FOUNDATION SETTLEMENT ANALYSIS

GeoSyntec Consultants
COMPUTATION COVER SHEET

Client: Tennessee Valley Authority (TVA)

Project: Kingston Fossil Plant Gypsum Disposal Facility **Project/Proposal #:** GR3731 **Task #:** 06

Title of Computations: *Foundation Settlement Analysis*

Computation Package: ____________

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Revisions: (Number and Initial All Revisions)

No.	Sheet	Date	By	Checked By	Approval

FOUNDATION SETTLEMENT ANALYSIS

PURPOSE

The purpose of this calculation package is to evaluate the foundation settlements below the proposed gypsum disposal facility at the Kingston Fossil Plant-Peninsula Site. The gypsum will be placed using the rim ditch method to approximately Elevation 900 ft MSL, and placed using the dry stack method to approximately Elevation 985 ft MSL. A subgrade layer comprising relocated/recompacted native soils will be placed on top of the existing ground, followed by a 3-ft thick layer of compacted clay comprising the geologic buffer.

The calculated settlements were used to evaluate the post-settlement grades of the subgrade and geologic buffer and tensile strains in the geologic buffer.

METHOD OF ANALYSIS

Settlements of the foundation material were calculated using equations for conventional one-dimensional compression settlement. It was assumed that the settlements are caused by primary consolidation of the foundation soil layers due to overburden stresses resulting from the gypsum load.

Settlement calculations were performed using a spreadsheet created in Microsoft EXCEL®. The spreadsheet calculates the magnitude of settlement due to one-dimensional consolidation at sections taken at horizontal locations approximately every 100 ft along a selected cross-section. Calculation layers in the foundation material for each vertical section were at most 10 ft thick. This calculation method allows for the geometry of the bedrock and subsurface soil layers to be modeled.

In the EXCEL® spreadsheets, settlements resulting from primary consolidation of soil layers are calculated using the following equations for one-dimensional compression [Lambe, 1969]:

$$S_p = \frac{C_r}{1+e_o} H \log\left(\frac{\sigma'_{vo} + \Delta\sigma}{\sigma'_{vo}}\right) \; for\; \sigma'_{vo} + \Delta\sigma_v < \sigma'_p \qquad (1)$$

$$S_p = \frac{C_c}{1+e_o} H \log\left(\frac{\sigma'_{vo} + \Delta\sigma}{\sigma'_p}\right) + \frac{C_r}{1+e_o} H \log\left(\frac{\sigma'_p}{\sigma'_{vo}}\right) \; for\; \sigma'_{vo} + \Delta\sigma_v > \sigma'_p \qquad (2)$$

where: S_p = primary settlement (ft);

C_c = compression index;
C_r = recompression index;
e_o = initial void ratio;
H = initial thickness of compressible layer (ft);
σ'_{vo} = initial vertical effective stress in the ground before waste placement (psf);
σ'_p = preconsolidation stress (psf); and
$\Delta\sigma$ = increment of vertical stress (psf).

Alternatively, the modified compression index, $C_{c\varepsilon}$, and the modified recompression index, $C_{r\varepsilon}$, can be used in Equations 1 and 2. These parameters are defined below:

$$C_{c\varepsilon} = \frac{C_c}{1 + e_o} \quad (3)$$

$$C_{r\varepsilon} = \frac{C_r}{1 + e_o} \quad (4)$$

Tensile Strains in Geologic Buffer Layer

Foundation settlements due to gypsum loading have the potential to induce tensile strains in the geologic buffer. Tensile strain was calculated using the following formula:

$$\varepsilon = (L_f - L_o) / L_o \quad (5)$$

where:
ε = strain in the geologic buffer (tension is positive)
L_o = initial (pre-settlement) length between calculation points
L_f = final (post-settlement) length between calculation points

Calculated tensile strains were compared to allowable values. Typical allowable tensile strains for compacted clays are on the order of 0.1 to greater than 1 percent [La Gatta et al., 1997].

SUBSURFACE STRATIGRAPHY

Information on the site stratigraphy used in these analyses is summarized in MACTEC [2005], MACTEC [2006], and TVA [2005]. The top of bedrock elevations were obtained from a contour map developed from a series of site investigations that included soil borings, CPT soundings, and GeoProbe soundings performed at the site as presented in TVA [2005]. Current ground elevations were obtained from the Kingston Fossil Plant topographic map provided by TVA. Nearby borings were projected to the cross section to develop the thicknesses of the compressible native material along the cross section.

This native material was subdivided into two groups based on the Standard Penetration Test (SPT) blow count and water content of the material. A description of the subsurface stratigraphy is presented below.

Native Material

The onsite native material is primarily classified as a medium stiff to stiff silty clay. The blow count of the material onsite ranges from 6 to 20 blows per foot (bpf). "Soft" material, classified by Standard Penetration Test (SPT) N values less than or equal to 4 bpf was found in several borings. This soft material ranged in thickness from 0 to 20 ft along the cross sections selected for the settlement analyses and occurred just above the bedrock material. For the analyses performed herein, compression properties were selected for two layers of foundation material (i.e., N>4 and N≤4).

- N>4: Three one-dimensional consolidation tests were performed on samples representative of material with SPT blow counts greater than 4. The maximum past pressure of the native material was determined using the Casagrande construction method [Holtz and Kovacs, 1981]. According to the consolidation test results, the preconsolidation stress ranges from 7,350 psf to 10,850 psf. The average calculated preconsolidation stress is 9,121 psf (see Casagrande selection of preconsolidation stress on test result curves in Attachment A).

- N≤4: A single one-dimensional consolidation test was performed on a sample representative of material with SPT blow count less than 4. The calculated preconsolidation stress of this native material is 5,650 psf (See Attachment A).

Geologic Buffer/Subgrade Fill

A preconsolidation stress was selected for the geologic buffer and subgrade fill assuming that the material is placed at 95 percent of the maximum dry density, at or near optimum water content. The selected preconsolidation stress is 1,000 psf.

Ground Water Table

The groundwater table was found to be directly related to the surface water elevation of the Watts Bar Reservoir adjacent to the site. Based on the normal operating zone for the reservoir, the maximum reservoir elevation is 741 ft MSL during the months of May through October and is decreased to a low elevation of 737 ft MSL during the remainder of the year. The design ground water table was selected as approximately Elevation 741 ft MSL near the sump, based on the July 2005 potentiometric map presented in TVA [2005]. The July 2005 potentiometric map was used in this design to represent the historical high groundwater table because: (i) the July 2005 data were obtained during the maximum reservoir elevation and (ii) the recently obtained March 2006 elevations were lower than the July 2005 elevations. For the purposes of this analysis, the constant ground water table of Elevation 741 ft MSL was used.

Written by: JFR	Date: 5/23/2006	Reviewed by: PJS	Date: 5/4/2006
Client: TVA	Project: Kingston Fossil Plant Gypsum Stack	Project/Proposal No.: GR3731	Task No.: 06

ANALYSIS CROSS SECTION

Foundation settlements were calculated along the central drainage corridor (see stratigraphy in Figure 1 and Figure 2). The location of the cross section is provided on Figure 3. This cross section is selected to demonstrate that positive drainage will be maintained through the corridor after placement of the dry stack material.

The central drainage corridor is designed with a pre-settlement compound grade. From the eastern most limit of waste to horizontal location 1600 ft near the boundary between the Phase I and Phase II footprints, the corridor is designed at a 0.3 percent grade; and from horizontal location 1600 ft to the west towards the sump, the corridor is constructed at a 0.76 percent grade. These design grades were selected based on preliminary settlement calculations.

MATERIAL PARAMETERS

Input parameters for the EXCEL® spreadsheet calculations include the surface and subsurface topography profiles, unit weights, modified compression and recompression indices, and ground water surface. Unit weights and compressibility parameters were interpreted from consolidation test results provided in the *Report of Geotechnical Exploration* prepared by MACTEC [2005]. A discussion regarding the material parameters used in this analysis are presented below. A summary of the foundation material parameters is presented in Table 1.

Native Material (N>4)

For the modified compression index, $C_{c\varepsilon}$, a value of 0.14 was selected as the average value from three consolidation tests (as summarized in MACTEC [2005]) performed on foundation material samples at an average loading interval equal to 16,000 to 64,000 psf. The maximum load expected on the foundation material due to gypsum is approximately 25,000 psf. For the modified recompression index, $C_{r\varepsilon}$, a value of 0.0037 was calculated as the average of the unload cycle (i.e., from 4,000 psf to 1,000 psf) from three consolidation tests performed on foundation material samples as summarized in MACTEC [2005]. A total unit weight of 120 lb/ft^3 for the foundation material was selected based on dry unit weights and natural moisture content of the tested samples.

Native Material (N≤4)

A modified compression index, $C_{c\varepsilon}$, of 0.24 was selected from one consolidation test performed on a sample of low blow count material identified by the high moisture content of the material (i.e., moisture content of 54 percent). This modified compression index was selected for an average loading interval of 16,000 to 64,000 psf. For the modified recompression index, $C_{r\varepsilon}$, a value of 0.01 was calculated as the average of the unload cycle from 4,000 to 1,000 psf. A summary of the consolidation test performed on this material is in MACTEC [2005]. A total unit weight of 105 lb/ft^3 was used based on the laboratory results.

Geologic Buffer/Subgrade and Soil Fill

On site material will be used to construct the subgrade, the initial soil berm around the gypsum pond, and the geologic buffer. Standard Proctor tests were run on 17 samples of native material from depths ranging from 6 to 12.5 ft. The unit weight of the soil fill material was selected as 95 percent of the average of the maximum dry unit weights resulting from the Standard Proctor tests. A total unit weight of 117 lb/ft^3 was selected. In the absence of data, the compression and recompression indices chosen to represent the compressibility of the geologic buffer and soil fill materials were a $C_{c\varepsilon}$ value of 0.14 and a $C_{r\varepsilon}$ value of 0.0037.

RESULTS

Calculated settlements along the central drainage corridor under final configuration (i.e., end of dry stack operations) are presented in Table 2. As mentioned above, the calculated settlements account for the compressibility of the native material, subgrade layer, and geologic buffer. The initial (i.e., 0.3 to 0.76 percent) and calculated final post-settlement grade along the gravel drainage corridor are illustrated in Figure 4

Tensile strains in the geologic buffer were calculated along the gravel drainage corridor and are summarized in Table 3. The maximum calculated tensile strain is 0.01 percent.

Details of the consolidation settlement calculations for the native material, subgrade layer, and geologic buffer due to final waste loading along the gravel drainage corridor are provided in Attachment B.

SUMMARY AND CONCLUSIONS

Foundation settlements under final configuration of the gypsum disposal facility were calculated for a cross section along the centerline of the central drainage corridor. Based on settlement results, the maximum calculated settlement is 5.9 ft occurring at horizontal location of 1500 ft. Results indicate that the minimum calculated post-settlement grade is 0.03%, indicating that positive drainage will be maintained along the central drainage corridor.

Maximum tensile strains in the geologic buffer were calculated to be 0.01 percent. Typical allowable tensile strains for compacted clays are on the order of 0.1 to greater than 1 percent [La Gatta et al., 1997]. Therefore tensile strains in the geologic buffer are considered to be acceptable.

REFERENCES

Holtz, R.D., and W.D. Kovacs, "*An Introduction to Geotechnical Engineering*", Prentice Hall, New Jersey, 1981, 733 p.

LaGatta, M. D., Boardman, B.T., Cooley, B.H., and Daniel, D.E., "Geosynthetic Clay Liners Subjected to Differential Settlement", *Journal of Geotechnical and Geoenvironmental Engineering*, ASCE, Vol. 123, No. 5, 1997, pp. 402-410.

MACTEC, "*Laboratory Testing Results – Samples from Gypsum Pond at Cumberland Fossil Plant,*" MACTEC Project 3043041009/001, prepared for Parsons E&C on behalf of TVA, Knoxville, TN, May 2004, 48 p.

MACTEC, "*Report of Geotechnical Exploration: Proposed Gypsum Disposal Area at Kingston Fossil Plant, Kingston, Tennessee,*" MACTEC Project 3043051021.01, prepared for TVA, Knoxville, TN, October 2005.

MACTEC, "*Report of Additional Geotechnical Exploration: Proposed Gypsum Disposal Area at Kingston Fossil Plant, Kingston, Tennessee,*" MACTEC Project 3043051064.01, prepared for TVA, February 2006.

Tennessee Valley Authority (TVA), "*Kingston Fossil Plant – Peninsula Site Hydrogeologic Evaluation of Coal-Combustion Byproduct Disposal Facility*", WR2005-1-36-133. Prepared by Mr. Hank E. Julian and Mr. J. Mark Boggs for TVA, October 2005.

TABLES

TABLE 1
SUMMARY OF COMPRESSION PARAMETERS

Material	Unit Weight	Compression Properties		
	(pcf)	$C_{c\varepsilon}$	$C_{r\varepsilon}$	σ_p' (psf)
Dry Stack Gypsum	107	-	-	-
Coarse Gypsum	90	-	-	-
Fine Gypsum	100	-	-	-
Subgrade Fill	117	0.14	0.0037	1,000
Geologic Buffer	117	0.14	0.0037	1,000
Native Soil (N>4)	120	0.14	0.0037	9,121
Native Soil (N<4)	105	0.24	0.01	5,650
Bedrock	155	-	-	-

Written by: JFR Date: 5/23/2006 Reviewed by: PJS Date: 5/4/2006

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TABLE 2
SUMMARY OF CALCULATED SETTLEMENT ALONG CENTERLINE OF DRAINAGE CORRIDOR

Horizontal Location, (ft)	Initial Grade (%)	Settlement (ft)	Grade Changes[(1)] (%)	Final Grade[(1)] (%)
3450	0.3	0.1	-0.02	0.32
3400	0.3	0.1	-0.58	0.88
3300	0.3	0.7	-0.69	0.99
3200	0.3	1.4	-1.12	1.42
3100	0.3	2.5	0.00	0.30
3000	0.3	2.5	-0.11	0.41
2900	0.3	2.6	-0.25	0.55
2800	0.3	2.8	-0.33	0.63
2700	0.3	3.2	0.13	0.17
2600	0.3	3.0	0.15	0.15
2500	0.3	2.9	0.04	0.26
2400	0.3	2.8	-0.32	0.62
2300	0.3	3.2	-0.55	0.85
2200	0.3	3.7	-0.29	0.59
2100	0.3	4.0	-0.40	0.70
2000	0.3	4.4	-0.10	0.40
1900	0.3	4.5	-0.67	0.97
1800	0.3	5.2	0.19	0.11
1700	0.3	5.0	-0.53	0.83
1600	0.76	5.5	-0.41	1.17
1500	0.76	5.9	0.43	0.33
1400	0.76	5.5	0.12	0.64
1300	0.76	5.4	0.06	0.70
1200	0.76	5.3	-0.40	1.16
1100	0.76	5.7	0.62	0.14
1000	0.76	5.1	0.73	0.03
900	0.76	4.4	0.66	0.10
800	0.76	3.7	0.66	0.10
700	0.76	3.0	0.40	0.36
600	0.76	2.6	0.64	0.12
500	0.76	2.0	0.56	0.20
400	0.76	1.4	0.45	0.31
300	0.76	1.0	0.20	0.56
200	0.76	0.8	0.69	0.07
100	0.76	0.1	-	-

Note: (1) The reported value is calculated between the horizontal location where the value is presented and the adjacent horizontal location (i.e. between 1500 and 1400 ft, a grade change of 0.43 percent occurs).

Written by: JFR Date: 5/23/2006 Reviewed by: PJS Date: 5/4/2006

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TABLE 3
SUMMARY OF CALCULATED STRAINS DUE TO GYPSUM LOADING

Horizontal Location, (ft)	L_o, (ft)	L_f, (ft)	Strains $\varepsilon^{(1)}$, (%)
3450	**50.0025**	**50.00242**	**-0.0002**
3400	**100.005**	**100.0009**	**-0.0041**
3300	**100.005**	**100.0005**	**-0.0045**
3200	**100.005**	**100.0001**	**-0.0049**
3100	**100.005**	**100.005**	**0.0000**
3000	**100.005**	**100.004**	**-0.0010**
2900	**100.005**	**100.0028**	**-0.0022**
2800	**100.005**	**100.0023**	**-0.0027**
2700	**100.005**	**100.0064**	**0.0014**
2600	**100.005**	**100.0066**	**0.0016**
2500	**100.005**	**100.0054**	**0.0004**
2400	**100.005**	**100.0023**	**-0.0027**
2300	**100.005**	**100.001**	**-0.0040**
2200	**100.005**	**100.0025**	**-0.0025**
2100	**100.005**	**100.0018**	**-0.0032**
2000	**100.005**	**100.004**	**-0.0010**
1900	**100.005**	**100.0006**	**-0.0044**
1800	**100.005**	**100.0071**	**0.0021**
1700	**100.005**	**100.0011**	**-0.0039**
1600	**100.005**	**100.0017**	**-0.0033**
1500	**100.005**	**100.0103**	**0.0053**
1400	**100.005**	**100.0063**	**0.0013**
1300	**100.005**	**100.0056**	**0.0006**
1200	**100.005**	**100.0018**	**-0.0032**
1100	**100.005**	**100.0132**	**0.0082**
1000	**100.005**	**100.0149**	**0.0099**
900	**100.005**	**100.0137**	**0.0087**
800	**100.005**	**100.0139**	**0.0089**
700	**100.005**	**100.0098**	**0.0048**
600	**100.005**	**100.0134**	**0.0084**
500	**100.005**	**100.0122**	**0.0072**
400	**100.005**	**100.0105**	**0.0055**
300	**100.005**	**100.0072**	**0.0022**
200	**100.005**	**100.0144**	**0.0094**
100	-	-	-

Notes: (1) Positive strains are considered tensile. The reported value is calculated between the horizontal location where the value is presented and the adjacent horizontal location (i.e. between 1500 and 1400 ft, a strain of 0.0053 percent occurs).

FIGURES