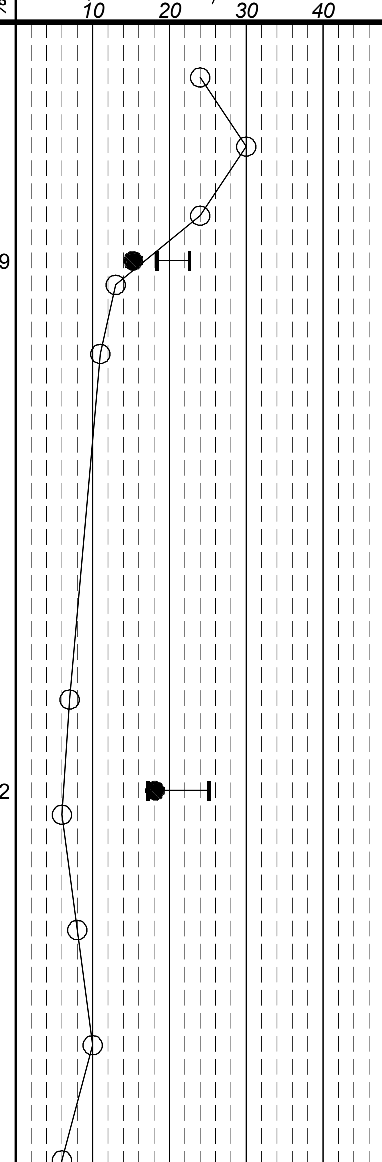
Client: OVEC-AEP	Project: Kyger Creek - Ash Impoundment Stability Analysis	Job No. 1021-3003.00
LOG OF: **Boring KC-1022**	Location: As per plan	Date Drilled: 9/1/2010

WATER OBSERVATIONS:
Water seepage at: 23.5'-40.0'
Water level at completion: 29.0' Prior to adding water.

FIELD NOTES:

Depth (ft)	Elev. (ft) 562.7	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
0.3	562.5						Topsoil - 3"						
		7 9 11	4	S-1		4.5+	FILL: Hard brown sandy LEAN CLAY (CL); contains cinders; damp.						
		7 10 15	12	S-2		4.5+							
4.5	558.2	6 10 10	14	S-3		4.5+							
5		5 5 6	10	S-4		1.0	FILL: Stiff to very stiff brown sandy SILTY CLAY (CL-ML); damp.	0	0	0	41	40	19
		1 5 4	18	S-5		2.5							
10							@ 8.5'-10.5', unsuccessful attempt to collect press tube sample.						
11.0	551.7				ST-1		Very stiff brown LEAN CLAY with sand (CL); damp.						
15		1 3 3	18	S-6		2.5							
16.0	546.7	1 2 3	18	S-7		1.50	Stiff brown sandy LEAN CLAY (CL); damp to moist.	0	0	0	40	38	22
20		3 3 4	18	S-8									
		3 4 4	18	S-9		1.75							
23.5	539.2	1 2 3	18	S-10			Medium stiff brown sandy LEAN CLAY (CL); contains moist to wet sandy silt seams; moist to wet.						
25	537.7												

STANDARD PENETRATION (N60)
Natural Moisture Content, % - ●
PL ├──┤ LL
Blows per foot - ○ / Non-Plastic - NP



Client: OVEC-AEP | *Project:* Kyger Creek - Ash Impoundment Stability Analysis | *Job No.* 1021-3003.00

LOG OF: Boring KC-1022 | *Location:* As per plan | *Date Drilled:* 9/1/2010

WATER OBSERVATIONS:
Water seepage at: *23.5'-40.0'*
Water level at completion: *29.0' Prior to adding water.*
FIELD NOTES:

Depth (ft)	Elev. (ft) 537.7	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay	Standard Penetration (N60) / Natural Moisture Content
26.0	536.7	WOH WOH 3	18	S-11		1.0	Medium stiff brown LEAN CLAY with sand (CL); moist.							
28.5	534.2	WOH WOH 1	18	S-12		0.50	Medium stiff brown sandy LEAN CLAY (CL); wet.							
					ST-2									
33.5	529.2	WOH WOH 2	18	S-13			Very loose to loose brown silty SAND (SM), trace gravel; wet.	0	0	1	80	--19--		NP
		WOH 3 4	18	S-14				0	0	1	74	--25--		NP
40.0	522.7	1 6 8	18	S-15			@ 38.5', medium dense.							
							Bottom of Boring - 40.0'							

APPENDIX III

Hydrologic and Hydraulic Evaluations

Hydrologic and Hydraulic Analysis Related to Compliance Requirements
South Fly Ash Pond, Boiler Slag Pond and Clearwater Pond
Kyger Creek Power Plant, Gallia County, Ohio

General

The intent of this section is to ascertain the compliance of the South Fly Ash Pond, Boiler Slag Pond, and Clearwater Pond with the recently mandated coal combustion residuals (CCR) rules with regard to the hydrologic and hydraulic capacity requirements for surface impoundments (Ref 1). All three impoundments are up ground reservoirs which function as tailings ponds for the Ohio Valley Electric Corporation's (OVEC's) Kyger Creek Power Plant. A site map is shown in Figure 1.

The CCR rules require that the impoundments undergo periodic hazard potential classification. Currently, South Fly Ash Pond and Boiler Slag Pond (which includes Clearwater Pond) are listed under the Class II Hazard Classification for dams in the State of Ohio. This classification is somewhat different from the hazard classification listed in Section 257.73 (a) (2) of the CCR but may be construed as equivalent to a significant hazard potential CCR surface impoundment. As per Section 257.82 (a) (3) (ii) the inflow design flood for a significant hazard CCR surface impoundment is the 1,000-yr flood. However, since the primary classification is the State of Ohio Class II Hazard classification, the minimum design flood for such structures as per Ohio Administrative Code Rule 1501:21-13-02 is the 50% probable maximum flood (50% PMF). In addition, the 50% PMP depths for this location are larger than the 1000-yr rainfall depths for the same duration and thus the use of the 50% PMP for this analysis is conservative. Consequently, the inflow design flood chosen to determine the hydraulic capacity requirement is the 50% PMF.

The CCR rules also only state that the CCR unit must adequately manage the flow into and from the unit during and after the inflow design flood. No specific criterion for freeboard in the CCR unit is specifically listed. However, Ohio Administrative Code Rule 1501:21-13-07 for Class II dams that are up ground reservoirs specifically states that the minimum elevation of the embankment crest shall be 5 feet higher than the elevation of the designed maximum operating pool level. As part of this compliance certification, checks are conducted to verify that the 5 ft freeboard criterion for the top of dam as compared to the operating pool level is met. In addition, surcharge elevations associated with the inflow of the 50% PMF with maximum operating pool as the initial condition are also determined to ensure adequate storage capacity of the tailings ponds.

PMP Estimates

The rainfall depth for the 6-hr 1 sq. mile PMP for the Kyger Creek Plant as per the latest guidelines (Ref 2) developed by the Ohio Department of Natural Resources (ODNR) is 19 inches. Since the drainage areas to the ponds are relatively small and the associated time of concentrations will be much less than 6 hours, it is reasonable to use the 6-hr 1 sq. mile value for the PMP. It should be noted that the point 1000-yr 6-hr rainfall depth for the area is 5.6 inches as compared to the 0.5 PMP depth of 9.5 inches.

Topographic Data

Topographic data for all three ponds were generated using the 2007 LiDAR information for the project site that is available online from the Ohio Geographically Referenced Information Program (OGRIP) website. The drainage areas and elevation-area data for each of the ponds were developed using the above data. It should be noted that the elevations with the LiDAR data are referenced to the NAVD 88 vertical datum. Since the historical information for the ponds are based on the NGVD 29 datum, all elevations based on this data are converted to the NGVD 29 elevations by adding 0.7 ft, which is the appropriate correction factor for the project area. All elevations in this document are referenced to the NGVD 29 datum unless otherwise expressly stated.

Historic Data and Previous Studies

Historic data on the tailing ponds were primarily taken from several previous studies (Refs 3 and 4). This includes outlet structure information and normal pool elevations. Information was also obtained from communications with OVEC and American Electric Power (AEP) personnel. A site visit was also conducted on 7/22/15 to observe the various facilities on site.

South Fly Ash Pond

The drainage area for the South Fly Ash Pond is approximately 67.7 acres. The outlet structure for South Fly Ash Pond is located near the south west corner of the pond and consists of a 36-inch concrete pipe, with a 42 inch by 39 inch concrete riser pipe with the principal spillway at elevation 582 ft. As per OVEC and AEP personnel, the maximum operating pool is at elevation 585 ft.

The site visit revealed that the Kyger Creek Plant's coal yard drainage as well as storm drainage from a portion of the plant site is pumped to the pond. This information is not available from any of the previous reports. Discussions with OVEC and AEP personnel revealed that originally four Goyne pumps each rated at 5,000 GPM delivered the drainage flow to the ponds. Currently, only two are working and there are no current plans to replace the other two. For the purpose of this study, it is assumed that two pumps will be active during storm events. The combined coal yard/plant drainage area is approximately 38 acres as per OVEC and AEP personnel.

Conservatively, it is assumed that the outlet structure is blocked during the occurrence of the 0.5 PMP event, the initial pond elevation is at the maximum operating pool, and that the direct inflow to the reservoir from the 0.5 PMP rainfall and the associated pumped drainage from the coal yard/plant area are instantaneously imposed on the pond.

Assuming no losses, the direct inflow volume to the pond = 0.5*19/12*67.7 = 53.6 ac-ft. Drainage volume to the pond from the pumps will be the minimum of the pump delivery or the flow volume associated with the drainage area. Maximum pump delivery during the 6-he PMP will be the rated pump capacity multiplied by the 6-hr duration. Maximum pump volume = 5,000*2*60*6/7.48/43,560 = 11.0 ac-ft. Assuming no losses, the maximum volume from the 38 acre coal yard/plant drainage area during the 0.5 PMP = 0.5*19/12*38 = 30 ac-ft. It appears that flow from the drainage area will be limited by the pump capacity which may not be the case in reality since there will be losses associated with the rainfall over the coal/plant yard. A runoff coefficient of approximately 0.37 will make the runoff volume almost the same as the pump capacity. Conservatively, the total volume to the pond can be estimated as 53.6+11.0 = 64.6 ac-ft.

The resulting water surface elevation is calculated to be 586.0 ft (see Table 1). The top elevation of the embankment around the pond is considered to be at elevation 590 ft, though the 2007 LIDAR data indicate variations in the elevations. Therefore, the freeboard for the 0.5 PMP event (assuming the initial water level is at maximum operating pool) is of the order of 4 ft.

Also, there is a freeboard of 5 ft above the maximum operating level, which satisfies the minimum freeboard requirements of the State of Ohio for up ground reservoirs.

Boiler Slag Pond

The drainage area for the Boiler Slag Pond is approximately 30.1 acres. The outlet structure for Boiler Slag Pond is located at the southern end of the pond adjacent to the west end of the splitter dike between Boiler Slag Pond and the associated Clearwater Pond. The outlet consists of a 36-inch concrete pipe with a 42 inch by 39 inch concrete riser pipe with the principal spillway at elevation 557 ft. Water entering the outlet structure is discharged to Clearwater Pond, through a 30-inch CMP which passes through the splitter dike. There is no drainage from other sources entering Boiler Slag Pond. The maximum operating pool level is reported by OVEC and AEP personnel to be approximately 558 ft.

Conservatively, it is assumed that the outlet structure is blocked during the occurrence of the 0.5 PMP event, the initial pond elevation is at maximum operating pool, and that the inflow to the reservoir is only from the 0.5 PMP rainfall. Assuming no losses, the direct inflow volume to the pond = 0.5*19/12*30.1 = 23.8 ac-ft. The initial storage in the pond corresponding to the maximum operating pool elevation of 558.0 ft is 17.7 ac-ft, so the total storage in the pond corresponding to the 0.5 PMP is 41.5 ac-ft. The resulting water surface elevation in the pond due to the 0.5 PMP event is 559.3 ft.

The top elevation of the embankment around the pond is considered to be at elevation 582 ft, though the 2007 LIDAR data indicate variations in the elevations. Therefore, the freeboard for the 0.5 PMP event is of the order of 22.7 ft. The detailed calculations are shown in Table 2.

Clearwater Pond

The drainage area for the Clearwater Pond is 9.9 acres. The outlet structure for Clearwater Pond is located at the southeast corner of the pond and is discharged to the Ohio River through a 30-inch CMP. Details of the outlet structure do not appear to be available. The maximum operating pool level is reported by OVEC and AEP personnel to be approximately 553 ft. The only incoming flow to Clearwater Pond is from direct rainfall to the pond as well as the inflow from Boiler Slag Pond.

Clearwater Pond is not strictly a CCR unit since the purpose of Boiler Slag Pond is to store CCRs.

Assuming no losses, the combined inflow volume from the drainage areas of both Boiler Slag Pond and Clearwater Pond is = 0.5*19/12*(30.1+9.99) = 31.7 ac-ft. It is also assumed that the initial storage of 17.7 ac-ft in Boiler Slag Pond corresponding to the maximum operating pool there will drain to Clearwater Pond. In addition, since the initial elevation in Clearwater Pond is assumed to be at the maximum operating level of 553 ft, there is an initial storage in Clearwater Pond of 5.5 ac-ft. Thus the total storage volume in Clearwater Pond for these conditions assuming that the outlet is blocked is 54.9 ac-ft.

It should be noted that if the pool elevation at Clearwater Pond exceeds 557 ft (spillway elevation at Boiler Slag Pond), the storage in Boiler Slag Pond above this elevation will also be activated in addition to the storage in Clearwater Pond. The resulting water surface elevation in the pond for the 0.5 PMP event assuming that the outlet is blocked is 558.6 ft.

The top elevation of the embankment around the pond is considered to be at elevation 582 ft, though the 2007 LIDAR data indicate variations in the elevations. Therefore, the freeboard for the 0.5 PMP event is of the order of 23.4 ft. The detailed calculations are shown in Table 3.

<u>Summary and Conclusions</u>

A summary table of the water level conditions in the three ponds is given in Table 4. It is concluded that South Fly Ash Pond, Boiler Slag Pond and Clearwater Pond have sufficient storage capacity and freeboard to satisfy the minimum requirements of CCR rules as well as the dam safety requirements of the State of Ohio.

<u>References</u>

1. Hazardous and Solid Waste Management System; Disposal of Coal Combustion Residuals From Electric Utilities; Final Rule, 40 CFR Parts 257 and 261, Environmental Protection Agency, Part II, Federal Register, Vol. 80, No.74, Friday, April 17, 2015..

2. Probable Maximum Precipitation Study for the State of Ohio, Ohio Department of Natural Resources, February 2013.

3. Assessment of Dam Safety of Coal Combustion Surface Impoundments (Task 3) Final Report, Ohio Valley Electric Corporation, Kyger Creek Power Station, Gallipolis, Ohio, February 24, 2010.

4. Report on Dam Safety Inspection, Kyger Creek Fly Ash and Bottom Ash Ponds, Kyger Creek Generation Plant, Addison, Ohio, February 1985.

Figure 1 Areal View of Project Site

Table 1: Detailed Calculations for South Fly Ash Pond

South Fly Ash Pond

Drainage Area 67.7 acres

Feature	Elevation (ft)	Surface Area (ac)	Incr Storage (ac-ft)
Principal Spillway	582.0	64.3	0.0
	582.7	64.6	45.1
	583.7	64.9	109.8
	584.7	65.2	174.9
	585.0	65.3	194.4
	585.7	65.5	240.2
	586.7	65.9	305.9
	587.7	66.3	371.9
	588.7	66.8	438.5
	589.7	68.1	505.9
Top of Dam	590.0	68.7	526.4

Inflow Volumes

(Calculations assume that outlet structure is inoperable)

50% 6hr-1sq mile PMP volume to South Fly Ash Pond	53.6	ac-ft
Coal yard drainage max pump vol for 6 hrs	11.0	ac-ft
Drainage volume from 38 acre coal yard for 50% 6-hr PMP	30.1	ac-ft
Combined flow volume from 50% 6-hr PMP to South Fly Ash Pond	64.6	ac-ft
Storage in South Fly Ash Pond due to 50% 6-hr PMP	64.6	ac-ft
Assumed initial level (maximum operating pool)	585.0	ft
Initial storage	194.4	ac-ft
Total storage in South Fly Ash Pond	259.0	ac-ft
Max South Fly Ash Pond elevation	586.0	ft
Freeboard	4.0	ft

Table 2: Detailed Calculations for Boiler Slag Pond

Boiler Slag Pond

Drainage Area 30.1 acres

Feature	Elevation (ft)	Surface Area (ac)	Incr Storage (ac-ft)
Principal Spillway	557.0	16.7	0.0
	560.7	19.5	67.0
	570.7	26.3	296.0
	579.7	29.0	544.5
Top of Dam	582.0	29.2	611.4

Inflow Volumes

(Calculations assume that outlet structure is inoperable)

50% 6hr-1sq mile PMP volume	23.8	ac-ft
Storage in Boiler Slag Pond due to 50% 6-hr PMP	23.8	ac-ft
Assumed initial level (maximum operating pool)	558.0	ft
Initial storage (curve fit)	17.7	ac-ft
Total storage in Boiler Slag Pond	41.5	ac-ft
Max Boiler Slag Pond elevation (curve fit)	559.3	ft
Freeboard	22.7	ft

Table 3: Detailed Calculations for Clearwater Pond

Clearwater Pond

Drainage Area 9.99 acres

Feature	Elevation (ft)	Surface Area (ac)	Incremental Storage (ac-ft)	Add Storage Boiler Slag Pond (ac-ft)	Total Storage (ac-ft)
Principal Spillway	552.0	5.7	0.0		0.0
	552.7	5.8	4.0		4.0
	556.7	6.4	28.4		28.4
	557.0	6.4	30.4	0.0	30.4
	560.7	6.9	54.9	67.0	122.0
	570.7	8.2	130.5	296.0	426.5
	579.7	9.6	210.7	544.5	755.2
Top of Dam	582.0	10.3	233.6	611.4	845.0

Inflow Volumes

(Calculations assume that outlet structure is inoperable)

50% 6hr-1sq mile PMP volume from Clearwater Pond	7.9	ac-ft
50% 6hr-1sq mile PMP volume from Boiler Slag Pond	23.8	ac-ft
Initial flow volume in Boiler Slag Pond	17.7	ac-ft
Combined Flow Volume to Clearwater Pond	49.4	ac-ft
Assumed initial level (maximum operating pool)	553.0	ft
Initial storage (curve fit)	5.5	ac-ft
Total storage in Clearwater Pond	54.9	ac-ft
Max Clearwater Pond elevation (curve fit)	558.6	ft
Freeboard	23.4	ft

Table 4: Summary Table of Elevations

Summary Table

Feature	Elevation (ft) – NGVD 29 Normal Pool	Max Operating Pool	50% PMP Elevation	Freeboard (ft) 50% PMP Event	Max Operating Pool	Top of Embankment Elevation(ft) – NGVD 29
South Fly Ash Pond	582.0	585.0	586.0	4.0	5.0	590.0
Boiler Slag Pond	557.0	558.0	559.3	22.7	24.0	582.0
Clearwater Pond	552.0	553.0	558.6	23.4	29.0	582.0

Note: Initial pond elevation for 50% PMP event assumed to be the maximum operating pool

APPENDIX IV

Piezometer Readings and Pool Elevation Data Provided by AEP
A Summary of the Laboratory Testing and the Results of Strength Tests Performed in the 2010 Subsurface Investigation

Table 3 - South Fly Ash Pond Static Water Elevations

Dates	Elevation (ft)					
	KC-1003	KC-1004	KC-1007	KC-1008	KC-1011	KC-1012
8/20/2010	558.09	ND	559.23	Dry	ND	ND
8/23/2010	561.35	ND	559.22	Dry	ND	ND
8/25/2010	561.35	ND	559.28	Dry	ND	ND
8/26/2010	561.43	551.24	559.27	Dry	ND	ND
8/30/2010	561.61	549.95	559.51	Dry	567.31	ND
9/1/2010	561.7	549.96	559.58	Dry	567.23	ND
9/7/2010	561.91	549.64	560.15	Dry	567.09	ND
9/8/2010	561.91	549.63	560.2	Dry	566.96	ND
9/9/2010	561.94	549.64	560.26	Dry	566.89	ND
9/10/2010	562.04	549.57	560.34	Dry	566.89	561.77
9/13/2010	562.24	549.49	560.64	Dry	567.07	561.67
9/14/2010	562.21	549.44	560.72	Dry	566.94	561.71
9/15/2010	562.27	549.43	560.83	Dry	567.04	561.75
5/20/2011	568.49	551.09	569.93	Dry	567.89	561.47
8/19/2011	566.94	ND	ND	Dry	ND	ND
9/27/2011	564.37	550.39	576.73	Dry	567.28	561.39
3/20/2012	567.29	550.46	573.48	Dry	567.18	561.42
6/1/2012	567.32	549.74	572.63	Dry	565.27	561.6
8/3/2012	567.68	549.35	572.65	Dry	564.61	560.78
10/25/2012	570.04	548.89	573.43	554.81	564.77	560.57
2/21/2013	ND	549.99	581.71	557.21	564.99	560.47
5/23/2013	572.59	549.34	576.33	554.01	565.49	560.47
8/16/2013	572.69	549.59	574.63	552.21	566.69	560.77
11/15/2013	572.79	549.79	575.63	Dry	566.79	560.67
3/7/2014	572.39	550.99	576.03	Dry	566.99	560.77
6/12/14	570.89	550.49	570.83	Dry	566.49	560.67
9/9/14	570.79	550.59	571.83	559.81	566.19	560.77

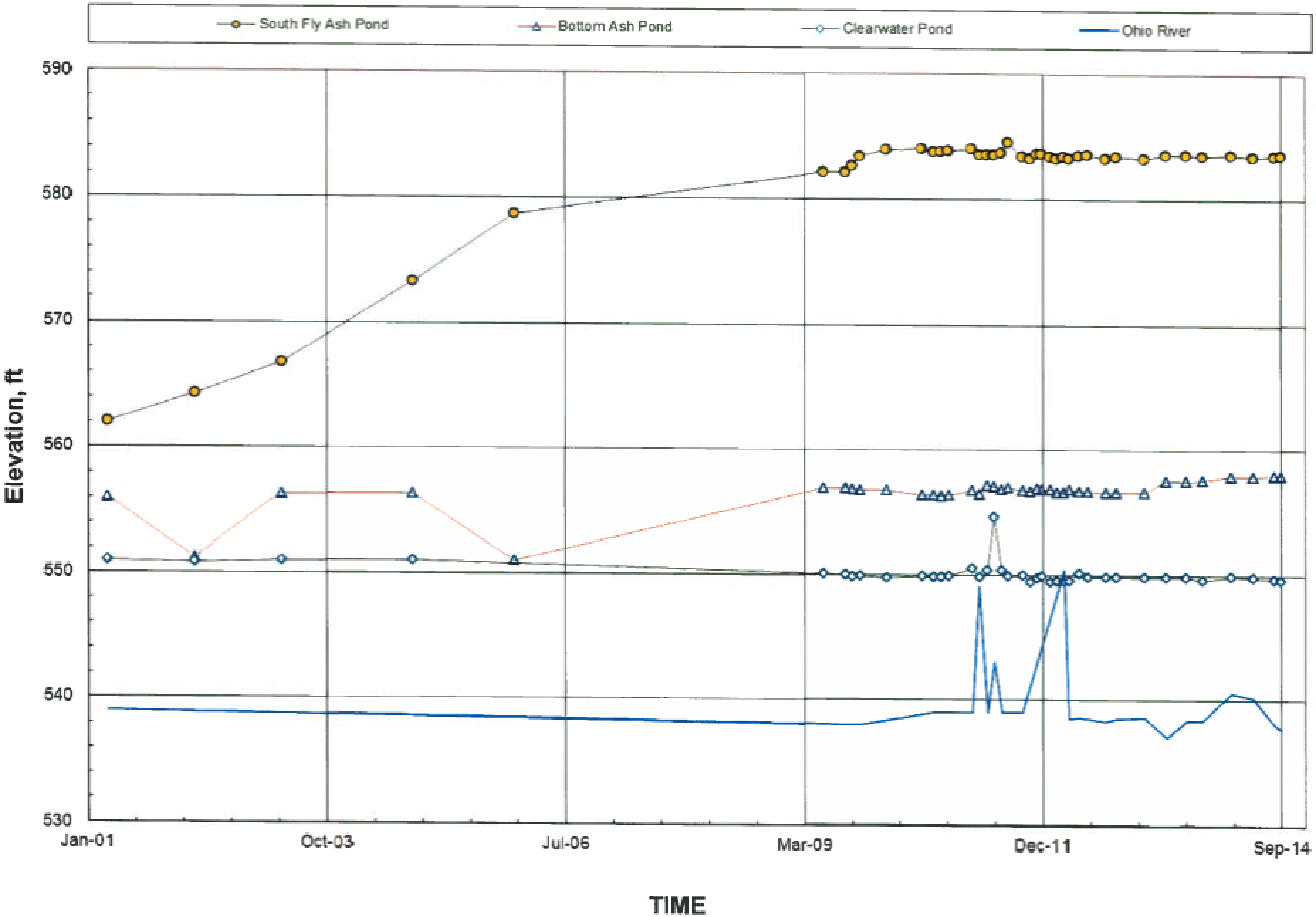


Figure 9 – Ponds Water Elevations

Table 2 - Bottom Ash Pond Static Water Elevations

Dates	Elevation (ft)					
	KC-1015	KC-1016	KC-1017	KC-1018	KC-1021	KC-1022
8/30/2010	ND	ND	ND	ND	539.83	ND
9/1/2010	545.98	ND	ND	ND	539.85	ND
9/7/2010	545.83	ND	535.3	ND	539.76	538.79
9/8/2010	545.86	ND	535.5	530.6	539.73	538.78
9/9/2010	545.82	536.3	535.74	531.85	539.72	538.84
9/10/2010	545.81	538.85	536	533.09	539.75	538.89
9/13/2010	546.02	539.3	537.06	535.85	539.72	539.04
9/14/2010	545.89	539.25	537.29	536.3	539.72	539
9/15/2010	546.02	539.15	537.59	536.7	539.72	538.94
5/20/2011	550.52	ND	549.79	ND	545.32	545.94
6/7/2011	ND	539.15	ND	536.7	ND	ND
9/27/2011	546.97	537.98	546	541.65	540.01	539.36
3/20/2012	547.65	541.1	550.79	537.5	542.38	541.74
6/1/2012	544.75	537.28	549.89	538.9	540.21	539.73
8/3/2012	546.41	536.78	547.41	536.86	539.52	539
10/25/2012	546.02	536.95	548.29	535.05	539.82	538.99
2/21/2013	546.47	539.1	549.39	539.2	541.52	540.14
5/23/2013	545.85	539.27	549.59	534.41	540.22	539.56
8/16/2013	546.67	537.9	548.99	534.8	540.02	539.24
11/15/2013	546.77	538.4	548.69	534.3	539.92	539.34
3/7/2014	548.27	539.5	556.49	539.7	544.22	541.34
6/12/2014	547.07	538.8	551.59	534.2	540.62	535.74
Sep-14	546.47	538.9	551.19	536.5	539.42	538.84

ND - No Data

Bottom Ash Pond is also known as Boiler Slag Pond

Table 1 - SUMMARIZED WATER ELEVATION DATA.

Dates	Elevation (ft)			
	SFAP	BAP	CWP	Ohio River
Apr-01	562	556	551	539
Apr-02	564.25	551.2	550.8	
Apr-03	566.75	556.3	551	
Oct-04	573.31	556.3	551	
Dec-05	578.7	551	ND	
Jun-09	582.18	556.92	550.03	
Sep-09	582.11	556.87	549.97	
Oct-09	582.68	556.8	549.82	
Nov-09	583.43	556.78	549.94	538
Mar-10	583.97	556.72	549.75	
Aug-10	584.01	556.39	549.87	
Sep-10	583.85	556.34	549.79	539
Oct-10	583.8	556.3	549.83	ND
Nov-10	583.86	556.36	549.89	539
Mar-11	584.06	556.76	550.5	539
Apr-11	583.56	556.43	549.83	549
May-11	583.59	557.09	550.33	539
Jun-11	583.56	557.03	554.62	543
Jul-11	583.76	556.84	550.33	539
Aug-11	584.6	556.96	549.91	539
Sep-11	583.41	556.76	549.95	539
Nov-11	583.3	556.68	549.45	
Nov-11	583.66	556.87	549.77	
Dec-11	583.63	556.79	549.9	
Jan-12	583.45	556.8	549.46	
Feb-12	583.3	556.63	549.5	
Mar-12	583.4	556.6	549.51	550.4
Apr-12	583.3	556.8	549.5	538.5
May-12	583.5	556.7	550.1	538.6
Jun-12	583.6	556.7	549.8	538.5
Sep-12	583.3	556.6	549.8	538.3
Oct-12	583.4	556.6	549.8	538.5
Feb-13	583.3	556.6	549.8	538.6
May-13	583.6	557.5	549.8	537
Aug-13	583.6	557.5	549.8	538.4
Oct-13	583.5	557.6	549.6	538.4
Feb-14	583.6	557.9	549.9	540.6
May-14	583.4	557.9	549.8	540.2
Aug-14	583.5	558	549.7	538.1
Sep-14	583.6	558	549.6	537.7

SFAP - South Fly Ash Pond -Crest Elevation :588
BAP - Bottom Ash Pond -Crest Elevation :582
CWP - Clearwater Pond -Crest Elevation :582
ND - No Data

Table 1 - SUMMARIZED WATER ELEVATION DATA.

Dates	Elevation (ft)			
	SFAP	BAP	CWP	Ohio River
Apr-01	562	556	551	539
Apr-02	564.25	551.2	550.8	
Apr-03	566.75	556.3	551	
Oct-04	573.31	556.3	551	
Dec-05	578.7	551	ND	
Jun-09	582.18	556.92	550.03	
Sep-09	582.11	556.87	549.97	
Oct-09	582.68	556.8	549.82	
Nov-09	583.43	556.78	549.94	538
Mar-10	583.97	556.72	549.75	
Aug-10	584.01	556.39	549.87	
Sep-10	583.85	556.34	549.79	539
Oct-10	583.8	556.3	549.83	ND
Nov-10	583.86	556.36	549.89	539
Mar-11	584.06	556.76	550.5	539
Apr-11	583.56	556.43	549.83	549
May-11	583.59	557.09	550.33	539
Jun-11	583.56	557.03	554.62	543
Jul-11	583.76	556.84	550.33	539
Aug-11	584.6	556.96	549.91	539
Sep-11	583.41	556.76	549.95	539
Nov-11	583.3	556.68	549.45	
Nov-11	583.66	556.87	549.77	
Dec-11	583.63	556.79	549.9	
Jan-12	583.45	556.8	549.46	
Feb-12	583.3	556.63	549.5	
Mar-12	583.4	556.6	549.51	550.4
Apr-12	583.3	556.8	549.5	538.5
May-12	583.5	556.7	550.1	538.6
Jun-12	583.6	556.7	549.8	538.5
Sep-12	583.3	556.6	549.8	538.3
Oct-12	583.4	556.6	549.8	538.5
Feb-13	583.3	556.6	549.8	538.6
May-13	583.6	557.5	549.8	537
Aug-13	583.6	557.5	549.8	538.4
Oct-13	583.5	557.6	549.6	538.4
Feb-14	583.6	557.9	549.9	540.6
May-14	583.4	557.9	549.8	540.2
Aug-14	583.5	558	549.7	538.1
Sep-14	583.6	558	549.6	537.7

SFAP - South Fly Ash Pond -Crest Elevation :588
BAP - Bottom Ash Pond -Crest Elevation :582
CWP - Clearwater Pond -Crest Elevation :582
ND - No Data

Bottom Ash Pond is also known as Boiler Slag Pond

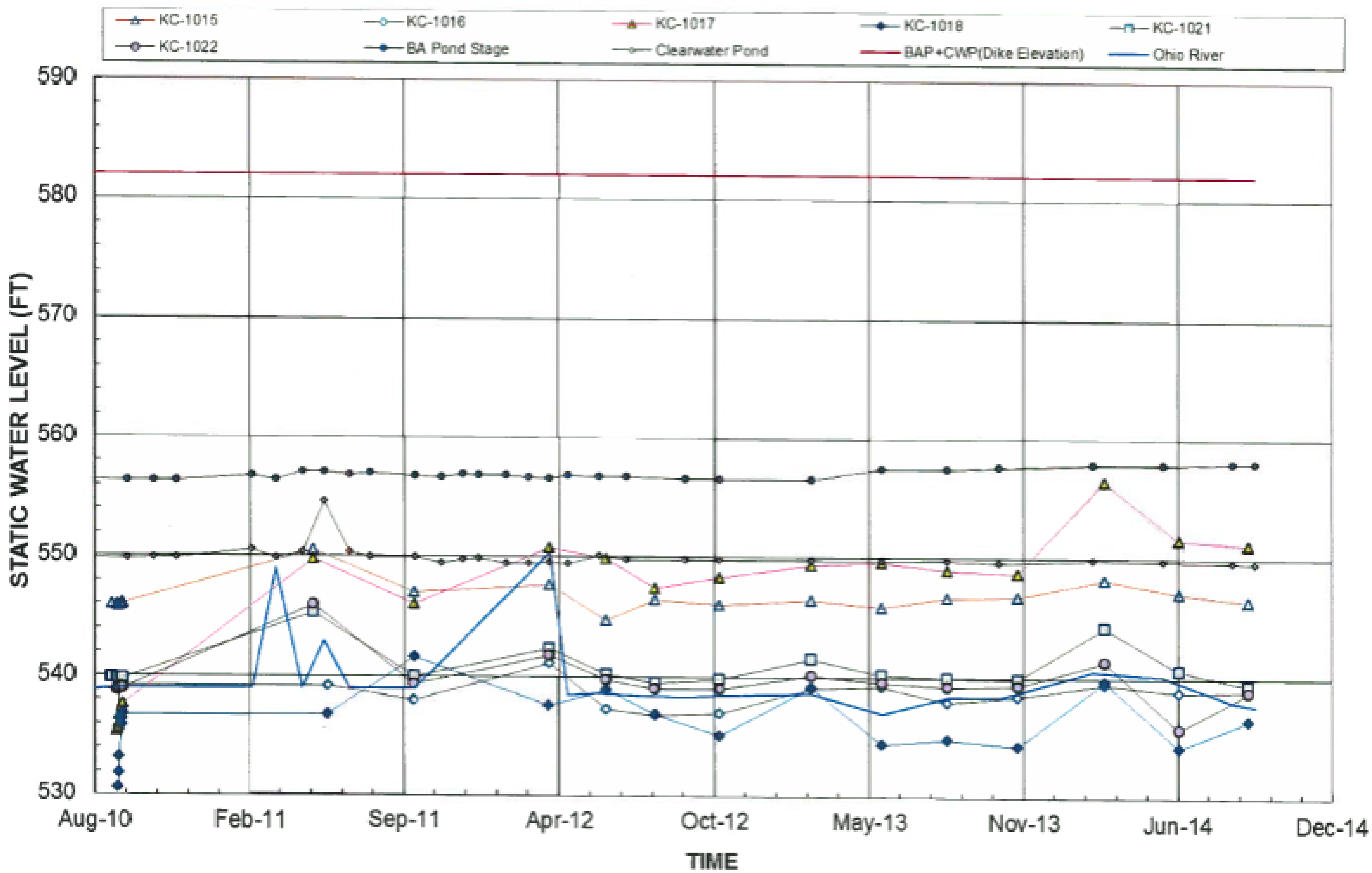


Figure 12 – Bottom Ash Pond Static Water Elevations

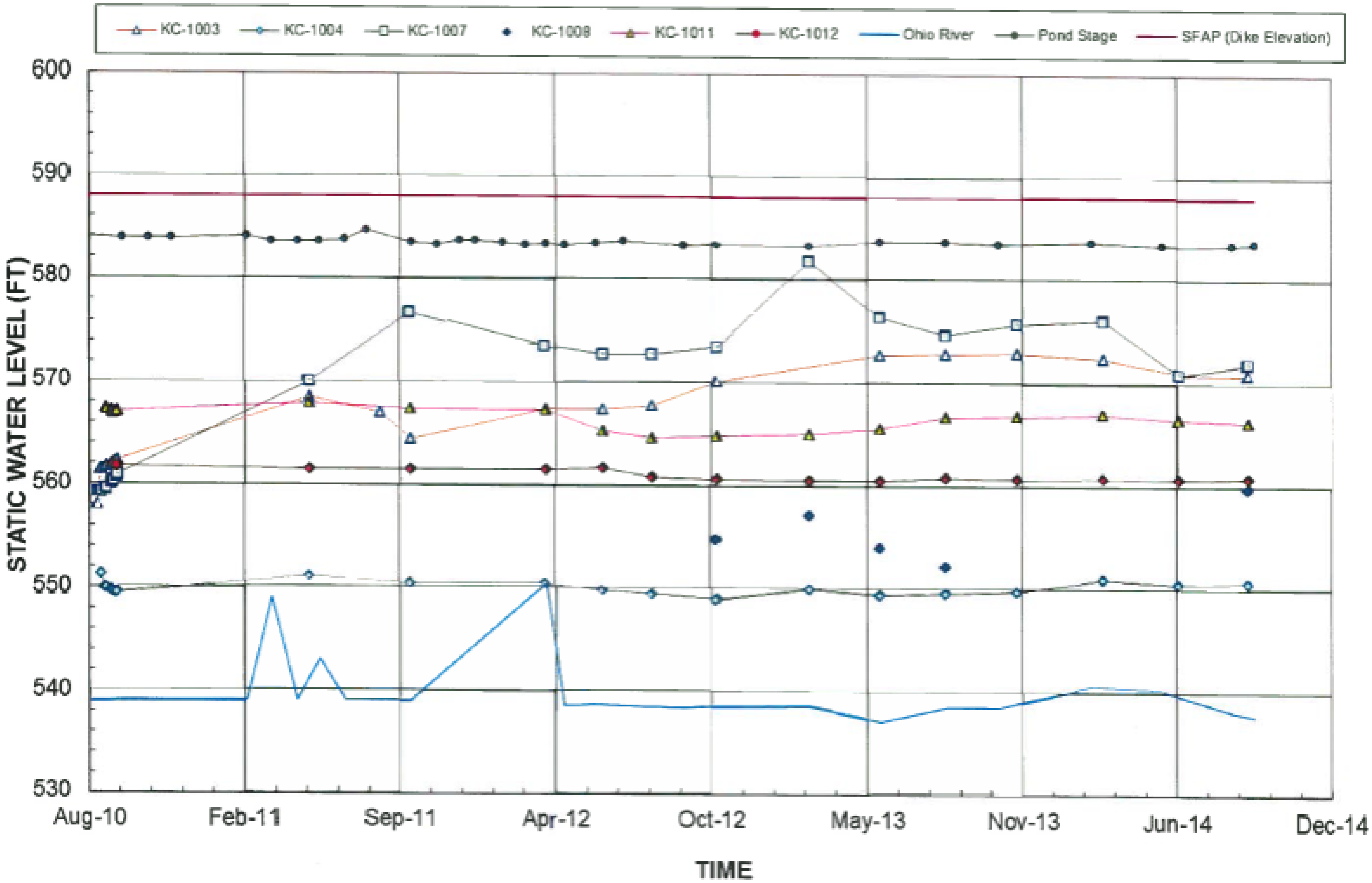


Figure 13 – South Fly Ash Pond Static Water Elevations

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American Electric Power Service Corporation
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Columbus, OH 43215
PH: (614) 716-2241
Audinet: 200-2241

Table 3 - South Fly Ash Pond Static Water Elevations

Dates	Elevation (ft)					
	KC-1003	KC-1004	KC-1007	KC-1008	KC-1011	KC-1012
8/20/2010	558.09	ND	559.23	Dry	ND	ND
8/23/2010	561.35	ND	559.22	Dry	ND	ND
8/25/2010	561.35	ND	559.28	Dry	ND	ND
8/26/2010	561.43	551.24	559.27	Dry	ND	ND
8/30/2010	561.61	549.95	559.51	Dry	567.31	ND
9/1/2010	561.7	549.96	559.58	Dry	567.23	ND
9/7/2010	561.91	549.64	560.15	Dry	567.09	ND
9/8/2010	561.91	549.63	560.2	Dry	566.96	ND
9/9/2010	561.94	549.64	560.26	Dry	566.89	ND
9/10/2010	562.04	549.57	560.34	Dry	566.89	561.77
9/13/2010	562.24	549.49	560.64	Dry	567.07	561.67
9/14/2010	562.21	549.44	560.72	Dry	566.94	561.71
9/15/2010	562.27	549.43	560.83	Dry	567.04	561.75
5/20/2011	568.49	551.09	569.93	Dry	567.89	561.47
8/19/2011	566.94	ND	ND	Dry	ND	ND
9/27/2011	564.37	550.39	576.73	Dry	567.28	561.39
3/20/2012	567.29	550.46	573.48	Dry	567.18	561.42
6/1/2012	567.32	549.74	572.63	Dry	565.27	561.6
8/3/2012	567.68	549.35	572.65	Dry	564.61	560.78
10/25/2012	570.04	548.89	573.43	554.81	564.77	560.57
2/21/2013	ND	549.99	581.71	557.21	564.99	560.47
5/23/2013	572.59	549.34	576.33	554.01	565.49	560.47
8/16/2013	572.69	549.59	574.63	552.21	566.69	560.77
11/15/2013	572.79	549.79	575.63	Dry	566.79	560.67
3/7/2014	572.39	550.99	576.03	Dry	566.99	560.77
6/12/14	570.89	550.49	570.83	Dry	566.49	560.67
9/9/14	570.79	550.59	571.83	559.81	566.19	560.77

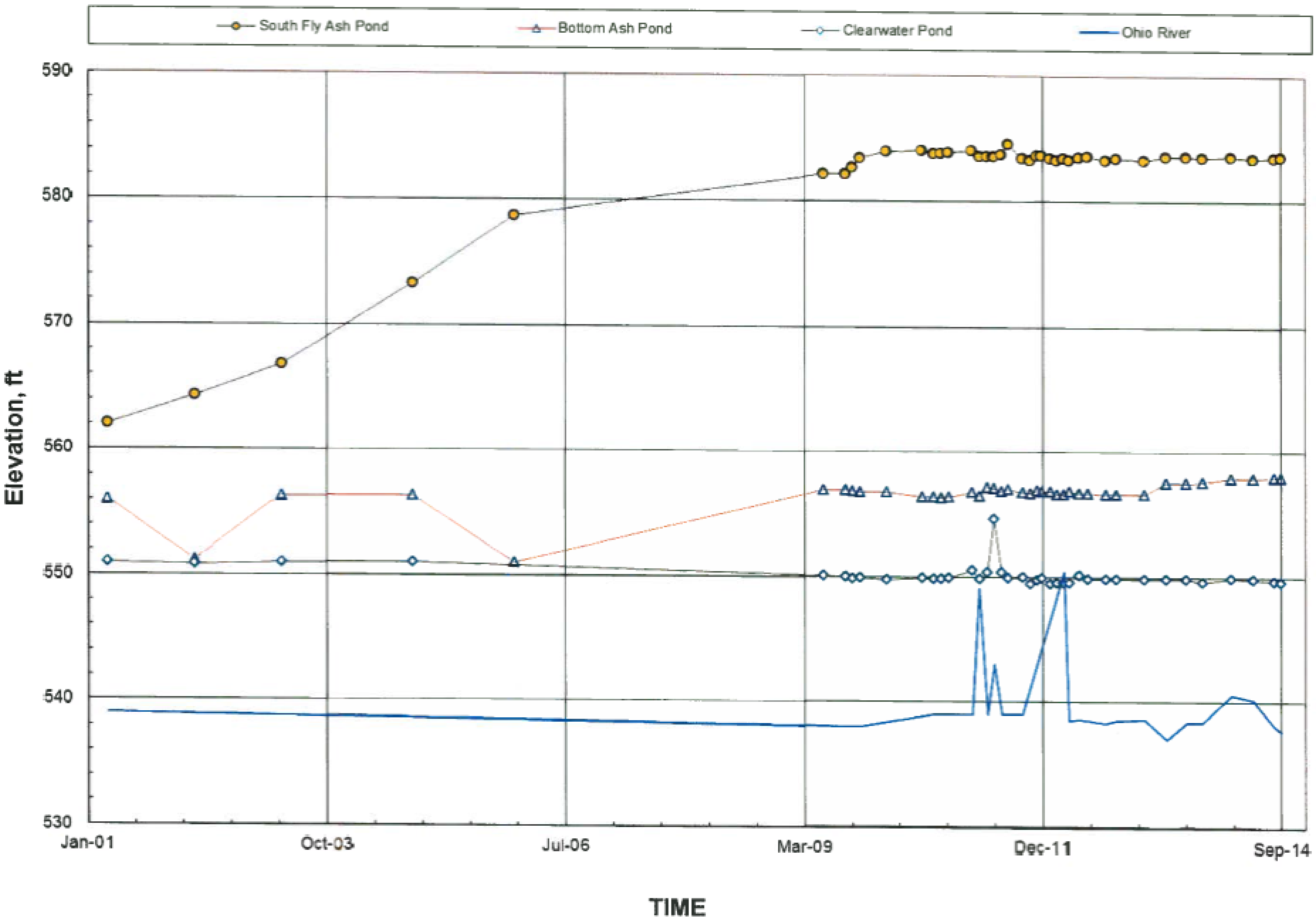
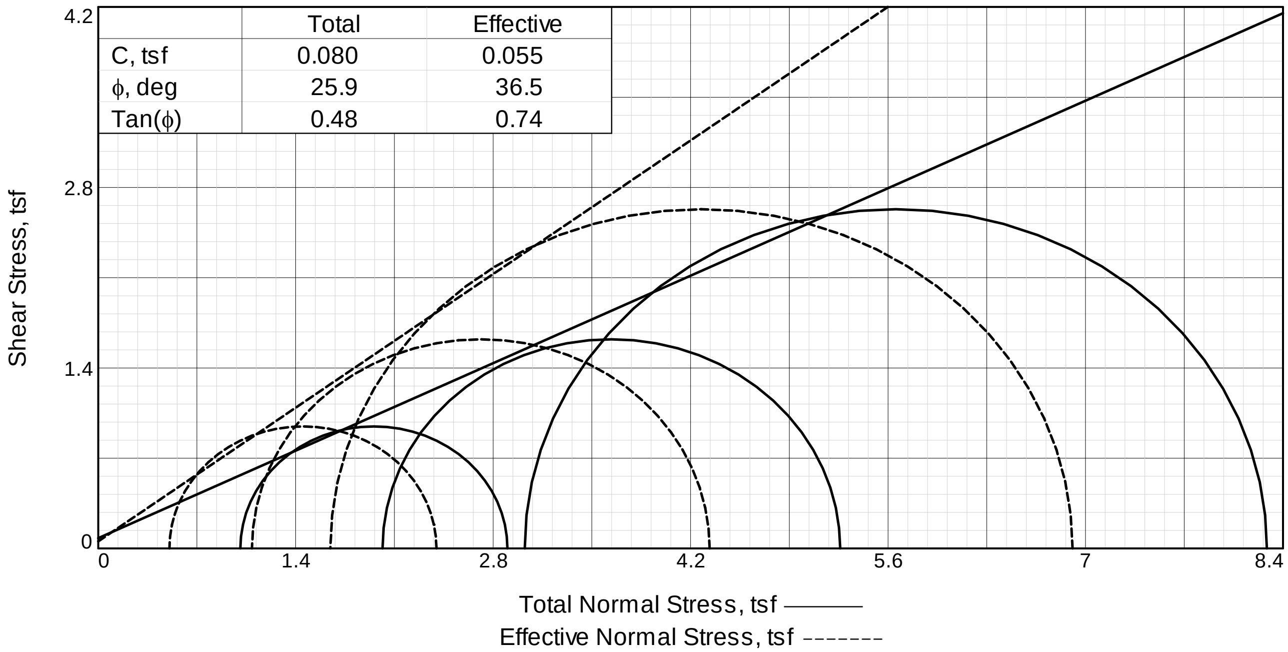
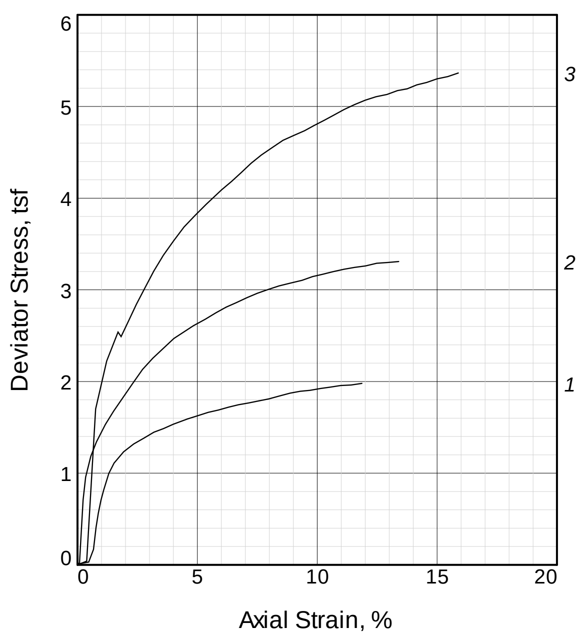


Figure 9 – Ponds Water Elevations





Sample No.		1	2	3
Initial	Water Content,	23.0	22.9	22.0
	Dry Density, pcf	101.6	105.5	106.0
	Saturation,	91.8	100.4	98.0
	Void Ratio	0.6899	0.6267	0.6189
	Diameter, in.	2.82	2.83	2.83
	Height, in.	5.53	5.26	5.53
At Test	Water Content,	24.6	21.4	19.6
	Dry Density, pcf	102.5	108.1	111.6
	Saturation,	100.0	100.0	100.0
	Void Ratio	0.6756	0.5884	0.5385
	Diameter, in.	2.81	2.81	2.78
	Height, in.	5.51	5.22	5.43
Strain rate, in./min.		0.01	0.01	0.01
Back Pressure, tsf		1.30	1.30	1.30
Cell Pressure, tsf		2.30	3.31	4.32
Fail. Stress, tsf		1.89	3.24	5.26
Total Pore Pr., tsf		1.80	2.22	2.67
Ult. Stress, tsf		1.98	3.31	5.37
Total Pore Pr., tsf		1.75	2.11	2.59
$\overline{\sigma}_1$ Failure, tsf		2.40	4.33	6.91
$\overline{\sigma}_3$ Failure, tsf		0.50	1.09	1.65

Type of Test:
CU with Pore Pressures

Sample Type: 3" press tube

Description: Light brown lean clay, damp, decreasing moisture with increasing depth, stiff at

LL= 34 **PL=** 20 **PI=** 14

Specific Gravity= 2.75

Remarks: Actual strain rate = 0.0120 in/min.

Figure ________

Client: OVEC/AEP

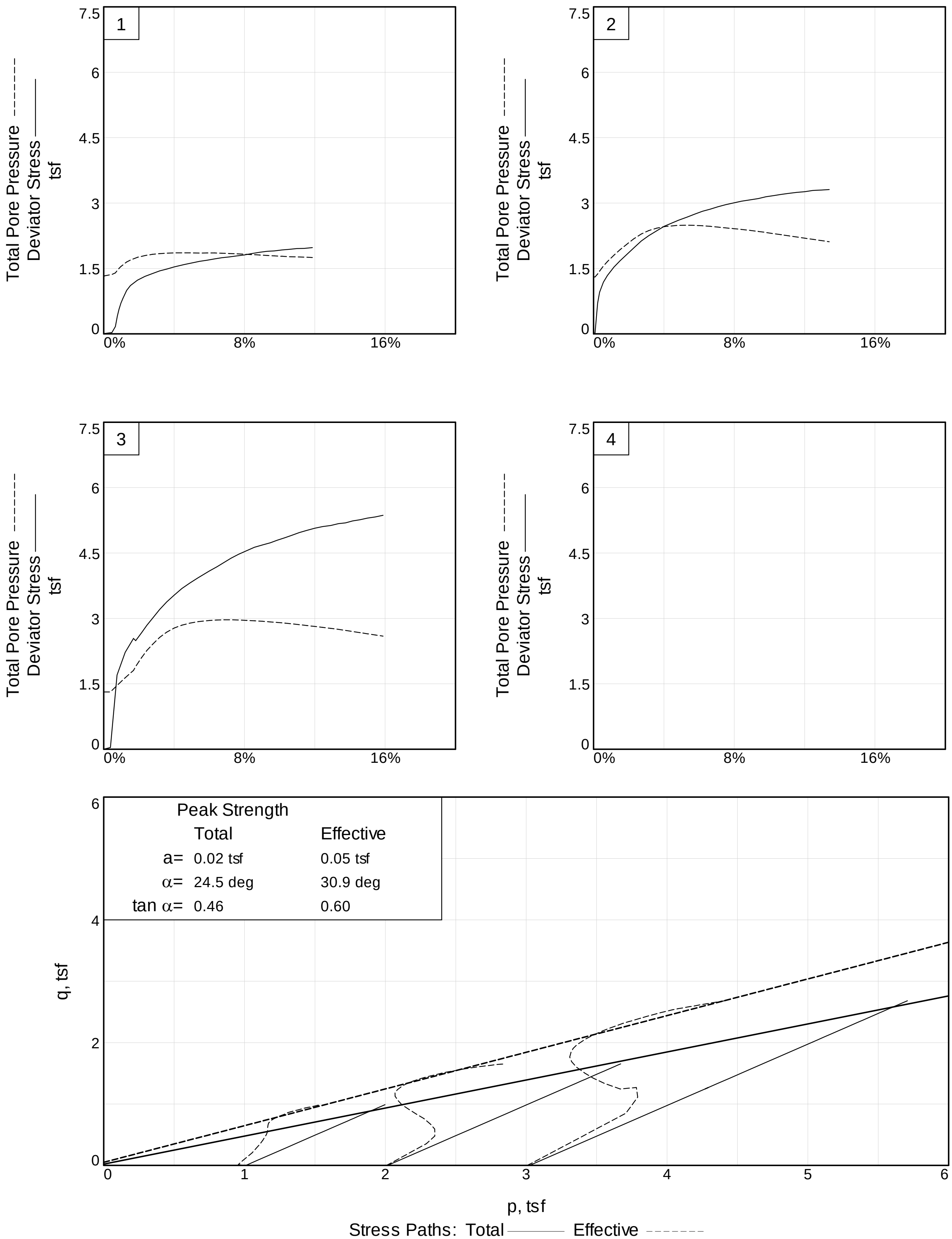
Project: OVEC: Kyger Creek - Ash Inpoundment Stability Analysis
DLZ Project No: 1021-3003.00

Source of Sample: KC-1001 **Depth:** 28.5'-30.0'

Sample Number: ST-2

Proj. No.: 1021-3003.00 **Date:** 9/30/2010

DLZ



	Peak Strength	
	Total	Effective
a=	0.02 tsf	0.05 tsf
α=	24.5 deg	30.9 deg
tan α=	0.46	0.60

Client: OVEC/AEP

Project: OVEC: Kyger Creek - Ash Inpoundment Stability Analysis

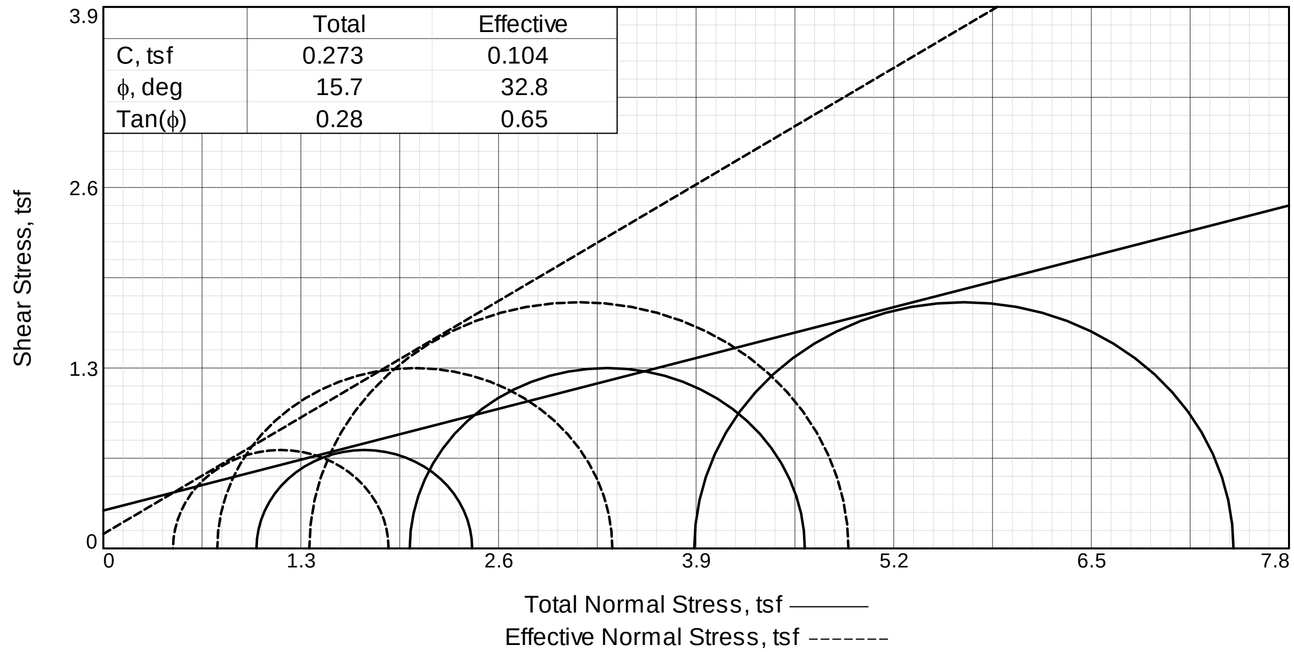
Source of Sample: KC-1001 **Depth:** 28.5'-30.0' **Sample Number:** ST-2

Project No.: 1021-3003.00 **Figure** ________

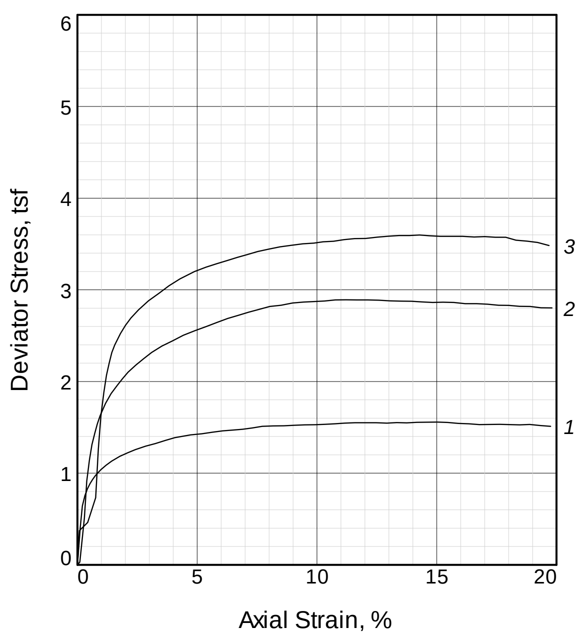
DLZ, INC.

KYGER CREEK - SUMMARY OF RESULTS OF LABORATORY TESTING

						Soil Classification		Particle Size Distribution				Atterberg Limits			Percent		Hand	Permea-	Consolidation-Undrained Parameters			
Location	Cross-section No.	Boring No.	Sample No.	Depth, ft	Elevation, ft	Textural	USCS	Percent Gravel	Percent Sand	Percent Silt	Percent Clay	Liquid Limit, LL	Plastic Limit, PL	Plasticity Index, PI	Moisture, Wc	N60 N-values	Penetro-meter,tsf	bility cm/sec	C, psf	ϕ, degree	C', psf	ϕ', degree
South Fly Ash Pond	1	KC-1001	ST-2	28.5	560.8	Lean Clay	CL	0	8	47	45	34	20	14	23	N/A	2.5		160	25.9	110	36.5
South Fly Ash Pond	1	KC-1001	S-17	46	543.3	Lean Clay	CL	0	8	58	34	34	20	14	29.5	5	1.5					
South Fly Ash Pond	1	KC-1001	S-19	53.5	535.8	Sand with gravel	SW	42	56	3	0		Non-plastic		8.9	59	N/A					
South Fly Ash Pond	1	KC-1002	ST-1	8.5	549.8	Sandy Lean Clay	CL	0	16	52	32	32	13	19	25.8	N/A	--					
South Fly Ash Pond	1	KC-1002	S-15	33.5	525.3	Sand with silt with gravel	SW-SM	45	47	8	0		Non-plastic		9.9	56	N/A					
South Fly Ash Pond	1	KC-1002	S-19	43.5	514.8	Sand with silt with gravel	SP-SM	18	75	7	0		Non-plastic		16.5	19	N/A					
South Fly Ash Pond	1	KC-1002	S-21	48.5	509.8	Sand	SW	4	96	0	0		Non-plastic		19.7	23	N/A					
South Fly Ash Pond	2	KC-1003	S-7	16	572.4	Lean Clay	CL	0	24	45	31	30	18	12	19.5	11	2.25					
South Fly Ash Pond	2	KC-1003	ST-2	31	557.4	Lean Clay	CL	0	17	47	36	31	18	13	18.6	N/A	4	1.8x10-7				
South Fly Ash Pond	2	KC-1003	S-19	53.5	534.9	Lean Clay with sand	CL	0	17	50	33	31	21	10	33.7	4	0.5					
South Fly Ash Pond	2	KC-1004	S-8	16	539.8	Lean Clay with sand	CL	0	20	51	29	32	19	13	28.3	1	0.75					
South Fly Ash Pond	2	KC-1004	S-12	26	529.3	Sand with silt with gravel	SW-SM	40	54	6	0		Non-plastic		10.8	69	N/A					
South Fly Ash Pond	2	KC-1004	S-15	33.5	521.8	Sand with gravel	SW	33	65	2	0		Non-plastic		14.9	16	N/A					
South Fly Ash Pond	3	KC-1005	ST-2	18.5	569.7	Lean Clay	CL	0	13	48	39	37	21	16	21	N/A	4	4.5x10-8				
South Fly Ash Pond	3	KC-1005	S-18	48.5	540.2	Sandy Silty Clay	CL-ML	0	30	46	24	25	21	4	25.3	4	0.25					
South Fly Ash Pond	3	KC-1005	S-19	53.5	534.7	Silty Clay with sand	CL-ML	0	26	51	23	26	19	7	32.1	2	0.25					
South Fly Ash Pond	3	KC-1006	S-7	13.5	563.4	Lean Clay	CL	0	10	42	48	41	21	20	24.2	10	2.5					
South Fly Ash Pond	3	KC-1006	S-14	31	545.4	Lean Clay with sand	CL	0	20	45	35	48	20	28	23.2	12	1.5					
South Fly Ash Pond	4	KC-1007	S-7	16	573	Lean Clay	CL	0	13	44	43	39	22	17	24.9	13	3.00					
South Fly Ash Pond	4	KC-1007	S-19	46	543.5	Lean Clay with sand	CL	0	22	52	26	28	18	10	26	7	0.5					
South Fly Ash Pond	4	KC-1007	S-23	63.5	526	Sand with silt with gravel	SW-SM	33	58	9	0		Non-plastic			64	N/A					
South Fly Ash Pond	4	KC-1008	S-5	6	574.9	Lean Clay	CL	0	5	53	42	40	22	17	24.4	17	3.5					
South Fly Ash Pond	4	KC-1008	S-11	21	559.9	Lean Clay	CL	0	6	47	47	41	22	19	24.5	14	3.5					
South Fly Ash Pond	4	KC-1008	S-18	38.5	542.4	Sandy Lean Clay	CL	0	35	43	22	24	16	8	25.5	6	0.5					
South Fly Ash Pond	5	KC-1009	ST-1	16	573.2	Lean Clay	CL	0	29	36	35	32	18	14	21.5	N/A	2.25	1.9x10-8				
South Fly Ash Pond	5	KC-1009	ST-2	26	563.2	Lean Clay	CL	0	7	52	41	38	22	16	22.9	N/A	4					
South Fly Ash Pond	5	KC-1009	S-19	53.5	535.7	Sandy Lean Clay	CL	0	31	45	24	28	20	8	27.4	4	0.5					
South Fly Ash Pond	5	KC-1010	S-5	6	559.1	Lean Clay with sand	CL	0	4	58	38	36	20	16	22.8	10	1.75					
South Fly Ash Pond	5	KC-1010	S-11	23.5	541.6	Sandy Lean Clay	CL	0	44	35	20	24	18	6	25.2	5	0.5					
South Fly Ash Pond	5	KC-1010	ST-2	31	534.1	Sandy Lean Clay	CL	0	31	50	19	29.4	26	18	8	N/A	0.75	1.8x10-7				
South Fly Ash Pond	5	KC-1010	S-16	41	524.1	Gravel	Gw	54	43	3	0		Non-plastic		11.5	47	N/A					
South Fly Ash Pond	5	KC-1010	S-17	43.5	521.6	Sand with silt with gravel	SW-SM	23	70	7	0		Non-plastic		13.9	23	N/A					
South Fly Ash Pond	6	KC-1011	S-5	11	578.2	Lean Clay	CL	0	11	55	34	34	20	14	22.2	8	2.00					
South Fly Ash Pond	6	KC-1011	S-16	38.5	550.7	Lean Clay with sand	CL	0	15	51	34	33	19	14	26.4	8	1.25					
South Fly Ash Pond	6	KC-1011	S-20	48.5	540.7	Sandy Silt	ML	0	42	38	20		Non-plastic		29.7	2	N/A					
South Fly Ash Pond	6	KC-1011	S-23	63.5	525.7	Sand with silt with gravel	SW-SM	20	68	12	0		Non-plastic		13.7	25	N/A					
South Fly Ash Pond	6	KC-1011	S-24	68.5	520.7	Sand with silt with gravel	SP-SM	15	79	6	0		Non-plastic		17.5	16	N/A					
South Fly Ash Pond	6	KC-1012	S-5	6	557	Lean Clay with sand	CL	0	1	56	43	41	22	19	25.3	10	2.00					
South Fly Ash Pond	6	KC-1012	ST-2	21	542	Sandy Lean Clay	CL	0	35	43	22	26	19	7	25.7	N/A	--		546	15.7	208	32.8
South Fly Ash Pond	6	KC-1012	S-13	33.5	529.5	Sandy Gravel	GP	59	37	4	0		Non-plastic		13.9	27	N/A					
Bottom Ash Pond	1	KC-1013	S-5	11	570.3	Lean Clay with sand	CL	2	8	52	38	37	21	16	25.9	7	3					
Bottom Ash Pond	1	KC-1013	S-18	48.5	532.8	Sandy Lean Clay	CL	0	23	47	30	30	18	12	28	7	0.75					
Bottom Ash Pond	1	KC-1013	S-19	53.5	527.8	Sandy Silt	ML	0	44	36	20		Non-plastic			2	N/A					
Bottom Ash Pond	1	KC-1014	ST-1	11	547.6	Lean Clay	CL	0	2	57	41	40	22	18	25.7	N/A	2.25	$2.2x10^{-8}$				
Bottom Ash Pond	1	KC-1014	S-13	31	527.6	Sandy Lean Clay	CL	0	32	43	25	25	16	9	26.9	5	0.25					
Bottom Ash Pond	1	KC-1014	S-16	38.5	520.1	Gravel with silt with sand	GW-GM	52	42	6	0		Non-plastic		8.7	60	N/A					
Bottom Ash Pond	2	KC-1015	S-6	13.5	566.9	Sandy Lean Clay	CL	0	12	54	34	34	20	14	21.1	11	2.75					
Bottom Ash Pond	2	KC-1015	S-16	46	534.4	Sandy Lean Clay	CL	0	32	44	24	28	19	9	25.5	1	0.5					
Bottom Ash Pond	2	KC-1015	S-19	58.5	521.9	Sand with silt with gravel	SW-SM	43	51	6	0		Non-plastic		13.4	40	N/A					
Bottom Ash Pond	2	KC-1016	ST-1	8.5	535.3	Lean Clay with sand	CL	0	1	54	45	40	22	18	34.4	N/A	--		356	16.2	276	32.2
Bottom Ash Pond	2	KC-1016	S-12	26	517.8	Sand with silt with gravel	SW-SM	34	60	6	0		Non-plastic		16.1	19	N/A					
Bottom Ash Pond	2	KC-1016	S-13	28.5	515.3	Gravel with sand	GW	53	44	3	0		Non-plastic		10.8	16	N/A					
Clearwater Pond	3	KC-1017	ST-1	18.5	561.6	Sandy Lean Clay	CL	0	23	46	31	29	18	11	22.4	N/A	1.5		356	20.3	216	37.2
Clearwater Pond	3	KC-1017	S-15	41	539.1	Lean Clay	CL	0	3	51	46	42	25	17	31.9	7	1					
Clearwater Pond	3	KC-1017	S-19	53.5	526.6	Sandy Lean Clay	CL	0	18	54	28	33	20	13	27.3	1	0.75					
Clearwater Pond	3	KC-1018	ST-1	8.5	538.8	Lean Clay	CL	0	4	53	43	44	24	20	21.8	N/A	4.5	$9.3x10^{-6}$				
Clearwater Pond	3	KC-1018	S-9	18.5	529.3	Lean Clay	CL	0	5	63	32	36	21	15	30.5	0	0.25					
Clearwater Pond	3	KC-1018	S-13	31	516.3	Sandy Silt	ML	0	48	39	13		Non-plastic		33	5	N/A					
Clearwater Pond	3	KC-1018	S-14	33.5	513.8	Sand with silt	SW-SM	1	88	11	0		Non-plastic		21.7	5	N/A					
Clearwater Pond	3	KC-1018	S-16	38.5	508.8	Gravel with silt with sand	GP-GM	52	38	10	0		Non-plastic		16.3	13	N/A					
Clearwater Pond	3	KC-1018	S-19	46	501.3	Sand with gravel	SW	38	59	3	0		Non-plastic		12.9	19	N/A					
Clearwater Pond	4	KC-1019	S-8	21	559.7	Lean Clay	CL	0	13	51	36	33	20	13	23.9	8	1.25					
Clearwater Pond	4	KC-1019	ST-2	26	554.7	Sandy Silt	ML	0	38	38	24	21	18	3	22	N/A	0	$3.3x10^{-4}$				
Clearwater Pond	4	KC-1019	S-19	53.5	527.2	Sand with silt	SP-SM	0	90	10	0		Non-plastic		26.9	11	N/A					
Clearwater Pond	4	KC-1020	S-5	6	553.5	Lean Clay	CL	0	7	58	35	38	22	17	23.1	7	2					
Clearwater Pond	4	KC-1020	S-7	16	543.5	Sandy Lean Clay	CL	0	19	54	27	32	20	12	23.7	6	1					
Clearwater Pond	4	KC-1020	S-12	28.5	531	Sandy Lean Clay	CL	0	30	46	24	28	17	11	25.4	1	1					
Clearwater Pond	4	KC-1020	S-14	36	523.5	Silty Sand	SM	0	86	14	0		Non-plastic		28.6	7	N/A					
Bottom Ash Pond	5	KC-1021	ST-1	18.5	561.7	Sandy Lean Clay	CL	0	21	46	33	32	20	12	21.4	N/A	2.5	$8x10^{-8}$				
Bottom Ash Pond	5	KC-1021	S-15	41	539.2	Sandy Lean Clay	CL	0	34	46	20	28	19	9	25.6	0	0.75					
Bottom Ash Pond	5	KC-1021	S-20	58.5	521.7	Silty Sand	SM	0	87	13	0		Non-plastic		27.8	13	N/A					
Bottom Ash Pond	5	KC-1022	S-4	4.5	558.2	Sandy Silty Clay	CL-ML	0	41	40	19	22	18	4	15.2	13	1					
Bottom Ash Pond	5	KC-1022	S-7	16	546.7	Sandy Lean Clay	CL	0	40	38	22	25	17	8	18.1	6	1.5					
Bottom Ash Pond	5	KC-1022	S-13	33.5	529.2	Silty Sand	SM	0	81	19	0		Non-plastic		29.6	2	N/A					
Bottom Ash Pond	5	KC-1022	S-14	36	526.7	Silty Sand	SM	0	75	25			Non-plastic		26.6	8	N/A					



	Total	Effective
C, tsf	0.273	0.104
ϕ, deg	15.7	32.8
Tan(ϕ)	0.28	0.65



Sample No.		1	2	3
Initial	Water Content,	28.6	28.6	28.6
	Dry Density, pcf	96.3	96.0	96.4
	Saturation,	100.6	99.8	100.7
	Void Ratio	0.7826	0.7884	0.7818
	Diameter, in.	2.85	2.84	2.84
	Height, in.	5.53	5.27	5.48
At Test	Water Content,	25.2	25.9	22.4
	Dry Density, pcf	101.4	100.2	106.3
	Saturation,	100.0	100.0	100.0
	Void Ratio	0.6925	0.7128	0.6147
	Diameter, in.	2.79	2.80	2.76
	Height, in.	5.48	5.19	5.25
Strain rate, in./min.		0.01	0.01	0.01
Back Pressure, tsf		2.59	2.59	2.59
Cell Pressure, tsf		3.60	4.61	6.48
Fail. Stress, tsf		1.42	2.60	3.55
Total Pore Pr., tsf		3.14	3.86	5.12
Ult. Stress, tsf		1.42	2.60	3.55
Total Pore Pr., tsf		3.14	3.86	5.12
$\bar{\sigma}_1$ Failure, tsf		1.88	3.35	4.90
$\bar{\sigma}_3$ Failure, tsf		0.46	0.75	1.36

Type of Test:
CU with Pore Pressures

Sample Type: 3" press tube

Description:

Specific Gravity= 2.75

Remarks: Actual strain rate = 0.0120 in/min

Figure ________

Client: OVEC/AEP

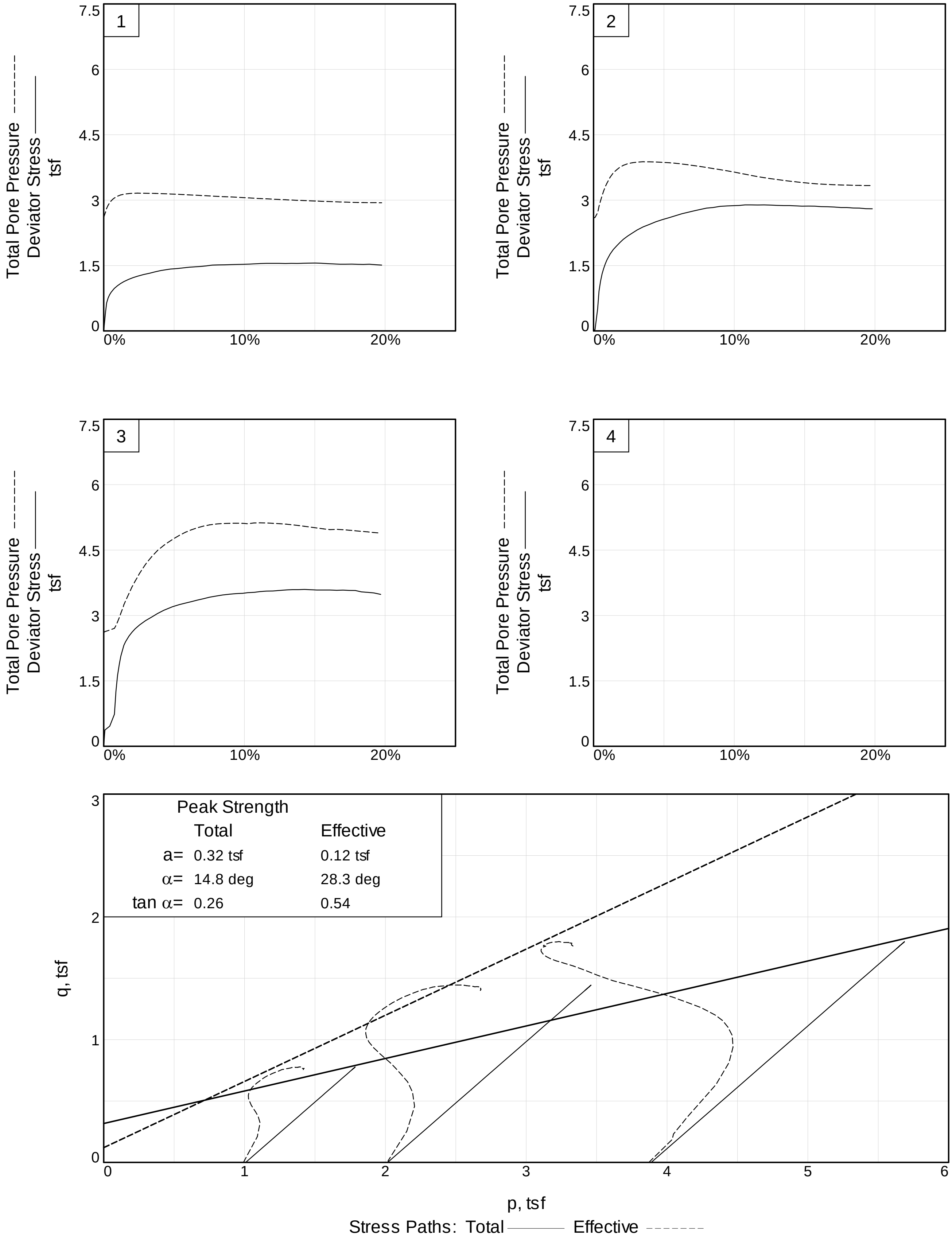
Project: OVEC: Kyger Creek - Ash Inpoundment Stability Analysis
DLZ Project No: 1021-3003.00

Source of Sample: KC-1012 **Depth:** 21.0'-23.0'

Sample Number: ST-2

Proj. No.: 1021-3003.00 **Date:**

DLZ



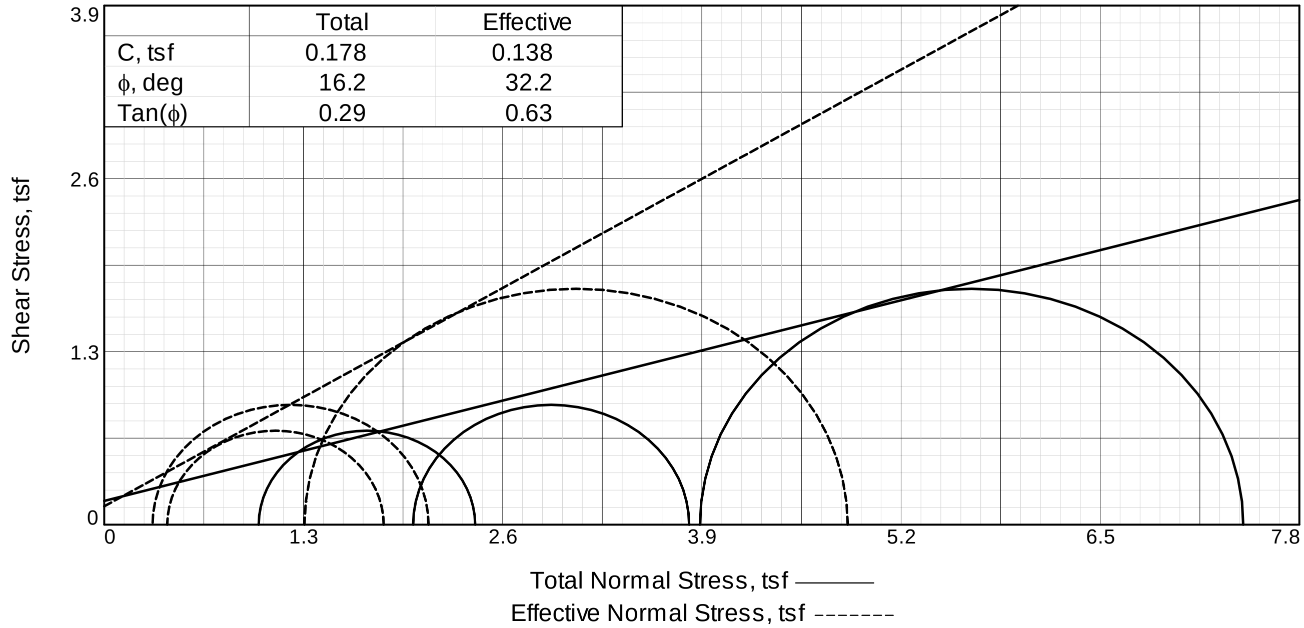
Client: OVEC/AEP

Project: OVEC: Kyger Creek - Ash Inpoundment Stability Analysis

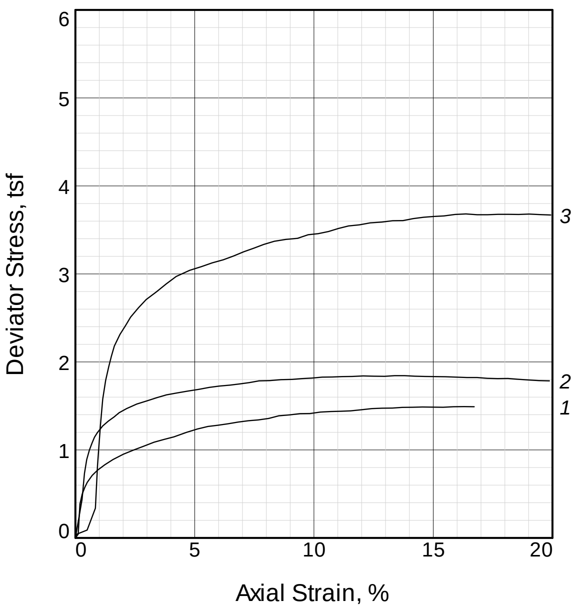
Source of Sample: KC-1012 **Depth:** 21.0'-23.0' **Sample Number:** ST-2

Project No.: 1021-3003.00 **Figure** ________

DLZ, INC.



	Total	Effective
C, tsf	0.178	0.138
ϕ, deg	16.2	32.2
Tan(ϕ)	0.29	0.63



	Sample No.	1	2	3
Initial	Water Content,	35.1	35.5	30.8
	Dry Density, pcf	87.6	86.8	92.3
	Saturation,	100.5	99.8	98.4
	Void Ratio	0.9607	0.9784	0.8607
	Diameter, in.	2.82	2.83	2.83
	Height, in.	5.52	5.50	5.44
At Test	Water Content,	31.6	30.4	26.5
	Dry Density, pcf	91.8	93.5	99.3
	Saturation,	100.0	100.0	100.0
	Void Ratio	0.8692	0.8371	0.7288
	Diameter, in.	2.76	2.75	2.77
	Height, in.	5.46	5.43	5.28
	Strain rate, in./min.	0.01	0.01	0.01
	Back Pressure, tsf	2.59	2.59	2.59
	Cell Pressure, tsf	3.60	4.61	6.48
	Fail. Stress, tsf	1.41	1.80	3.55
	Total Pore Pr., tsf	3.19	4.29	5.17
	Ult. Stress, tsf	1.41	1.80	3.55
	Total Pore Pr., tsf	3.19	4.29	5.17
	$\bar{\sigma}_1$ Failure, tsf	1.82	2.12	4.85
	$\bar{\sigma}_3$ Failure, tsf	0.41	0.32	1.31

Type of Test:
CU with Pore Pressures

Sample Type: 3" press tube

Description: Light brown lean clay (CL) Very stiff @ top & middle to stiff @ bottom, damp

LL= 40 **PL=** 22 **PI=** 18

Assumed Specific Gravity= 2.75

Remarks: Actual strain rate = 0.055 in/min.
Hand Penetrometer: Top = 2.25 TSF
Middle = 2.50 TSF
Bottom = 1.25 TSF

Figure ________

Client: OVEC/AEP

Project: OVEC: Kyger Creek - Ash Inpoundment Stability Analysis
DLZ Project No: 1021-3003.00

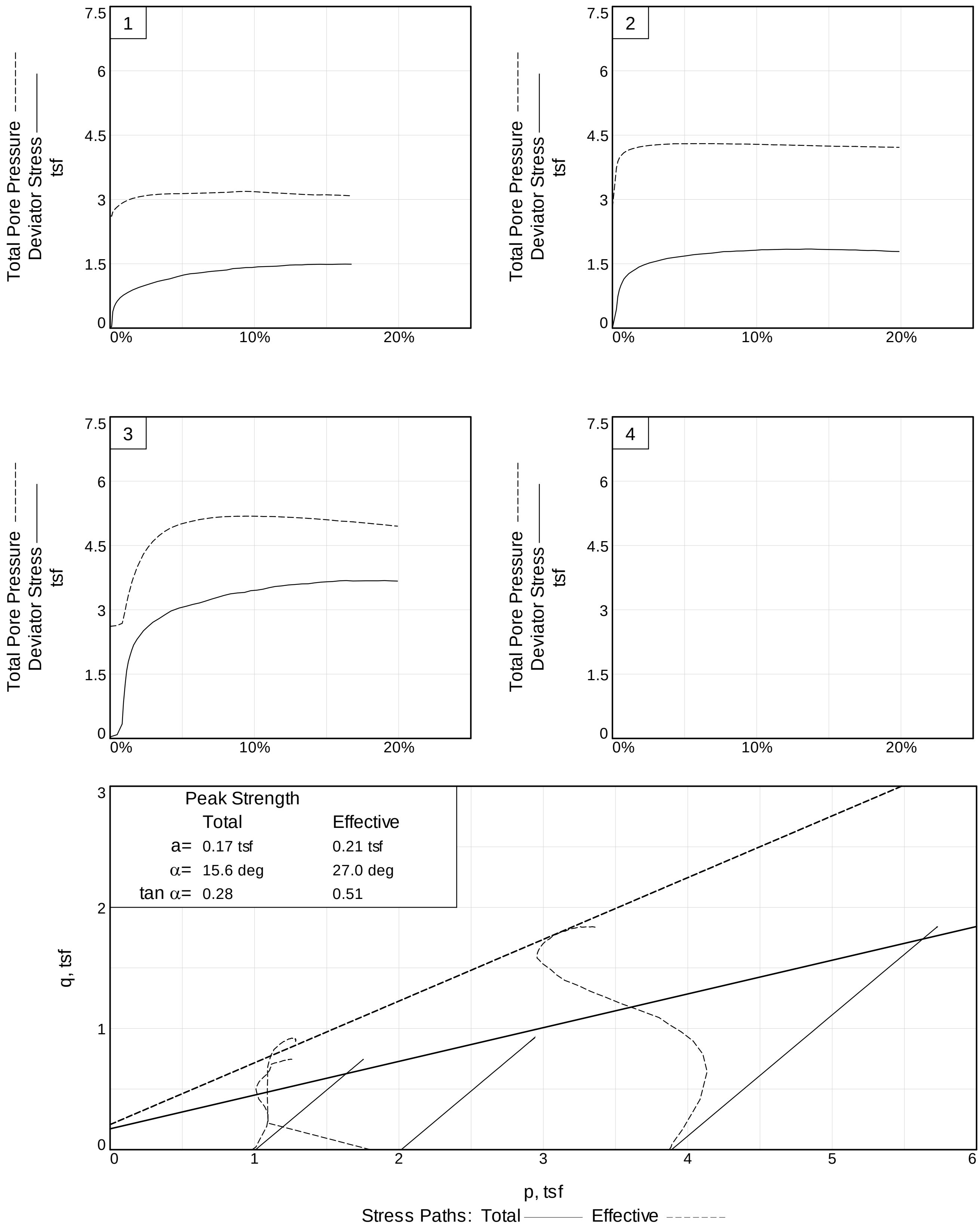
Source of Sample: KC-1016 **Depth:** 8.5'-10.5'

Sample Number: ST-1

Proj. No.: 1021-3003.00 **Date:** 10/16/2010

DLZ

Tested By: Justin Bukey **Checked By:** Barry Wong



Client: OVEC/AEP

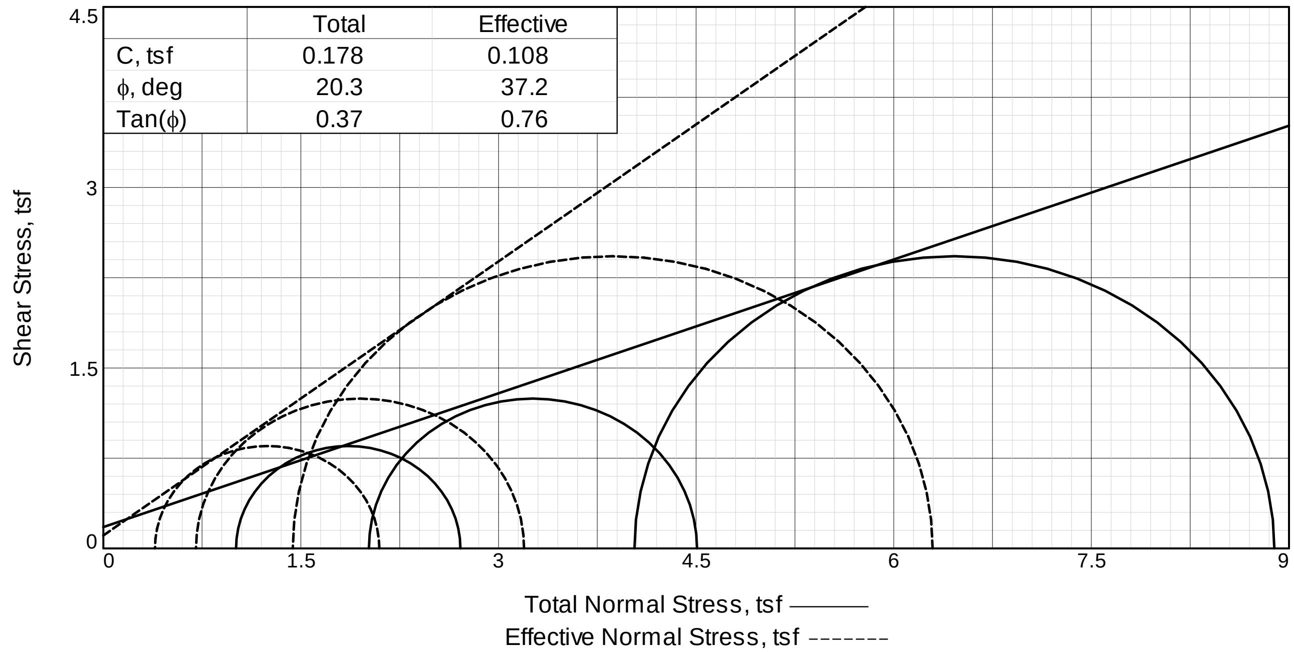
Project: OVEC: Kyger Creek - Ash Inpoundment Stability Analysis

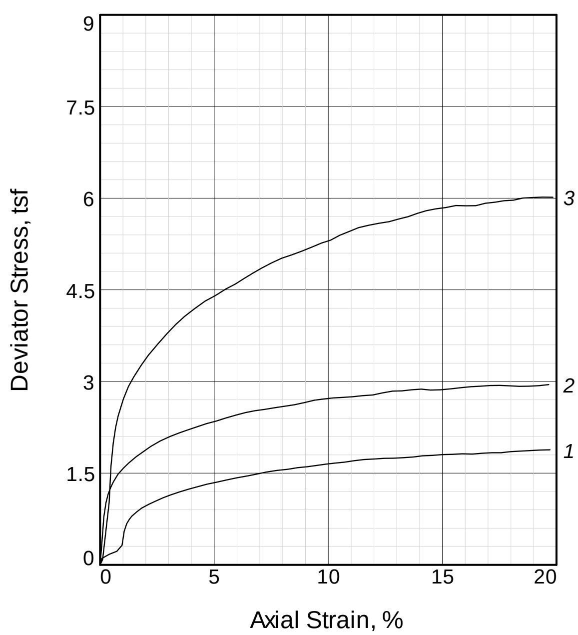
Source of Sample: KC-1016 **Depth:** 8.5'-10.5' **Sample Number:** ST-1

Project No.: 1021-3003.00 **Figure** ________

DLZ, INC.

Tested By: Justin Bukey **Checked By:** Barry Wong





Sample No.		1	2	3
Initial	Water Content,	22.4	22.4	22.0
	Dry Density, pcf	104.2	102.6	106.9
	Saturation,	95.1	91.6	99.6
	Void Ratio	0.6483	0.6730	0.6061
	Diameter, in.	2.84	2.84	2.84
	Height, in.	5.53	5.57	5.56
At Test	Water Content,	21.9	22.4	17.7
	Dry Density, pcf	107.1	106.1	115.4
	Saturation,	100.0	100.0	100.0
	Void Ratio	0.6032	0.6174	0.4873
	Diameter, in.	2.80	2.80	2.74
	Height, in.	5.52	5.52	5.50
Strain rate, in./min.		0.01	0.01	0.01
Back Pressure, tsf		2.59	2.59	2.59
Cell Pressure, tsf		3.60	4.61	6.62
Fail. Stress, tsf		1.70	2.49	4.86
Total Pore Pr., tsf		3.21	3.90	5.19
Ult. Stress, tsf		1.83	2.85	5.82
Total Pore Pr., tsf		3.09	3.73	4.94
$\bar{\sigma}_1$ Failure, tsf		2.10	3.19	6.30
$\bar{\sigma}_3$ Failure, tsf		0.39	0.70	1.44

Type of Test:
CU with Pore Pressures

Sample Type: 3" press tube

Description: Light brown lean clay with sand, damp to moist, little to some very fine sand, medium stiff

LL= 29 **PL=** 18 **PI=** 11

Specific Gravity= 2.75

Remarks: Actual strain rate = 0.0120 in/min.

Client: OVEC/AEP

Project: OVEC: Kyger Creek - Ash Inpoundment Stability Analysis
DLZ Project No: 1021-3003.00

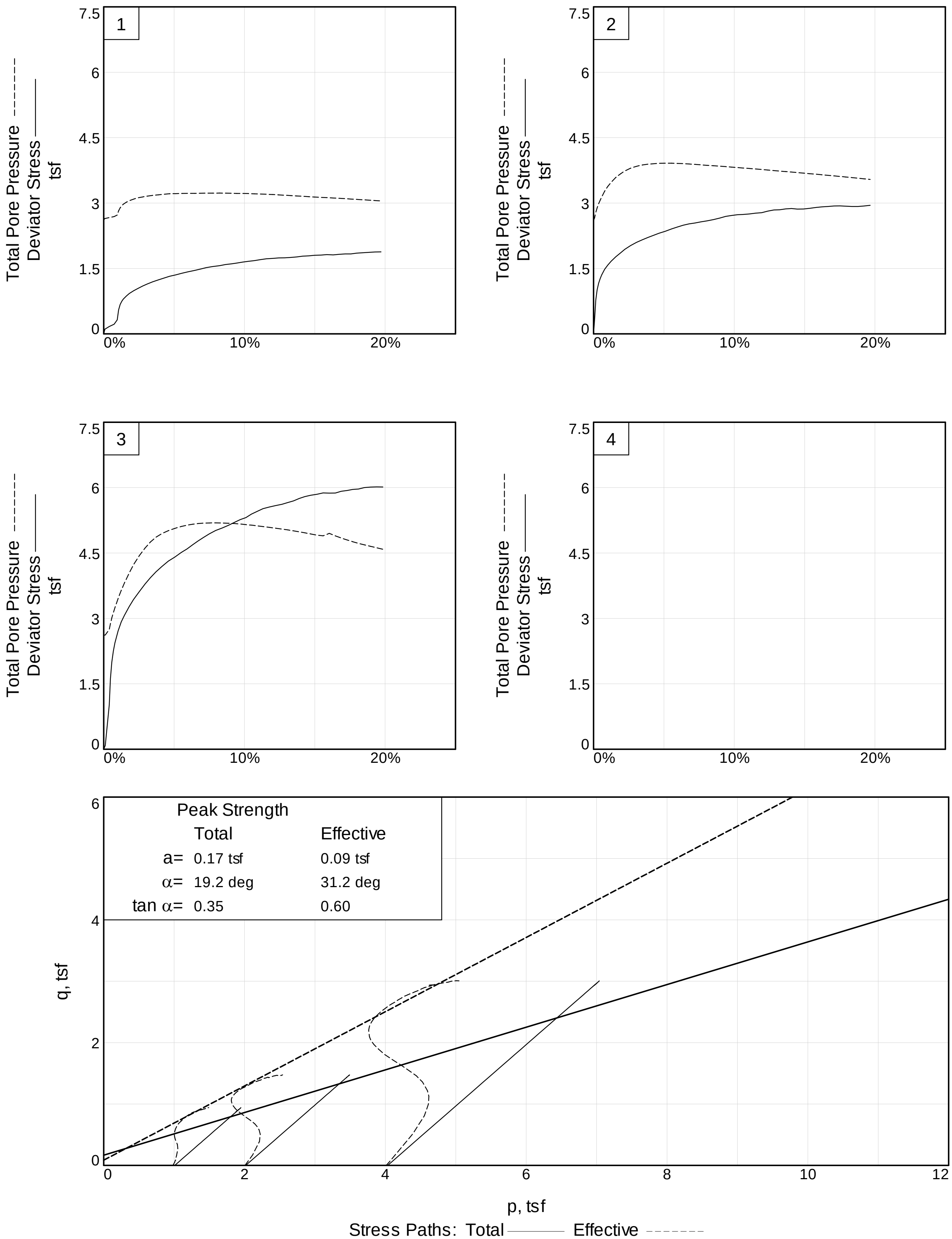
Source of Sample: KC-1017 **Depth:** 18.5'-20.5'

Sample Number: ST-1

Proj. No.: 1021-3003.00 **Date:** 10/4/2010

DLZ

Figure ________



Client: OVEC/AEP

Project: OVEC: Kyger Creek - Ash Inpoundment Stability Analysis

Source of Sample: KC-1017 **Depth:** 18.5'-20.5' **Sample Number:** ST-1

Project No.: 1021-3003.00 **Figure** ________ **DLZ, INC.**

APPENDIX V

Exhibit 6 – USGS 2014 Seismic Hazard Map for the United States and Detailed Calculations of Seismic Coefficient

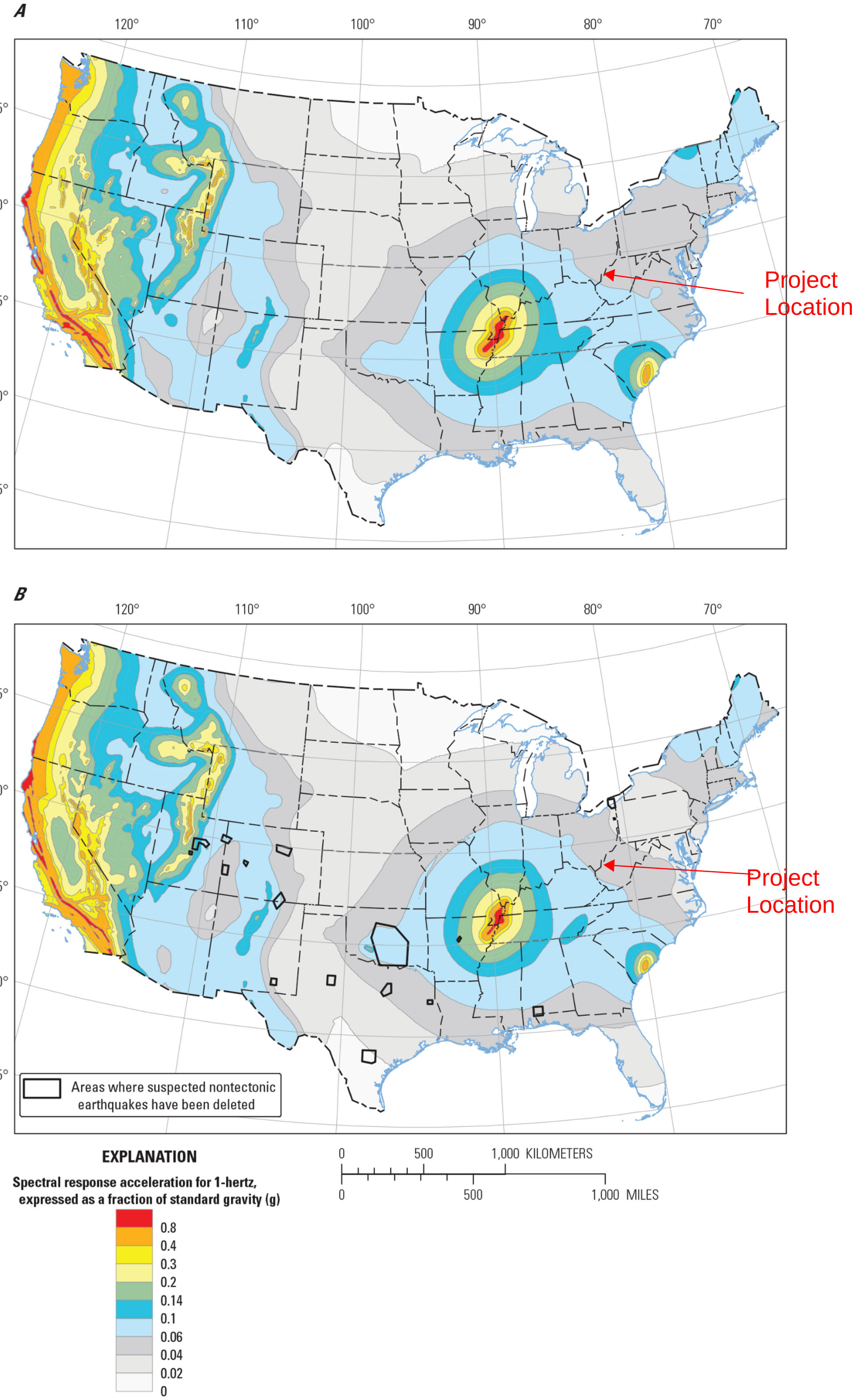


Figure 3. Maps showing 1-hertz (1-second) spectral acceleration for 2-percent probability of exceedance in 50 years and V_{S30} site condition of 760 meters per second. *A*, 2008 version of the national seismic hazard maps and *B*, 2014 version.

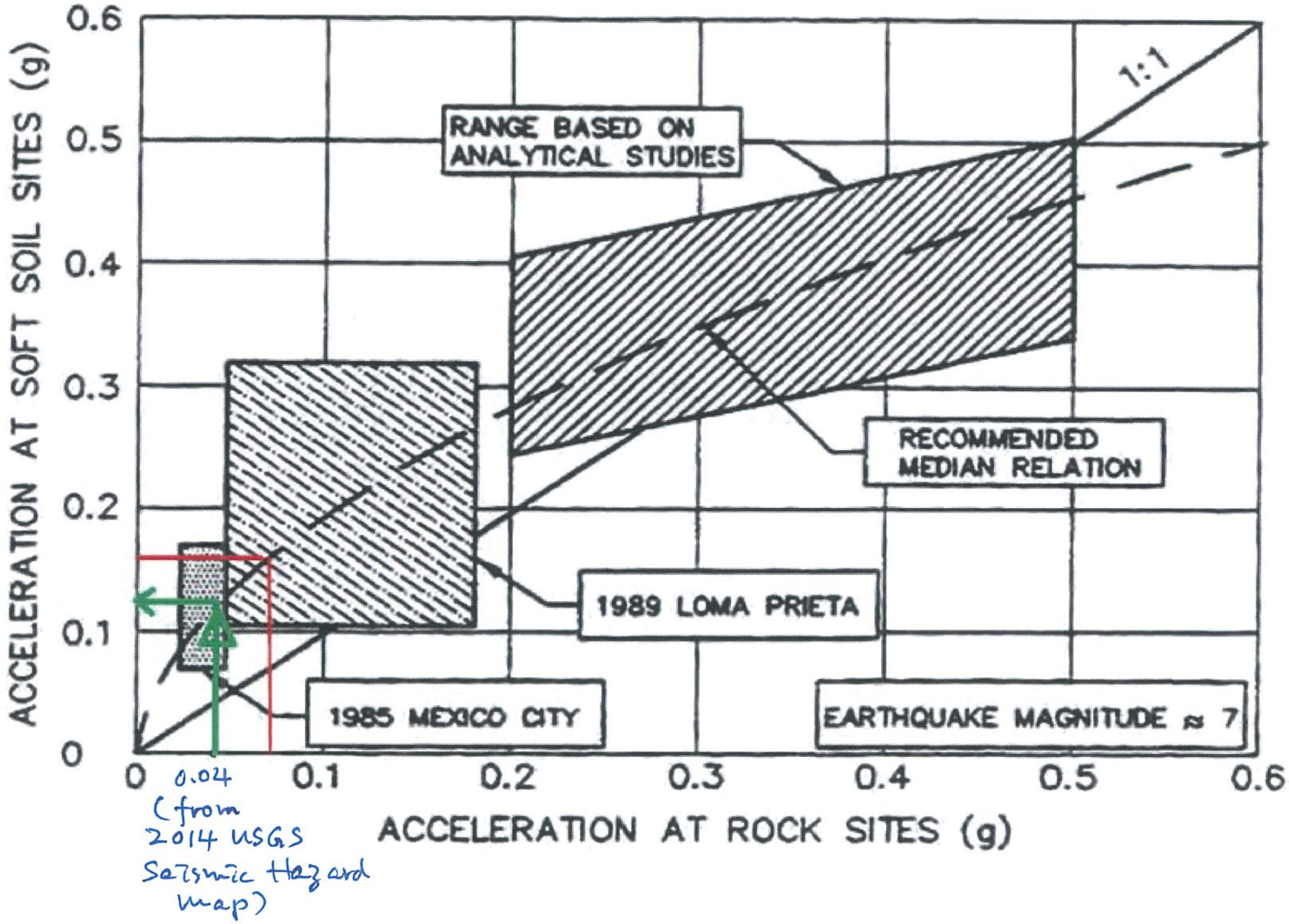
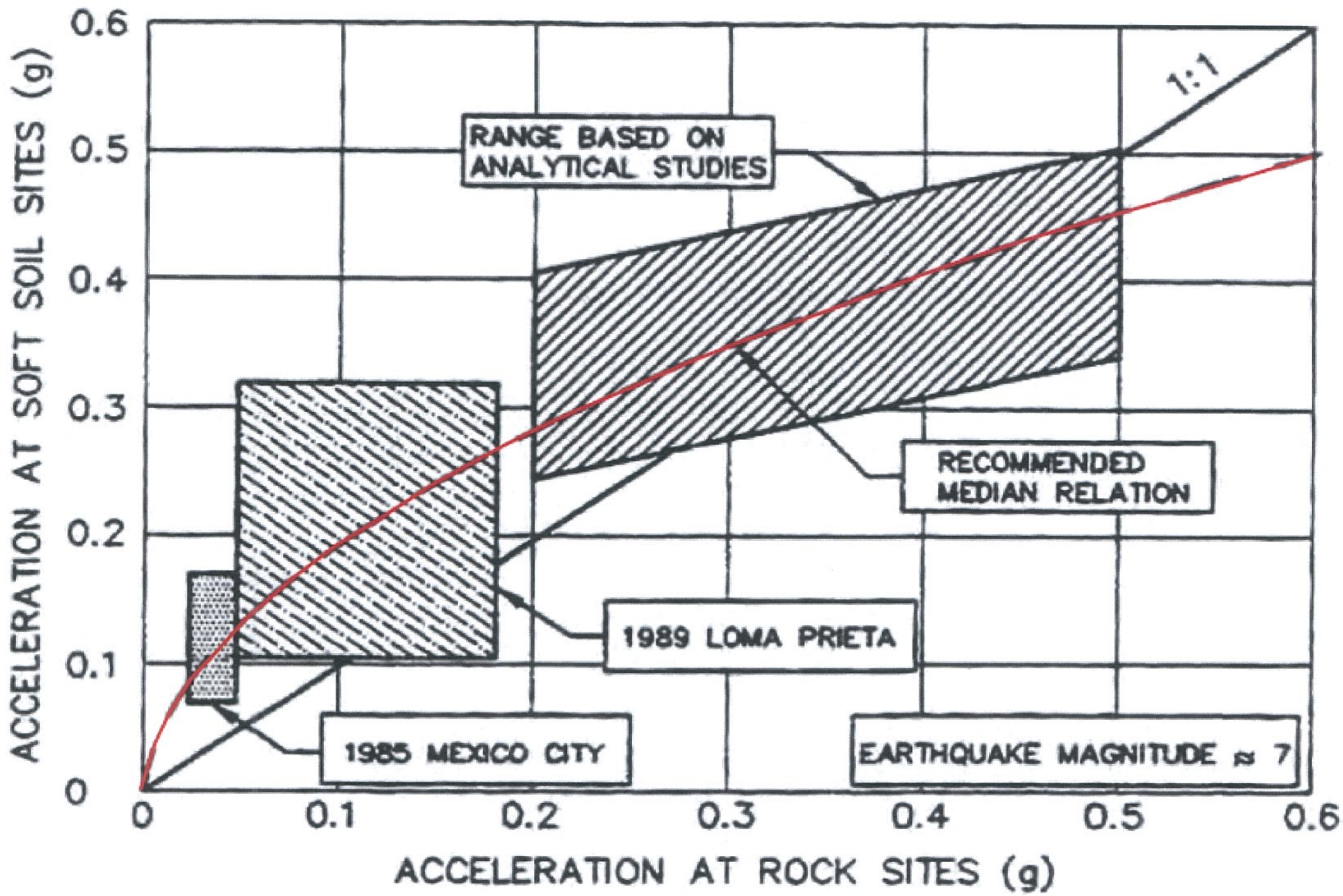


Figure 5-4 Relationship between PHGA on Rock and on Soft Soil Sites (Idriss, 1990)

$a = 0.5\,PGA$

For $PGA = 0.12g$ (Above) & $a = 0.5 \times 0.12g = 0.06g$

$k = a/g = 0.06g/g = \underline{\underline{0.06}}$



For the determination of the factor in equation 1. And based on my research to the available work on the subject
I recommend the use of a factor of 0.5 in the pseudo static slope stability analysis for Dams.
Equation 1 becomes **a=0.5 PGA**

Please also see below the section of the GEOTECHNICAL EARTHQUAKE ENGINEERING HANDBOOK (2002) which summarize
The state of the art of the subject:

period, and is consistent with federal dam safety guidance, specifically FEMA. FEMA recommends in *Federal Guidelines for Dam Safety* that dams be formally assessed at a frequency not to exceed five years by a qualified professional engineer. EPA has adopted this timeframe to maintain consistency with FEMA guidance. The inspection and assessment requirements in this rule will ensure that there are consistent and uniform inspection and assessment practices across states and facilities and will ensure that problems related to their stability will be promptly identified and remediated as necessary.

b. Static, Seismic, and Liquefaction Factors of Safety

(1) Static Factors of Safety.

Factor of safety (FOS) means the ratio of the forces tending to resist the failure of a structure, as compared to the forces tending to cause such failure as determined by accepted engineering practice. This analysis is used to determine whether a CCR surface impoundment's dikes are engineered to withstand the specific loading conditions that can be reasonably anticipated to occur during the lifetime of the unit without failure of the dike, if accepted good engineering practices are employed. Static factors of safety refer to the factors of safety (FOS) under static loading conditions that can reasonably be anticipated to occur during the lifetime of the unit. Static loading conditions are unique from other loading conditions (*e.g.*, seismic, liquefaction) in that static loading conditions are those which are in equilibrium, meaning the load is at rest or is applied with constant velocity.

EPA reviewed a series of USACE guidance documents addressing how to determine static FOS. These documents included, but were not limited to, Engineer Manual EM 1110–2–1902 "Slope Stability" (October 2003), and EM 1110–2–1902 "Stability of Earth and Rock-Fill Dams." The Agency also assessed the recommendations on how to conduct static analysis contained in the Engineering and Design Manual for Coal Refuse Disposal Facilities, originally published by the Mining Enforcement and Safety Administration (MESA) in 1975 and updated for MSHA in May 2009, and in particular Chapter 6, "Geotechnical Exploration, Material Testing, Engineering Analysis and Design." Based on recommendations from ASDSO, among others, the Agency adopted the USACE guidance to determine static FOS, both in the Assessment Program and in this rulemaking, as these manuals are recognized throughout industry as the standard routinely used in field assessment of structural integrity.

In EPA's Assessment Program all CCR units were assessed to determine their static FOS. Each assessment classified a CCR unit as having sufficient structural stability under static loading conditions if analysis of critical sections of embankments demonstrated FOS that met or exceeded the values defined by USACE for static specific loading conditions. EPA found that most CCR surface impoundments exhibited sufficient calculated factors of safety under static loading conditions. EPA also found that in those CCR units which insufficient factors of safety against failure due to static loading were calculated, the owner or operator was able to implement actions which increased the factors of safety under static loading conditions to acceptable levels. Oftentimes, these implemented actions were of a simple nature, such as installing riprap (rock armoring the slopes) or buttressing the slopes.

Similarly, this rule adopts the static FOS from USACE Engineer Manual EM 1110–2–1902 "Slope Stability," with the exception of the rapid drawdown loading condition,[11] which was determined not to be relevant to CCR surface impoundments. EPA found the factors of safety identified by EM 1110–2–1902, specifically the Maximum Storage pool, Maximum Surcharge pool, and End-Of-Construction loading conditions, provided consistent, achievable levels of safety in CCR surface impoundment dikes, comprehensively assessed static stability, and provided sufficient consideration of compounding stresses on dikes (*e.g.*, factors of safety values greater than 1.00 to account for unanticipated loadings acting in conjunction or misidentified strength of materials).

(2) Seismic Factor of Safety.

Seismic FOS means the FOS determined using analysis under earthquake conditions for a seismic loading event, based on the U.S. Geological Survey (USGS) seismic hazard maps for seismic events with a specified return period for the location where the CCR surface impoundment is located. The seismic FOS analysis is used to determine whether a dam would remain stable during an earthquake or other seismic event. The Agency relied on guidance from USACE and MSHA to evaluate the appropriate methods to determine if a dam would remain stable during a seismic event. This includes the USACE guidance Engineer Circular 1110–2–6061: Safety of Dams—Policy and Procedures 2204, Engineer Circular 1110–2–6000: Selection of Design Earthquakes and Associated Ground Motions 2008, and Engineer Circular 1110–2–6001: Dynamic Stability of Embankment Dams 2004). EPA also reviewed MSHA's 2009 Engineering and Design Manual for Coal Refuse Disposal Facilities, in particular Chapter 7, "Seismic Design: Stability and Deformation Analyses." These documents are viewed by ASDSO, FEMA and MSHA as generally accepted guidance on how to conduct seismic stability analyses.

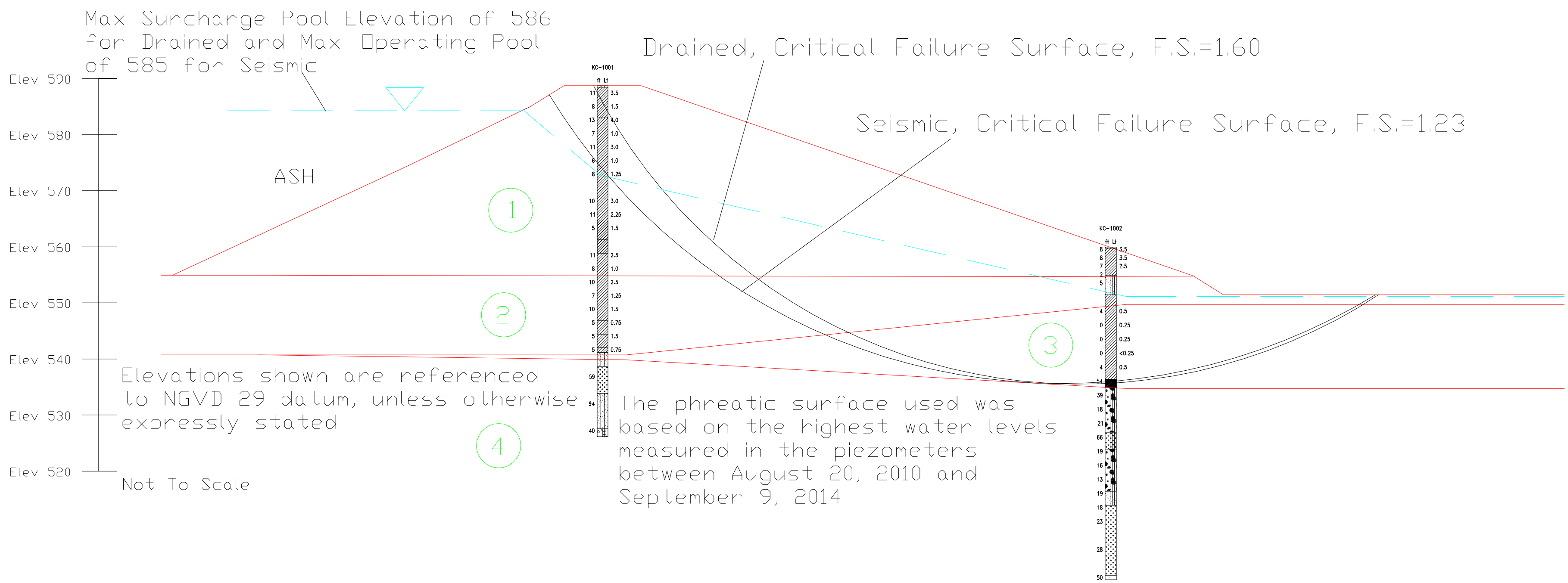
As noted earlier, in performing the assessments, EPA directed its engineering contractors to assess seismic stability of CCR impoundments during and following a seismic event with a 2% probability of exceedance in 50 years (*i.e.* probable earthquake within approximately 2,500 years) and a horizontal spectral response acceleration for 1.0-second period (5% of Critical Damping). EPA selected this return period for determining the maximum design earthquake (MDE) by first considering the operating life anticipated for CCR surface impoundments. EPA has identified the operating life of CCR surface impoundments to range between 40–80 years. EPA then consulted the United States Geological Survey (USGS) and ASDSO to determine a conservative probability that should be used in the assessments.[12] To reduce the likelihood of a CCR unit failing during a seismic

[11] Rapid (or sudden) drawdown is a condition in earthen dikes that may develop when the embankment becomes saturated through seepage during a high pool elevation in the reservoir. Rapid drawdown becomes a threat to the dike when the reservoir pool is drawn down or lowered at a rate significantly higher than the excess poor water pressure within the dike can dissipate. Typically, rapid drawdown scenarios are considered for dikes with reservoirs used for water supply and management or agricultural supply. In these scenarios, a high pool elevation is maintained in the reservoir in storage months. Subsequently, the water supply is drawn on in months where there is a demand for the reservoirs contents. This drawing down of the pool can present issues for the structural integrity of the unit. However, the management of CCR surface impoundments differs from that of conventional water supply reservoirs. CCR surface impoundments are never used for water supply, and the only instance in which EPA determined through its Assessment Program that rapid drawdown loading conditions would be relevant to CCR surface impoundments was in the event that the CCR surface impoundment had already released the contents of the impoundment through a breach of the dike or emergency discharge. Since the threat of release of CCR and the reservoir has already been realized, any failure due to rapid drawdown of the embankment is no longer critical to the overall containment of the now-released contents of the CCR unit.

[12] Wieland, M., "Seismic Design and Performance Criteria for Large Storage Dams", Proc. 15th World Conf. on Earthquake Engineering, Lisbon, Portugal, Sep. 24–28, 2012.

APPENDIX VI
Results of Slope Stability Analyses

Material	Consistency	Soil Type	Undrained C (psf)	Undrained Φ (deg)	Drained C' (psf)	Drained Φ' (deg)	γ (pcf)
Material 1	Stiff/Very Stiff	Emb. Fill	350	20	100	32	125
Material 2	Med. Stiff/Stiff	Clay	350	16	100	30	125
Material 3	Very Soft	Clay	250	16	50	26	120
Material 4	Dense	Sand/Gravel	0	35	0	35	125

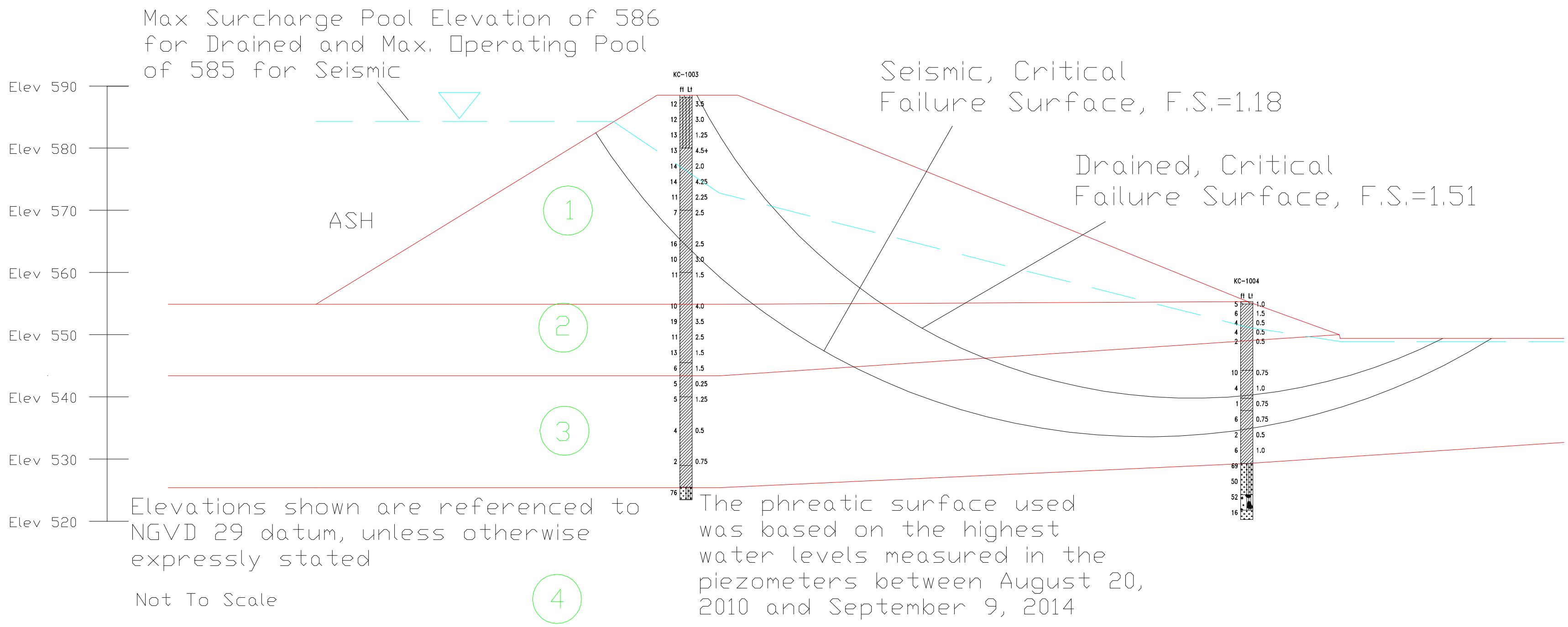


KYGER CREEK - ASH IMPOUNDMENT
STABILITY ANALYSIS

SOUTH FLY ASH POND SECTION 1

PROJECT NO. 1521-3007.00	CALC: EWT	DATE 12/8/15

Material	Consistency	Soil Type	Undrained C (psf)	Undrained Φ (deg)	Drained C' (psf)	Drained Φ' (deg)	γ (pcf)
Material 1	Stiff/Very Stiff	Emb. Fill	350	20	100	32	125
Material 2	Stiff/Very Stiff	Clay	500	16	100	32	125
Material 3	Soft/Med. Stiff	Clay	300	16	100	28	125
Material 4	Dense	Sand/Gravel	0	35	0	35	125

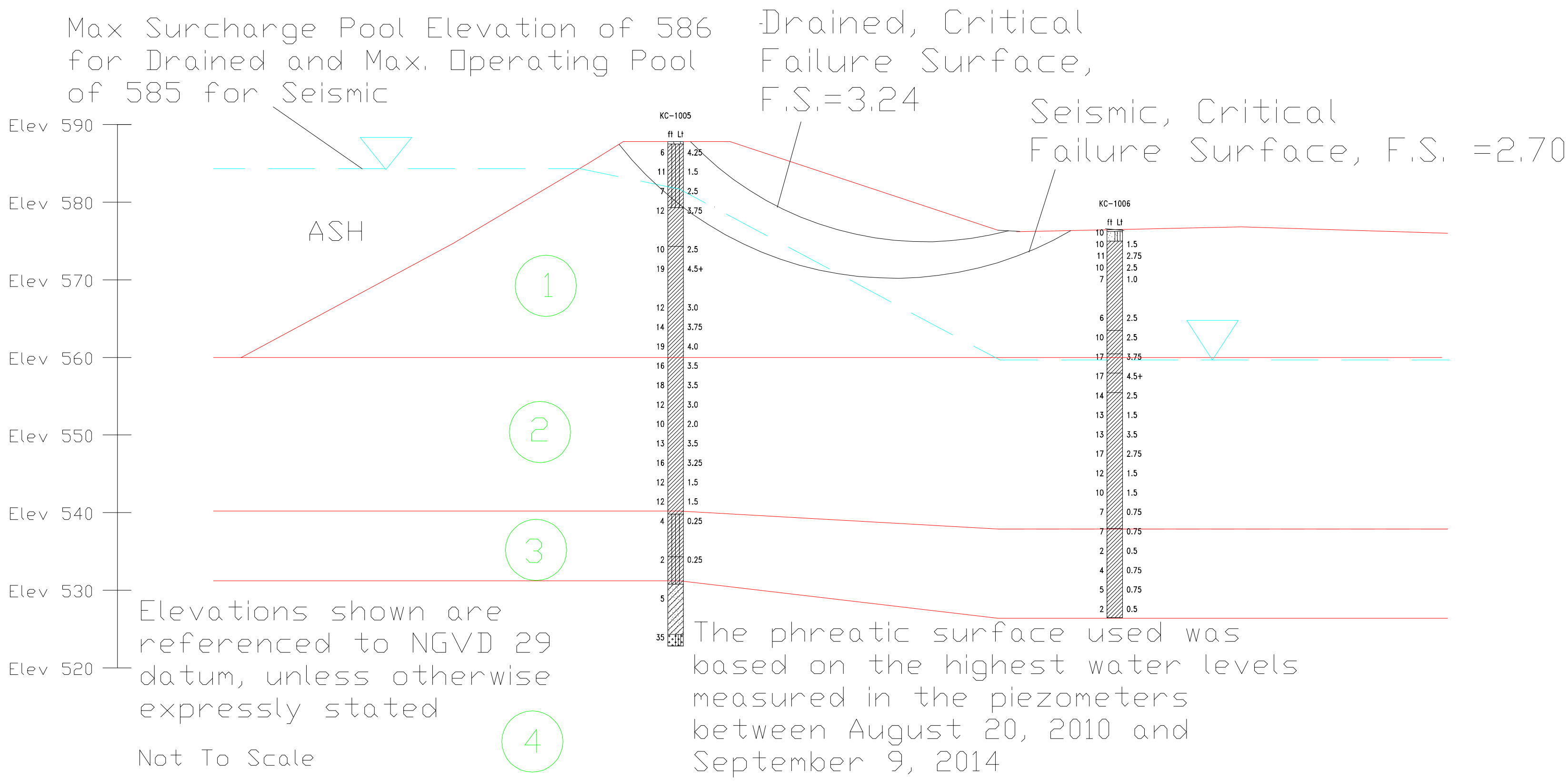


KYGER CREEK - ASH IMPOUNDMENT
STABILITY ANALYSIS

SOUTH FLY ASH POND SECTION 2

PROJECT NO. 1521-3007.00	CALC: EWT	DATE 12/8/15

Material	Consistency	Soil Type	Undrained		Drained		
			C (psf)	Φ (deg)	C' (psf)	Φ' (deg)	γ (pcf)
Material 1	Stiff/Very Stiff	Emb. Fill	350	20	100	32	125
Material 2	Stiff/Very Stiff	Clay	500	16	100	32	125
Material 3	Soft/Med. Stiff	Clay	300	16	100	28	125
Material 4	Dense	Sand/Gravel	0	35	0	35	125

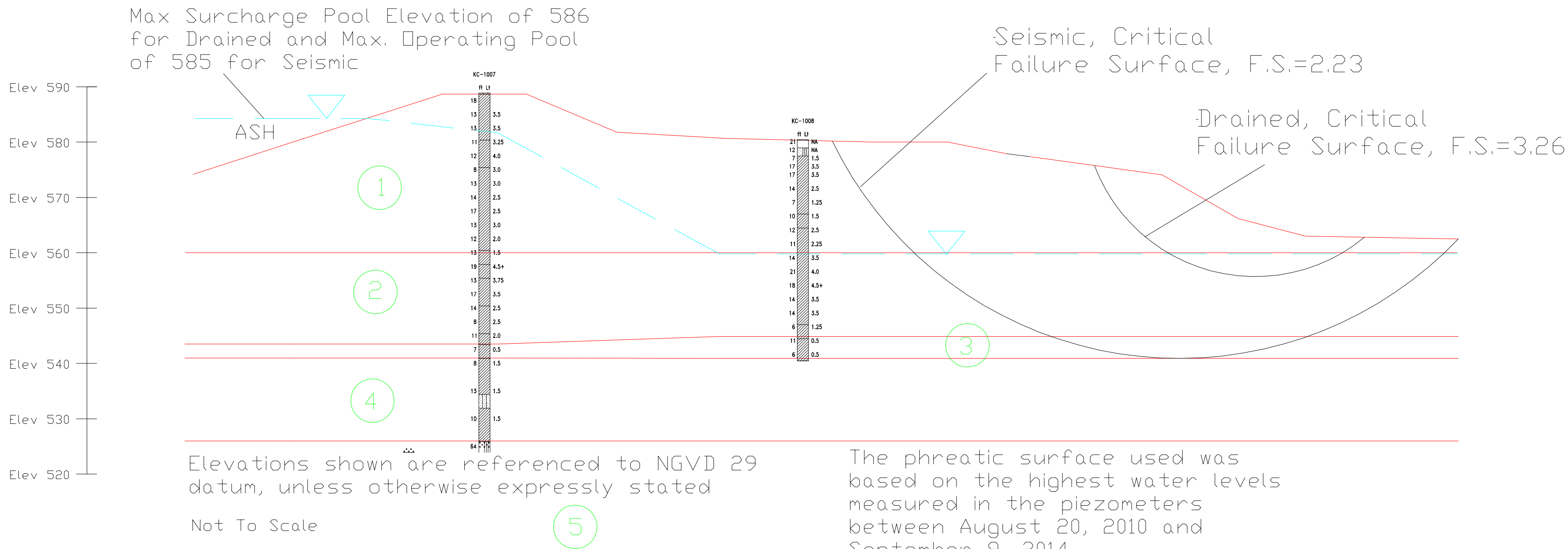


KYGER CREEK - ASH IMPOUNDMENT
STABILITY ANALYSIS

SOUTH FLY ASH POND SECTION 3

PROJECT NO. 1521-3007.00	CALC: EWT	DATE 12/8/15

			Undrained		Drained		
Material	Consistency	Soil Type	C (psf)	Φ (deg)	C' (psf)	Φ' (deg)	γ (pcf)
Material 1	Stiff/Very Stiff	Emb. Fill	350	20	100	32	125
Material 2	Stiff/Very Stiff	Clay	500	16	100	32	125
Material 3	Soft/Med. Stiff	Clay	300	16	100	28	125
Material 4	Med. Stiff/Stiff	Clay	350	16	0	30	125
Material 5	Dense	Sand/Gravel	0	35	0	35	125



Elevations shown are referenced to NGVD 29 datum, unless otherwise expressly stated

Not To Scale

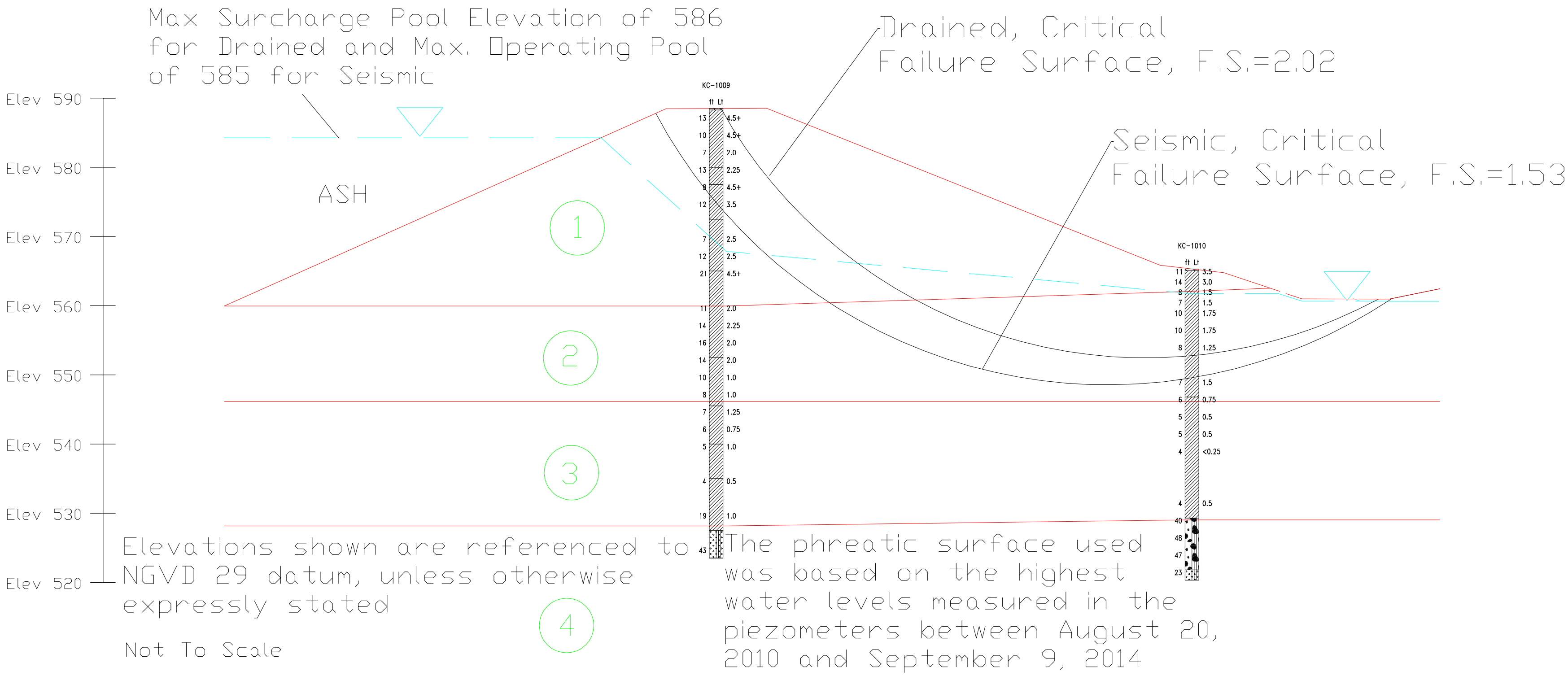
The phreatic surface used was based on the highest water levels measured in the piezometers between August 20, 2010 and September 9, 2014

KYGER CREEK - ASH IMPOUNDMENT
STABILITY ANALYSIS

SOUTH FLY ASH POND SECTION 4

PROJECT NO. 1521-3007.00	CALC: EWT	DATE 12/8/15

Material	Consistency	Soil Type	Undrained C (psf)	Undrained Φ (deg)	Drained C' (psf)	Drained Φ' (deg)	γ (pcf)
Material 1	Stiff/Very Stiff	Emb. Fill	350	20	100	32	125
Material 2	Med. Stiff/Stiff	Clay	350	16	100	30	125
Material 3	Soft/Med. Stiff	Clay	300	16	100	28	125
Material 4	Dense	Sand/Gravel	0	35	0	35	125



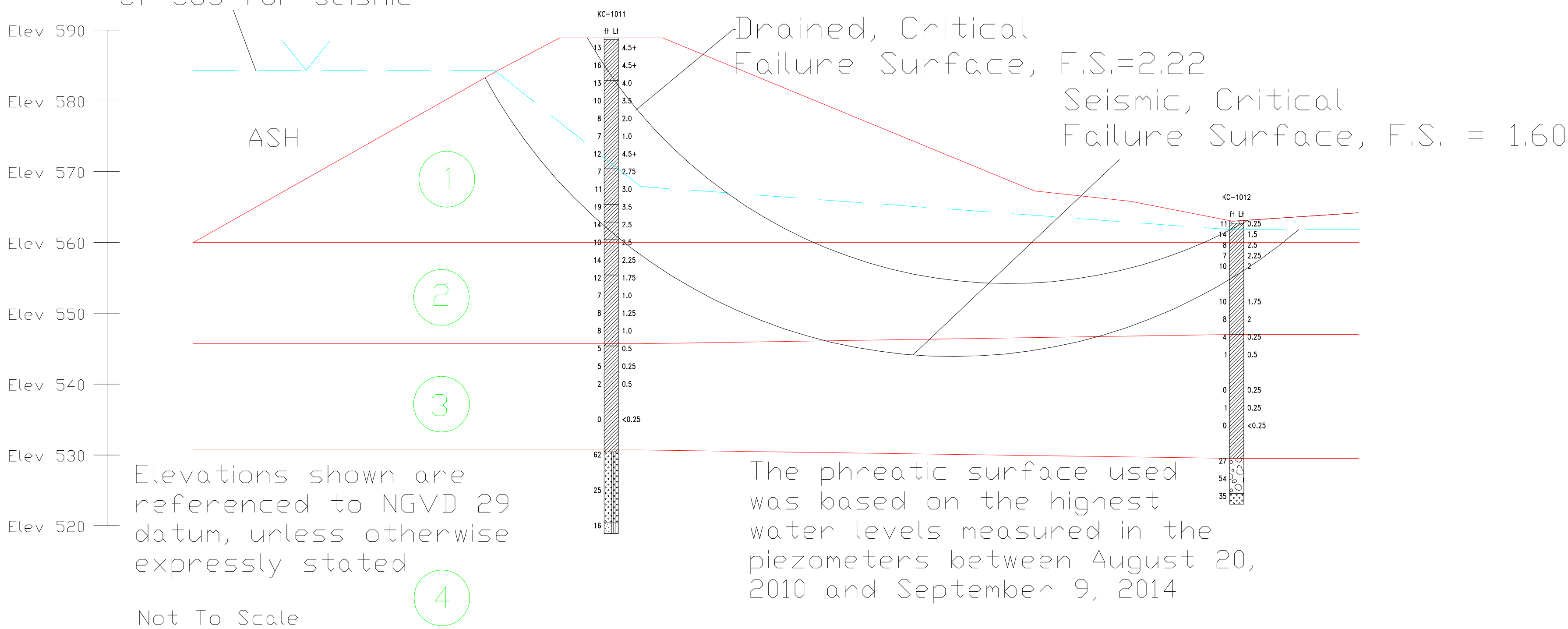
KYGER CREEK – ASH IMPOUNDMENT
STABILITY ANALYSIS

SOUTH FLY ASH POND SECTION 5

PROJECT NO. 1521-3007.00	CALC: EWT	DATE 12/8/15

Material	Consistency	Soil Type	Undrained C (psf)	Undrained Φ (deg)	Drained C' (psf)	Drained Φ' (deg)	γ (pcf)
Material 1	Stiff/Very Stiff	Emb. Fill	350	20	100	32	125
Material 2	Med. Stiff/Stiff	Clay	350	16	100	30	125
Material 3	Soft/Med. Stiff	Clay	300	16	100	28	125
Material 4	Dense	Sand/Gravel	0	35	0	35	125

Max Surcharge Pool Elevation of 586 for Drained and Max. Operating Pool of 585 for Seismic



Elevations shown are referenced to NGVD 29 datum, unless otherwise expressly stated

Not To Scale

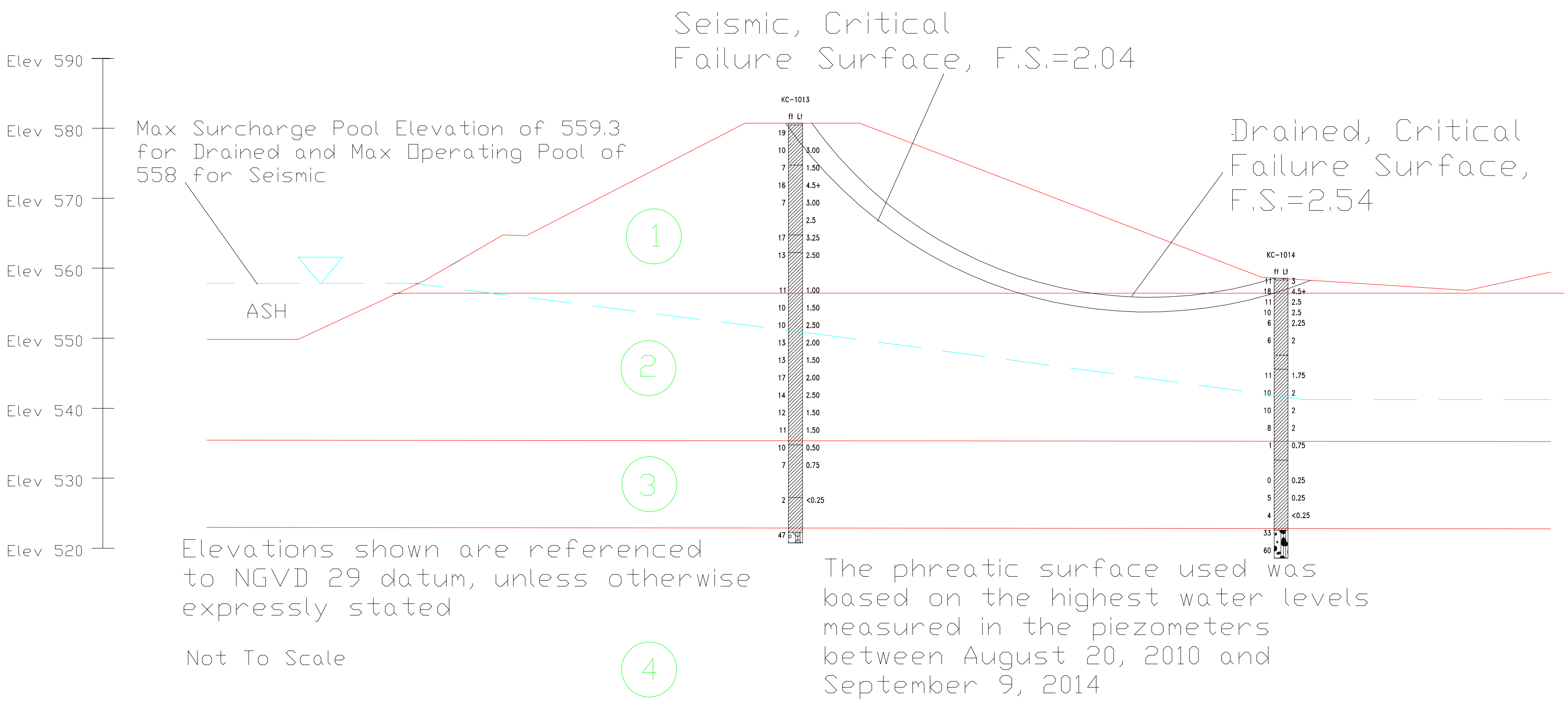
The phreatic surface used was based on the highest water levels measured in the piezometers between August 20, 2010 and September 9, 2014

KYGER CREEK - ASH IMPOUNDMENT STABILITY ANALYSES

SOUTH FLY ASH POND SECTION 6

PROJECT NO. 1521-3007.00	CALC: EWT	DATE 12/8/15

Material	Consistency	Soil Type	Undrained		Drained		
			C (psf)	φ (deg)	C' (psf)	φ' (deg)	γ (pcf)
Material 1	Stiff/Very Stiff	Emb. Fill	350	20	100	32	125
Material 2	Stiff/Very Stiff	Clay	500	16	100	32	125
Material 3	Soft/Med. Stiff	Clay	300	16	100	28	125
Material 4	Dense	Sand/Gravel	0	35	0	35	125

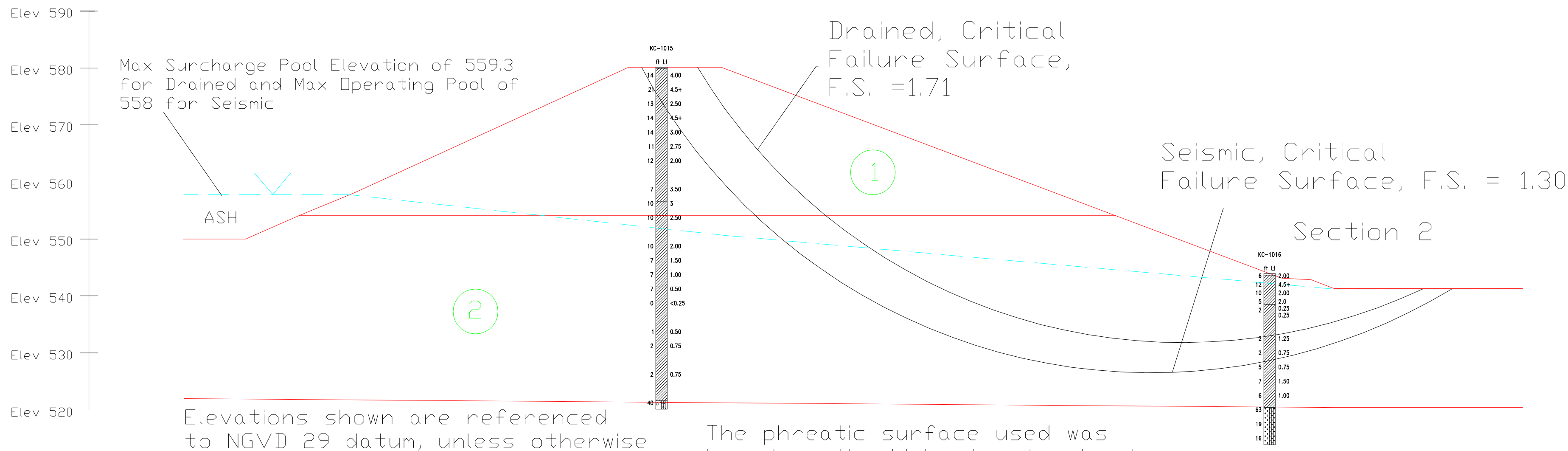


KYGER CREEK - ASH IMPOUNDMENT
STABILITY ANALYSIS

BOTTOM ASH POND SECTION 1

PROJECT NO. 1521-3007.00	CALC: EWT	DATE 12/8/15

Material	Consistency	Soil Type	Undrained C (psf)	Undrained Φ (deg)	Drained C' (psf)	Drained Φ' (deg)	γ (pcf)
Material 1	Stiff/Very Stiff	Emb. Fill	350	20	100	32	125
Material 2	Soft/Med. Stiff	Clay	300	16	100	28	125
Material 3	Dense	Sand/Gravel	0	35	0	30	125



Elevations shown are referenced to NGVD 29 datum, unless otherwise expressly stated

Not To Scale

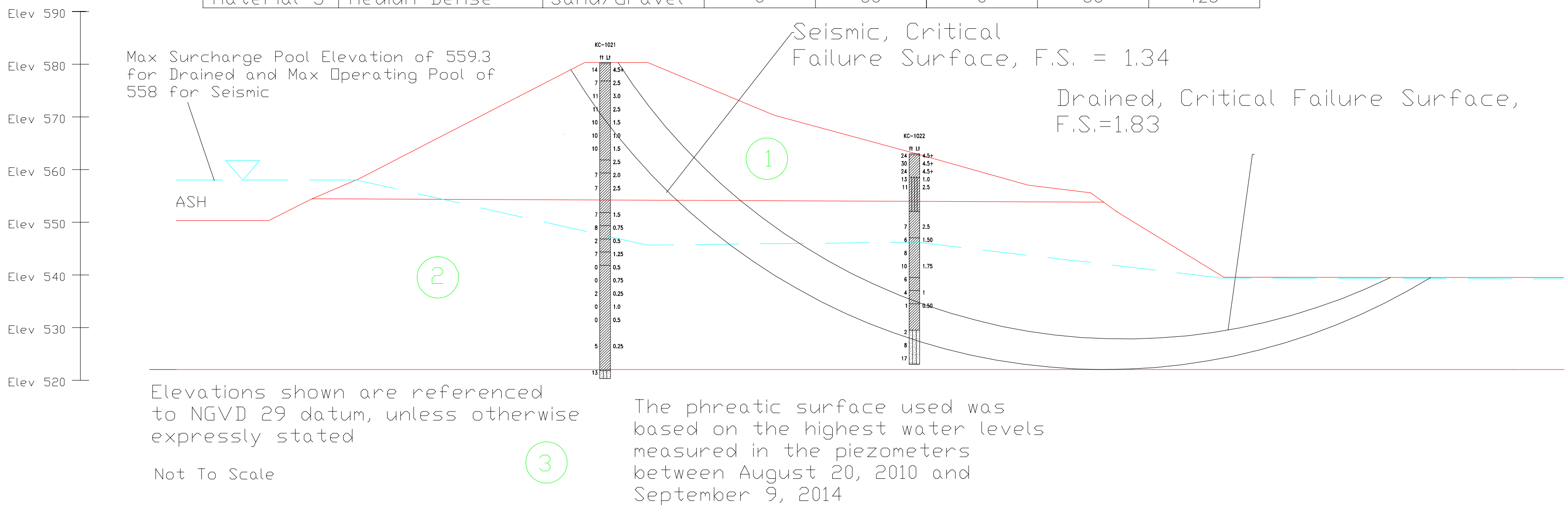
The phreatic surface used was based on the highest water levels measured in the piezometers between August 20, 2010 and September 9, 2014

KYGER CREEK - ASH IMPOUNDMENT
STABILITY ANALYSIS

BOTTOM ASH POND SECTION 2

PROJECT NO. 1521-3007.00	CALC: EWT	DATE 12/8/15

Material	Consistency	Soil Type	Undrained C (psf)	Undrained Φ (deg)	Drained C' (psf)	Drained Φ' (deg)	γ (pcf)
Material 1	Stiff/Very Stiff	Emb. Fill	350	20	100	32	125
Material 2	Soft/Med. Stiff	Clay	300	16	100	28	125
Material 3	Medium Dense	Sand/Gravel	0	30	0	30	125

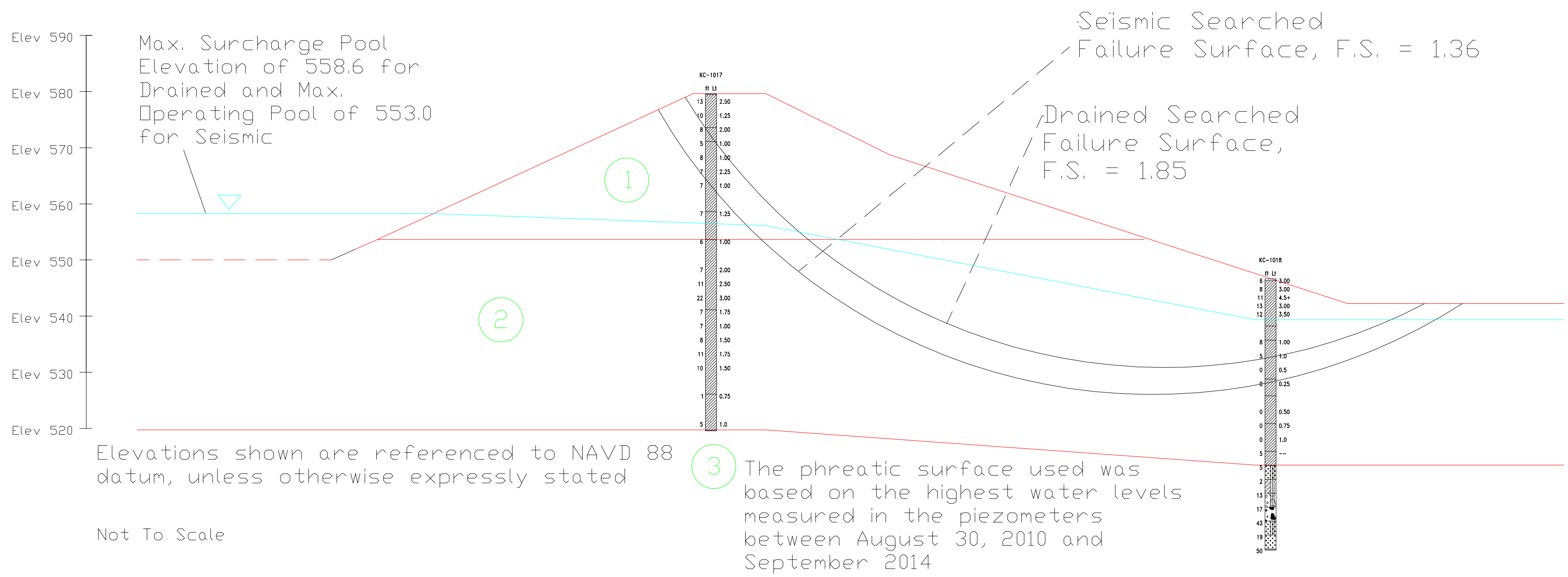


KYGER CREEK - ASH IMPOUNDMENT
STABILITY ANALYSIS

BOTTOM ASH POND SECTION 5

PROJECT NO. 1521-3007.00	CALC: EWT	DATE 12/8/15

			Undrained		Drained		
Material	Consistency	Soil Type	C (psf)	Φ (deg)	C' (psf)	Φ' (deg)	γ (pcf)
Material 1	Stiff/Very Stiff	Emb. Fill	350	20	100	32	125
Material 2	Soft/Med. Stiff	Clay	300	16	100	28	125
Material 3	Medium Dense	Sand/Gravel	0	30	0	30	125

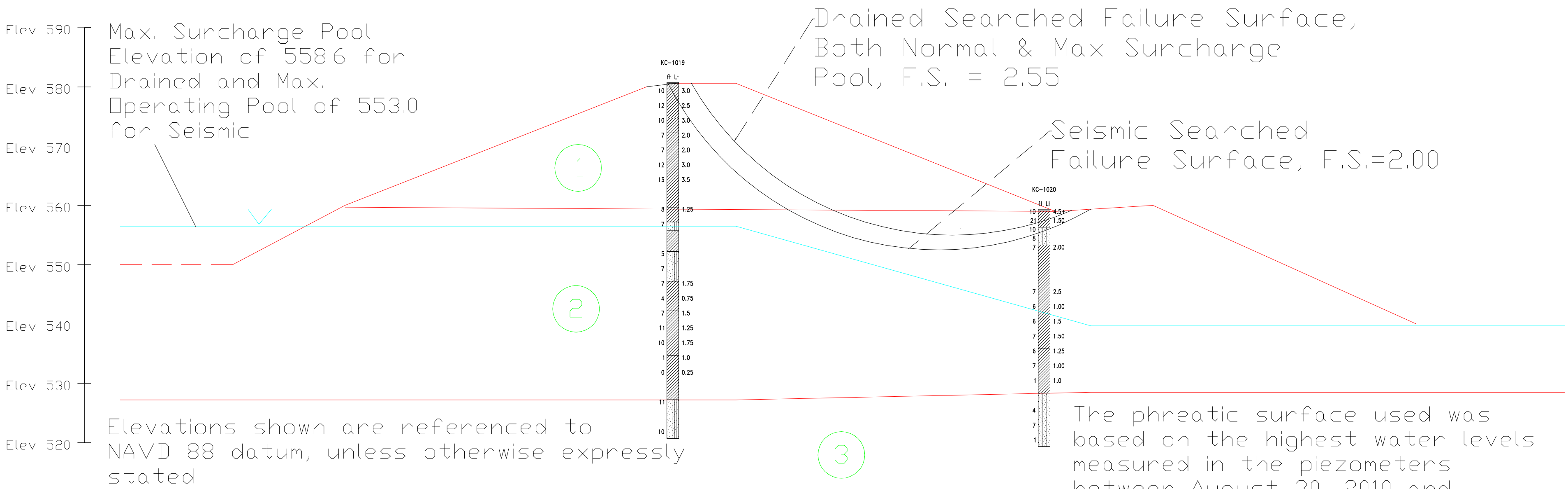


KYGER CREEK - ASH IMPOUNDMENT
STABILITY ANALYSIS

CLEARWATER POND SECTION 3

PROJECT NO. 1521-3007.00	CALC: EWT	DATE 12/8/15

Material	Consistency	Soil Type	Undrained C (psf)	Undrained φ (deg)	Drained C' (psf)	Drained φ' (deg)	γ (pcf)
Material 1	Stiff/Very Stiff	Emb. Fill	350	20	100	32	125
Material 2	Med. Stiff/Stiff	Clay	350	16	100	30	125
Material 3	Medium Dense	Sand/Gravel	0	28	0	28	125



Not To Scale

KYGER CREEK - ASH IMPOUNDMENT
STABILITY ANALYSIS

CLEARWATER POND SECTION 4

PROJECT NO. 1521-3007.00	CALC: EWT	DATE 12/8/15

APPENDIX VII

Exhibit 7 – Liquefaction Analysis of Granular Soils
Exhibit 8 – USGS Map, "Earthquakes in Ohio and Vicinity, 1776-2007"
Exhibit 9 – Liquefaction Analysis of Fine-grained Soils
Exhibit 10 – Additional Liquefaction Analysis of Potentially Liquefiable Fine-grained Soils
AGMU Memo 10.1 – Liquefaction Analysis, dated January 2010, from the Illinois DOT
USACE Slope Stability, Engineering Manual 1110-2-1902. October, 2003, page 1-6
Chapter 5 "Liquefaction Potential Evaluation and Analysis" of EPA/600/R-95/051

EXHIBIT 7 - KYGER CREEK ASH IMPOUNDMENT - LIQUEFACTION ANALYSIS OF GRANULAR SOILS

Location	Cross-section No.	Boring No.	Depth to Top of Layer (ft, bgs)	Depth to Bottom of Layer (ft, bgs)	Mid-point Depth of Layer (ft, bgs)	Mid-point Depth of Layer (m, bgs)	Elevation to Top of Layer (ft, bgs)	Sampler Type	Soil Type	Groundwater Level During Seismic Event (ft, bgs)	Total Overburden Stress, σ, psf	Effective Overburden Stress, σ', psf	N_m, field N-Values	C_N	CE	CB	CR	CS	$(N_1)_{60}$ (blows/ft)	Fine Content (%)	α	β	$(N_1)_{60\,cs}$ (blows/ft)	r_d	CSR	$(CRR)_{7.5}$	MSF	FS_{Liq}	Liquefaction Potential
South Fly Ash Pond	1	KC-1001	49.4	52	50.7	15.21	539.9	SS	SM	0	6084	2920.32	4	0.85	1.21	1.00	1.00	1.00	4.11	13.00	1.89	2.82	13.49	0.75	0.06	0.15	5.33	12.65	NO
South Fly Ash Pond	1	KC-1001	52	57	54.5	16.35	537.3	SS	SW	0	6540	3139.2	49	0.82	1.21	1.00	1.00	1.00	48.61	3.00	0.00	0.00	0.00	0.72	0.06	0.05	5.33	4.50	NO
South Fly Ash Pond	1	KC-1001	57	63.5	60.25	18.075	532.3	SS	SM	0	7230	3470.4	78	0.78	1.21	1.00	1.00	1.00	73.59	13.00	1.89	2.82	209.44	0.66	0.05	No Liquefaction	5.33	No Liquefaction	NO
South Fly Ash Pond	1	KC-1001	63.5	65	64.25	19.275	525.8	SS	GP-GM	0	7710	3700.8	33	0.76	1.21	1.00	1.00	1.00	30.15	5.00	0.00	0.00	0.00	0.63	0.05	0.05	5.33	5.08	NO
South Fly Ash Pond	1	KC-1002	5	8.5	6.75	2.025	553.3	SS	SP-SM	0	810	388.8	3	1.70	1.21	1.00	1.00	1.00	6.16	5.00	0.00	0.00	0.00	0.99	0.08	0.05	5.33	3.27	NO
South Fly Ash Pond	1	KC-1002	23.5	33	28.25	8.475	534.8	SS	GW-GM	0	3390	1627.2	27	1.14	1.21	1.00	1.00	1.00	37.20	5.00	0.00	0.00	0.00	0.93	0.08	0.05	5.33	3.46	NO
South Fly Ash Pond	1	KC-1002	33	36	34.5	10.35	525.3	SS	SW-SM	0	4140	1987.2	55	1.03	1.21	1.00	1.00	1.00	68.57	8.00	0.30	2.75	189.07	0.90	0.07	No Liquefaction	5.33	No Liquefaction	NO
South Fly Ash Pond	1	KC-1002	36	43.5	39.75	11.925	522.3	SS	GW-GM	0	4770	2289.6	13	0.96	1.21	1.00	1.00	1.00	15.10	5.00	0.00	0.00	0.00	0.86	0.07	0.05	5.33	3.75	NO
South Fly Ash Pond	1	KC-1002	43.5	46	44.75	13.425	514.8	SS	SP-SM	0	5370	2577.6	16	0.91	1.21	1.00	1.00	1.00	17.52	7.00	0.12	2.74	48.14	0.81	0.07	No Liquefaction	5.33	No Liquefaction	NO
South Fly Ash Pond	1	KC-1002	46	58.5	52.25	15.675	512.3	SS	SW	0	6270	3009.6	19	0.84	1.21	1.00	1.00	1.00	19.25	0.00	0.00	0.00	0.00	0.74	0.06	0.05	5.33	4.36	NO
South Fly Ash Pond	2	KC-1003	63	65	64	19.2	525.4	SS	SW-SM	0	7680	3686.4	63	0.76	1.21	1.00	1.00	1.00	57.67	5.00	0.00	0.00	0.00	0.64	0.05	0.05	5.33	5.07	NO
South Fly Ash Pond	2	KC-1004	26	31	28.5	8.55	529.3	SS	SW-SM	0	3420	1641.6	54	1.14	1.21	1.00	1.00	1.00	74.07	6.00	0.03	2.73	202.33	0.93	0.08	No Liquefaction	5.33	No Liquefaction	NO
South Fly Ash Pond	2	KC-1004	31	33.5	32.25	9.675	524.3	SS	GW-GM	0	3870	1857.6	43	1.07	1.21	1.00	1.00	1.00	55.45	5.00	0.00	0.00	0.00	0.91	0.07	0.05	5.33	3.54	NO
South Fly Ash Pond	2	KC-1004	33.5	35	34.25	10.275	521.8	SS	SW	0	4110	1972.8	13	1.04	1.21	1.00	1.00	1.00	16.27	2.00	0.00	0.00	0.00	0.90	0.07	0.05	5.33	3.58	NO
South Fly Ash Pond	3	KC-1005	57	63.5	60.25	18.075	531.2	SS	SC	0	7230	3470.4	4	0.78	1.21	1.00	1.00	1.00	3.77	13.00	1.89	2.82	12.53	0.66	0.05	0.14	5.33	13.43	NO
South Fly Ash Pond	3	KC-1005	63.5	65	64.25	19.275	524.7	SS	SW-SM	0	7710	3700.8	29	0.76	1.21	1.00	1.00	1.00	26.49	5.00	0.00	0.00	0.00	0.63	0.05	0.05	5.33	5.08	NO
South Fly Ash Pond	3	KC-1006	0.3	1.5	0.9	0.27	576.2	SS	SP-SM	0	108	51.84	8	1.70	1.21	1.00	1.00	1.00	16.43	5.00	0.00	0.00	0.00	1.00	0.08	0.05	5.33	3.22	NO
South Fly Ash Pond	4	KC-1007	54.5	57	55.75	16.725	534.5	SS	SM	0	6690	3211.2	11	0.81	1.21	1.00	1.00	1.00	10.79	13.00	1.89	2.82	32.32	0.70	0.06	No Liquefaction	5.33	No Liquefaction	NO
South Fly Ash Pond	4	KC-1007	63	65	64	19.2	526	SS	SW-SM	0	7680	3686.4	53	0.76	1.21	1.00	1.00	1.00	48.52	9.00	0.56	2.76	134.70	0.64	0.05	No Liquefaction	5.33	No Liquefaction	NO
South Fly Ash Pond	4	KC-1008	0.2	1.5	0.85	0.255	580.7	SS	GC-GM	0	102	48.96	17	1.70	1.21	1.00	1.00	1.00	34.91	13.00	1.89	2.82	100.35	1.00	0.08	No Liquefaction	5.33	No Liquefaction	NO
South Fly Ash Pond	4	KC-1008	1.5	3	2.25	0.675	579.4	SS	SP-SM	0	270	129.6	10	1.70	1.21	1.00	1.00	1.00	20.54	5.00	0.00	0.00	0.00	1.00	0.08	0.05	5.33	3.23	NO
South Fly Ash Pond	5	KC-1009	61	65	63	18.9	528.2	SS	SW-SM	0	7560	3628.8	36	0.76	1.21	1.00	1.00	1.00	33.21	5.00	0.00	0.00	0.00	0.64	0.05	0.05	5.33	5.01	NO
South Fly Ash Pond	5	KC-1010	36	41	38.5	11.55	529.1	SS	GW-GM	0	4620	2217.6	36	0.98	1.21	1.00	1.00	1.00	42.49	5.00	0.00	0.00	0.00	0.87	0.07	0.05	5.33	3.71	NO
South Fly Ash Pond	5	KC-1010	41	43.5	42.25	12.675	524.1	SS	GW	0	5070	2433.6	39	0.93	1.21	1.00	1.00	1.00	43.94	3.00	0.00	0.00	0.00	0.84	0.07	0.05	5.33	3.85	NO
South Fly Ash Pond	5	KC-1010	43.5	45	44.25	13.275	521.6	SS	SW-SM	0	5310	2548.8	19	0.91	1.21	1.00	1.00	1.00	20.92	7.00	0.12	2.74	57.46	0.82	0.07	No Liquefaction	5.33	No Liquefaction	NO
South Fly Ash Pond	6	KC-1011	48.5	50	49.25	14.775	540.7	SS	ML	0	5910	2836.8	2	0.86	1.21	1.00	1.00	1.00	2.09	58.00	5.00	1.20	7.50	0.77	0.06	0.09	5.33	7.84	NO
South Fly Ash Pond	6	KC-1011	58.5	68.5	63.5	19.05	530.7	SS	SW-SM	0	7620	3657.6	36	0.76	1.21	1.00	1.00	1.00	33.08	12.00	1.55	2.81	94.37	0.64	0.05	No Liquefaction	5.33	No Liquefaction	NO
South Fly Ash Pond	6	KC-1011	68.5	70	69.25	20.775	520.7	SS	SP-SM	0	8310	3988.8	13	0.73	1.21	1.00	1.00	1.00	11.44	6.00	0.03	2.73	31.27	0.60	0.05	No Liquefaction	5.33	No Liquefaction	NO
South Fly Ash Pond	6	KC-1012	33.5	38.4	35.95	10.785	529.5	SS	GP	0	4314	2070.72	33	1.01	1.21	1.00	1.00	1.00	40.31	4.00	0.00	0.00	0.00	0.89	0.07	0.05	5.33	3.63	NO
South Fly Ash Pond	6	KC-1012	38.5	40	39.25	11.775	524.5	SS	SW	0	4710	2260.8	29	0.97	1.21	1.00	1.00	1.00	33.90	0.00	0.00	0.00	0.00	0.86	0.07	0.05	5.33	3.73	NO
Bottom Ash Pond	1	KC-1013	53.5	55	54.25	16.275	527.8	SS	ML	0	6510	3124.8	2	0.82	1.21	1.00	1.00	1.00	1.99	56.00	5.00	1.20	7.39	0.72	0.06	0.09	5.33	8.29	NO
Bottom Ash Pond	1	KC-1013	58.5	60	59.25	17.775	522.8	SS	GP-GM	0	7110	3412.8	39	0.79	1.21	1.00	1.00	1.00	37.10	5.00	0.00	0.00	0.00	0.67	0.05	0.05	5.33	4.79	NO
Bottom Ash Pond	1	KC-1014	36	40	38	11.4	522.6	SS	GW-GM	0	4560	2188.8	38	0.98	1.21	1.00	1.00	1.00	45.14	6.00	0.03	2.73	123.32	0.87	0.07	No Liquefaction	5.33	No Liquefaction	NO
Bottom Ash Pond	2	KC-1015	58.5	60	59.25	17.775	521.9	SS	SW-SM	0	7110	3412.8	33	0.79	1.21	1.00	1.00	1.00	31.40	6.00	0.03	2.73	85.77	0.67	0.05	No Liquefaction	5.33	No Liquefaction	NO
Bottom Ash Pond	2	KC-1016	23.5	28.5	26	7.8	520.3	SS	SW-SM	0	3120	1497.6	34	1.19	1.21	1.00	1.00	1.00	48.83	6.00	0.03	2.73	133.39	0.94	0.08	No Liquefaction	5.33	No Liquefaction	NO
Bottom Ash Pond	2	KC-1016	28.5	30	29.25	8.775	515.3	SS	GW	0	3510	1684.8	13	1.12	1.21	1.00	1.00	1.00	17.60	3.00	0.00	0.00	0.00	0.93	0.08	0.05	5.33	3.48	NO
Clearwater Pond	3	KC-1018	31	33.5	32.25	9.675	516.3	SS	ML	0	3870	1857.6	4	1.07	1.21	1.00	1.00	1.00	5.16	52.00	5.00	1.20	11.19	0.91	0.07	0.12	5.33	8.91	NO
Clearwater Pond	3	KC-1018	33.5	36	34.75	10.425	513.8	SS	SW-SM	0	4170	2001.6	4	1.03	1.21	1.00	1.00	1.00	4.97	11.00	1.21	2.79	15.08	0.90	0.07	0.16	5.33	11.78	NO
Clearwater Pond	3	KC-1018	36	38.5	37.25	11.175	511.3	SS	SC-SM	0	4470	2145.6	2	0.99	1.21	1.00	1.00	1.00	2.40	13.00	1.89	2.82	8.66	0.88	0.07	0.10	5.33	7.58	NO
Clearwater Pond	3	KC-1018	38.5	41	39.75	11.925	508.8	SS	GP-GM	0	4770	2289.6	11	0.96	1.21	1.00	1.00	1.00	12.78	10.00	0.87	2.78	36.36	0.86	0.07	No Liquefaction	5.33	No Liquefaction	NO
Clearwater Pond	3	KC-1018	41	43.5	42.25	12.675	506.3	SS	GW	0	5070	2433.6	14	0.93	1.21	1.00	1.00	1.00	15.77	0.00	0.00	0.00	0.00	0.84	0.07	0.05	5.33	3.85	NO
Clearwater Pond	3	KC-1018	43.5	46	44.75	13.425	503.8	SS	SW-SM	0	5370	2577.6	36	0.91	1.21	1.00	1.00	1.00	39.41	5.00	0.00	0.00	0.00	0.81	0.07	0.05	5.33	3.96	NO
Clearwater Pond	3	KC-1018	46	48.5	47.25	14.175	501.3	SS	SW	0	5670	2721.6	16	0.88	1.21	1.00	1.00	1.00	17.05	3.00	0.00	0.00	0.00	0.79	0.06	0.05	5.33	4.09	NO
Clearwater Pond	4	KC-1019	23.5	25	24.25	7.275	557.2	SS	SP-SM	0	2910	1396.8	6	1.23	1.21	1.00	1.00	1.00	8.92	5.00	0.00	0.00	0.00	0.95	0.08	0.05	5.33	3.41	NO
Clearwater Pond	4	KC-1019	28.5	33.5	31	9.3	552.2	SS	SP-SM	0	3720	1785.6	5	1.09	1.21	1.00	1.00	1.00	6.58	5.00	0.00	0.00	0.00	0.92	0.07	0.05	5.33	3.51	NO
Clearwater Pond	4	KC-1019	53.5	60	56.75	17.025	527.2	SS	SP-SM	0	6810	3268.8	8	0.80	1.21	1.00	1.00	1.00	7.78	10.00	0.87	2.78	22.47	0.70	0.06	0.25	5.33	23.49	NO
Clearwater Pond	4	KC-1020	3	6	4.5	1.35	556.5	SS	SM	0	540	259.2	7	1.70	1.21	1.00	1.00	1.00	14.38	13.00	1.89	2.82	42.43	0.99	0.08	No Liquefaction	5.33	No Liquefaction	NO
Clearwater Pond	4	KC-1020	31	40	35.5	10.65	528.5	SS	SM	0	4260	2044.8	3	1.02	1.21	1.00	1.00	1.00	3.69	14.00	2.20	2.84	12.66	0.89	0.07	0.14	5.33	10.12	NO
Bottom Ash Pond	5	KC-1021	58.5	60	59.25	17.775	521.7	SS	SM	0	7110	3412.8	11	0.79	1.21	1.00	1.00	1.00	10.47	13.00	1.89	2.82	31.40	0.67	0.05	No Liquefaction	5.33	No Liquefaction	NO
Bottom Ash Pond	5	KC-1022	33.5	40	36.75	11.025	529.2	SS	SM	0	4410	2116.8	7	1.00	1.21	1.00	1.00	1.00	8.46	19.00	3.43	2.92	28.16	0.88	0.07	0.38	5.33	27.91	NO

Note:
1. The "Simplified Method" described by Youd et al (2001) was used.
2. An earthquake moment magnitude (Mw) of 3.9 was assumed.
3. A peak ground acceleration of 0.06 g was used.

Bottom Ash Pond is also known
as Boiler Slag Pond

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

OPEN-FILE REPORT 2008–1221

Prepared in cooperation with the Ohio Department of Natural Resources, Division of Geological Survey

Earthquakes in Ohio and Vicinity 1776–2007

***Compiled by* Richard L. Dart[1] and Michael C. Hansen[2]**

2008

This map summarizes more than 200 years of Ohio earthquake history. The history of Ohio earthquakes was derived from letters, journals, diaries, newspaper accounts, scholarly articles and, beginning in the early twentieth century, instrumental recordings (seismograms). All historical (pre-instrumental) earthquakes that were large enough to be felt have been located based on anecdotal accounts. Some of these events caused damage to buildings and their contents. The more recent widespread use of seismographs has allowed many small earthquakes, previously undetected, to be recorded and accurately located. The seismicity map (right) shows the historically located and instrumentally recorded earthquakes in and near Ohio.

EARTHQUAKES

Earthquakes occur as a result of slip on faults, typically many kilometers underground, and most earthquakes occur along the boundaries of moving crustal plates. Ohio is within the North American plate, far away from any plate boundaries. Usually it is not possible to determine exactly which fault causes an earthquake. Accordingly, the most direct indicators of earthquake hazards are the earthquakes themselves, not the faults on which they occur nor the motions of crustal plates.

Before earthquakes were instrumentally recorded, estimated locations were typically within a few tens of kilometers of the actual epicenters. Even with modern instrumentation, however, earthquake locations within the Earth are only approximations, usually within several kilometers of their actual locations. However, in areas where networks of closely spaced recording instruments exist earthquakes can be more accurately located. Despite location uncertainties earthquakes have occurred in most parts of Ohio during the last 200 years.

Magnitude (M) is the most common measure of an earthquake's size. An earthquake's magnitude reflects the total energy released as seismic waves. There are several methods to measure earthquake magnitude. The first and most frequently cited is the "Richter scale." The different methods used can give slightly different magnitude values for the same earthquake. As a result, differences of several tenths of a magnitude may be reported.

Although the size of an earthquake is characterized by its *magnitude*, a single number, the levels of ground shaking are characterized by a range of *intensity* values, which vary over the affected area. The Modified Mercalli Intensity (MMI) scale defines recognized intensity values from I (barely felt or not felt) to XII (total destruction; see table at far right). Modified Mercalli Intensity VI marks the onset of slight damage to poorly built structures, whereas MMI VII or higher generally results in considerable damage to buildings—even their collapse. An earthquake's intensity usually decreases away from its epicenter location. Earthquake isoseismal (intensity) maps show this pattern of decreasing seismic shaking away from the place where the earthquake occurred. Isoseismal maps also illustrate how different ground conditions affect intensity values resulting in intensity patterns that are more irregular than might be expected. Two isoseismal maps for Ohio earthquakes are shown (far right).

EASTERN U.S. EARTHQUAKES

Earthquakes are less common east of the Rocky Mountains than in Pacific coast states, such as California. However, because of differences in crustal properties, an earthquake that occurs in the eastern U. S. of the same magnitude as a west coast earthquake can affect a much larger area. A magnitude 4.0 eastern U.S. earthquake typically can be felt 100 km (60 mi) from where it occurred and will frequently cause damage near its source. A magnitude 5.5 eastern U.S. earthquake usually can be felt 500 km (300 mi) from where it occurred and can sometimes cause damage as far away as 40 km (25 mi).

EARTHQUAKES IN OHIO AND VICINITY

In terms of tectonic setting, Ohio is part of a much larger geographic area known as the Stable Continental Region (Wheeler, 2003). This region includes all of eastern North America. Exclusive of several selected areas, such as the New Madrid seismic zone, this region experiences infrequent earthquakes. Earthquakes, as previously stated, are generated as the result of movement on faults often thousands of feet below ground. Although there are many known faults within the Stable Continental Region, few of the earthquakes that occur here are associated with known faults.

Ohio has experienced more than 160 felt earthquakes since 1776. Most of these events caused no damage or injuries. However, 15 Ohio earthquakes resulted in property damage and some minor injuries. The largest historic earthquake in the State occurred in 1937. This event had an estimated magnitude of 5.4 and caused considerable damage in the town of Anna and in several other western Ohio communities. At least 40 earthquakes have been felt in this area since 1875. Northeastern Ohio, east of Cleveland, is another area of seismic interest. There a 5.0 magnitude event in 1986 caused moderate damage. In southern Ohio more than 30 earthquakes have been felt. Due to a lack of information and location uncertainty, two early felt events in 1776 and 1779 (Hansen, 2006) are not plotted on this map.

The origins of Ohio earthquakes, as with earthquakes throughout the central and eastern U.S., are poorly understood. However, Ohio earthquakes appear to be associated with ancient zones of weakness within the North American continental crust. These zones of weakness are characterized by deeply buried and poorly documented faults. Some of these weak zones periodically release accumulated strain in the form of earthquakes.

Ohio is on the periphery of the New Madrid seismic zone, site of the 1811–1812 earthquake sequence, the largest earthquake sequence to occur in historical times in the continental U.S. Some of the events in this sequence had magnitudes in the range of 8.0 and were felt throughout all of the eastern U.S. The intensity of ground shaking generated by these large earthquakes toppled chimneys as far away from the epicenter as Cincinnati.

The table below lists notable earthquakes, magnitude 3.5 and greater, located in Ohio and vicinity. On the earthquake location map at right, these events, with one exception, are labeled with their dates of occurrence. The single exception is the earliest recorded earthquake in the State, a magnitude 4.0 event, that occurred in the summer of 1776 near the Muskingum River in south-central Ohio. The location for this event is an approximation and is not considered accurate. It is not listed in the table.

NOTABLE OHIO AND VICINITY EARTHQUAKES MAGNITUDE ≥ 3.5

YR	MO	DY	LAT(°N)	LON(°W)	MAG	SOURCE
1824	7	15	39.7	80.5	4.1	NCEER
1834	11	20	39.6	84.3	3.5	OSN
1834	11	20	38.65	83.8	3.5	OSN
1843	6	19	40.1	83.8	3.5	OSN
1848	4	6	39.65	82.53	3.7	NCEER
1854	1	11	39.4	83.7	3.5	CERI
1857	2	27	42.31	80.94	4.1	OSN
1873	1	4	40.2	83.0	3.8	NCEER
1875	6	18	40.2	84.0	4.7	NCEER
1884	9	19	40.7	84.1	4.8	PDE
1885	1	18	41.15	81.55	3.8	NCEER
1886	5	3	39.36	82.24	3.8	NCEER/OSN
1892	4	15	40.55	84.57	3.8	NCEER
1894	11	24	39.27	81.56	3.8	OSN
1901	5	17	38.73	82.99	4.3	NCEER
1926	11	5	39.1	82.1	3.6	NCEER
1929	3	8	40.4	84.2	3.7	NCEER
1930	9	30	40.3	84.3	4.2	NCEER
1931	9	20	40.43	84.27	4.7	NCEER
1937	3	2	40.49	84.27	4.9	NCEER
1937	3	9	40.47	84.28	5.4	NCEER/PDE
1943	3	9	41.63	81.31	4.4	NCEER
1944	11	13	40.4	84.4	4.1	NCEER
1947	8	10	41.93	85.0	4.5	NCEER
1952	6	20	39.64	82.02	3.9	NCEER
1953	6	12	41.7	83.6	3.5	NCEER
1956	1	27	40.5	84.0	3.7	NCEER
1956	1	27	40.4	84.2	3.7	NCEER
1961	2	22	41.2	83.3	3.7	NCEER
1967	4	8	39.65	82.53	3.7	NCEER
1974	10	20	39.06	81.61	3.8	NCEER
1979	11	9	38.49	82.81	3.8	NCEER/OSN
1983	8	17	38.47	82.77	3.5	NCEER/OSN
1986	1	31	41.65	81.16	5.0	PDE
1986	7	12	40.55	84.39	4.5	ASN
1987	7	13	41.896	80.767	3.8	PDE
1991	1	26	41.61	81.594	3.5	JCU
1993	10	16	41.698	81.012	3.6	PDE
1995	2	19	39.12	83.47	3.6	PDE
1998	9	25	41.495	80.388	5.2	PDE
2001	1	26	41.942	80.802	4.3	PDE
2003	6	30	41.8	81.2	3.6	PDE
2006	6	20	41.84	81.23	3.8	PDE

OHIO SEISMIC NETWORK

The Division of Geological Survey of the Ohio Department of Natural Resources coordinates a 25-station cooperative network of seismograph stations (OhioSeis) in order to continuously record earthquake activity in the state and the surrounding region as shown on the map. These stations are located across the state at colleges, universities, and other institutions, but are concentrated in the most seismically active areas or in areas that provide optimal conditions for detecting and locating small earthquakes. Small earthquakes are important because they occur more frequently than larger earthquakes and help to identify faults that may periodically produce larger, potentially damaging earthquakes.

The Ohio Division of Geological Survey coordinates the seismic network and operates from the Ohio Earthquake Information Center at the Division's Laboratory at Alum Creek State Park, north of Columbus. This seismograph system allows earthquakes anywhere in the state to be rapidly located and their magnitudes to be quickly calculated.

The OhioSeis network was established with the purposes of accurately locating and evaluating Ohio earthquakes, providing information to the public, and defining areas of seismic risk. The network is a joint State and Federal project, part of the National Earthquake Hazards Reduction Program (NEHRP, http://www.nehrp.gov/).

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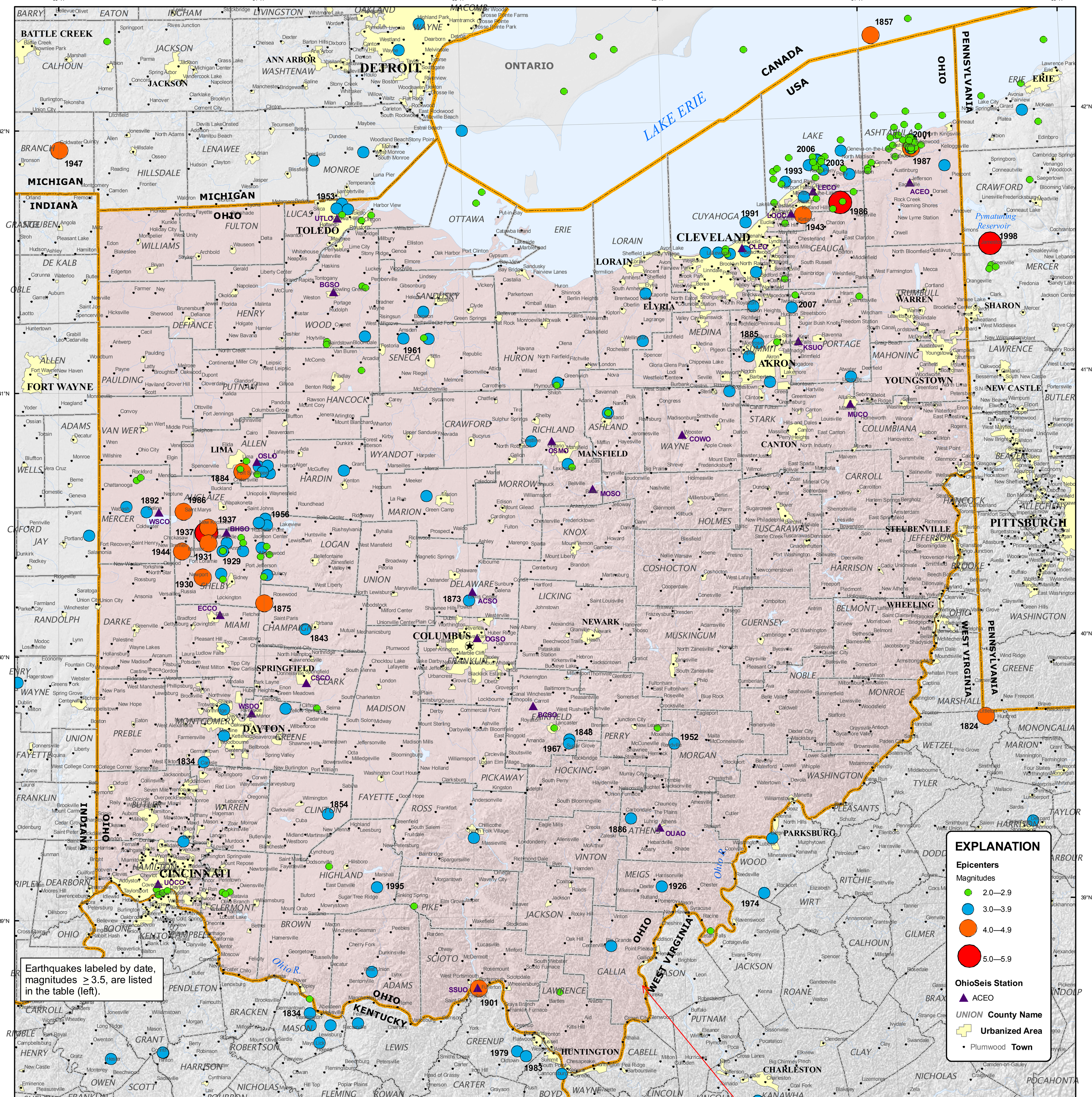
Earthquake Locations



Base from U.S. Geological Survey National Elevation Dataset, National Hydrologic Database, and Digital Chart of the World (ESRI, 1993)

Albers equal-area conic projection, standard parallels 30° 20′ 00′′ and 35° 40′ 00′′, central meridian -85° 00′ 00′′, latitude of origin 0° 00′ 00′′

SCALE 1:1,000,000

GENERAL SITE LOCATION

EARTHQUAKE CATALOGS

Various institutions and agencies compile catalogs of earthquake data. Each uses different criteria in determining the catalog's content. The earthquake locations shown on the map were taken from several catalogs. To some extent, these catalogs cover overlapping time periods. An attempt has been made to locate and remove duplicate events. In the case of event duplication the order of catalog preference, as listed, was generally applied:

- OSN, Ohio Seismic Network, 1999–2007
- ASN, Anna Seismic Network, 1977–1992
- JCU, John Carrol University Seismological Observatory, 1900–1992
- UTLO, University of Toledo seismic station
- UK, University of Kentucky
- LCSN, Lamont-Doherty Cooperative Seismic Network, 1990–2005
- DNAG, Decade of North American Geology, 1534–1985
- NCEER, National Center for Earthquake Engineering Research, 1627–1985
- SIGUS, *Significant Earthquakes in the U.S.* (Stover and Coffman, 1993), 1568–1989
- PDE, Preliminary Determination of Epicenters, 1973–2007
- CERI, Center for Earthquake Research and Information, 1974–2007

The catalogs used may contain mining-related and other types of non-earthquake events. Mining events are typically of small magnitude and may not be easily differentiated from small earthquakes (Street and others, 2002). An attempt was made to exclude non-earthquake events.

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SEISMIC HAZARD

Some level of seismic hazard from earthquake ground shaking exists in every part of the United States. The severity of the ground shaking, however, can vary greatly from place to place. Seismic hazard maps, like the one shown at right, illustrate this variation. The risk level shown on seismic hazard maps is based on a variety of factors, such as earthquake rate of occurrence, magnitude, extent of affected area, strength and pattern of ground shaking, and geologic setting.

Seismic hazard maps are tools for determining acceptable risk. As such, they are critical in helping to save lives and preserve property. They provide information essential to the creation and updating of seismic design provisions for local building codes. Because most buildings and other structures in the central United States were not built to withstand severe ground shaking, damage could be catastrophic in the event of a powerful earthquake. The work of seismic-hazard scientists and engineers provides the groundwork for future urban environments that will be safer if large magnitude earthquakes occur. Additional applications of the information derived from these maps include insurance-rates setting, estimating hillside stability and landslide potential, and estimating assistance funds needed for earthquake education and preparedness.

Seismic hazard maps are an estimation of how the ground in a particular area is likely to respond to local and regional earthquakes. They differ from isoseismal maps in that they are probability maps. They illustrate what shaking levels are likely, or example a 2 percent probability that it will be worse over a stated time period (for example, 50 years).

The seismic energy released during an earthquake radiates in all directions as waves. As the seismic waves move upward they are amplified or de-amplified as they travel through the sediment layers near the ground surface. Seismic wave amplification or de-amplification can significantly affect the way the ground shakes during an earthquake.

An additional factor in determining how the ground will respond during an earthquake is the rate of shaking. As a seismic wave passes a given map location, the ground will vibrate. If ground vibration (oscillation) is rapid (short-period motion), the seismic wave's energy will dissipate quickly. Conversely, if the ground vibration is slow (long-period motion), the wave's energy will dissipate less rapidly. Long-period waves propagate farther and retain their energy over longer distances than do short-period waves.

A final factor in determining ground response to earthquake shaking is the strength of shaking. If ground shaking is particularly violent, sediments may break apart, preventing seismic waves from continuing to be transmitted through them. This would have the beneficial effect of limiting shaking, but such extreme shaking could result in catastrophic ground failure.

The generalized seismic-hazard map (right) is a computer-generated contour map. It portrays seismic hazard calculated by the U.S. Geological Survey as bands of color (cooler blues and grays for less hazard, warmer greens and yellows for greater hazard). Shaking level is expressed as percentage of the acceleration of gravity (%*g*), and seismic hazard values are computed for particular time intervals (here, 50 years) and probability of exceedance (here, 2 percent). For example, the hazard value in Cincinnati is between 6%*g* and 8%*g*. That means a structure built on firm rock has 1 in 50 odds (2 percent probability) of undergoing ground shaking of 6% – 8%*g* or higher in the next 50 years. In terms of shaking, the acceleration a person or object experiences is proportional to the force applied to it by the passing seismic wave.

OHIO SEISMIC ZONES

Anna Seismic Zone
This small seismic zone in western Ohio (right) has had moderately frequent earthquakes at least since the first one was reported in 1875. The two largest earthquakes (March 2 and 9, 1937) located in the zone caused damage. Moderately damaging earthquakes occur in the Anna seismic zone every two or three decades, and smaller earthquakes are felt here two or three times per decade. Historically, seismicity has been episodic with periods of frequent activity and periods of low activity.

Some of the Anna seismic zone earthquakes appear to coincide with the known faults, while others do not. At earthquake depths the positions of even known faults are uncertain, and many small or deeply buried faults may remain undetected. Accordingly, few earthquakes in the seismic zone can be linked to known faults and it is difficult to determine if a specific known fault is active and capable of generating an earthquake.

The Anna seismic zone lacks paleoseismological evidence for faulting younger than Paleozoic. However, north-, north-northeast-, and northwest-striking faults in lower Paleozoic and Precambrian crystalline rocks have been mapped and are part of the Precambrian-age East Continental Rift Zone. No evidence has been found that the zone has had an earthquake larger than magnitude 7 in the past several thousand years.

Northeast Ohio Seismic Zone
The Northeast Ohio seismic zone (map at upper right) has had moderately frequent earthquakes at least since the first one was reported in 1836. The largest earthquake in this zone (magnitude 5.0) occurred in 1986. This event produced Modified Mercalli intensities of VI in the epicentral region. A damaging earthquake (magnitude 5.2) occurred in 1998 near Pymatuning in northwestern Pennsylvania, just east of the Ohio border. An earthquake in the Ashtabula, Ohio, area (magnitude 4.3) in 2001 caused minor damage. Historically this zone has recorded only a few earthquakes per decade, but felt earthquakes have been reported more frequently in recent decades. This is probably a result of increased population, greater public awareness, improved communications, and perhaps episodic seismicity.

NEARBY SEISMIC ZONES

Eastern Tennessee Seismic Zone
The Eastern Tennessee seismic zone (map at upper right) is one of the most active earthquake areas in the southeastern United States. A few earthquakes located within this zone have caused property damage. The largest recorded earthquake in this zone (magnitude 4.6) occurred in 2003, near Fort Payne, Alabama. Felt earthquakes occur about once a year in this seismic zone, and seismographs have recorded hundreds of smaller, unfelt earthquakes in recent decades.

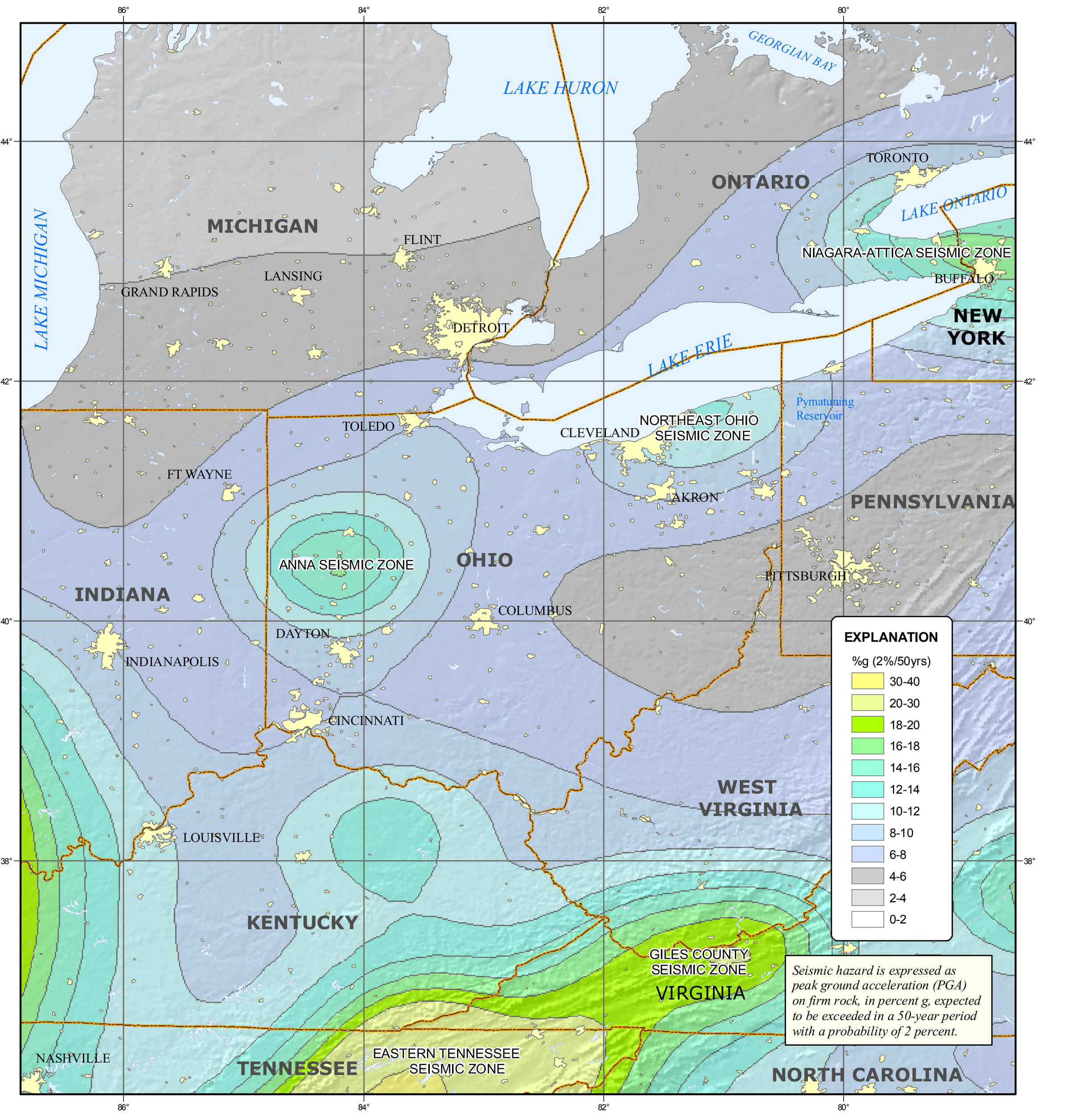
The Eastern Tennessee seismic zone contains many known faults. However, the locations of these faults are poorly known at earthquake depths. Few, if any, earthquakes in the Eastern Tennessee seismic zone can be linked to known faults, and it is difficult to determine if any known faults are seismically active.

Giles County Seismic Zone
Since at least 1828, earthquakes have been reported in the Giles County seismic zone. The largest known damaging earthquake (M5.6) in the zone occurred in 1897. Smaller earthquakes are felt or cause light damage once or twice a decade (Tarr and Wheeler, 2006).

Niagara-Attica Seismic Zone, New York-Ontario
The Niagara-Attica seismic zone in southern Ontario and western New York State (map at upper right) has had moderately frequent earthquakes at least since the first one was reported in 1840. The largest event (magnitude 4.9) in the zone caused moderate damage in 1929 near Attica, New York. Earthquakes too small to cause damage are felt roughly three or four times per decade.

In this zone many faults are known, but few have been traced to earthquake depths; and only a few earthquakes in the zone can be associated with named faults. It is, therefore, difficult to determine if any known faults are seismically active. Numerous smaller or deeply buried faults may remain undetected.

Regional Seismic Hazard



Base from U.S. Geological Survey National Elevation Dataset, National Hydrologic Database, and Digital Chart of the World (ESRI, 1993)

Geographic projection, Datum: D North American 1983

SCALE 1:2,500,000

ABBREVIATED MODIFIED MERCALLI INTENSITY SCALE

Expressed as Roman numerals, earthquake intensities are not instrumentally derived values. They are instead assigned based on descriptive reports from intensity.

- I. Not felt except by a very few under especially favorable conditions.
- II. Felt only by a few persons at rest, especially on upper floors of buildings.
- III. Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.
- IV. Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
- V. Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
- VI. Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
- VII. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
- VIII. Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
- IX. Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings with partial collapse. Buildings shifted off foundations.
- X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.
- XI. Few, if any (masonry) structures remain standing. Bridges destroyed. Rails bent greatly.
- XII. Damage total. Lines of sight and level are distorted. Objects thrown into the air.

INTENSITY AND MAGNITUDE

Intensity is an estimation of earthquake shaking level based on effects on people, buildings, and the landscape expressed here by using the Modified Mercalli Intensity Scale (table at left). During an earthquake, intensity will vary over the affected region. Intensity values for different locations are derived from written accounts (letters, journals and diaries) and published records (newspapers and official reports). These values diminish from a maximum, usually observed near the earthquake's epicenter, to the lowest levels of the scale near the edge of the felt area.

Although an earthquake has a wide distribution of intensity values (isoseismal maps, below left), it has only one *magnitude*. An earthquake's magnitude represents the total energy released. The magnitudes of pre-instrumental earthquakes are estimates based on intensity values recorded at the time of the earthquake or shortly after. The earthquake symbols plotted on the large state map (far left) represent the best estimates of time, location, and magnitude tabulated using several earthquake catalogs.

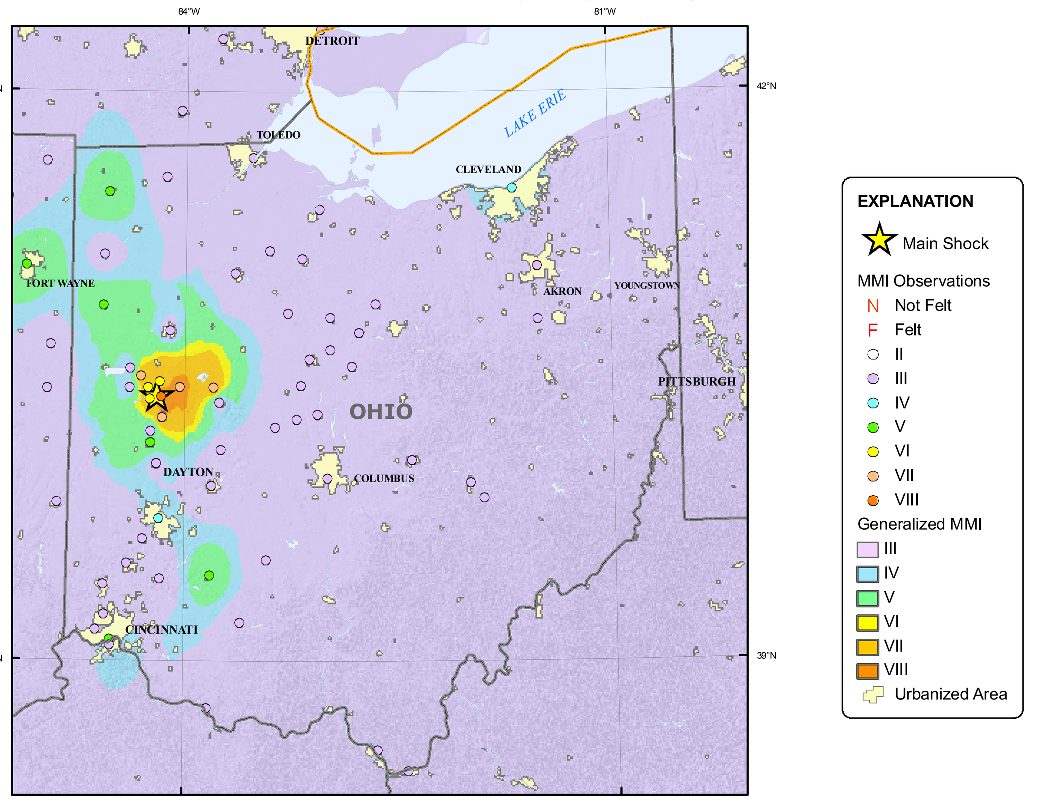
NOTES ON THE ISOSEISMAL MAPS

Isoseismal maps illustrate the level of ground shaking that occurred at various locations during a particular earthquake. The distributions of intensity values in Ohio and vicinity for two earthquakes are shown on the isoseismal maps (left). These events are the March 9, 1937, maximum intensity VII, magnitude 5.4, Anna earthquake and the January 31, 1986, maximum intensity VI, magnitude 5.0, northeast Ohio earthquake.

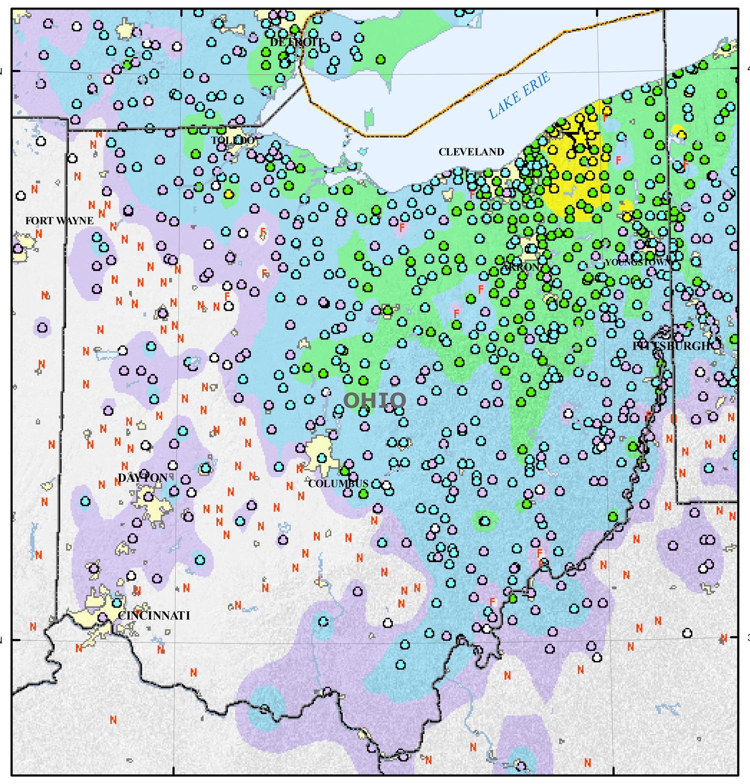
Contemporary accounts from newspapers of earthquake effects in cities and towns over a broad region were the sources of the intensity observations plotted on the isoseismal maps. The intensity observations are shown as color-coded circles. Each observation was assigned a Modified Mercalli Intensity (MMI) and the results were contoured. The mapped intensity values (integers) correspond to the Roman numeral values in the table (above left). An observation coded "F" is a location where shaking was felt but no MMI value was assigned and "N" if source document indicated that the event was not felt.

Contouring of the assigned intensity values, shown as circles on the maps (left), was computer generated using an inverse-distance weighted algorithm. The assigned values are from Neumann (1937) for the Anna earthquake and from Stover and Brewer (1994) for the northeast Ohio earthquake.

Isoseismal Map
Distribution of Intensities for the March 9, 1937, Anna, Ohio, Maximum Intensity VIII, Magnitude 5.4 Earthquake



Isoseismal Map
Distribution of Intensities for the January 31, 1986, Northeast Ohio, Maximum Intensity VI, Magnitude 5.0 Earthquake



SCALE 1:2,500,000

Author's Note

The information presented here was derived from existing sources and earlier publications. Specifically, general information on earthquake occurence and seismic hazard came from Tarr and Wheeler, 2006. This downloadable report is available at http://pubs.usgs.gov/of/2006/1017/. Several additional publications provided detailed information on Ohio earthquake history. They include Stover and Coffman, 1993; Crone and Wheeler, 2000; Wheeler, 2003; Hansen, 2006.

CITATION

Dart, R.L. and Hansen, M.C., 2008, Earthquakes in Ohio and Vicinity 1776–2007: U.S. Geological Survey Open–File Report 2008–1221.

For sale by U.S. Geological Survey Information services
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A PDF of this report is available at:
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EXHIBIT 8

EXHIBIT 9 - KYGER CREEK ASH IMPOUNDMENT - LIQUEFACTION ANALYSIS OF FINE-GRAINED SOILS

Location	Cross-section No.	Boring No.	Sample No.	Depth, ft	Elevation, ft	Soil Classification: Textural	Soil Classification: USCS	Particle Size Distribution: Percent Gravel	Percent Sand	Percent Silt	Percent Clay	Atterberg Limits: Liquid Limit, LL	Plastic Limit, PL	Plasticity Index, PI	Percent Moisture, Wc	ILLINOIS DOT[1]: IS PI<12	IS Wc/LL > 0.85	Is Soil Liquefiable	USACE Recommendation[2]: Is Fine Contents >20%	Is LL >=34	Is PI >=14	Is Soil Liquefiable	OHIO EPA Recommendations[3]: Is Fine Contents <15%	Is LL <35	IS Wc >0.9LL	Is Soil Liquefiable
South Fly Ash Pond	1	KC-1001	ST-2	28.5	560.8	Lean Clay	CL	0	8	47	45	34	20	14	23	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO
South Fly Ash Pond	1	KC-1001	S-17	46	543.3	Lean Clay	CL	0	8	58	34	34	20	14	29.5	NO	YES	NO	NO	NO	NO	NO	NO	YES	NO	NO
South Fly Ash Pond	1	KC-1002	ST-1	8.5	549.8	Sandy Lean Clay	CL	0	16	52	32	32	13	19	25.8	NO	NO	NO	NO	YES	NO	NO	NO	YES	NO	NO
South Fly Ash Pond	2	KC-1003	S-7	16	572.4	Lean Clay	CL	0	24	45	31	30	18	12	19.5	NO	NO	NO	NO	YES	YES	NO	NO	YES	NO	NO
South Fly Ash Pond	2	KC-1003	ST-2	31	557.4	Lean Clay	CL	0	17	47	36	31	18	13	18.6	NO	NO	NO	NO	YES	YES	NO	NO	YES	NO	NO
South Fly Ash Pond	2	KC-1003	S-19	53.5	534.9	Lean Clay with sand	CL	0	17	50	33	31	21	10	33.7	YES*	YES*	YES*	NO	YES	YES	NO	NO	YES	YES	NO
South Fly Ash Pond	2	KC-1004	S-8	16	539.8	Lean Clay with sand	CL	0	20	51	29	32	19	13	28.3	NO	YES	NO	NO	YES	YES	NO	NO	YES	NO	NO
South Fly Ash Pond	3	KC-1005	ST-2	18.5	569.7	Lean Clay	CL	0	13	48	39	37	21	16	21	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
South Fly Ash Pond	3	KC-1005	S-18	48.5	540.2	Sandy Silty Clay	CL-ML	0	30	46	24	25	21	4	25.3	YES*	YES*	YES*	NO	YES	YES	NO	NO	YES	YES	NO
South Fly Ash Pond	3	KC-1005	S-19	53.5	534.7	Silty Clay with sand	CL-ML	0	26	51	23	26	19	7	32.1	YES*	YES*	YES*	NO	YES	YES	NO	NO	YES	YES	NO
South Fly Ash Pond	3	KC-1006	S-7	13.5	563.4	Lean Clay	CL	0	10	42	48	41	21	20	24.2	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
South Fly Ash Pond	3	KC-1006	S-14	31	545.4	Lean Clay with sand	CL	0	20	45	35	48	20	28	23.2	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
South Fly Ash Pond	4	KC-1007	S-7	16	573	Lean Clay	CL	0	13	44	43	39	22	17	24.9	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
South Fly Ash Pond	4	KC-1007	S-19	46	543.5	Lean Clay with sand	CL	0	22	52	26	28	18	10	26	YES*	YES*	YES*	NO	YES	YES	NO	NO	YES	YES	NO
South Fly Ash Pond	4	KC-1008	S-5	6	574.9	Lean Clay	CL	0	5	53	42	40	22	17	24.4	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
South Fly Ash Pond	4	KC-1008	S-11	21	559.9	Lean Clay	CL	0	6	47	47	41	22	19	24.5	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
South Fly Ash Pond	4	KC-1008	S-18	38.5	542.4	Sandy Lean Clay	CL	0	35	43	22	24	16	8	25.5	YES*	YES*	YES*	NO	YES	YES	NO	NO	YES	YES	NO
South Fly Ash Pond	5	KC-1009	ST-1	16	573.2	Lean Clay	CL	0	29	36	35	32	18	14	21.5	NO	NO	NO	NO	YES	NO	NO	NO	YES	NO	NO
South Fly Ash Pond	5	KC-1009	ST-2	26	563.2	Lean Clay	CL	0	7	52	41	38	22	16	22.9	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
South Fly Ash Pond	5	KC-1009	S-19	53.5	535.7	Sandy Lean Clay	CL	0	31	45	24	28	20	8	27.4	YES*	YES*	YES*	NO	YES	YES	NO	NO	YES	YES	NO
South Fly Ash Pond	5	KC-1010	S-5	6	559.1	Lean Clay with sand	CL	0	4	58	38	36	20	16	22.8	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
South Fly Ash Pond	5	KC-1010	S-11	23.5	541.6	Sandy Lean Clay	CL	0	44	35	20	24	18	6	25.2	YES*	YES*	YES*	NO	YES	YES	NO	NO	YES	YES	NO
South Fly Ash Pond	5	KC-1010	ST-2	31	534.1	Sandy Lean Clay	CL	0	31	50	19	29.4	26	18	8	NO	NO	NO	NO	YES	NO	NO	NO	YES	NO	NO
South Fly Ash Pond	6	KC-1011	S-5	11	578.2	Lean Clay	CL	0	11	55	34	34	20	14	22.2	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO
South Fly Ash Pond	6	KC-1011	S-16	38.5	550.7	Lean Clay with sand	CL	0	15	51	34	33	19	14	26.4	NO	NO	NO	NO	YES	NO	NO	NO	YES	NO	NO
South Fly Ash Pond	6	KC-1012	S-5	6	557	Lean Clay with sand	CL	0	1	56	43	41	22	19	25.3	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
South Fly Ash Pond	6	KC-1012	ST-2	21	542	Sandy Lean Clay	CL	0	35	43	22	26	19	7	25.7	YES*	YES*	YES*	NO	YES	YES	NO	NO	YES	YES	NO
Bottom Ash Pond	1	KC-1013	S-5	11	570.3	Lean Clay with sand	CL	2	8	52	38	37	21	16	25.9	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Bottom Ash Pond	1	KC-1013	S-18	48.5	532.8	Sandy Lean Clay	CL	0	23	47	30	30	18	12	28	NO	YES	NO	NO	YES	YES	NO	NO	YES	YES	NO
Bottom Ash Pond	1	KC-1014	ST-1	11	547.6	Lean Clay	CL	0	2	57	41	40	22	18	25.7	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Bottom Ash Pond	1	KC-1014	S-13	31	527.6	Sandy Lean Clay	CL	0	32	43	25	25	16	9	26.9	YES*	YES*	YES*	NO	YES	YES	NO	NO	YES	YES	NO
Bottom Ash Pond	2	KC-1015	S-6	13.5	566.9	Sandy Lean Clay	CL	0	12	54	34	34	20	14	21.1	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO
Bottom Ash Pond	2	KC-1015	S-16	46	534.4	Sandy Lean Clay	CL	0	32	44	24	28	19	9	25.5	YES*	YES*	YES*	NO	YES	YES	NO	NO	YES	YES	NO
Bottom Ash Pond	2	KC-1016	ST-1	8.5	535.3	Lean Clay with sand	CL	0	1	54	45	40	22	18	34.4	NO	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO
Clearwater Pond	3	KC-1017	ST-1	18.5	561.6	Sandy Lean Clay	CL	0	23	46	31	29	18	11	22.4	YES	NO	NO	NO	YES	YES	NO	NO	YES	NO	NO
Clearwater Pond	3	KC-1017	S-15	41	539.1	Lean Clay	CL	0	3	51	46	42	25	17	31.9	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Clearwater Pond	3	KC-1017	S-19	53.5	526.6	Sandy Lean Clay	CL	0	18	54	28	33	20	13	27.3	NO	NO	NO	NO	YES	YES	NO	NO	YES	NO	NO
Clearwater Pond	3	KC-1018	ST-1	8.5	538.8	Lean Clay	CL	0	4	53	43	44	24	20	21.8	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Clearwater Pond	3	KC-1018	S-9	18.5	529.3	Lean Clay	CL	0	5	63	32	36	21	15	30.5	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Clearwater Pond	4	KC-1019	S-8	21	559.7	Lean Clay	CL	0	13	51	36	33	20	13	23.9	NO	NO	NO	NO	YES	YES	NO	NO	YES	NO	NO
Clearwater Pond	4	KC-1019	ST-2	26	554.7	Sandy Silt	ML	0	38	38	24	21	18	3	22	YES*	YES*	YES*	NO	YES	YES	NO	NO	YES	YES	NO
Clearwater Pond	4	KC-1020	S-5	6	553.5	Lean Clay	CL	0	7	58	35	38	22	17	23.1	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Clearwater Pond	4	KC-1020	S-7	16	543.5	Sandy Lean Clay	CL	0	19	54	27	32	20	12	23.7	NO	NO	NO	NO	YES	YES	NO	NO	YES	NO	NO
Clearwater Pond	4	KC-1020	S-12	28.5	531	Sandy Lean Clay	CL	0	30	46	24	28	17	11	25.4	YES*	YES*	YES*	NO	YES	YES	NO	NO	YES	YES	NO
Bottom Ash Pond	5	KC-1021	ST-1	18.5	561.7	Sandy Lean Clay	CL	0	21	46	33	32	20	12	21.4	NO	NO	NO	NO	YES	YES	NO	NO	YES	NO	NO
Bottom Ash Pond	5	KC-1021	S-15	41	539.2	Sandy Lean Clay	CL	0	34	46	20	28	19	9	25.6	YES*	YES*	YES*	NO	YES	YES	NO	NO	YES	YES	NO
Bottom Ash Pond	5	KC-1022	S-4	4.5	558.2	Sandy Silty Clay	CL-ML	0	41	40	19	22	18	4	15.2	YES	NO	NO	NO	YES	YES	NO	NO	YES	NO	NO
Bottom Ash Pond	5	KC-1022	S-7	16	546.7	Sandy Lean Clay	CL	0	40	38	22	25	17	8	18.1	YES	NO	NO	NO	YES	YES	NO	NO	YES	NO	NO

*See Spreadsheet for Additional Liquefaction Analyses of Potentially Liquefiable Fine-grained Soils for Fnal Results

Note: 1) Illinois DOT - AGMU Memo 10.1-Liquefaction Analysis, dated January 14, 2010, from the Illinois Department of Transportation.

2) USACE Recommendations - U.S. Army Corps of Engineers. Slope Stability. Engineering Manual 1110-2-1902. October, 2003, page 1-6.

3) OHIO EPA Recommendations - Chapter 5, Liquefaction Potential Evaluation and Analysis, RCRA Subtitle D (258) Seismic Design Guidance for Muncipal Solid Waste Landfill Facilities, EPA/600/R-95/051, April 1995.

Bottom Ash Pond is also known as
Boiler Slag Pond

EXHIBIT 10 - KYGER CREEK ASH IMPOUNDMENT - ADDITIONAL LIQUEFACTION ANALYSES OF POTENTIALLY LIQUEFIABLE FINE-GRAINED SOILS

Location	Cross-section No.	Boring No.	Depth to Top of Layer (ft, bgs)	Depth to Bottom of Layer (ft, bgs)	Mid-point Depth of Layer (ft, bgs)	Mid-point Depth of Layer (m, bgs)	Elevation to Top of Layer (ft, bgs)	Sampler Type	Soil Type	Groundwater Level During Seismic Event (ft, bgs)	Total Overburden Stress, σ, psf	Effective Overburden Stress, σ', psf	N_m, field N-Values	C_N	CE	CB	CR	CS	$(N_{1})_{60}$ (blows/ft)	Fine Content (%)	α	β	$(N_{1})_{60 cs}$ (blows/ft)	r_d	CSR	$(CRR)_{7.5}$	MSF	FS_{Liq}	Liquefaction Potential
South Fly Ash Pond	2	KC-1003	53.5	55.5	54.5	16.35	534.9	SS	CL	0	6540	3139.2	3	0.82	1.21	1.00	1.00	1.00	2.98	83.00	5.00	1.20	8.57	0.72	0.06	0.10	5.33	9.23	NO
South Fly Ash Pond	3	KC-1005	48.5	53.5	51	15.3	540.2	SS	CL-ML	0	6120	2937.6	3	0.85	1.21	1.00	1.00	1.00	3.08	70.00	5.00	1.20	8.69	0.75	0.06	0.10	5.33	8.90	NO
South Fly Ash Pond	3	KC-1005	53.5	57	55.25	16.575	534.7	SS	CL-ML	0	6630	3182.4	2	0.82	1.21	1.00	1.00	1.00	1.97	74.00	5.00	1.20	7.36	0.71	0.06	0.09	5.33	8.39	NO
South Fly Ash Pond	4	KC-1007	46	48	47	14.1	543	SS	CL	0	5640	2707.2	6	0.88	1.21	1.00	1.00	1.00	6.41	78.00	5.00	1.20	12.69	0.79	0.06	0.14	5.33	11.42	NO
South Fly Ash Pond	4	KC-1008	38.5	40	39.25	11.775	542.4	SS	CL	0	4710	2260.8	5	0.97	1.21	1.00	1.00	1.00	5.84	65.00	5.00	1.20	12.01	0.86	0.07	0.13	5.33	9.99	NO
South Fly Ash Pond	5	KC-1009	53.5	55.5	54.5	16.35	535.7	SS	CL	0	6540	3139.2	3	0.82	1.21	1.00	1.00	1.00	2.98	69.00	5.00	1.20	8.57	0.72	0.06	0.10	5.33	9.23	NO
South Fly Ash Pond	5	KC-1010	23.5	25.5	24.5	7.35	541.6	SS	CL	0	2940	1411.2	4	1.22	1.21	1.00	1.00	1.00	5.92	55.00	5.00	1.20	12.10	0.94	0.08	0.13	5.33	9.18	NO
South Fly Ash Pond	6	KC-1012	21	23	22	6.6	542	SS	CL	0	2640	1267.2	1	1.29	1.21	1.00	1.00	1.00	1.56	65.00	5.00	1.20	6.87	0.95	0.08	0.09	5.33	5.97	NO
Bottom Ash Pond	1	KC-1014	31	32	31.5	9.45	527.6	SS	CL	0	3780	1814.4	4	1.08	1.21	1.00	1.00	1.00	5.22	68.00	5.00	1.20	11.26	0.92	0.07	0.12	5.33	8.92	NO
Bottom Ash Pond	2	KC-1015	46	47.5	46.75	14.025	534.4	SS	CL	0	5610	2692.8	1	0.89	1.21	1.00	1.00	1.00	1.07	68.00	5.00	1.20	6.29	0.79	0.06	0.08	5.33	6.78	NO
Clearwater Pond	4	KC-1019[4]	26	28	27	8.1	554.7	SS	ML	0	3240	1555.2	4	1.17	1.21	1.00	1.00	1.00	5.64	62.00	5.00	1.20	11.76	0.94	0.08	0.13	5.33	9.05	NO
Clearwater Pond	4	KC-1020	28.5	31	29.75	8.925	531	SS	CL	0	3570	1713.6	1	1.11	1.21	1.00	1.00	1.00	1.34	70.00	5.00	1.20	6.61	0.92	0.08	0.08	5.33	6.00	NO
Bottom Ash Pond	5	KC-1021	41	42	41.5	12.45	539.2	SS	CL	0	4980	2390.4	0	0.94	1.21	1.00	1.00	1.00	0.00	66.00	5.00	1.20	5.00	0.84	0.07	0.07	5.33	5.61	NO

Note:

1. The "Simplified Method" described by Youd et al (2001) was used.
2. An earthquake moment magnitude (Mw) of 3.9 was assumed.
3. A peak ground acceleration of 0.06g was used.
4. The sample is a Shelby tube sample but was assumed as a split spoon sample for analysis.

Bottom Ash Pond is also known as
Boiler Slag Pond

Liquefaction Analysis

This design guide illustrates the Department's recommended procedures for analyzing the liquefaction potential of soil during a seismic event considering Article 10.5.4.2 of the 2009 Interim Revisions for the AASHTO LRFD Bridge Design Specifications and various research. The phenomenon of liquefaction and how it should be evaluated continues to be the subject of considerable study and debate. It is expected that enhancements will evolve and modify how liquefaction should be evaluated and accounted for in design. This design guide outlines the Department's current recommended procedure for identifying potentially liquefiable soils. Also included are recommendations for characterizing the properties and behavior of liquefiable soils so that substructure stiffness and embankment response to seismic loading can be modeled.

Liquefaction Description and Design

Saturated loose to medium dense cohesionless soils and low plasticity silts tend to densify and consolidate when subjected to cyclic shear deformations inherent with large seismic ground motions. Pore-water pressures within such layers increase as the soils are cyclically loaded, resulting in a decrease in vertical effective stress and shear strength. If the shear strength drops below the applied cyclic shear loadings, the layer is expected to transition to a semi fluid state until the excess pore-water pressure dissipates.

Embankments and foundations are particularly susceptible to damage, depending on the location and extent of the liquefied soil layers. Such soils may adequately carry everyday loadings, however once liquefied, retain insufficient capacity for such loads or additional seismic forces. Substructure foundations shall either be designed to withstand the liquefaction or ground improvement techniques shall be used to achieve the IDOT performance objectives of no loss of life or loss of span. End slopes and roadway embankments on liquefiable soils require an analysis to determine the likely extent of pavement/slope damage so that the cost of ground improvement techniques can be compared to alternatives such as re-routing traffic around the damaged lanes or quickly effecting emergency repairs.

The stiffness of liquefiable soils supporting foundations is anticipated to degrade over the duration of the seismic event and reduces the lateral stiffness of the substructure. The reduced stiffness results in increased deflection and moment arm, concern for buckling, and potentially additional loading on adjacent substructures. The lateral stiffness, moments and forces carried by such foundations supported by liquefiable soils is best determined using programs such as COM624 or LPILE. The liquefied soil layers can be modeled in these programs with reduced strength parameters or the p-y curves can be modified to reflect the residual strength of the liquefied layers. Note that the estimated fixity depths indicated in Design Guide 3.15 (Seismic Design) should not be used for analyzing substructures with liquefiable soils.

Vertical ground settlement should be expected to occur following liquefaction. As such, spread footings should not be specified at sites expected to liquefy unless ground improvement techniques are employed to mitigate liquefaction. For driven pile and drilled shaft foundations, the vertical settlement will result in a loss of skin friction capacity and an added negative skin friction (NSF) downdrag load when the liquefiable layers are overlain by non-liquefiable soils. Geotechnical losses from liquefaction and any liquefaction induced NSF loadings shall only be considered with the Extreme Event I limit state group loading, since the strength limit state group loadings represent the conditions prior to, not after a seismic event.

Since liquefaction may or may not fully occur while the peak seismic bridge loadings are applied, structures at sites where liquefaction is anticipated must be analyzed and designed to resist the seismic loadings with nonliquefied conditions as well as a configuration that reflects the locations, extent and reduced strength of the liquefiable layers. However, the design spectra used for both configurations shall be the spectra determined for the nonliquefied configuration.

Embankments and bridge cones are susceptible to lateral movements in addition to vertical settlement during a seismic event. When the seismic slope stability factor of safety approaches 1.0, slope deformations become likely and when liquefaction is expected, these movements can be substantial. The ability of embankments and bridge cones to resist such failures when liquefiable soils are present should be investigated using the slope geometry and static stresses along with residual strength properties for the liquefied soils as described later in the design guide. A new AGMU Memo 10.3 (Slope Stability Design Criteria for Bridges and Roadways) is expected to be issued this year to provide further guidance on the seismic analysis of embankments.

Liquefaction Analysis Criteria

All sites located in Seismic Performance Zones (SPZ) 3 and 4 as well as sites located in SPZ 2 with a peak seismic ground surface acceleration, A_S (PGA modified by the zero-period site factor, F_{pga}), equal to or greater than 0.15, require liquefaction analysis. The exception to this is when the all liquefaction susceptible soils at a site have corrected standard penetration test (SPT) blow counts $(N_1)_{60}$ above 25 blows/ft. or the anticipated groundwater is not within 50 ft of the ground surface. The groundwater elevation used in the analysis should be the seasonally averaged groundwater elevation for the site which may not be equal to that encountered during the soil boring drilling.

Low plasticity silts and clays may experience pore-water pressure increases, softening, and strength loss during earthquake shaking similar to cohesionless soils. Fine-grained soils with a plasticity index (PI) less than 12 and water content (w_c) to liquid limit (LL) ratio greater than 0.85 are considered potentially liquefiable and require liquefaction analysis. While PI is regularly investigated for pavement subgrades, it has rarely been considered in the past for structure soil borings. However, in order to investigate liquefaction susceptibility of fine-grained soils, the plasticity of such soils should be examined when conducting structure soil borings. Drillers should inspect and describe the plasticity of fine-grained soil samples. Low plasticity fine-grained soils, particularly loams and silty loams, should be retained for the Atterberg Limit testing with the results indicated on the soil boring log.

For typical projects, liquefaction analysis shall be limited to the upper 60 ft of the geotechnical profile measured from the existing or final ground surface (whichever is lower). This depth encompasses a significant number of past liquefaction observations used to develop the simplified liquefaction analysis procedure described below. If the liquefaction analysis indicates that the factor of safety (FS) against liquefaction is greater than or equal to 1.0, no further concern for liquefaction is necessary. However, if soil layers are present indicating a FS less than 1.0, the potential for these layers to liquefy and the effect on the slope or foundation but be further evaluated.

Liquefaction Analysis Procedure

The method described below is provided to assist Geotechnical Engineers in facilitating liquefaction analysis for typical or routine projects. For simplicity, numerical expressions or directions are provided for determining values of the variables necessary to conduct the liquefaction analysis for such projects. Non-linear site response analysis programs can be used to determine more exacting values for some of the variables, however this should only be considered necessary for large or unique projects where a more refined liquefaction analysis is desired.

The "Simplified Method" described by Youd et al. (2001) as well as refinements suggested by Cetin et al. (2004) shall be used to estimate liquefaction potential as contained herein. The simplified method compares the resistance of a soil layer against liquefaction (Cyclic Resistance Ratio, CRR) to the seismic demand on a soil layer (Cyclic Stress Ratio, CSR) to estimate the FS of a given soil layer against triggering liquefaction. The FS for each soil sample should be computed to allow thin, isolated layers to be discounted and the specific locations and extent of those determined liquefiable to be indicated in the SGR and accounted for in design.

An Excel spreadsheet that performs these calculations has been prepared to assist Geotechnical Engineers with conducting a liquefaction analysis and may be downloaded from IDOT's website.

$$\mathrm{FS} = \frac{\mathrm{CRR}}{\mathrm{CSR}}$$

Where:

$$\mathrm{CRR} = \mathrm{CRR}_{7.5} K_{\sigma} K_{\alpha} \mathrm{MSF}$$

$$\mathrm{CSR} = 0.65 A_S \left(\frac{\sigma_{vo}}{\sigma'_{vo}} \right) r_d$$

$\mathrm{CRR}_{7.5}$ = cyclic resistance ratio for magnitude 7.5 earthquake

$$= \frac{1}{34-(N_1)_{60cs}} + \frac{(N_1)_{60cs}}{135} + \frac{50}{[10(N_1)_{60cs}+45]^2} - \frac{1}{200}$$

K_σ = overburden correction factor

$$= \left(\frac{\sigma'_{vo}}{2.12}\right)^{(f-1)} \text{ and } 1.5 \le K_\sigma \le 9^{(f-1)}$$

f = soil relative density factor

$$= 0.831 - \frac{(N_1)_{60cs}}{160} \text{ and } 0.6 \le f \le 0.8$$

K_α = sloping ground correction factor

= 1.0 for generally level ground surfaces or slopes flatter than 6 degrees. See the following discussions for liquefaction evaluation of slopes and embankments.

MSF = magnitude scaling factor

= $87.2(M_w)^{-2.215}$

M_w = earthquake moment magnitude.

A_S = peak horizontal acceleration coefficient at the ground surface

= F_{pga} PGA

F_{pga} = site amplification factor for zero-period spectral acceleration (LRFD Article 3.10.3.2)

PGA = peak seismic ground acceleration on rock.

σ_{vof} = total vertical soil pressure for final condition (ksf)

σ'_{vof} = effective vertical soil pressure for final condition (ksf)

σ_{vof}, σ'_{vof}, and σ'_{voi} may be calculated using the following correlations for estimating the unit weight of soil (kcf):

Above water table: $\gamma_{granular} = 0.095N_m^{0.095}$

$\gamma_{cohesive} = 0.1215Q_u^{0.095}$

Below water table: $\gamma_{granular} = 0.105N_m^{0.07} - 0.0624$

$\gamma_{cohesive} = 0.1215Q_u^{0.095} - 0.0624$

Fill soils being modeled for the final condition may be assumed to have unit weights of 0.120 kcf and 0.058 kcf above and below the water table.

r_d = soil shear mass participation factor

$$= \frac{\left[1 + \frac{-23.013 - 2.949A_S + 0.999M_w + 0.016V^*_{s,40'}}{16.258 + 0.201e^{0.104\left(-d + 0.0785V^*_{s,40'} + 24.888\right)}}\right]}{\left[1 + \frac{-23.013 - 2.949A_S + 0.999M_w + 0.016V^*_{s,40'}}{16.258 + 0.201e^{0.104\left(0.0785V^*_{s,40'} + 24.888\right)}}\right]} \text{ for d < 65 ft}$$

$$= \frac{\left[1 + \frac{-23.013 - 2.949A_S + 0.999M_w + 0.016V^*_{s,40'}}{16.258 + 0.201e^{0.104\left(-65 + 0.0785V^*_{s,40'} + 24.888\right)}}\right]}{\left[1 + \frac{-23.013 - 2.949A_S + 0.999M_w + 0.016V^*_{s,40'}}{16.258 + 0.201e^{0.104\left(0.0785V^*_{s,40'} + 24.888\right)}}\right]} - 0.0014(d - 65) \text{ for } d \geq 65 \text{ ft}$$

$V^*_{s,40'}$ = average shear wave velocity within the top 40 ft of the finished grade (ft/sec).

$$= \frac{40}{\sum_{i=1}^{n} \frac{d_i}{v_{si}}}$$

v_{si} = shear wave velocity of individual soil layer (ft/sec)

$= 169N_m^{0.516}$

Fill soils may be assumed to have a shear wave velocity of 600 ft/sec.

d_i = thickness of individual soil layer (ft)

d = depth of soil sample below finished grade (ft)

$(N_1)_{60cs}$ = $(N_1)_{60}$ adjusted to an equivalent clean sand value (blows/ft)

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

α = clean sand adjustment factor coefficient

= 0 for $FC \leq 5\%$

$= e^{\left(1.76 - \frac{190}{FC^2}\right)}$ for $5\% < FC < 35\%$

= 5 for $FC \geq 35\%$

β = clean sand adjustment factor coefficient

= 1.0 for $FC \leq 5\%$

$= 0.99 + \frac{FC^{1.5}}{1000}$ for $5\% < FC < 35\%$

= 1.2 for $FC \geq 35\%$

FC = % passing No. 200 sieve

$(N_1)_{60}$ = corrected SPT blow count (blows/ft)

$= N_m C_N C_E C_B C_R C_S$

N_m = field measured SPT blow count recorded on the boring logs (blows/ft)

C_N = overburden correction factor

$$= \frac{2.2}{\left(1.2 + \frac{\sigma'_{voi}}{2.12}\right)} \leq 1.7$$

σ'_{voi} = effective vertical soil pressure during drilling (ksf)

C_E = hammer energy rating correction factor

$= \frac{ER}{60}$; ER = hammer efficiency rating (%)

C_B = borehole diameter correction factor

= 1.0 for boreholes approximately $2\frac{1}{2}$ to $4\frac{1}{2}$ inches in diameter

= 1.05 for boreholes approximately 6 inches in diameter

= 1.15 for boreholes approximately 8 inches in diameter

C_R = rod length correction factor

$$= (-2.1033 \times 10^{-11})\ell^6 + (7.9025 \times 10^{-9})\ell^5 - (1.2008 \times 10^{-6})\ell^4 + (9.4538 \times 10^{-5})\ell^3$$
$$- (4.0911 \times 10^{-3})\ell^2 + (9.3996 \times 10^{-2})\ell + 0.0615 \text{ and } 0.75 \leq C_R \leq 1.0$$

C_S = split-spoon sampler lining correction factor

= 1.0 for samplers with liners

$= 1 + \frac{C_N N_m}{100}$ for samplers without liners where $1.1 \leq C_S \leq 1.3$

ER = hammer efficiency rating (%)

Unless more exacting information is available, use 73% for automatic type hammers and 60% for conventional drop type hammers.

ℓ = drill rod length (ft) measured from the point of hammer impact to tip of sampler. ℓ may be estimated as the depth below the top of boring for the soil sample under consideration plus 5 ft to account for protrusion of the drill rod above the top of borehole.

For soils explorations conducted by IDOT, boreholes are typically advanced using hollow stem augers that are 8 inches in diameter or using wash boring methods with a cutting bit that results in approximately a 4½ inch diameter borehole. The diameter and methods of advancing the borehole can vary between Districts and Consultants performing soils explorations for IDOT. As such, it is recommended that the borehole diameter be included on the soil boring log in addition to the drilling procedure (hollow stem auger, mud rotary, etc.). Geotechnical engineers conducting a liquefaction analysis and calculating the borehole diameter correction factor (C_B) should inquire with the soils exploration provider if the borehole diameter is not provided.

SPT tests are generally conducted in accordance with AASHTO T 206 and the split-spoon samplers are designed to accept a metal or plastic liner for collecting and transporting soil samples to the laboratory. Omitting the liner provides an enlarged internal barrel diameter that reduces friction between the soil sample and interior of the sampler, resulting in a reduced SPT blow count. Past experience indicates that interior liners are seldom used and the AASHTO T 206 specification indicates that the use of liners is to be noted on the penetration record. Thus, it shall be assumed in the calculation of the split-spoon sampler lining correction factor (C_S) that liners were not used unless otherwise indicated the soil boring log.

The field measured SPT blow count values obtained in Illinois commonly use an automatic type hammer which typically offer hammer efficiency (ER) values greater than the standard 60% associated with drop type hammers. For soils exploration conducted with automatic type hammers, an ER of 73% may be assumed unless more exacting information is available.

Liquefaction resistance improves with increased fines content. As such, sieve analysis should be conducted for low plasticity fine-grained loams and silts below the anticipated groundwater elevation and within the upper 60 ft when the $(N_1)_{60}$ is less than or equal to 25 blows/ft to determine percent passing a No. 200 sieve (Fines Content, FC). These data should be included in the SGR and/or reported on the soil boring log.

M_w and PGA Values for Liquefaction Analysis

The spectral accelerations for the 0.0 second, 0.2 second and 1.0 second structure period are typically used by the structural engineer to conduct a pseudo-static seismic analysis and design of the bridge and foundation elements. These are commonly obtained from U.S. Geological Survey (USGS) maps which were developed using a probabilistic seismic hazard analysis (PSHA). PSHA estimates the likelihood that various seismic accelerations will be exceeded at a given site, over a future specific period of time, by analyzing various potential seismic sources, earthquake magnitudes, site to source distances, and estimated rates of occurrence. With this methodology, as the desired probability of exceedance is decreased (or design return period is increased), the corresponding spectral accelerations increase. The 0.0 second spectral acceleration is commonly considered as the PGA (hereafter referred to as the PSHA PGA) for the structure's design return period.

In addition to PGA, duration of shaking is a key factor in triggering liquefaction and is represented in the liquefaction analysis procedure by the earthquake Moment Magnitude (M_w). In the past, IDOT used the PSHA PGA with the Mean Earthquake Moment Magnitude ($\overline{M_W}$) provided by the USGS for the site location and design return period. However, this PGA and M_w combination will not properly indentify a site's liquefaction potential for the design return period. Portions of Illinois considered multi-modal, meaning that there are multiple earthquake scenarios that have a significant contribution to the overall hazard, require liquefaction potential be checked for multiple PGA and M_w pairs to determine the controlling values. Multi-modal conditions are often characterized by a distant seismic source, capable of producing a large M_w with a smaller PGA, and a near-site source capable of producing a smaller M_w with a larger PGA. The distant seismic source will almost always be the New Madrid seismic zone (NMSZ). The near-site source will typically be the "background seismicity" sources gridded by the USGS, although the Wabash Valley seismic zone (WVSZ) will control the near-site source for some sites in southeastern Illinois. Sites near the southern most portion of the state become less multi-modal and are solely controlled the NMSZ. The PGA and M_w values to be checked must be determined using the USGS 2008 PSHA deaggregation data, located at: http://eqint.cr.usgs.gov/deaggint/2008/, which summarizes the contribution of various earthquake scenarios to the hazard.

The distant seismic source (NMSZ) is typically represented by the Modal source-site distance (R*) and magnitude (M_w*) values provided at the base of the deaggregation, which reflect the largest contribution to the overall site hazard. The PGA to be used with this source must be calculated using the R*, M_w* and the ground motion prediction equations (GMPE's) used by the USGS for the NMSZ. The USGS uses a weighted average of 8 different ground GMPE's for the NMSZ, which due to their complexity, are not presented herein. They are provided in IDOT's Liquefaction Analysis Excel spreadsheet and used to compute the distant seismic source PGA with input of R*, M_w*, and selecting "NMSZ" for the proper ground motion prediction equations.

The R and M_w values representing the near-site sources can be identified by evaluating the "ALL_EPS" and source-site distance "DIST(KM)" columns of the deaggregation data. The ALL_EPS column indicates the percent contribution each earthquake scenario adds to the overall hazard. Scenarios contributing more than 5% to the hazard with a source-site distance not extending to the NMSZ should be selected as near-site sources to be investigated. The PGA to be used with each selected near-site R and M_w pair shall be calculated using the USGS ground motion prediction equations for the Central Eastern United States (CEUS). The USGS uses a weighted average of 7 different GMPE's to for the CEUS. These GMPE's are also programmed into the IDOT Liquefaction Analysis spreadsheet to provide near-site PGA values for each selected R, and M_w when the "CEUS" is input as the proper ground motion prediction equations.

Two examples for interpreting the deaggregation data and determining the PGA and M_w pairs to be used for the liquefaction analysis are included at the end of the design guide.

Liquefaction Analysis Procedure for Slopes and Embankments

The liquefaction resistance of dense granular materials under low confining stress (dilative soils) tends to increase with increased static shear stresses. Such static shear stresses are typically the result of ground surface inclinations associated with slopes and embankments. Conversely, the liquefaction resistance of loose soils under high confining stress (contractive soils) tends to decrease with increased static shear stresses. Such soils are susceptible to undrained strain softening. The effects of sloping ground and static shear stresses on the liquefaction resistance of soils is accounted for in the previously described Simplified Procedure by use of the sloping ground correction factor, K_α.

K_α is a function of the static shear stress to effective overburden pressure ratio and relative density of the soil. Graphical curves have been published that correlate K_α with these variables (Harder and Boulanger 1997). With the exception of earth masses of a constant slope, the ratio of the static shear stress to effective overburden pressure will vary at different points under an embankment, and most slopes, making it difficult to determine an appropriate K_α. Researchers that developed the Simplified Procedure have indicated that there is a wide range of proposed K_α values indicating a lack of convergence and need for additional research. It is recommended that the graphical curves that have been published for establishing K_α not be used by nonspecialists in geotechnical earthquake engineering or in routine engineering practice.

Olson and Stark (2003) have presented an alternative approach for analyzing the effects of static shear stress due to sloping ground on the liquefaction resistance of soils. A detailed description of the method is not included herein and Geotechnical Engineers should obtain a copy of the reference document for further information.

The method provides a numerical relationship for determining whether soils are contractive or dilative. If soils are determined to be contractive, an additional analysis should be conducted to investigate the effects of static shear stress on the liquefaction resistance of soils. The additional analysis is an extension of a traditional slope stability analysis typically performed with commercial software, and can be readily facilitated with the use of a spreadsheet and data obtained from the slope stability software. If the additional analysis indicates soil layers with a FS < 1.0 against liquefaction, a post-liquefaction slope stability analysis should be conducted with residual shear strengths assigned to the soil layers expected to liquefy. While Olson and Stark (2003) present one acceptable method for estimating the residual shear strength of liquefied soil layers, there are also a number of other methods presented in various reference documents concerning liquefaction.

The Department's Liquefaction Analysis spreadsheet that estimates liquefaction resistance of soil using the Simplified Method described above also estimates whether soils are contractive or dilative based upon the relationship provided by Olson and Stark (2003). As the classification of contractive or dilative soils is affected by overburden pressure, the presence of such soils should be assessed considering a soil column that starts at the top of the embankment/slope and another soil column that begins at the base of the embankment/slope.

Note that the method provided by Olson and Stark (2003) also includes an equation for estimating the seismic shear stress on a soil layer (Eq. 3a in the reference document). The variable C_M included in the referenced equation shall be replaced with the variable MSF and both variables MSF and r_d shall be calculated using the equations outlined above for the Simplified Method.

Examples for Determining M_w and PGA Values

The first of two examples is for a location near Grayville, Illinois and the corresponding deaggregation data, obtained from the USGS website, is provided in below in Figure 1. In this case, the five earthquake scenarios highlighted in the figures have an "ALL_EPS" contribution to the total hazard greater than 5%.

```
*** Deaggregation of Seismic Hazard at One Period of Spectral Accel. ***
*** Data from U.S.G.S. National Seismic Hazards Mapping Project, 2008 version ***
PSHA Deaggregation. %contributions. site: Grayville,_IL long:  88.015 W., lat: 38.257 N.
 Vs30(m/s)= 760.0 CEUS atten. model site cl BC(firm) or A(hard).
NSHMP 2007-08  See USGS OFR 2008-1128. dM=0.2 below
Return period: 975   yrs. Exceedance PGA =0.2147   g. Weight * Computed_Rate_Ex 0.104E-02
#Pr[at least one eq with median motion>=PGA in 50 yrs]=0.02123
#This deaggregation corresponds to Mean Hazard w/all GMPEs
DIST(KM) MAG(MW) ALL_EPS EPSILON>2  1<EPS<2 0<EPS<1 -1<EPS<0 -2<EPS<-1 EPS<-2
   11.6    4.60    3.493     0.343    1.627    1.385    0.139    0.000    0.000
   28.5    4.61    0.589     0.466    0.123    0.000    0.000    0.000    0.000
   12.1    4.80    7.215     0.564    3.247    2.915    0.488    0.000    0.000
   29.2    4.81    1.674     1.065    0.609    0.000    0.000    0.000    0.000
   12.6    5.03    6.111     0.365    2.177    2.831    0.738    0.000    0.000
   30.0    5.04    2.112     0.981    1.129    0.002    0.000    0.000    0.000
   55.8    5.05    0.086     0.086    0.000    0.000    0.000    0.000    0.000
   13.0    5.21    2.627     0.130    0.780    1.338    0.378    0.001    0.000
   30.6    5.21    1.205     0.427    0.731    0.047    0.000    0.000    0.000
   57.6    5.21    0.081     0.081    0.000    0.000    0.000    0.000    0.000
   13.4    5.39    4.419     0.189    1.130    2.343    0.735    0.022    0.000
   31.1    5.40    2.638     0.692    1.677    0.269    0.000    0.000    0.000
   58.8    5.40    0.262     0.262    0.000    0.000    0.000    0.000    0.000
   13.7    5.61    2.434     0.089    0.532    1.315    0.473    0.024    0.000
   31.9    5.62    1.959     0.336    1.190    0.434    0.000    0.000    0.000
   59.7    5.62    0.288     0.267    0.020    0.000    0.000    0.000    0.000
   13.9    5.80    2.291     0.077    0.459    1.152    0.562    0.042    0.000
   32.3    5.81    2.234     0.289    1.267    0.678    0.000    0.000    0.000
   60.1    5.81    0.395     0.313    0.082    0.000    0.000    0.000    0.000
   88.4    5.82    0.052     0.052    0.000    0.000    0.000    0.000    0.000
   12.9    6.01    1.740     0.050    0.301    0.757    0.569    0.063    0.000
   32.6    6.01    2.166     0.196    1.036    0.911    0.023    0.000    0.000
   61.2    6.01    0.434     0.252    0.182    0.000    0.000    0.000    0.000
   88.5    6.01    0.078     0.078    0.000    0.000    0.000    0.000    0.000
   12.5    6.21    1.725     0.047    0.279    0.700    0.619    0.080    0.000
   34.1    7.39    0.999     0.031    0.183    0.461    0.314    0.010    0.000
   59.4    7.40    0.369     0.020    0.120    0.222    0.007    0.000    0.000
   85.0    7.38    0.168     0.017    0.101    0.050    0.000    0.000    0.000
  120.6    7.39    0.144     0.027    0.113    0.004    0.000    0.000    0.000
  155.1    7.44    5.773     1.406    3.581    0.786    0.000    0.000    0.000
   14.4    7.59    0.060     0.001    0.008    0.021    0.021    0.008    0.000
   34.3    7.59    0.158     0.005    0.027    0.068    0.055    0.003    0.000
   62.2    7.59    0.062     0.003    0.018    0.038    0.004    0.000    0.000
  155.1    7.70   15.821     2.080    7.962    5.779    0.000    0.000    0.000
  155.1    8.00    7.989     0.623    3.017    3.584    0.765    0.000    0.000

Summary statistics for above PSHA PGA  deaggregation, R=distance, e=epsilon:
Contribution from this GMPE(%):  100.0
 Mean src-site R=   64.9 km; M= 6.33; eps0=   0.12. Mean calculated for all sources.
Modal src-site R=  155.1 km; M= 7.70; eps0=   0.67 from peak (R,M) bin
 MODE R*= 155.1km; M*= 7.70; EPS.INTERVAL: 1 to 2 sigma  % CONTRIB.=  7.962

Principal sources (faults, subduction, random seismicity having > 3% contribution)
Source Category:                  % contr.  R(km)    M   epsilon0 (mean values).
New Madrid SZ no clustering         29.53   155.1   7.73    0.63
CEUS gridded                        70.47    27.1   5.75   -0.09
Individual fault hazard details if its contribution to mean hazard > 2%:
Fault ID                          % contr.   Rcd(km)  M   epsilon0 Site-to-src azimuth(d)
New Madrid FZ, midwest               2.91   155.9   7.73    0.63     -139.1
New Madrid FZ, central              21.22   153.6   7.73    0.61     -143.6
New Madrid FZ, mideast               2.80   158.3   7.73    0.66     -146.9
#*********End of deaggregation corresponding to Mean Hazard w/all GMPEs  *********#
```

Figure 1. Grayville Deaggregation Data.

Three of the five sites have source-to-site distances indicative of the NMSZ and thus, the Modal source-site distance (R*) and magnitude (M_w*) values can be used to represent the distant seismic source. The remaining two earthquake scenarios are considered near-site sources which both requiring further investigation. The PGA for each of the three earthquake scenarios is then calculated using the indicated R and M_w values with selection of the proper GMPE model programmed in the IDOT Liquefaction Analysis spreadsheet.

- EQ Scenario #1, Dist. (R) = 155.1 km, M_w = 7.70 → PGA = 0.115 (NMSZ Model)
- EQ Scenario #2, Dist. (R) = 12.1 km, M_w = 4.80 → PGA = 0.175 (CEUS Model)
- EQ Scenario #3, Dist. (R) = 12.6 km, M_w = 5.03 → PGA = 0.209 (CEUS Model)

In this instance, it is clear that EQ Scenario #3 will control over EQ Scenario #2 and as such, EQ Scenario #2 does not require further consideration for the liquefaction analysis. The PGA and M_w pairs for EQ Scenario's #1 and #3 serve as an example of the potential multi-modal nature of some locations.

There will be many instances where the deaggregation data indicates that there are no near-site sources that contribute at least 5% to the hazard that need to be considered for liquefaction analysis. In such cases, the hazard is likely dominated by the NMSZ and only the Modal combination needs to be considered.

The second example is for a location near Cairo, Illinois and the site deaggregation data is provided in below in Figure 2.

There are three highlighted earthquake scenarios where the “ALL_EPS” contribution is greater than 5%.

```
*** Deaggregation of Seismic Hazard at One Period of Spectral Accel. ***
*** Data from U.S.G.S. National Seismic Hazards Mapping Project, 2008 version ***
PSHA Deaggregation. %contributions. site: Cairo,_IL long:  89.181 W., lat: 37.005 N.
 Vs30(m/s)= 760.0 CEUS atten. model site cl BC(firm) or A(hard).
NSHMP 2007-08  See USGS OFR 2008-1128. dM=0.2 below
Return period: 975   yrs. Exceedance PGA =1.1619   g. Weight * Computed_Rate_Ex 0.101E-02
#Pr[at least one eq with median motion>=PGA in 50 yrs]=0.04009
#This deaggregation corresponds to Mean Hazard w/all GMPEs
DIST(KM) MAG(MW) ALL_EPS EPSILON>2  1<EPS<2 0<EPS<1 -1<EPS<0 -2<EPS<-1 EPS<-2
    6.9    4.61    0.075    0.046    0.029    0.000    0.000    0.000    0.000
    7.6    4.80    0.203    0.114    0.090    0.000    0.000    0.000    0.000
    8.5    5.04    0.238    0.117    0.121    0.000    0.000    0.000    0.000
    9.2    5.21    0.132    0.064    0.068    0.000    0.000    0.000    0.000
   10.0    5.40    0.287    0.135    0.137    0.015    0.000    0.000    0.000
   11.1    5.62    0.218    0.083    0.110    0.024    0.000    0.000    0.000
   11.8    5.81    0.258    0.089    0.134    0.035    0.000    0.000    0.000
   11.7    6.02    0.315    0.079    0.169    0.067    0.000    0.000    0.000
   11.4    6.22    0.423    0.087    0.206    0.130    0.000    0.000    0.000
   12.4    6.42    0.377    0.065    0.184    0.128    0.000    0.000    0.000
   12.2    6.59    0.257    0.036    0.120    0.101    0.000    0.000    0.000
   12.1    6.79    0.404    0.038    0.187    0.178    0.001    0.000    0.000
   31.0    6.76    0.070    0.049    0.021    0.000    0.000    0.000    0.000
   14.0    7.00    0.370    0.035    0.168    0.164    0.003    0.000    0.000
   14.7    7.19    0.223    0.019    0.100    0.101    0.003    0.000    0.000
   11.4    7.42   31.476    1.447    8.511   17.760    3.758    0.000    0.000
   29.8    7.39    0.271    0.079    0.192    0.000    0.000    0.000    0.000
   11.5    7.70   48.171    2.025   12.040   27.292    6.814    0.000    0.000
   29.4    7.70    0.708    0.115    0.471    0.121    0.000    0.000    0.000
   11.5    8.00   14.768    0.594    3.535    8.424    2.215    0.000    0.000
   27.0    8.00    0.593    0.047    0.237    0.309    0.000    0.000    0.000

Summary statistics for above PSHA PGA  deaggregation, R=distance, e=epsilon:
Contribution from this GMPE(%):  100.0
 Mean src-site R=    11.8 km; M= 7.59; eps0=  -0.24. Mean calculated for all sources.
Modal src-site R=    11.5 km; M= 7.70; eps0=  -0.32 from peak (R,M) bin
 MODE R*=  11.4km; M*= 7.70; EPS.INTERVAL: 0 to 1 sigma  % CONTRIB.= 27.292

Principal sources (faults, subduction, random seismicity having > 3% contribution)
Source Category:                  % contr.  R(km)     M    epsilon0 (mean values).
New Madrid SZ no clustering         95.65    11.7    7.66    -0.28
CEUS gridded                         4.35    13.5    6.24     0.76
Individual fault hazard details if its contribution to mean hazard > 2%:
Fault ID                          % contr.   Rcd(km)   M    epsilon0 Site-to-src azimuth(d)
New Madrid FZ, midwest               7.47    17.4    7.68    -0.02       -50.3
New Madrid FZ, central              74.16    10.3    7.65    -0.35       -47.2
New Madrid FZ, mideast               9.94    12.1    7.66    -0.29       132.6
New Madrid FZ, east                  2.63    22.5    7.69     0.33       131.2
#*********End of deaggregation corresponding to Mean Hazard w/all GMPEs  *********#
```

Figure 2. Cairo Deaggregation Data.

By inspection, they all have source-to-site distances indicative of the NMSZ and can be represented by a single check of the Modal R and M combination. With no near-site scenarios contributing more than 5% to the hazard, only the single distant seismic source need be investigated.

- EQ Scenario #1, Dist. (R) = 11.5 km, M_w = 7.70 $\rightarrow$ PGA = 1.528 (NMSZ Model)

Similar to Example #1, the PGA value for the earthquake scenario has been determined using the IDOT Liquefaction Analysis Excel spreadsheet and the indicated GMPE model.

Relevant References

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CHAPTER 5

LIQUEFACTION POTENTIAL EVALUATION AND ANALYSIS

This chapter provides information to use when evaluating and analyzing the potential for failure due to liquefaction during a seismic event at an Ohio *waste containment facility*. Ohio EPA requires that the *soil units* at any *waste containment facility* be able to withstand the effects of a plausible earthquake and rule out the possibility of liquefaction. This is because it is generally expected that the engineered components of a *waste containment facility* will lose their integrity and no longer be able to function if a foundation soil layer liquefies.

> Soil liquefaction occurs in loose, *saturated* cohesionless *soil units* (sands and silts) and sensitive clays when a sudden loss of strength and loss of stiffness is experienced, sometimes resulting in large, permanent displacements of the ground. Even thin lenses of loose *saturated* silts and sands may cause an overlying sloping soil mass to slide laterally along the liquefied layer during earthquakes. Liquefaction beneath and in the vicinity of a *waste containment unit* can result in localized bearing capacity failures, lateral spreading, and excessive settlement that can have severe consequences upon the integrity of *waste containment systems*. Liquefaction-associated lateral spreading and flow failures can also affect the global stability of a *waste containment facility*.

REPORTING

This section describes the information that should be submitted to demonstrate that a facility is not susceptible to liquefaction. Ohio EPA recommends that the following information be included in its own section of a geotechnical and stability analyses report. At a minimum, the following information about the liquefaction evaluation and analysis should be reported to Ohio EPA:

> Any drawings or cross sections referred to in this policy that are already present in another part of the geotechnical and stability analyses report can be referenced rather than duplicated in each section. It is helpful if the *responsible* party ensures the referenced items are easy to locate and marked to show the appropriate information.

- A narrative and tabular summary of the findings of the liquefaction evaluation and analysis including all *soil units* evaluated.
- A detailed discussion of the liquefaction evaluation including:
    - A discussion and evaluation of the geologic age and origin, fines content, plasticity index, saturation, depth below ground surface, and soil penetration resistance of each of the *soil units* that comprise the *soil stratigraphy* of the *waste containment facility*,

- The scope, extent, and findings of the subsurface investigation as they pertain to the liquefaction potential evaluation.
- A narrative description of each potentially liquefiable layer, if any, at the facility, and
- All figures, drawings, or references relied upon during the evaluation marked to show how they relate to the facility.

! If the liquefaction evaluation identifies potentially liquefiable layers, then the following information should be included in the report:

- A narrative and tabular summary of the results of the analysis of each potentially liquefiable layer,
- Plan views of the facility that include the northings and eastings, the lateral extent of the potentially liquefiable layers, and the limits of the *waste containment unit(s)*,
- Cross sections of the facility showing *soil units*, full depictions of the potentially liquefiable layers, and the following:
  - location of engineered components of the facility,
  - material types, shear strengths, and boundaries,
  - geologic age and origin,
  - fines content and plasticity index,
  - depth below ground surface,
  - soil penetration resistance,
  - temporal high *phreatic surfaces* and *piezometric surfaces*, and
  - in situ field densities and, where applicable, the in situ *saturated* field densities.
- The scope, extent, and findings of the subsurface investigation as they pertain to the analysis of potentially liquefiable layers,
- A description of the methods used to calculate the factor of safety against liquefaction,
- Liquefaction analysis input parameters and assumptions, including a rationale for selecting the maximum expected horizontal ground acceleration,
- The actual calculations and/or computer inputs and outputs, and
- All figures, drawings, or references relied upon during the analysis marked to show how they relate to the facility.

FACTOR OF SAFETY

The following factor of safety should be used, unless superseded by rule, when demonstrating that a facility will resist failures due to liquefaction.

Liquefaction analysis: FS $\geq$ 1.00

> The number of digits after the decimal point indicates that rounding can only occur to establish the last digit. For example, 1.579 can be rounded to 1.58, but not 1.6.

The above factor of safety is appropriate, only if the design assumptions are conservative; site-specific, *higher quality data* are used; and the calculation methods chosen are shown to be valid and appropriate for the facility. It should be noted, however, that historically, occasions of liquefaction-induced instability have occurred when factors of safety using these methods and assumptions were calculated to be greater than 1.00. Therefore, the use of a factor of safety against liquefaction higher than 1.00 may be warranted whenever:

- A failure would have a catastrophic effect upon human health or the environment,
- Uncertainty exists regarding the accuracy, consistency, or validity of data, and no opportunity exists to conduct additional testing to improve or verify the quality of the data,
- Large uncertainty exists about the effects that changes to the site conditions over time may have on the stability of the facility, and no engineered controls can be carried out that will significantly reduce the uncertainty.

> Designers may want to consider increasing the required factor of safety if repairing a facility after a failure would create a hardship for the *responsible parties* or the waste disposal customers.

Using a factor of safety less than 1.00 against liquefaction is not considered a sound engineering practice. This is because a factor of safety less than 1.00 indicates failure is likely to occur. Furthermore, performing a deformation analysis to quantify the risks and damage expected to the *waste containment facility* should liquefaction occur is not considered justification for using a factor of safety less than 1.00 against liquefaction. This is because the strains allowed by deformation analysis are likely to result in decreased performance and loss of integrity in the engineering components. Thus, any failure to the *waste containment facility* due to liquefaction is likely to be substantial and very likely to increase the potential for harm to human health and the environment. If a facility has a factor of safety against liquefaction less than 1.00, mitigation of the liquefiable layers will be necessary, or another site not at risk of liquefaction will need to be used.

> If the liquefaction analysis does not result in a factor of safety of at least 1.00, consideration may be given to performing a more sophisticated liquefaction potential assessment, or to liquefaction mitigation measures such as eliminating the liquefiable layer, or choosing an alternative site.
>
> A variety of techniques exist to remediate potentially liquefiable soils and mitigate the liquefaction hazard. Liquefaction of Soils During Earthquakes (National Research Council, Committee of Earthquake Engineering, 1985) includes a table summarizing available methods for improvement of liquefiable soil foundation conditions. However, Ohio EPA approval must be obtained prior to use of any methods for mitigation of liquefiable layers.

The *responsible party* should ensure that the designs and specifications in all authorizing documents and the quality assurance and quality control (QA/QC) plans clearly require that the assumptions and specifications used in the liquefaction analysis for the facility will be followed during construction, operations, and closure. If the *responsible party* does not do this, it is likely that Ohio EPA will require the assumptions and specifications from the liquefaction analysis to be used during construction, operations, and closure of a facility through such means as are appropriate (e.g., regulatory compliance requirements, approval conditions, orders, settlement agreements).

From time to time, changes to the facility design may be needed that will alter the assumptions and specifications used in the liquefaction analysis. If this occurs, a request to change the facility design is required to be submitted for Ohio EPA approval in accordance with applicable rules. The request to change the facility design must include a new liquefaction analysis that uses assumptions and specifications appropriate for the change.

LIQUEFACTION EVALUATION

Ohio EPA requires the assessment of liquefaction potential as a key element in the seismic design of a *waste containment facility*. To determine the liquefaction potential, Ohio EPA recommends using the five screening criteria included in the U.S. EPA guidance document titled RCRA Subtitle D (258) Seismic Design Guidance for Municipal Solid Waste Landfill Facilities, EPA/600/R-95/051, April 1995, published by the Office of Research and Development. As of the writing of this policy, the U.S. EPA guidance document is available at www.epa.gov/clhtml/pubtitle.html on the U.S. EPA Web site.

Recommended Screening Criteria for Liquefaction Potential

The following five screening criteria, from the above reference, are recommended by Ohio EPA for completing a liquefaction evaluation:

- Geologic age and origin. If a soil layer is a fluvial, lacustrine or aeolian deposit of Holocene age, a greater potential for liquefaction exists than for till, residual deposits, or older deposits.

- Fines content and plasticity index. Liquefaction potential in a soil layer increases with decreasing fines content and plasticity of the soil. Cohesionless soils having less than 15 percent (by weight) of particles smaller than 0.005 mm, a liquid limit less than 35 percent, and an in situ water content greater than 0.9 times the liquid limit may be susceptible to liquefaction (Seed and Idriss, 1982).

- Saturation. Although low water content soils have been reported to liquefy, at least 80 to 85 percent saturation is generally deemed to be a necessary condition for soil liquefaction. The highest anticipated temporal *phreatic surface* elevations should be considered when evaluating saturation.

- Depth below ground surface. If a soil layer is within 50 feet of the ground surface, it is more likely to liquefy than deeper layers.

- Soil Penetration Resistance. Seed et al, 1985, state that soil layers with a normalized SPT blowcount [$(N_1)_{60}$] less than 22 have been known to liquefy. Marcuson et al, 1990, suggest an SPT value of [$(N_1)_{60}$] less than 30 as the threshold to use for suspecting liquefaction potential. Liquefaction has also been shown to occur if the normalized CPT cone resistance (q_c) is less than 157 tsf (15 MPa) (Shibata and Taparaska, 1988).

> In some cases, it is necessary to stabilize a borehole due to heaving soils. The use of hollow-stem augers or drilling mud has been proven effective for stabilizing a borehole without affecting the blow counts from a standard penetration test. Casing off the borehole as it is advanced has also been used, but it has been found that for non-cohesive soils, such as sands, it has an adverse effect on the standard penetration test results (Edil, 2002).

If three or more of the above criteria indicate that liquefaction is not likely, the potential for liquefaction can be dismissed. Otherwise, a more rigorous analysis of the liquefaction potential at a facility is required. However, it is possible that other information, especially historical evidence of past liquefaction or *sample* testing data collected during the subsurface investigation, may raise enough of a concern that a full liquefaction analysis would be appropriate even if three or more of the liquefaction evaluation criteria indicate that liquefaction is unlikely.

LIQUEFACTION ANALYSIS

If potential exists for liquefaction at a facility, additional subsurface investigation may be necessary. Once all testing is complete, a factor of safety against liquefaction is then calculated for each *critical layer* that may liquefy.

A liquefaction analysis should, at a minimum, address the following:

- Developing a detailed understanding of site conditions, the *soil stratigraphy*, material properties and their variability, and the areal extent of potential *critical layers*. Developing simplified cross sections amenable to analysis. SPT and CPT procedures are widely used in practice to characterize the soil (field data are easier to obtain on loose cohesionless soils than trying to obtain and test undisturbed *samples*). The data needs to be corrected as necessary, for example, using the normalized SPT blowcount [$(N_1)_{60}$] or the normalized CPT. The total vertical stress (σ_0) and effective vertical stress (σ_0') in each stratum also need to be evaluated. This should take into account the changes in overburden stress across the lateral extent of each *critical layer*, and the temporal high *phreatic* and *piezometric surfaces*,

- Calculation of the force required to liquefy the critical zones, based on the characteristics of the critical zone(s) (e.g., fines content, normalized standardized blowcount, overburden stresses, level of saturation),

- Calculation of the design earthquake's effect on each potentially liquefiable layer should be performed using the site-specific in situ soil data and an understanding of the earthquake magnitude potential for the facility, and

- Computing the factor of safety against liquefaction for each liquefaction susceptible *critical layer*.

Liquefaction Potential Analysis - Example Method

The most common procedure used in practice for liquefaction potential analysis, the "Simplified Procedure," was developed by H. B. Seed & I. M. Idriss. Details of this procedure can be found in RCRA Subtitle D (258) Seismic Design Guidance for Municipal Solid Waste Landfill Facilities (U.S.EPA, 1995). As of the publication date of this policy, the U.S. EPA guidance document was available from www.epa.gov/clhtml/pubtitle.html on the U.S. EPA Web site. Due to the expected range of ground motion in Ohio, the Simplified Procedure is applicable. However, if the expected peak horizontal ground acceleration is larger than 0.5 g, more sophisticated, truly nonlinear effective stress-based analytical approaches should be considered, for which there are computer programs available. The simplified procedure comprises the following four steps:

1. Identify the potentially liquefiable layers to be analyzed.

2. Calculate the shear stress required to cause liquefaction (resisting forces). Based on the characteristics of the potentially liquefiable layers (e.g., fines content, normalized standardized blowcount), the critical (cyclic) stress ratio (CSR_L) can be determined using the graphical methods included in the U.S. EPA guidance referenced above. Note: this determination is typically based on an earthquake of magnitude 7.5. If the design earthquake is of a different magnitude, or if the site is not level, the CSR_L will need to be corrected as follows.

$$CSR_{L(M-M)} = CSR_{L(M=7.5)} \cdot k_M \cdot k_\sigma \cdot k_\alpha \qquad (5.1)$$

where

$CSR_{L(M-M)}$ = corrected critical stress ratio resisting liquefaction,
$CSR_{L(M=7.5)}$ = critical stress ratio resisting liquefaction for a magnitude 7.5 earthquake,
k_M = magnitude correction factor,
$k\sigma$ = correction factor for stress levels exceeding 1 tsf, and
k_α = correction factor for the driving static shear stress if sloping ground conditions exist at the facility. Special expertise is required for evaluation of liquefaction resistance beneath ground sloping more than six percent (Youd, 2001).

The k-values are available from tabled or graphical sources in the referenced materials.

The correction factors can be obtained from different sources, such as the 1995, U.S. EPA, Seismic Design Guidance, or the summary report from the 1996 and 1998 NCEER/NSF Liquefaction Workshops. The U.S. EPA document tends to be somewhat more conservative for earthquakes with a magnitude less than 6.5. In 1999, I.M. Idriss proposed yet a different method for calculating the empirical stress reduction factor (r_d), which was less conservative than the method included in the U.S. EPA guidance, but more conservative than the method included in the NCEER method. Designers should select correction factors based on site-specific circumstances and include documentation explaining their choices in submittals to Ohio EPA.

3. Calculation of the design earthquake's effect on the critical zone (driving force). The following equation can be used.

$$CSR_{EQ} = 0.65\left(\frac{a_{\max,z}}{g}\right) r_d \left(\frac{\sigma_0}{\sigma_0'}\right) \qquad (5.2)$$

where
CSR_{eq} = equivalent uniform cyclic stress ratio induced by the earthquake,
σ_0 = total vertical overburden stress,
σ_0' = effective vertical overburden stress,
$a_{max,z}$ = the maximum horizontal ground acceleration, and
g = the acceleration of gravity.

Liquefaction Potential Analysis - Example Method (cont.)

$$a_{\max,z} = \left(a_{\max}\right)\left(r_d\right) \tag{5.3}$$

where $a_{max,z}$ = the maximum horizontal ground acceleration,
a_{max} = peak ground surface acceleration, and
r_d = empirical stress reduction factor.

$$r_d = \frac{a_{\max@depth\ D}}{\sigma_{0@depth\ D}\left(\frac{a_{\max@surface}}{g}\right)} \tag{5.4}$$

4. Calculate the factor of safety against liquefaction (resisting force divided by driving force).

$$FS_L = \frac{CSR_{L(M-M)}}{CSR_{EQ}} \geq 1.00 \tag{5.5}$$

where FS_L = factor of safety against liquefaction,
$CSR_{L(M-M)}$ = shear stress ratio required to cause liquefaction, and
CSR_{EQ} = equivalent uniform cyclic stress ratio.

REFERENCES

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the embankment or foundation may be excessive. It may be necessary in such cases to use the shearing resistance mobilized at 10 or 15 percent strain, rather than peak strengths, or to limit placement water contents to the dry side of optimum to reduce the magnitudes of failure strains. However, if cohesive soils are compacted too dry, and they later become wetter while under load, excessive settlement may occur. Also, compaction of cohesive soils dry of optimum water content may result in brittle stress-strain behavior and cracking of the embankment. Cracks can have adverse effects on stability and seepage. When large strains are required to develop shear strengths, surface movement measurement points and piezometers should be installed to monitor movements and pore water pressures during construction, in case it becomes necessary to modify the cross section or the rate of fill placement.

d. Liquefaction. The phenomenon of soil liquefaction, or significant reduction in soil strength and stiffness as a result of shear-induced increase in pore water pressure, is a major cause of earthquake damage to embankments and slopes. Most instances of liquefaction have been associated with saturated loose sandy or silty soils. Loose gravelly soil deposits are also vulnerable to liquefaction (e.g., Coulter and Migliaccio 1966; Chang 1978; Youd et al. 1984; and Harder 1988). Cohesive soils with more than 20 percent of particles finer than 0.005 mm, or with liquid limit (LL) of 34 or greater, or with the plasticity index (PI) of 14 or greater are generally considered not susceptible to liquefaction. The methodology to evaluate liquefaction susceptibility will be presented in an Engineer Circular, "Dynamic Analysis of Embankment Dams," which is still in draft form.

e. Piping. Erosion and piping can occur when hydraulic gradients at the downstream end of a hydraulic structure are large enough to move soil particles. Analyses to compute hydraulic gradients and procedures to control piping are contained in EM 1110-2-1901.

f. Other types of slope movements. Several types of slope movements, including rockfalls, topples, lateral spreading, flows, and combinations of these, are not controlled by shear strength (Huang 1983). These types of mass movements are not discussed in this manual, but the possibility of their occurrence should not be ignored.