



**TETRA TECH**

Tucson Office  
3031 West Ina Road  
Tucson, AZ 85741  
Tel 520.297.7723 Fax 520.297.7724  
www.tetrattech.com

## Technical Memorandum

<b>To:</b>	<u>Joel Carrasco</u>	<b>From:</b>	<u>Marvin Silva, P.E.</u>
<b>Company:</b>	<u>Tetra Tech</u>	<b>Date:</b>	<u>August 11, 2010</u>
<b>Re:</b>	<u>Rosemont Heap Leach Pad Settlement Analysis</u>	<b>Doc #:</b>	<u>209/10-320877-5.3</u>
<b>CC:</b>	<u>David Krizek, P.E.</u>		

### 1.0 Introduction

This Technical Memorandum provides a summary of Tetra Tech's settlement analysis related to the Heap Leach Facility (HLF) at the proposed Rosemont Copper Project (Project) in Pima County, Arizona. This information is in response to the April 14, 2010 Comprehensive Request for Additional Information from the Arizona Department of Environmental Quality (ADEQ) to Rosemont Copper Company (Rosemont). Specifically, this Technical Memorandum answers item no. 2 on pages 5 and 6 of 18.

- ***Subgrade Material*** – Rosemont plans to construct a heap leach pad that will meet Prescriptive BADCT and proposes the use of geosynthetic clay liner (GCL) of 6 millimeter (mm) thickness and a permeability of  $1 \times 10^{-9}$  cm/sec as an engineering equivalent. (Ref. Rosemont Heap Leach Facility Permit Design Report Volume 1 p. 28).

*As stated in the Arizona Mining BADCT Guidance Manual, Prescriptive BADCT design criteria for a heap leach pad composite liner requires that a geomembrane is underlain by at least 12 inches of native or natural 3/8-inch minus materials compacted in two 6-inch lifts to achieve a saturated hydraulic conductivity no greater than  $1 \times 10^{-6}$  cm/sec.*

*ADEQ will consider Rosemont's proposed placement of geosynthetic clay liner (GCL) of 6 millimeter (mm) thickness and a permeability of  $1 \times 10^{-9}$  cm/sec as an engineering equivalent provided it is demonstrated that:*

- a) Strength properties of compacted subgrade under the liner are suitable for bearing load to prevent significant differential settlement.*
- b) Foundation settlement beneath the proposed pad footprint should not adversely affect the integrity of the Linear Low Density Polyethylene (LLDPE) liner.*

Tetra Tech has proposed to use a geosynthetic clay liner (GCL) underneath the proposed 60 mil double-side textured LLDPE liner in lieu of a 12-inch thick layer of compacted low-permeability material. The purpose of the calculations presented herein was to estimate the maximum settlement in the foundation soils of the Heap Leach Pads, followed by a determination of



possible differential settlement and its effect on the proposed liner system (against allowable strain). This analysis takes into account loading due to 350 feet of oxide ore material.

The results of our calculations presented in this Technical Memorandum indicate that the liner system will not be damaged by settlement induced by the weight of ore material.

## 2.0 Settlement Calculation

### 2.1 Settlement Prediction Method

Foundation settlements were calculated using the Schmertmann strain influence methodology. Originally proposed by Schmertmann (1970) and modified by Schmertmann, Hartmann, and Brown (1978), this method was developed to estimate foundation settlements in cohesionless soils. This procedure provides settlement compatible with field measurements in many different areas. The analysis assumes that the distribution of vertical strain is compatible with a linear elastic half space subjected to a uniform pressure. To utilize this method, the subsurface is broken into layers. Each layer has a constant value of strain and soil modulus. The soil parameters used in the settlement calculation were selected based on the results of the geotechnical investigation performed by Tetra Tech (2007). Settlement is calculated by summing the influence of all layers, as calculated by equation (1):

$$\Delta H = C_1 C_2 \Delta p \sum_{i=1}^n \left( \frac{I_{zi}}{E_{si}} \right) \Delta z_i \quad (1)$$

where:

- $C_1$  = embedment correction factor =  $1 - 0.5(\sigma'_{od}/\Delta p) \geq 0.5$
- $C_2$  = creep correction factor =  $1 + 0.2 \log(10t)$
- $\sigma'_{od}$  = overburden pressure at foundation level or depth d, tsf<sup>1</sup>
- $\Delta P$  = net foundation pressure increase =  $q - \sigma'_{od}$ , tsf
- t = lapsed time in years
- $I_{zi}$  = influence factor of soil layer i
- $E_{si}$  = elastic modulus of soil layer i, 0.2B, tsf
- $\Delta z_i$  = depth increment i, inches

<sup>1</sup>tons per square foot

Schmertmann developed the diagram shown in Illustration 1 to determine the appropriate strain influence factor,  $I_z$ , for each layer within the profile. Two distributions are shown: one for square or circular footings ( $L/B=1$ , axisymmetric), and a second for strip footings ( $L/B>10$ , plane strain). Both are triangular distributions, and the one for square or circular footings begins at a value of 0.1 at the base of the footing, while the one for strip footings begins at a value of 0.2 at the base of the footing. The maximum strain factor,  $I_{zp}$ , occurs at a depth equal to  $B/2$  for square footings and  $B$  for strip footings, and is calculated using equation (2):

$$I_{zp} = 0.5 + 0.1 \sqrt{\frac{\Delta P}{\sigma'_{1z}}} \quad (2)$$

where:

$\sigma'_{lzp}$  = initial effective stress at the depth of maximum strain influence

Axisymmetric:  $\sigma'_{lzp} = 0.5B\gamma' + D\gamma'$

Plane strain:  $\sigma'_{lzp} = B\gamma' + D\gamma'$

where:

$\gamma'$  = effective unit weight, tcf<sup>1</sup>

B = footing width, ft

D = excavated or embedded depth, ft

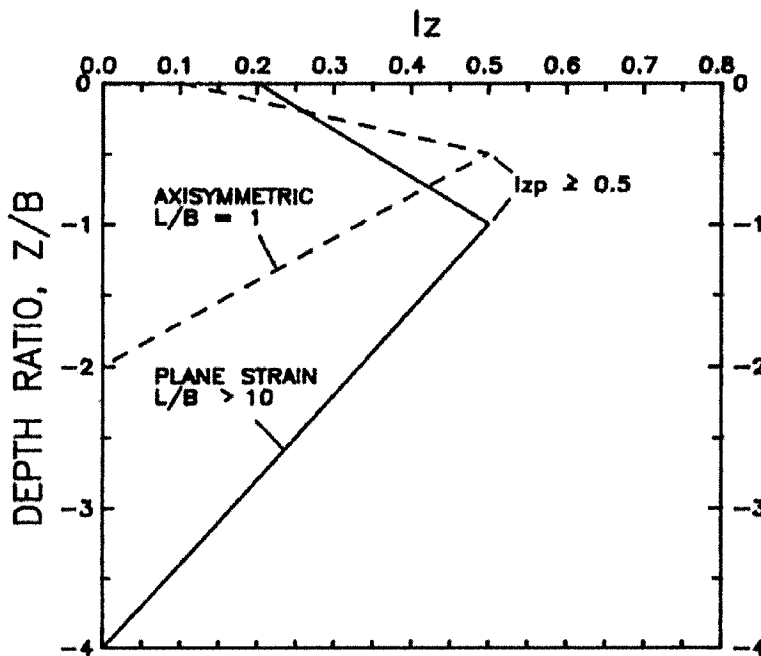
<sup>1</sup>tons per cubic foot

Values of soil modulus,  $E_s$ , were established using the following relationship (NAVFAC, 1986) for coarse sands and sands with little gravel (alluvium):

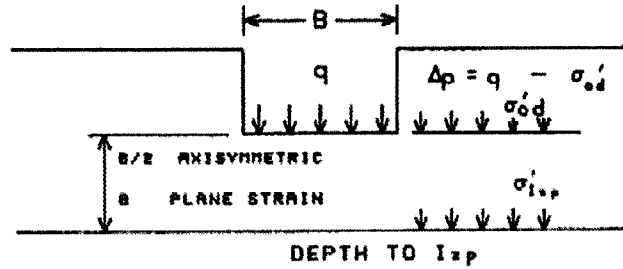
$$E_s = 10N_{spt} \text{ (tsf)} \quad (3)$$

where:

$N_{spt}$  = corrected blow count from standard penetration tests (SPT)



**Illustration 1 Strain Influence Factors for Schmertmann's Approximation (From Engineer Manual No. 1110-1-1904, USACOE, 30 Sep 90, page 3-8)**

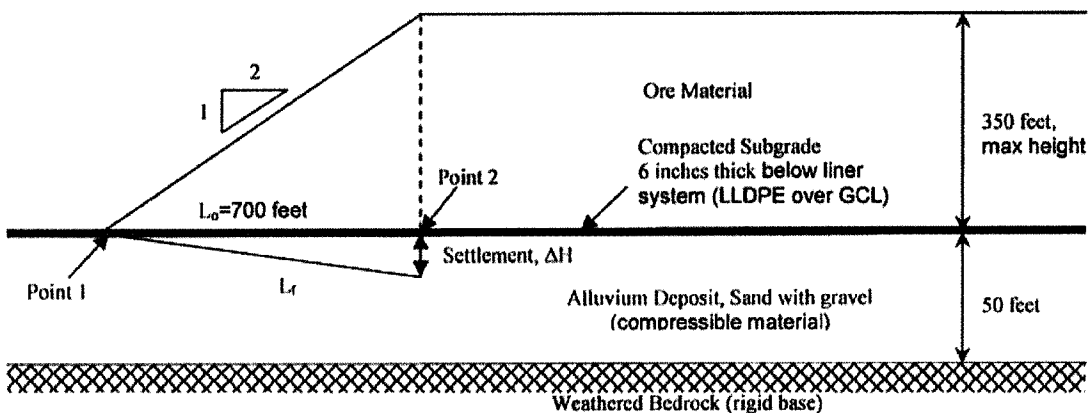


- Z - DEPTH BELOW FOOTING BOTTOM, FT
- B - FOOTING WIDTH, FT
- I<sub>z</sub> - DEPTH INFLUENCE FACTOR
- I<sub>zp</sub> - PEAK DEPTH INFLUENCE FACTOR

**Illustration 1** Strain Influence Factors for Schmertmann's Approximation (From Engineer Manual No. 1110-1-1904, USACOE, 30 Sep 90, page 3-8)

## 2.2 Settlement Analysis

Based on the results of the geotechnical investigation, the foundation soils below the Heap Leach Pads are expected to consist primarily of alluvium (Gila Conglomerate with some Apache Canyon Formation and some Younger Alluvium) overlying weathered bedrock. The alluvium thickness is variable and it was found to be as thick as 50 feet in the wash area. The alluvium is predominantly a moderately to weakly cemented sand with silt and gravel. Because the bedrock is much stiffer, the majority of the elastic compression is expected to occur in the alluvium deposits. Illustration 2 shows the geometry of the HLF and the profile of the foundation soil. It was assumed that the alluvium deposit has a thickness of 50 feet. Based on this geometry, the maximum foundation loading is expected to occur at point 2, which will have approximately 350 feet of ore material.



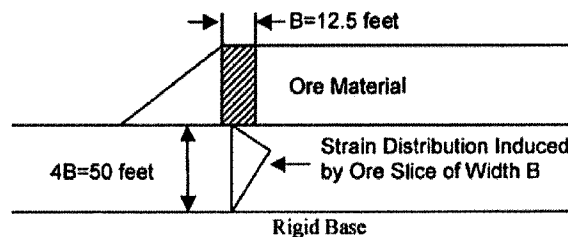
**Illustration 2** Geometry of HLF and Foundation Profile (not to scale)

The maximum differential settlement is expected to occur between point 1 and point 2. Between these two points the liner system will experience the maximum tensile stresses and the maximum elongation. The liner system will increase in length from the original length ( $L_o = 700$  feet) to the final length ( $L_f$ ). The strain on the foundation liner system was calculated using the following steps:

- Use the Schmertmann's method to calculate the settlement ( $\Delta H$ ) at point 2;
- Determine the differential settlement between points 1 and 2 (settlement at point 1 is assumed to be zero);
- Calculate the change in length of the liner system caused by the differential settlement; and
- Calculate the strain on the liner system by dividing the change in the liner length by the initial, pre-settlement liner length between point 1 and point 2, using Equation (4). This calculation assumes that the strain will be uniformly distributed across the liner.

$$\text{Strain (\%)} = \frac{L_f - L_o}{L_o} \times 100 \quad (4)$$

In order to conduct the settlement calculation, it was assumed that the maximum settlement at point 2 will be caused by a strip footing (plane strain) whose strain influence will reach the top of the weathered bedrock (rigid base assumed to be uncompressible). Therefore, a 12.5-foot wide strip footing was assumed in the settlement calculation. This footing width ( $B=12.5$  feet) will induce strains up to a depth of 50 feet ( $4B$ ), which is the depth of the top of the rigid base. Illustration 3 shows the geometry of the assumed conditions.



**Illustration 3 Assumed Geometry for Calculation of Maximum Settlement (not to scale)**

### 2.3 Settlement Results

Table 1 shows the Schmertmann's method to calculate the settlement at point 2. The material parameters used in the settlement calculations are:

- $\gamma_{om}$  = unit weight of the ore material = 125 pcf<sup>1</sup>
- $\gamma$  = unit weight of compacted subgrade and alluvium deposit = 132.7 pcf



B = width of slice at point B causing maximum settlement = 12.5 feet

<sup>1</sup>pounds per cubic foot

Illustration 3 shows the strain factor distribution calculated using the procedure described in Section 2.1.1. This illustration was used to determine the strain factors in Column 9 of Table 1 using the values of Column 8.

**Table 1 Settlement Calculation Table using Schmertmann's Method**

1	2	3	4	5	6	7	8	9	10
Layer No.	Layer Thickness $\Delta z$ (in)	Depth to bottom of layer $z$ (ft)	Blow Count $N$	$E_s/N$	Elasticity Modulus $E_s$ (tsf)	Depth to center of layer $z_c$ (in)	$z_c/B$	$I_z$	$I_z \Delta z / E_s$ (in/tsf)
1	6	0.5	30	10	300	3	0.02	0.20	0.004
2	30	3.0	14	10	140	21	0.14	0.32	0.069
3	30	5.5	14	10	140	51	0.34	0.48	0.103
4	30	8.0	14	10	140	81	0.54	0.64	0.137
5	30	10.5	15	10	150	111	0.74	0.80	0.160
6	30	13.0	15	10	150	141	0.94	0.97	0.194
7	30	15.5	15	10	150	171	1.14	0.96	0.192
8	30	18.0	20	10	200	201	1.34	0.89	0.134
9	30	20.5	20	10	200	231	1.54	0.83	0.125
10	30	23.0	20	10	200	261	1.74	0.76	0.114
11	30	25.5	30	10	300	291	1.94	0.69	0.069
12	30	28.0	30	10	300	321	2.14	0.62	0.062
13	30	30.5	30	10	300	351	2.34	0.56	0.056
14	30	33.0	30	10	300	381	2.54	0.49	0.049
15	30	35.5	40	10	400	411	2.74	0.42	0.032
16	30	38.0	40	10	400	441	2.94	0.35	0.026
17	30	40.5	40	10	400	471	3.14	0.28	0.021
18	30	43.0	40	10	400	501	3.34	0.22	0.017
19	30	45.5	50	10	500	531	3.54	0.15	0.009
20	30	48.0	50	10	500	561	3.74	0.08	0.005
21	30	50.5	50	10	500	591	3.94	0.02	0.001
22	30	53.0	50	10	500	621	4.14	0	0.000

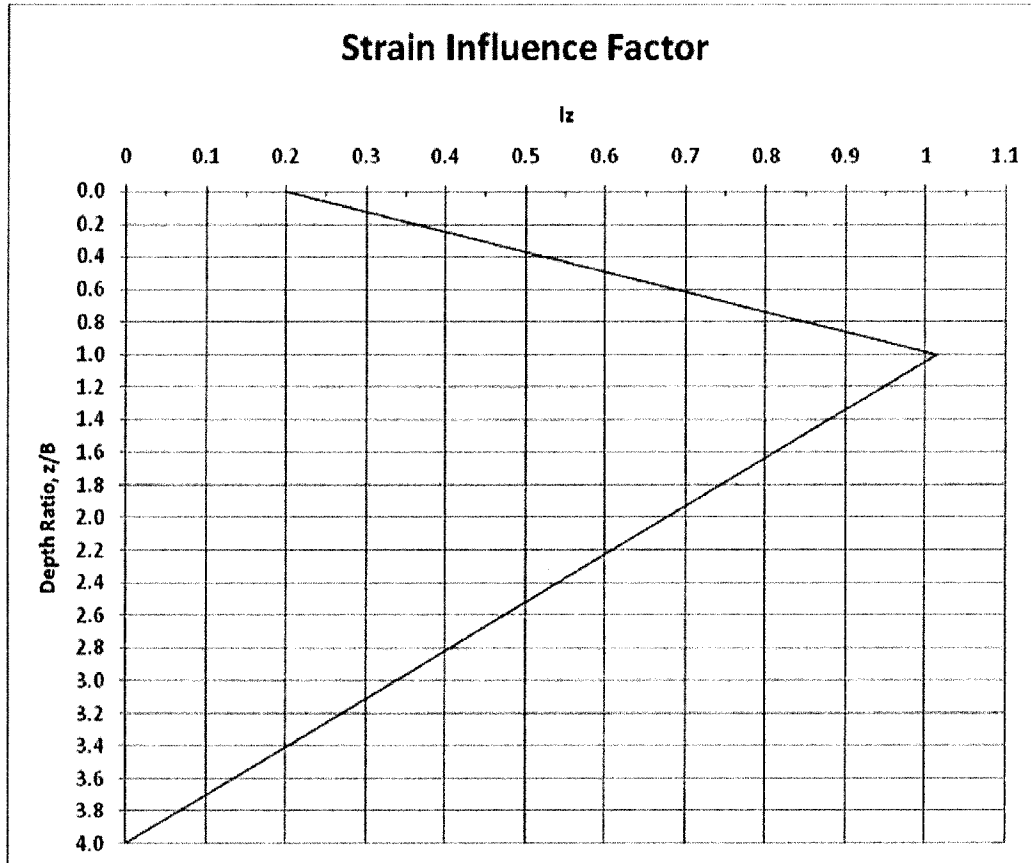
$$\sum_{i=1}^{i=22} \left( \frac{I_{zi}}{E_{si}} \right) = 1.577$$

The settlement at point B is  $\Delta H = C_1 C_2 \Delta p \sum_{i=1}^n \left( \frac{I_{zi}}{E_{si}} \right) \Delta z_i = 41.4$  inches (3.4 feet).

The final length of the liner system due to the differential settlement is

$$L_f = \sqrt{L_o^2 + \Delta H^2} = \sqrt{700^2 + 3.4^2} = 700.008 \text{ feet, and the strain of the liner system is}$$

$$\text{Strain (\%)} = \frac{L_f - L_o}{L_o} \times 100 = 0.0012\%.$$



**Illustration 3 Strain Influence Factor Distribution at Point 2**

#### 2.4 Criteria for Determining Acceptable Settlements

The maximum allowable strain on the liner system is controlled by the strain tolerance of the LLDPE and the GCL components. The allowable yield strain for the proposed 60 mil double-side textured LLDPE is 12 percent, and the elongation at break is 250 percent. There is additional concern when a geomembrane is exposed to tension perpendicular to seams. In these cases, a general rule-of-thumb is that the allowable strain on the geomembrane is about half the value of the un-seamed sheet material (Giroud et al. 1995). For this reason, horizontal seams are not allowed on side slopes. Tensile stresses applied to a geomembrane parallel to the seams are generally not a large concern, provided that the seams are good quality, and



**TETRA TECH**

were installed in accordance with the specifications. For these reasons, strains of up to 12 percent will be considered acceptable for the proposed LLDPE geomembrane.

For GCL materials, the yield strain is not typically included on standard specifications. For these materials, the yield strain is typically controlled by the geotextile layers on the top and bottom of the clay. Geotextiles generally have yield strains in excess of 50 percent. The bentonite component of GCLs also has a high strain tolerance, and can heal cracks (if they occur) over time. If the GCL were to experience such large strains, thinning of the bentonite layer (and a corresponding increase in permeability) would likely be the primary concern. Differential settlement studies performed using GCLs show that they can maintain a hydraulic conductivity below  $1 \times 10^{-7}$  cm/sec when subjected to strains between 1 and 10 percent (LaGatta et al. 1997). A second concern would be the GCL panel overlap. To avoid separation of panels caused by strain on the liner system, project specifications include required overlaps twice as large as typical manufacturer recommended overlaps.

In summary, the least strain-tolerant component of the liner system is the GCL. Accordingly, the maximum acceptable strain on the liner system is 10 percent, which is the allowable yield strain of the GCL to maintain the specified hydraulic conductivity.

The settlement calculation shows that the differential settlement on the foundation liner system caused by the ore material will be approximately 3.4 feet over an initial length of 700 feet. This differential settlement will produce an increase in the liner system length of 0.008 feet, which is equivalent to a strain of 0.0012 percent. This strain is below the suggested allowable strain of the GCL of ten percent. Therefore, the liner system will not be damaged by settlement induced by the weight of the ore material and the liner system will maintain its integrity.

### **3.0 Conclusions**

The settlement calculations show that the maximum differential settlement on the foundation induced by the weight of the ore material will not damaged any component of the proposed liner system. The strains imposed on the LLDPE and GCL liners will be within allowable limits.





## REFERENCES

- Giroud, J. P., Pelte, T., and Bathurst, R. J. (1995). *Uplift of Geomembranes by Wind*. Geosynthetics International, 2(6), 897-952.
- LaGatta, M.D., Boardman, B.H, and Daniel, D.E. (1997). *Geosynthetic Clay Liners Subject to Differential Settlement*. Journal of Geotechnical and Geoenvironmental Engineering, Vol. 123, No. 5, p. 402. [Abstract]
- Naval Facilities Engineering Command. (NAVFAC) (1986). *Soil Mechanics Design Manual 7.01*, September 1, 1986. [http://web.mst.edu/~rogersda/umrcourses/ge441/dm7\\_01.pdf](http://web.mst.edu/~rogersda/umrcourses/ge441/dm7_01.pdf)
- Schmertmann, J.H. (1970). *Static Cone to Compute Static Settlement over Sand*. ASCE Journal of Soil Mechanics & Foundations Division, 96 (3), 1011-1043.
- Schmertmann, J.H., Hartmann, J.P. and Brown, P.R. (1978). *Improved Strain Influence Factor Diagrams*, ASCE Journal of the Geotechnical Engineering Division, 104 (GT8), 1131-1135.
- Tetra Tech (2009). *Rosemont Heap Leach Facility Permit Design Report*. Prepared for Rosemont Copper Company. Report Dated May 2009.
- Tetra Tech (2007). *Geotechnical Study*. Prepared for Rosemont Copper. Report Dated June 2007.
- U.S. Army Corps of Engineers (USACOE) (1990). *Engineering and Design Settlement Analysis*. Engineer Manual No. 1110-1-1904. September 30, 1990. <http://140.194.76.129/publications/engine-manuals/em1110-1-1904/toc.htm>