GOLDER

Unstable Areas Documentation

Clover Power Station
Stage 3 Landfill

Submitted to:

Virginia Electric and Power Company d/b/a Dominion Energy Virginia

5000 Dominion Boulevard
Glen Allen, VA 23060

Submitted by:

Golder Associates Inc.

2108 West Laburnum Ave, Suite 200
Richmond, Virginia 23227

Project No. 1139-627717
October 17, 2018

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1.0 CERTIFICATION

I certify that the information contained within this Unstable Areas Demonstration Report was prepared by me or under my direct supervision and meets the requirements of Section §257.64 of the Federal Hazardous and Solid Waste Management System; Disposal of Coal Combustion Residuals (CCR) from Electric Utilities; Final Rule (40 CFR 257; the *CCR rule*). The document and Certification/Statement of Professional Opinion are based on and limited to information that Golder has relied on from Virginia Electric and Power Company d/b/a Dominion Energy Virginia (Dominion) and others, but not independently verified, as well as work products produced by Golder.

As used herein, the words "certification" and/or "certify" shall mean an expression of the Engineer's professional opinion to the best of his or her information, knowledge, and belief, and does not constitute a warranty or guarantee by the Engineer.

Daniel McGrath, P.E.	Associate and Senior Consultant
Print Name	Title
Daniel McGrath	10/17/18
Signature	Date

COMMONWEALTH OF VIRGINIA
Daniel McGrath
DANIEL P. McGRATH
Lic. No. 040703
10/17/18
PROFESSIONAL ENGINEER

2.0 INTRODUCTION

This Unstable Areas Demonstration was prepared for the Clover Power Station Stage 3 Coal Combustion Residual (CCR) Landfill (*Landfill*) located in Halifax County, Virginia, in accordance with 40 CFR §257.64. This demonstration documents how the Landfill meets the requirements of each condition in the CCR Rule section. As of the date of this report (October 2018), Dominion continues to operate the Stage 3 Landfill for CCR disposal.

2.1 Landfill Site Background

The Stage 3 Landfill is permitted as an approximately 79-acre lined facility for the disposal of CCR from the Clover Power Station. The Stage 3 Landfill was originally permitted in October 2000, as a major amendment adding the Stage 3 disposal area to the existing solid waste permit # 556. The Landfill is permitted under the Virginia Solid Waste Management Regulations (VSWMR) as a *Captive Industrial Landfill*. Construction of the last permitted disposal phase was completed in April 2011. A Site Location Map is included as Figure 1.

3.0 UNSTABLE AREA EVALUATION

3.1 Requirement

§257.64 (a): *An existing or new CCR landfill, existing or new CCR surface impoundment, or any lateral expansion of a CCR unit must not be located in an unstable area unless the owner or operator demonstrates by the dates specified in paragraph (d) of this section that recognized and generally accepted good engineering practices have been incorporated into the design of the CCR unit to ensure that the integrity of the structural components of the CCR unit will not be disrupted*.

3.2 Demonstration

Assessment of unstable areas includes an evaluation of the soil conditions at the site, which may result in significant differential settling, a review of site geologic or geomorphologic features, and consideration of human-made features on site that may cause unstable conditions. A summary of the unstable area evaluation is presented in this document.

3.2.1 *Soil Conditions*

Based on the soil boring records and geotechnical testing of soils encountered, the subsurface conditions at the Landfill are expected to adequately support the landfill without significant differential settlement. The site investigations did not identify features that would suggest recent landslide activities or other indicators of unstable soil conditions, such as sinkholes or significant unconsolidated materials.

Between 1996 and 2003, approximately 40 investigative test borings, piezometer installations, test pits and monitoring wells were made by Golder and others to characterize the hydrogeologic and geotechnical properties of the subsurface soils. Geotechnical test borings were advanced to various depths ranging between 25 and 89 feet below grade. In general, the test borings drilled during these investigations were advanced to a depth required for a minimum 20 feet below the lowest elevation of the bottom liner. Six soil test pits were excavated across the landfill footprint to evaluate soil types and determine their suitability for future construction.

The subsurface site investigations show the soils are generally thicker on the eastern side of the site, being approximately 20 to 40 feet thick. On the western side of the site, nearest to Black Walnut Creek, the soil thickness was found to be 10 to 15 feet thick. A layer of weathered bedrock approximately 10 feet thick overlays competent bedrock consisting of high quality gneiss. The top of the competent bedrock layer is approximately at elevation 330 across the site, which is approximately 35 to 70 feet below the landfill base grades.

3.2.2 *Differential Settlement*

Significant differential settlement is not anticipated to occur at the Stage 3 Landfill. Calculations prepared by Golder (1997) during the Stage 3 Landfill permitting process predicted subgrade settlement ranging from 8.9 to 15.6 inches. To evaluate foundation settlement in terms of differential settlement, an evaluation of the settlement's effect on the bottom liner materials was made. The resulting calculations show the anticipated differential settlement is well within the strain tolerance of the liner materials. Calculations are presented in Appendix B.

3.2.3 *Site Geology and Geomorphology*

The Landfill is located on layers of competent soils, densely compacted sands, and bedrock with no evidence of karst topography. The subsurface soil layers were determined to be of adequate strength to support the Landfill.

No active seismic faults are located within 20 miles of the Landfill site. The closest active fault area is the Central Virginia seismic zone, located approximately 65 miles away. The Seismic Activity Map in Appendix A shows the location of the site relative to the Central Virginia seismic zone.

The Landfill site is located immediately adjacent to Black Walnut Creek and approximately 1/2 mile from the Roanoke River; however, the landfill is not located within the 100-year floodplain of either waterway. The 100-Year flood map for the area is included in Appendix A. Please note that the mapped 100-year floodplain shown in Appendix A is based on approximate topographic mapping performed on a regional scale. During the permitting and construction of the Landfill, site-specific topography and elevation data was used to ensure the landfill was not sited in the 100-year floodplain.

3.2.4 *Human-Made Features*

An evaluation of the site's history does not reveal, nor has evidence been found of, human-made conditions on site that could cause unstable conditions. Historical research as part of the cultural resources evaluation indicates the site was used for small farming from the mid-1800's through the late-20th century. No evidence of surficial or shaft mining on the site has been encountered in either the literature or during on-site evaluations. There are no known impounding structures upstream or downstream of the landfill that pose inundation threat due to structure failure.

4.0 CONCLUSIONS

Golder Associates Inc. has performed an evaluation of site conditions and historical documentation in relation to requirements established in 40 CFR 257.64. Our evaluation shows that the Stage 3 Landfill, as designed, constructed, and operated, meets the requirements of this regulation.

5.0 REFERENCES

Sources evaluated for this report include the following:

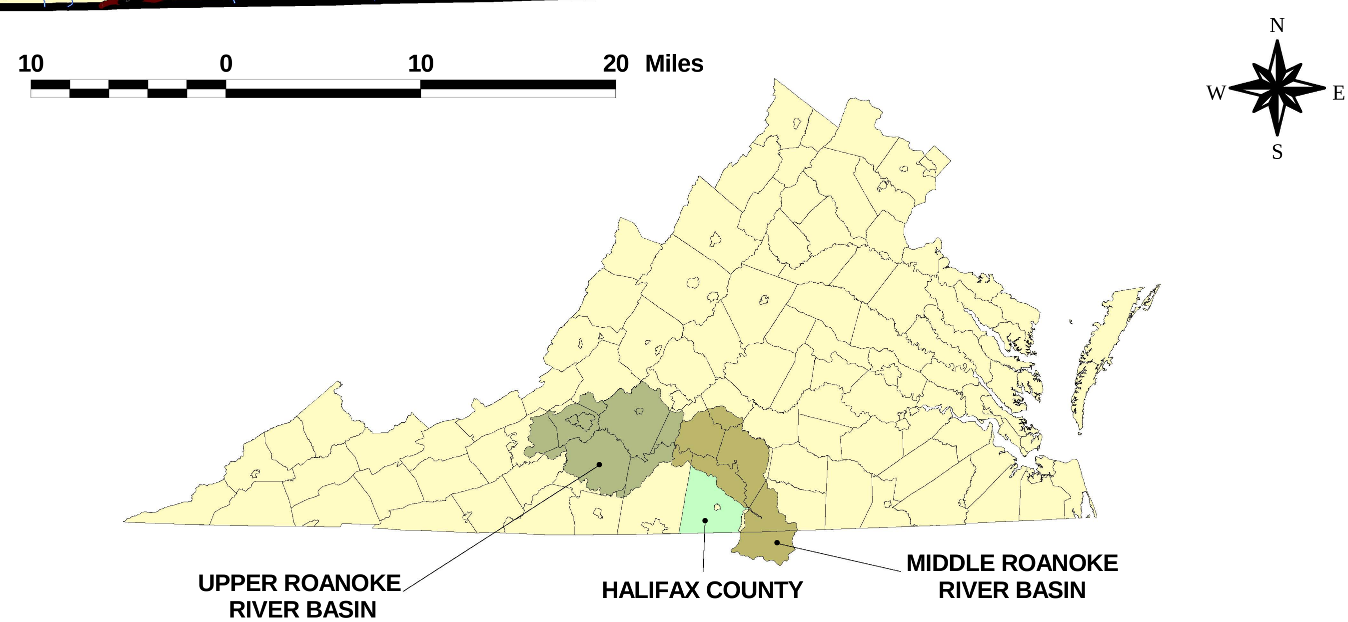
1. Soil boring logs, test pit logs, and well installation logs from Golder Associates, Inc., Black and Veatch Engineers, United Engineers & Constructors, and Resource International, Ltd.
2. Louis Berger & Associates, Inc. Cultural Resource Investigations of the Clover Property – Old Dominion Electric Cooperative, 1994
3. Virginia Department of Mines, Minerals and Energy (DMME) Interactive Maps (https://www.dmme.virginia.gov/webmaps/options.shtml)
4. United States Geological Service (USGS) historical topographic maps (http://historicalmaps.arcgis.com/usgs/):
    a. Clover Quadrangle (1954)
    b. Clover Quadrangle (1968)
5. USGS Historical Aerial Imagery (https://earthexplorer.usgs.gov/)
    a. March 1, 1967 aerial
    b. May 4, 1974 aerial
6. Google Earth (https://www.google.com/earth/)
7. Federal Emergency Management Agency (FEMA) National Flood Hazard Layer (NFHL) Viewer (https://www.fema.gov/national-flood-hazard-layer-nfhl)
8. Clover Stage 3 Landfill Design Drawings, June 2002, Golder Associates Inc.

APPENDIX A

FIGURE 1 – SITE LOCATION MAP

FIGURE 2 – SEISMIC ACTIVITY MAP

FIGURE 3 – 100-YEAR FLOOD MAP



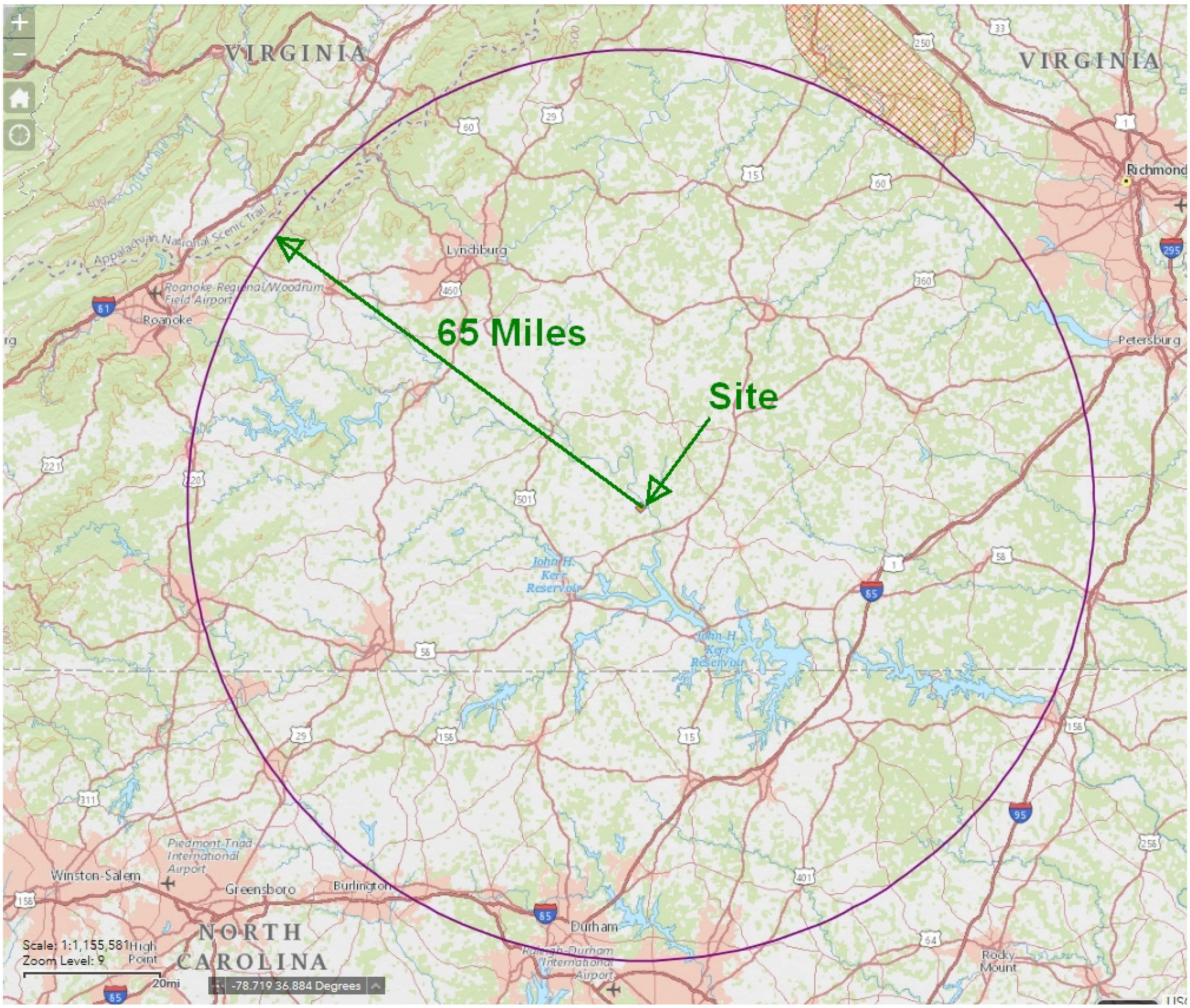
GOLDER

DATE:	04-24-2017
SCALE:	As Shown
Prepared By:	BBW
Reviewed By:	DPM

Title:

AREA MAP
Clover Power Station
Halifax County, Virginia

Figure No. 1



REFERENCE

IMAGE FROM USGS NATIONAL MAPPER
https://viewer.nationalmap.gov/advanced-viewer/

CLIENT DOMINION ENERGY	PROJECT CLOVER POWER STATION HALIFAX COUNTY, VIRGINIA

CONSULTANT			TITLE
GOLDER	YYYY-MM-DD	2018-09-13	**SEISMIC ACTIVITY MAP**
	DESIGNED	DPM	
	PREPARED	BPG	
	REVIEWED	BPG	
	APPROVED	DPM	

PROJECT NO.	REV.	FIGURE
1139-6277	0	2

National Flood Hazard Layer FIRMette

FEMA

36°52'58.41"N

78°43'20.96"W

78°42'43.50"W

36°52'29.63"N

0 250 500 1,000 1,500 2,000 Feet

1:6,000

Legend

SEE FIS REPORT FOR DETAILED LEGEND AND INDEX MAP FOR FIRM PANEL LAYOUT

SPECIAL FLOOD HAZARD AREAS
- Without Base Flood Elevation (BFE) *Zone A, V, A99*
- With BFE or Depth *Zone AE, AO, AH, VE, AR*
- Regulatory Floodway

OTHER AREAS OF FLOOD HAZARD
- 0.2% Annual Chance Flood Hazard, Areas of 1% annual chance flood with average depth less than one foot or with drainage areas of less than one square mile *Zone X*
- Future Conditions 1% Annual Chance Flood Hazard *Zone X*
- Area with Reduced Flood Risk due to Levee. See Notes. *Zone X*
- Area with Flood Risk due to Levee *Zone D*

OTHER AREAS
- NO SCREEN Area of Minimal Flood Hazard *Zone X*
- Effective LOMRs
- Area of Undetermined Flood Hazard *Zone D*

GENERAL STRUCTURES
- Channel, Culvert, or Storm Sewer
- Levee, Dike, or Floodwall

OTHER FEATURES
- B 20.2 17.5 Cross Sections with 1% Annual Chance Water Surface Elevation
- 8 Coastal Transect
- 513 Base Flood Elevation Line (BFE)
- Limit of Study
- Jurisdiction Boundary
- Coastal Transect Baseline
- Profile Baseline
- Hydrographic Feature

MAP PANELS
- Digital Data Available
- No Digital Data Available
- Unmapped

N

The pin displayed on the map is an approximate point selected by the user and does not represent an authoritative property location.

This map complies with FEMA's standards for the use of digital flood maps if it is not void as described below. The basemap shown complies with FEMA's basemap accuracy standards

The flood hazard information is derived directly from the authoritative NFHL web services provided by FEMA. This map was exported on 9/7/2018 at 2:29:10 PM and does not reflect changes or amendments subsequent to this date and time. The NFHL and effective information may change or become superseded by new data over time.

This map image is void if the one or more of the following map elements do not appear: basemap imagery, flood zone labels, legend, scale bar, map creation date, community identifiers, FIRM panel number, and FIRM effective date. Map images for unmapped and unmodernized areas cannot be used for regulatory purposes.

Figure 3

APPENDIX B

1997 FOUNDATION SETTLEMENT CALCULATIONS

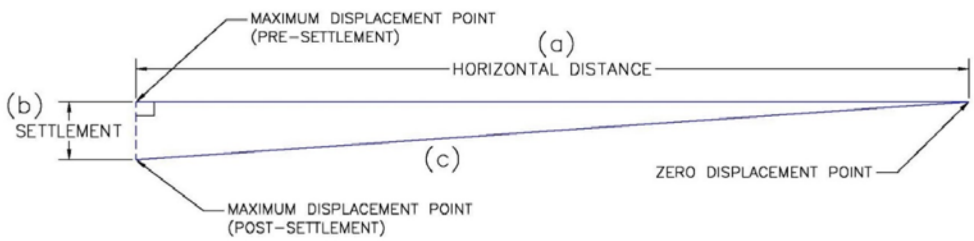
GOLDER	Subject: Differential Settlement of Landfill Foundation					
	Job No:	1139-627717	Made by:	DPM	Date:	10/1/2018
			Checked:	SDRM		
Richmond, Virginia	Ref:		Reviewed:	JRD	Sheet 1	of 1

Objective

Compute the differential settlement of the landfill base liner system as related to the total anticipated settlement computed from the 1997 permit application package.

Method

Typically, more subgrade settlement is anticipated to occur at areas of highest surcharge loading, which are generally associated with highest (thickest) fill point. Assuming a point at the landfill's edge experiences zero settlement, the strain induced by foundation settlement can be calculated. By choosing the shortest distance between points of maximum foundation settlement and zero settlement, the worst-case condition can be evaluated. This relationship is shown in the figure below:



The post-settlement foundation length can be calculated as the hypotenuse of the triangle formed by the Horizontal Distance (a) and the Settlement length (b). This new length corresponds to a theoretical deformation (stretching) of the liner. The new length (c) is calculated using the Pythagorean theorem.

$$c = \sqrt{a^2 + b^2}$$

Calculations

Given the total settlement calculated by Golder in the 1997 permit application package:

Point Number	Immediate Settlement (inches)	Consolidation Settlement (inches)	Total Settlement (inches)
1	2.41	8.04	**10.5**
2	3.92	11.64	**15.6**
3	3.53	5.36	**8.9**
4	3.41	7.19	**10.6**
5	5.87	9.76	**15.6**
6	2.58	8.11	**10.7**
7	2.25	6.86	**9.1**

The shortest horizontal distance from the landfill edge to the center of the highest fill point is 670 feet.

Compute the new length and linear strain usig the Pythagorean theorem

Point Number	Horizontal Distance, ft (a)	Settlement ft (b)	New Length, ft (c)	Strain, ft/ft	Strain, %
1	670	0.87	670.000567	8.4578E-07	0.0000846%
2	670	1.30	670.001255	1.87255E-06	0.0001873%
3	670	0.74	670.00041	6.1194E-07	0.0000612%
4	670	0.88	670.000583	8.69512E-07	0.0000870%
5	670	1.30	670.001266	1.8901E-06	0.0001890%
6	670	0.89	670.000591	8.82828E-07	0.0000883%
7	670	0.76	670.00043	6.41388E-07	0.0000641%

Conclusions

The allowable deformation strain for High Density Polyethylene (HDPE) geomembrane liner is 10%. The calculated strain values are significantly less than 10% and therefore are acceptable.

Golder Associates	Subject: SETTLEMENT EVALUATION – STAGE III EXPANSION		
	Job No. 973-6399	Made by TLM	Date 12/31/97
	Ref. VIRGINIA POWER/ CLOVER PART B/VA	Checked DPM	Sheet 1 of 3
		Reviewed JRD	

Project Location: Clover, Virginia

Objective: Perform subgrade settlement evaluation resulting from immediate and consolidation settlement of in-situ subgrade soils at seven points throughout the Stage III Landfill Expansion.

Method: The settlement evaluation of in-situ subgrade soils includes both immediate settlement and consolidation settlement. Immediate settlement occurs as the load is applied or within a time period of about 7 days and is a function of the subgrade modulus and thickness of the soil layers. Consolidation, or time dependent settlement, can take months to years to obtain. Traditional 1-D consolidation theory includes primary consolidation of subgrade soil layers plus recompression consolidation of and subgrade soil at various locations around the Stage III Expansion area.

Total estimated settlement is:

$$\Delta H_{TOTAL} = \Delta H_{IMMEDIATE} + \Delta H_{SUBGRADE\ (PRIMARY)} + \Delta H_{SUBGRADE\ (RECOMPRESSION)}$$

<u>The following equations apply for immediate settlement:</u>

$$\Delta H_{IMMEDIATE} = H_o * (\delta\sigma / E_{sc})$$

where:

$\Delta H_{IMMEDIATE}$ = Immediate settlement caused by elastic deformation.

$\delta\sigma$ = Effective Stress (ksf)

E_{sc} = Corrected Modulus of Elasticity (ksf)

<u>The following equations apply for consolidation settlement:</u>

$$\Delta H_{PRIMARY} = H_o * \frac{C_c}{1+e_o} * \log\left(\frac{\sigma_{+\|} + \delta\sigma_{+}}{\sigma_{©}}\right);$$

$$\Delta H'_{RECOMPRESSION} = H_o * \frac{C_c}{1+e_o} * \log\left(\frac{\sigma_p'}{\sigma_{+\|}'}\right); \text{ and}$$

where, H_o = Initial thickness of compressible layer

C_c = Compression index of compressible layer

C_{re} = Recompression index of compressible layer

ΔH = Compression for normally consolidated soil layer

$\Delta H'$ = Compression for over-consolidated soil layer

$\sigma_{+\|}'$ = Initial effective vertical pressures for normally consolidated soils

σ_p' = Preconsolidation pressures for over-consolidated soils (for recompression calculation)

$\delta\sigma_+$ = Increase in vertical pressure from the landfill and cover.

References:

1) Golder Associates boring logs from field investigation at Clover Stage III Expansion dated June 9th through 11th, 1997.

2) Golder Associates laboratory test results from samples collected during field investigation noted in Reference (1).

3) Golder Associates Construction Drawings for Stage III Landfill Expansion including Existing Site Conditions and Top of Primary Liner Grades and the Operations and Management Drawings including Final Grading Plan.

4) "Bottom Ash as Embankment Material", Geotechnics of Waste Fills - Theory and Practice, ASTM STP 1070 (1990)

5) "An Introduction to Geotechnical Engineering", Robert D. Holtz and William D. Kovacs, 1981.

6) Foundation Engineering Handbook, 2nd Edition, Van Nostrand Reinhold, 1991.

7) "Foundation Analysis and Design", Joseph E. Bowles, Fourth Edition, 1988.

8) "Laboratory Testing Report for the Chesterfield Power Station Coals Ash Study, Chesterfield County, Virginia, Golder Associates Inc. report to Virginia Power, dated August 11, 1997.

Conclusions:

1) Based on the calculations on the sheets that follow, the in-situ subgrade settlement at the locations selected in the Stage III Expansion ranged from 8.9 to 15.6 inches during at the full height of the landfill in each of the locations.

Golder Associates Inc.
Stage III Expansion
Clover Power Station
Clover, Virginia

Subgrade Settlement Summary

Point Number	Immediate Settlement (inches)	Consolidation Settlement (inches)	Total Settlement (inches)
1	2.41	8.04	**10.5**
2	3.92	11.64	**15.6**
3	3.53	5.36	**8.9**
4	3.41	7.19	**10.6**
5	5.87	9.76	**15.6**
6	2.58	8.11	**10.7**
7	2.25	6.86	**9.1**

Golder Associates Inc.
Stage III Expansion
Clover Power Station
Clover, Virginia

Settlement Calculations

Isotropic Soil Parameters

Soil Unit Number	Soil Type	Unit Weight Moist (pcf)	Unit Weight Sat. (pcf)	Void Ratio	Specific Gravity	Compression Index (C_c)	Recompression Index (C_r)	Preconsolidation Stress (ksf)	SPT Blowcount (N)	Modulus of Elasticity (E_s) ksf	Method Calculation of E_s
1	Sandy Silt	120.0	123.4	0.78	2.74	0.183	0.025	3.8	20	156	E_s=300(N+6)/50
2	Silty Sand	125.0	128.2	0.65	2.74	0.183	0.025	3.8	16	155	E_s=300(N+6)/50
3	Silty Clay	115.0	124.8	0.65	2.65	0.367	0.06	3.9	10	125	E_s=320(N+15)/50
4	Clayey Silt	122.0	124.8	0.65	2.65	0.367	0.06	3.9	7	110	E_s=320(N+15)/50
5	Sandy Clay	115.0	126.6	0.71	2.76	0.367	0.06	3.9	10	160	E_s=320(N+15)/50
6	Fine Sand	115.0	126.8	0.60	2.65	-	-	-	90	525	E_s=250(N+15)/50
7	CCB	90.0	107.2	0.81	2.30	0.15	-	-	-	600	Triaxial Test
8	Bottom Ash	100.0	105.3	0.89	2.30	-	-	-	-	600	Literature
4	Compacted Fill	122.0	124.8	0.65	2.65	0.15	-	-	-	600	Triaxial Test

Settlement Calculations

Settlement at Point 1

Soil Units Listed from the Bottom Up

Soil Unit Number	Soil Type	Unit Thickness (ft)	Unit Weight Moist (pcf)	Unit Weight Sat. (pcf)	Void Ratio	Specific Gravity	Compression Index (C_c)	Recompression Index (C_r)	SPT Blowcount (N)	Modulus of Elasticity (E_s) ksf	Method Calculation of E_s
2	Silty Sand	5.0	125.0	128.2	0.65	2.74	0.183	0.025	16	155	Es=300(N+6)/50
1	Sandy Silt	8.4	120.0	123.4	0.78	2.74	0.183	0.025	20	156	Es=300(N+6)/50
4	Compacted Fill	7.6	122.0	124.8	0.65	2.65	0.367	0.06	7	110	Es=320(N+15)/50
8	Bottom Ash	1.5	100.0	105.3	0.89	2.30	-	-	-	600	Literature
7	CCB	72.0	90.0	107.2	0.81	2.30	0.15	-	-	600	Triaxial Test
4	Cover Soil	2.0	122.0	124.8	0.65	2.65	0.367	0.06	7	110	Es=320(N+15)/50

Elastic Settlement

Soil Unit Number	Soil Type	Unit Thickness (ft)	Unit 2 Effective Stress (ksf)	Unit 1 Effective Stress (ksf)	Estimated Modulus of Elasticity (E_s) ksf	Depth Factor (K')	Corrected Modulus of Elasticity (E_{sc}) ksf	Calculated Elastic Settlement (ft)	Calculated Elastic Settlement (inches)
2	Silty Sand	5.0	0.165	-	155.0	188.36	403.0	0.0968	1.16
1	Sandy Silt	8.4	0.513	0.256	156.0	308.12	628.2	0.1043	1.25
	Totals	13.4	0.677	0.256				0.2011	2.41
Increase due to fill, liner system, CCB, and Cover									
4	Compacted Fill	7.6	0.927		$s = (\delta d_v/E_{sc}) * H$				
8	Bottom Ash	1.5	0.150						
7	CCB	72.0	6.480						
4	Cover Soil	2.0	0.244						
		Totals	7.801						

Consolidation Settlement

Soil Unit Number	Soil Type	Unit Thickness (ft)	Unit 2 Effective Stress (ksf)	Unit 1 Effective Stress (ksf)	Void Ratio	Preconsolidation Stress (ksf)	Compression Index (C_c)	Recompression Index (C_r)	Calculated Consol. Settlement (ft)	Calculated Consol. Settlement (inches)
2	Silty Sand	5.0	0.165	-	0.65	3.80	0.183	0.025	0.250	3.00
1	Sandy Silt	8.4	0.513	0.256	0.78	3.80	0.183	0.025	0.420	5.04
	Totals	13.4	0.677	0.256					0.670	8.04
Increase due to fill, liner system, CCB, and Cover					$s=C_r*(H_o/(1+e_o))*\log(d_p/\delta d_{vo}) + C_c*(H_o/(1+e_o))*(\log(d_{vo}+\delta d_v)/d_p)$					
4	Compacted Fill	7.6	0.9272							
8	Bottom Ash	1.5	0.1500							
7	CCB	72.0	6.4800							
4	Cover Soil	2.0	0.2440							
		Total	7.801							

Total Settlement

Soil Unit Number	Soil Type	Unit Thickness (ft)	Calculated Elastic Settlement (inches)	Calculated Consol. Settlement (inches)	Calculated Total Settlement (inches)
2	Silty Sand	5.0	1.16	3.00	4.16
1	Sandy Silt	8.4	1.25	5.04	6.30
	Totals	13.4	2.41	8.04	**10.46**

Settlement Calculations

Settlement at Point 2

Soil Units Listed from the Bottom Up

Soil Unit Number	Soil Type	Unit Thickness (ft)	Unit Weight Moist (pcf)	Unit Weight Sat. (pcf)	Void Ratio	Specific Gravity	Compression Index (C_c)	Recompression Index (C_r)	SPT Blowcount (N)	Modulus of Elasticity (E_s) ksf	Method Calculation of E_s
6	Fine Sand	21	115.0	126.8	0.60	2.65	-	-	90	525	Es=250(N+15)/50
2	Silty Sand	2.0	125.0	128.2	0.65	2.74	0.183	0.025	16	155	Es=300(N+6)/50
3	Silty Clay	4.0	115.0	124.8	0.65	2.65	0.367	0.06	10	125	Es=320(N+15)/50
5	Sandy Clay	3.0	115.0	126.6	0.71	2.76	0.367	0.06	7	110	Es=320(N+15)/50
4	Compacted Fill	13.0	122.0	124.8	0.65	2.65	0.367	0.06	7	110	Es=320(N+15)/50
8	Bottom Ash	1.5	100.0	105.3	0.89	2.30	-	-	-	600	Literature
7	CCB	72.0	90.0	107.2	0.81	0.15	0.15	-	-	600	Triaxial Test
4	Cover Soil	2.0	122.0	124.8	0.65	2.65	0.367	0.06	7	110	Es=320(N+15)/50

Elastic Settlement

Soil Unit Number	Soil Type	Unit Thickness (ft)	Unit 6 Effective Stress (ksf)	Unit 2 Effective Stress (ksf)	Unit 3 Effective Stress (ksf)	Unit 5 Effective Stress (ksf)	Estimated Modulus of Elasticity (E_s) ksf	Depth Factor (K')	Corrected Modulus of Elasticity (E_{sc}) ksf	Calculated Elastic Settlement (ft)	Calculated Elastic Settlement (inches)
6	Fine Sand	21	1.351				525	378.38	938.7	0.1893	2.27
2	Silty Sand	2.0	0.132	0.066	-	-	155.0	217.48	473.4	0.0357	0.43
3	Silty Clay	4.0	0.250	0.250	0.125	-	125.0	221.89	473.2	0.0715	0.86
5	Sandy Clay	3.0	0.193	0.193	0.193	0.096	125.0	402.85	837.9	0.0303	0.36
	Totals	30.0	1.925	0.508	0.317	0.096				0.3268	3.92
Increase due to fill, liner system, CCB, and Cover											
4	Compacted Fill	13.0	1.586		$s = (\delta d_v/E_{sc}) * H$						
8	Bottom Ash	1.5	0.150								
7	CCB	72.0	6.480								
4	Cover Soil	2.0	0.244								
		Totals	8.460								

Consolidation Settlement

Soil Unit Number	Soil Type	Unit Thickness (ft)	Unit 6 Effective Stress (ksf)	Unit 2 Effective Stress (ksf)	Unit 3 Effective Stress (ksf)	Unit 5 Effective Stress (ksf)	Void Ratio	Preconsolidation Stress (ksf)	Compression Index (C_c)	Recompression Index (C_r)	Calculated Consol. Settlement (ft)	Calculated Consol. Settlement (inches)
6	Fine Sand	21	1.351	-	-	-	0.60	-	-	-	-	-
2	Silty Sand	2.0	0.132	0.066	-	-	0.65	3.80	0.183	0.025	0.109	1.31
3	Silty Clay	4.0	0.250	0.250	0.125	-	0.65	3.90	0.367	0.06	0.472	5.66
5	Sandy Clay	3.0	0.193	0.193	0.193	0.096	0.71	3.90	0.367	0.06	0.389	4.66
	Totals	9.0	1.925	0.508	0.317	0.096					0.970	11.64
Increase due to fill, liner system, CCB, and Cover						$s=C_r*(H_o/(1+ e_o))*\log(d_p/\delta d_{vo}) + C_c*(H_o/(1+ e_o))*(\log(d_{vo}+ \delta d_v)/d_p)$						
4	Compacted Fill	7.6	1.5860									
8	Bottom Ash	1.5	0.1500									
7	CCB	72.0	6.4800									
4	Cover Soil	2.0	0.2440									
		Totals	8.460									

Total Settlement

Soil Unit Number	Soil Type	Unit Thickness (ft)	Calculated Elastic Settlement (inches)	Calculated Consol. Settlement (inches)	Calculated Total Settlement (inches)
6	Fine Sand	21	2.27		2.27
2	Silty Sand	2.0	0.43	1.31	1.74
3	Silty Clay	4.0	0.86	5.66	6.52
5	Sandy Clay	3.0	0.36	4.66	5.03
	Totals	9.0	1.65	11.64	**15.56**

Settlement Calculations

Settlement at Point 3

Soil Units Listed from the Bottom Up

Soil Unit Number	Soil Type	Unit Thickness (ft)	Unit Weight Moist (pcf)	Unit Weight Sat. (pcf)	Void Ratio	Specific Gravity	Compression Index (C_c)	Recompression Index (C_r)	SPT Blowcount (N)	Modulus of Elasticity (E_s) ksf	Method Calculation of E_s
6	Fine Sand	6	115	126.8	0.60	2.65	-	-	90	525	Es=250(N+15)/50
1	Sandy Silt	13.0	120.0	123.4	0.78	2.74	0.183	0.025	20	156	Es=300(N+6)/50
2	Silty Sand	3.0	125.0	128.2	0.65	2.74	0.183	0.025	16	155	Es=300(N+6)/50
4	Clayey Silt	3.0	122.0	124.8	0.65	2.65	0.367	0.06	7	110	Es=320(N+15)/50
4	Compacted Fill	7.0	122.0	124.8	0.65	2.65	0.367	0.06	7	110	Es=320(N+15)/50
8	Bottom Ash	1.5	100.0	105.3	0.89	2.30	-	-	-	600	Literature
7	CCB	27.0	90.0	107.2	0.81	0.15	0.15	-	-	600	Triaxial Test
4	Cover Soil	2.0	122.0	124.8	0.65	2.65	0.367	0.06	7	110	Es=320(N+15)/50

Elastic Settlement

Soil Unit Number	Soil Type	Unit Thickness (ft)	Unit 6 Effective Stress (ksf)	Unit 1 Effective Stress (ksf)	Unit 2 Effective Stress (ksf)	Unit 4 Effective Stress (ksf)	Estimated Modulus of Elasticity (E_s) ksf	Depth Factor (K')	Corrected Modulus of Elasticity (E_{sc}) ksf	Calculated Elastic Settlement (ft)	Calculated Elastic Settlement (inches)
6	Fine Sand	6	0.345	-	-	-	525.0	322.75	683.5	0.0323	0.39
1	Sandy Silt	13.0	1.56	0.780	-	-	156.0	126.49	231.9	0.2062	2.47
2	Silty Sand	3.0	0.375	0.375	0.188	-	155.0	208.34	322.3	0.0342	0.41
4	Clayey Silt	3.0	0.366	0.366	0.366	0.183	155.0	362.33	515.2	0.0214	0.26
	Totals	19.0	2.646	1.521	0.554	0.183				0.2942	3.53

Increase due to fill, liner system, CCB, and Cover

4	Compacted Fill	7.0	0.854
8	Bottom Ash	1.5	0.150
7	CCB	27.0	2.430
4	Cover Soil	2.0	0.244
		Totals	3.678

$s = (\delta d_v / E_{sc}) * H$

Consolidation Settlement

Soil Unit Number	Soil Type	Unit Thickness (ft)	Unit 6 Effective Stress (ksf)	Unit 1 Effective Stress (ksf)	Unit 2 Effective Stress (ksf)	Unit 4 Effective Stress (ksf)	Void Ratio	Preconsolidation Stress (ksf)	Compression Index (C_c)	Recompression Index (C_r)	Calculated Consol. Settlement (ft)	Calculated Consol. Settlement (inches)
6	Fine Sand	6	0.345	-	-	-	0.60	-	-	-	-	-
1	Sandy Silt	13.0	1.56	0.780	-	-	0.78	3.80	0.183	0.025	0.255	3.06
2	Silty Sand	3.0	0.375	0.375	0.188	-	0.65	3.90	0.183	0.025	0.050	0.60
4	Clayey Silt	3.0	0.366	0.366	0.366	0.183	0.65	3.90	0.367	0.06	0.142	1.70
	Totals	19.0	2.646	1.521	0.554	0.183					0.447	5.36

Increase due to fill, liner system, CCB, and Cover

$s=C_r*(H_o/(1+ e_o))*\log(d_p/\delta d_{vo}) + C_c*(H_o/(1+ e_o))*(\log(d_{vo}+ \delta d_v)/d_p)$

4	Compacted Fill	7.0	0.8540
8	Bottom Ash	1.5	0.1500
7	CCB	27.0	2.4300
4	Cover Soil	2.0	0.2440
		Totals	3.678

Total Settlement

Soil Unit Number	Soil Type	Unit Thickness (ft)	Calculated Elastic Settlement (inches)	Calculated Consol. Settlement (inches)	Calculated Total Settlement (inches)
6	Fine Sand	6	0.39		0.39
1	Sandy Silt	13.0	2.47	3.06	5.53
2	Silty Sand	3.0	0.41	0.60	1.01
4	Clayey Silt	3.0	0.26	1.70	1.96
	Totals	19.0	3.53	5.36	**8.89**

Settlement Calculations

Settlement at Point 4

Soil Units Listed from the Bottom Up

Soil Unit Number	Soil Type	Unit Thickness (ft)	Unit Weight Moist (pcf)	Unit Weight Sat. (pcf)	Void Ratio	Specific Gravity	Compression Index (C_c)	Recompression Index (C_r)	SPT Blowcount (N)	Modulus of Elasticity (E_s) ksf	Method Calculation of E_s
6	Fine Sand	11.5	115	126.8	0.60	2.65	-	-	90	525	Es=250(N+15)/50
2	Silty Sand	7.5	125.0	128.2	0.65	2.74	0.183	0.025	16	155	Es=300(N+6)/50
1	Sandy Silt	3.5	120.0	123.4	0.78	2.74	0.183	0.025	20	156	Es=300(N+6)/50
5	Sandy Clay	3.0	115.0	126.6	0.71	2.76	0.367	0.06	10	160	Es=320(N+15)/50
4	Compacted Fill	17.0	122.0	124.8	0.65	2.65	0.367	0.06	7	110	Es=320(N+15)/50
8	Bottom Ash	1.5	100.0	105.3	0.89	2.30	-	-	-	600	Literature
7	CCB	32.0	90.0	107.2	0.81	0.15	0.15	-	-	600	Triaxial Test
4	Cover Soil	2.0	122.0	124.8	0.65	2.65	0.367	0.06	7	110	Es=320(N+15)/50

Elastic Settlement

Soil Unit Number	Soil Type	Unit Thickness (ft)	Unit 6 Effective Stress (ksf)	Unit 1 Effective Stress (ksf)	Unit 2 Effective Stress (ksf)	Unit 5 Effective Stress (ksf)	Estimated Modulus of Elasticity (E_s) ksf	Depth Factor (K')	Corrected Modulus of Elasticity (E_{sc}) ksf	Calculated Elastic Settlement (ft)	Calculated Elastic Settlement (inches)
6	Fine Sand	11.5	0.661	-	-	-	525.0	341.47	766.4	0.0802	0.96
2	Silty Sand	7.5	0.938	0.938	-	-	155.0	208.06	435.3	0.0922	1.11
1	Sandy Silt	3.5	0.420	0.420	0.210	-	156.0	119.56	214.8	0.0871	1.05
5	Sandy Clay	3.0	0.345	0.345	0.345	0.173	160.0	385.23	650.0	0.0247	0.30
	Totals	25.5	2.364	1.703	0.555	0.173				0.2842	3.41
Increase due to fill, liner system, CCB, and Cover											
4	Compacted Fill	17.0	2.074		$s = (\delta d_v/E_{sc}) * H$						
8	Bottom Ash	1.5	0.150								
7	CCB	32.0	2.880								
4	Cover Soil	2.0	0.244								
		Totals	5.348								

Consolidation Settlement

Soil Unit Number	Soil Type	Unit Thickness (ft)	Unit 6 Effective Stress (ksf)	Unit 2 Effective Stress (ksf)	Unit 1 Effective Stress (ksf)	Unit 5 Effective Stress (ksf)	Void Ratio	Preconsolidation Stress (ksf)	Compression Index (C_c)	Recompression Index (C_r)	Calculated Consol. Settlement (ft)	Calculated Consol. Settlement (inches)
6	Fine Sand	11.5	0.661	-	-	-	0.60	-	-	-	-	-
2	Silty Sand	7.5	0.938	0.938	-	-	0.65	3.90	0.183	0.025	0.246	2.95
1	Sandy Silt	3.5	0.420	0.420	0.210	-	0.78	3.80	0.183	0.025	0.114	1.37
5	Sandy Clay	3.0	0.345	0.345	0.345	0.173	0.71	3.90	0.367	0.06	0.240	2.87
	Totals	25.5	2.364	1.703	0.555	0.173					0.599	7.19
Increase due to fill, liner system, CCB, and Cover						$s=C_r*(H_o/(1+ e_o))*\log(d_p/\delta d_{vo}) + C_c*(H_o/(1+ e_o))*(\log(d_{vo}+ \delta d_v)/d_p)$						
4	Compacted Fill	17.0	2.0740									
8	Bottom Ash	1.5	0.1500									
7	CCB	32.0	2.8800									
4	Cover Soil	2.0	0.2440									
		Totals	5.348									

Total Settlement

Soil Unit Number	Soil Type	Unit Thickness (ft)	Calculated Elastic Settlement (inches)	Calculated Consol. Settlement (inches)	Calculated Total Settlement (inches)
6	Fine Sand	11.5	0.96		0.96
2	Silty Sand	7.5	1.11	2.95	4.06
1	Sandy Silt	3.5	1.05	1.37	2.41
5	Sandy Clay	3.0	0.30	2.87	3.17
	Totals	25.5	3.41	7.19	**10.60**

Settlement Calculations

Settlement at Point 5

Soil Units Listed from the Bottom Up

Soil Unit Number	Soil Type	Unit Thickness (ft)	Unit Weight Moist (pcf)	Unit Weight Sat. (pcf)	Void Ratio	Specific Gravity	Compression Index (C_c)	Recompression Index (C_r)	SPT Blowcount (N)	Modulus of Elasticity (E_s) ksf	Method Calculation of E_s
6	Fine Sand	17.5	115	126.8	0.60	2.65	-	-	90	525	Es=250(N+15)/50
2	Silty Sand	13.0	125.0	128.2	0.65	2.74	0.183	0.025	16	155	Es=300(N+6)/50
4	Clayey Silt	7.0	122.0	124.8	0.65	2.65	0.367	0.06	7	110	Es=320(N+15)/50
4	Compacted Fill	1.0	122.0	124.8	0.65	2.65	0.367	0.06	7	110	Es=320(N+15)/50
8	Bottom Ash	1.5	100.0	105.3	0.89	2.30	-	-	-	600	Literature
7	CCB	46.0	90.0	107.2	0.81	0.15	0.15	-	-	600	Triaxial Test
4	Cover Soil	2.0	122.0	124.8	0.65	2.65	0.367	0.06	7	110	Es=320(N+15)/50

Elastic Settlement

Soil Unit Number	Soil Type	Unit Thickness (ft)	Unit 6 Effective Stress (ksf)	Unit 2 Effective Stress (ksf)	Unit 4 Effective Stress (ksf)	Estimated Modulus of Elasticity (E_s) ksf	Depth Factor (K')	Corrected Modulus of Elasticity (E_{sc}) ksf	Calculated Elastic Settlement (ft)	Calculated Elastic Settlement (inches)
6	Fine Sand	17.5	1.006	-	-	525.0	281.22	678.0	0.1202	1.44
2	Silty Sand	13.0	1.625	0.813	-	155.0	120.07	240.0	0.2522	3.03
4	Clayey Silt	7.0	0.854	0.854	0.427	110.0	168.34	279.4	0.1166	1.40
	Totals	37.5	3.485	1.667	0.427				0.4890	5.87
Increase due to fill, liner system, CCB, and Cover										
4	Compacted Fill	1.0	0.122		$s = (\delta d_v/E_{sc}) * H$					
8	Bottom Ash	1.5	0.150							
7	CCB	46.0	4.140							
4	Cover Soil	2.0	0.244							
	Totals		4.656							

Consolidation Settlement

Soil Unit Number	Soil Type	Unit Thickness (ft)	Unit 6 Effective Stress (ksf)	Unit 2 Effective Stress (ksf)	Unit 4 Effective Stress (ksf)	Void Ratio	Preconsolidation Stress (ksf)	Compression Index (C_c)	Recompression Index (C_r)	Calculated Consol. Settlement (ft)	Calculated Consol. Settlement (inches)
6	Fine Sand	17.5	1.006	-	-	0.60	-	-	-	-	-
2	Silty Sand	13.0	1.625	0.813	-	0.65	3.90	0.183	0.025	0.375	4.50
4	Clayey Silt	7.0	0.854	0.854	0.427	0.65	3.80	0.367	0.06	0.438	5.26
	Totals	37.5	3.485	1.667	0.427					0.814	9.76
Increase due to fill, liner system, CCB, and Cover											
4	Compacted Fill	1.0	0.1220								
8	Bottom Ash	1.5	0.1500								
7	CCB	46.0	4.1400								
4	Cover Soil	2.0	0.2440								
	Totals		4.656								

$s=C_r*(H_o/(1+ e_o))*\log(d_p/\delta d_{vo}) + C_c*(H_o/(1+ e_o))*(\log(d_{vo}+ \delta d_v)/d_b)$

Total Settlement

Soil Unit Number	Soil Type	Unit Thickness (ft)	Calculated Elastic Settlement (inches)	Calculated Consol. Settlement (inches)	Calculated Total Settlement (inches)
6	Fine Sand	17.5	1.44		1.44
2	Silty Sand	13.0	3.03	4.50	7.53
4	Clayey Silt	7.0	1.40	5.26	6.66
	Totals	37.5	5.87	9.76	**15.63**

Settlement Calculations

Settlement at Point 6

Soil Units Listed from the Bottom Up

Soil Unit Number	Soil Type	Unit Thickness (ft)	Unit Weight Moist (pcf)	Unit Weight Sat. (pcf)	Void Ratio	Specific Gravity	Compression Index (C_c)	Recompression Index (C_r)	SPT Blowcount (N)	Modulus of Elasticity (E_s) ksf	Method Calculation of E_s
6	Fine Sand	14.0	115	126.8	0.60	2.65	-	-	90	525	Es=250(N+15)/50
2	Silty Sand	5.0	125.0	128.2	0.65	2.74	0.183	0.025	16	155	Es=300(N+6)/50
4	Clayey Silt	5.0	122.0	124.8	0.65	2.65	0.367	0.06	7	110	Es=320(N+15)/50
4	Compacted Fill	9.0	122.0	124.8	0.65	2.65	0.367	0.06	7	110	Es=320(N+15)/50
8	Bottom Ash	1.5	100.0	105.3	0.89	2.30	-	-	-	600	Literature
7	CCB	50.0	90.0	107.2	0.81	0.15	0.15	-	-	600	Triaxial Test
4	Cover Soil	2.0	122.0	124.8	0.65	2.65	0.367	0.06	7	110	Es=320(N+15)/50

Elastic Settlement

Soil Unit Number	Soil Type	Unit Thickness (ft)	Unit 6 Effective Stress (ksf)	Unit 2 Effective Stress (ksf)	Unit 4 Effective Stress (ksf)	Estimated Modulus of Elasticity (E_s) ksf	Depth Factor (K')	Corrected Modulus of Elasticity (E_{sc}) ksf	Calculated Elastic Settlement (ft)	Calculated Elastic Settlement (inches)
6	Fine Sand	14.0	0.450	-	-	525.0	502.52	1016.0	0.0826	0.99
2	Silty Sand	5.0	0.329	0.165	-	155.0	224.54	418.4	0.0716	0.86
4	Clayey Silt	5.0	0.312	0.312	0.156	110.0	278.50	494.5	0.0606	0.73
	Totals	24.0	1.091	0.477	0.156				0.2148	2.58
Increase due to fill, liner system, CCB, and Cover										
4	Compacted Fill	9.0	1.098		$s = (\delta d_v/E_{sc}) * H$					
8	Bottom Ash	1.5	0.150							
7	CCB	50.0	4.500							
4	Cover Soil	2.0	0.244							
		Totals	5.992							

Consolidation Settlement

Soil Unit Number	Soil Type	Unit Thickness (ft)	Unit 6 Effective Stress (ksf)	Unit 2 Effective Stress (ksf)	Unit 4 Effective Stress (ksf)	Void Ratio	Preconsolidation Stress (ksf)	Compression Index (C_c)	Recompression Index (C_r)	Calculated Consol. Settlement (ft)	Calculated Consol. Settlement (inches)
6	Fine Sand	14.0	0.450	-	-	0.60	-	-	-	-	-
2	Silty Sand	5.0	0.329	0.165	-	0.65	3.90	0.183	0.025	0.191	2.29
4	Clayey Silt	5.0	0.312	0.312	0.156	0.65	3.80	0.367	0.06	0.484	5.81
	Totals	24.0	1.091	0.477	0.156					0.676	8.11
Increase due to fill, liner system, CCB, and Cover											
4	Compacted Fill	9.0	1.0980								
8	Bottom Ash	1.5	0.1500								
7	CCB	50.0	4.5000								
4	Cover Soil	2.0	0.2440								
		Totals	5.992								

$$s=C_r*(H_o/(1+ e_o))*\log(d_p/\delta d_{vo}) + C_c*(H_o/(1+ e_o))*(\log(d_{vo}+ \delta d_v)/d_p)$$

Total Settlement

Soil Unit Number	Soil Type	Unit Thickness (ft)	Calculated Elastic Settlement (inches)	Calculated Consol. Settlement (inches)	Calculated Total Settlement (inches)
6	Fine Sand	14.0	0.99		0.99
2	Silty Sand	5.0	0.86	2.29	3.15
4	Clayey Silt	5.0	0.73	5.81	6.54
	Totals	24.0	2.58	8.11	**10.68**

Settlement Calculations

Settlement at Point 7

Soil Units Listed from the Bottom Up

Soil Unit Number	Soil Type	Unit Thickness (ft)	Unit Weight Moist (pcf)	Unit Weight Sat. (pcf)	Void Ratio	Specific Gravity	Compression Index (C_c)	Recompression Index (C_r)	SPT Blowcount (N)	Modulus of Elasticity (E_s) ksf	Method Calculation of E_s
6	Fine Sand	10.5	115	126.8	0.60	2.65	-	-	90	525	Es=250(N+15)/50
2	Silty Sand	3.0	125.0	128.2	0.65	2.74	0.183	0.025	16	155	Es=300(N+6)/50
3	Silty Clay	4.0	115.0	124.8	0.65	2.65	0.367	0.06	10	125	Es=320(N+15)/50
4	Compacted Fill	18.0	122.0	124.8	0.65	2.65	0.367	0.06	7	110	Es=320(N+15)/50
8	Bottom Ash	1.5	100.0	105.3	0.89	2.30	-	-	-	600	Literature
7	CCB	51.0	90.0	107.2	0.81	0.15	0.15	-	-	600	Triaxial Test
4	Cover Soil	2.0	122.0	124.8	0.65	2.65	0.367	0.06	7	110	Es=320(N+15)/50

Elastic Settlement

Soil Unit Number	Soil Type	Unit Thickness (ft)	Unit 6 Effective Stress (ksf)	Unit 2 Effective Stress (ksf)	Unit 4 Effective Stress (ksf)	Estimated Modulus of Elasticity (E_s) ksf	Depth Factor (K')	Corrected Modulus of Elasticity (E_{sc}) ksf	Calculated Elastic Settlement (ft)	Calculated Elastic Settlement (inches)
6	Fine Sand	10.5	0.604	-	-	525.0	437.69	981.5	0.0768	0.92
2	Silty Sand	3.0	0.375	0.188	-	155.0	192.62	396.5	0.0543	0.65
3	Silty Clay	4.0	0.460	0.460	0.230	125.0	260.64	509.4	0.0564	0.68
	Totals	17.5	1.439	0.648	0.230				0.1875	2.25

Increase due to fill, liner system, CCB, and Cover

Soil Unit Number	Soil Type	Unit Thickness (ft)	Stress (ksf)
4	Compacted Fill	18.0	2.196
8	Bottom Ash	1.5	0.150
7	CCB	51.0	4.590
4	Cover Soil	2.0	0.244
		Totals	7.180

$s = (\delta d_v / E_{sc}) * H$

Consolidation Settlement

Soil Unit Number	Soil Type	Unit Thickness (ft)	Unit 6 Effective Stress (ksf)	Unit 2 Effective Stress (ksf)	Unit 4 Effective Stress (ksf)	Void Ratio	Preconsolidation Stress (ksf)	Compression Index (C_c)	Recompression Index (C_r)	Calculated Consol. Settlement (ft)	Calculated Consol. Settlement (inches)
6	Fine Sand	10.5	0.604	-	-	0.60	-	-	-	-	-
2	Silty Sand	3.0	0.375	0.188	-	0.65	3.90	0.183	0.025	0.136	1.63
3	Silty Clay	4.0	0.460	0.460	0.230	0.65	3.80	0.367	0.06	0.435	5.22
	Totals	17.5	1.439	0.648	0.230					0.571	6.86

Increase due to fill, liner system, CCB, and Cover

$s=C_r*(H_o/(1+ e_o))*\log(d_p/\delta d_{vo}) + C_c*(H_o/(1+ e_o))*(\log(d_{vo}+ \delta d_v)/d_p)$

Soil Unit Number	Soil Type	Unit Thickness (ft)	Stress (ksf)
4	Compacted Fill	18.0	2.1960
8	Bottom Ash	1.5	0.1500
7	CCB	51.0	4.5900
4	Cover Soil	2.0	0.2440
		Totals	7.180

Total Settlement

Soil Unit Number	Soil Type	Unit Thickness (ft)	Calculated Elastic Settlement (inches)	Calculated Consol. Settlement (inches)	Calculated Total Settlement (inches)
6	Fine Sand	10.5	0.92		0.92
2	Silty Sand	3.0	0.65	1.63	2.29
3	Silty Clay	4.0	0.68	5.22	5.90
	Totals	17.5	2.25	6.86	**9.11**

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